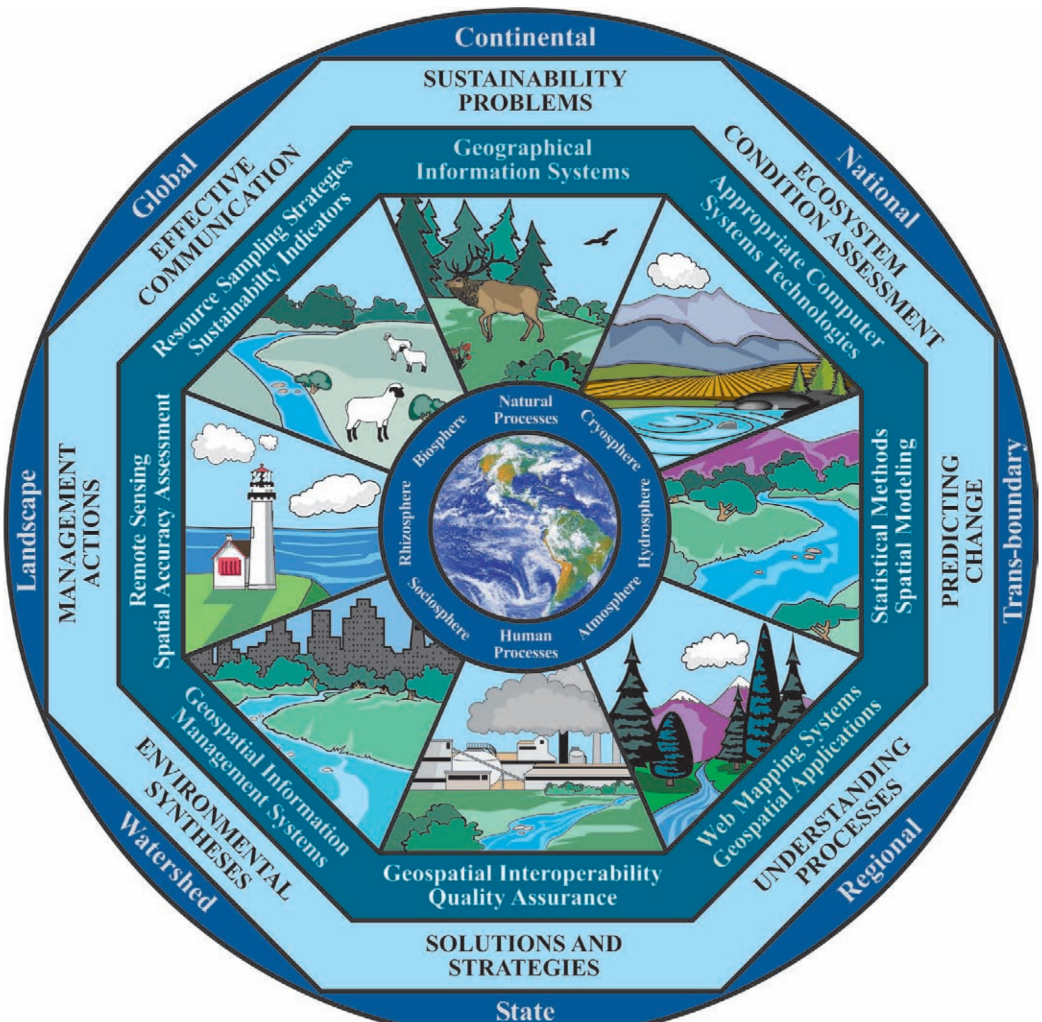
Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere



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Abstract—A rational approach to monitoring and assessment is prerequisite for sustainable management of ecosystem resources. This features innovative ways to advance the concept of monitoring ecosystem sustainability across spheres of environmental concern, natural and anthropogenic processes, and other hemispheric issues over a variety of spatial scales and resolution levels. Individuals and institutions, committed to mutual sustainability of ecosystem resources and human institutions, shared experiences and outlined a foundation for advancing the science and practice of monitoring and assessment at multiple geographical and organizational scales. Questions addressed in the proceedings papers include: What is the status and condition, and what are the trends in ecosystem sustainability? What are the strategies and opportunities for solving the sustainability dilemma? What are the individual and institutional responses to the sustainability challenge? Discussion during the symposium fostered the creation of coherent and unified ecosystem resource sustainability assessments and syntheses valuable to support environmental management and decision-making processes. The proceedings is a testimonial to the wealth of information presented at the symposium and a positive indicator of inter- and trans-disciplinary scientific and technical success.

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Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere

September 20-24, 2004
Denver, CO

Organizers:
C. Aguirre-Bravo, Patrick J. Pellicane,
Denver P. Burns, and Sidney Draggan

USDA Forest Service
Rocky Mountain Research Station
Fort Collins, CO 80526

Gobierno del Estado de Jalisco, Mexico
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Preface

In recent decades, we have witnessed the growth of world-wide efforts to realize the goal of human societies living in harmony with the natural world. At the beginning of the 21st century, the world is poised on the threshold of a new era in which the unification of information, knowledge, and applications is emerging as the basis for understanding the complex and dynamic interactions between nature and society. The Monitoring Science and Technology Symposium, Unifying Knowledge for Sustainability in the Western Hemisphere, was organized in response to this opportunity. Sponsored by a consortium of government and non-government institutions across the Americas, the symposium brought together a diverse group of individuals and institutions, committed to the mutual sustainability of ecosystem resources and human institutions, to share their experiences and create a unified foundation for sustainability science and management.

Human processes have impacted practically every pixel of the multi-dimensional spatial grid of our planet. In this challenging new era, we need to recognize the social and economic importance of monitoring and assessment processes, and utilization of the resulting information for many purposes. Modern institutions are now facing a complex world where people from all cultural, social, and economic backgrounds need to be empowered with the appropriate knowledge and tools so that they can successfully confront the variety of sustainability challenges and opportunities associated with their local environment. Meeting these needs and concerns at the appropriate spatial-temporal scales clearly makes monitoring and assessment processes among the most challenging activities institutions face today and in the years to come.

A large number of high-profile speakers shared their perspectives on the simultaneous sustainability of environmental and socio-economic systems. Over 800 participants from 24 countries had the opportunity to share experiences and gain insights from a diverse group of people with a wide spectrum of cultural and scientific backgrounds. People who attended the symposium were deeply committed to the challenge of achieving both a healthy and vibrant environment for this and future generations, and creating thriving and sustainable economies and other social institutions upon which society relies.

The symposium was designed to promote the integration and exchange of information and knowledge about environmental and human sustainability gathered at different geographic scales. Numerous benefits resulted from this symposium. Specifically, the symposium contributed significantly to the process of advancing the development and application of defensible monitoring and assessment methods for the sustainable management of ecosystem resources and human institutions. The interactions of concerned people representing different disciplines—and cultural and geographic backgrounds—brought about new perspectives on sustainability strategies and solutions. In addition, exposure to the latest scientific and technological innovations—as well as the state-of-the-art in commercially-available products and services for environmental monitoring—were displayed in a variety of technical presentations, poster sessions, and technology exhibits.

I thank the organizers of this symposium and the participants for their outstanding work of making it an extraordinarily successful event.

Marcia Patton-Mallory, Ph. D.
USDA Forest Service
Director, Rocky Mountain Research Station
September 2004

Acknowledgments

The organizers of the Monitoring Science and Technology Symposium wish to thank the individuals and organizations whose support of the Symposium was critical to its success. The topic matter of the Symposium obviously matched the interests of many wide ranging organizations as demonstrated by their support as well as the participation of their employees. Session chairpersons took the responsibility to develop the themes for their sessions. Sponsors are identified below, as are individuals who gave of their time and prestige to make the meeting successful. Finally we wish to thank the principals of Colorado Event Organizers, Ms. Sheryl Babiarz and Ms. Kathy Baker, who handled the logistics and venue of the Symposium with professionalism at every turn, and, as a bonus, kept the organizers reasonably calm as we hit the bumps attendant to organizing and conducting a meeting as large as the Symposium. Finally, we thank the participants who assured the success of the Symposium by their interest, participation, and constant intellectual stimulation.

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Ing. L. Artemio Alonso Torres, Gerente, FIPRODEFO, Jalisco, Mexico

The Organizers:

Dr. Celedonio Aguirre-Bravo, USDA Forest Service, Rocky Mountain Research Station
Dr. Sidney Draggan, U.S. Environmental Protection Agency, Office of Research and Development
Dr. Patrick Pellicane, Professor, Warner College of Natural Resources, Colorado State University
Dr. Denver Burns, consultant

Contents

Atmosphere Systems and Processes

The Effects of Nitrogen Deposition, Ambient Ozone, and Climate Change on Forests in the Western U.S.

M.E. Fenn is a Research Plant Pathologist with the USDA Forest Service, Pacific Southwest Research Station, Riverside, CA

Abstract—*Nitrogen (N) deposition in the western United States is most severe near major urban areas or downwind of agricultural regions, particularly in areas where confined animal feeding operations such as dairies or feedlots are located. Nitrogen saturated ecosystems are predominantly found in hotspots located within 60 km of urban or agricultural emissions source areas, where N deposition inputs are 20 kg ha^{-1} yr^{-1} or greater. Nitrogen deposition gradients are steep with rapidly decreasing deposition with increasing distance from the source area. More subtle ecological effects of N deposition, such as fertilization effects and changes in sensitive biotic communities (for example, lichens and diatoms) occur over a much wider area than the severely affected hotspots. Effects on these sensitive ecosystem components are observed with N deposition levels as low as 3 to 8 kg ha^{-1} yr^{-1}. Visual ozone injury in the West is most severe in pine trees in forests in southern California and in the southern Sierra Nevada in central California. Recent ozone exposure data from passive monitoring networks demonstrate that elevated ozone exposures can occur as far as 250 km from emissions source areas. The geographic scope of the areas affected by ozone has increased in the past 30 years as human populations and urban zones have increased in size, and this trend is expected to continue. The combined effects of ozone and N deposition result in profound changes in plant physiological function, nutrient cycling, C storage, fuel accumulation, and susceptibility to insect attack. Predicting future ecosystem condition under scenarios of increasing CO_2 and temperature and altered precipitation patterns presents a complex research problem, particularly for areas also exposed to ozone and N deposition. Research approaches including controlled studies, manipulative field experiments, simulation modeling, and a consideration of disturbances such as pests, introduced species, fire, and drought are needed. Combined biogeography-biogeochemistry simulation models (also known as dynamic general vegetation models) incorporating all of these interacting factors will be needed to advance our understanding of these complex interactions.*

Introduction

Systematic studies of air pollution impacts on agriculture and natural ecosystems began about 50 years ago. Research on the effects of future climate conditions on crops and ecosystems is a more recent development. Trends in air pollution, concentrations of greenhouse gases, and future climatic changes are often referred to collectively as global change. Both greenhouse gases and air pollutants are primarily emitted from the combustion of fossil fuels, and air pollutants affect the capacity of ecosystems to sequester or emit greenhouse gases such as carbon dioxide, methane, or nitrogen oxides. One of the major objectives of the ecological research community is to increase our understanding of the ecological and environmental impacts of the combined effects of air pollution and climate change. Air pollution effects in the future will occur within an environment of continuing increases in CO_2 and temperature and changing precipitation patterns. The major objective of this paper is to summarize what is known of likely nitrogen (N) and ozone effects on forests of the western United States under a changing climate. I will suggest likely future general ecosystem responses in the West based on empirical and manipulative studies in conjunction with simulation modeling results, although the latter are largely from other geographic areas and only include a subset of the important global change factors.

Table 1. Air pollution and climate change factors in the western United States and possible effects on forest ecosystems. The potential ecosystem effects mentioned are of necessity simplified generalizations based on past observations, experimental results, and current understanding. Actual ecosystem responses will depend on specific site factors and conditions, future air pollution and climate scenarios, and interactions between all these factors.

Factor	Observed and potential ecosystem effects
Ozone	Phytotoxic; reduced productivity; altered phenology of sensitive species; high concentrations can cause loss of stomatal control; premature foliar senescence and abscission; ozone predisposes plants to pests and diseases; reduced root:shoot ratio; geographic extent of damaging ozone levels expected to increase as urbanization and population growth continues in the West; ozone effects can cancel out CO_2-induced growth stimulation
Nitrogen deposition	Increase in plant productivity; may partially offset growth decrease caused by ozone; reduced root:shoot ratio; may contribute to stand densification; N saturation conditions; elevated nitrate leaching and nitrogenous trace gas emissions from soil; soil acidification in highest deposition sites
Ozone + N deposition	Reduced root growth, but increased stem growth and litter accumulation; increased fuel buildup
Increasing CO_2	Increased plant growth; lower foliar nutrient concentrations; altered susceptibility to pathogens and pests; possibly altered litter decomposition rates; may reduce evapotranspiration losses
Increasing temperature	Increased plant growth initially, but may exacerbate drought stress as temperature continues to increase; may enhance ozone formation
Changing precipitation patterns	In early decades of this century is expected to increase forest growth, but in some areas of the West will likely lead to increased drought stress with more frequent extremely wet and dry years or because of drier summers
Drought	Increased drought will often be the primary controller of ecosystem condition
Pests and pathogens	Pest outbreaks are likely to increase with drought stress and the impacts of ozone, N deposition and increased CO_2
Forest fires	Severe forest fires may increase due to increasing drought stress and associated tree mortality from multiple stress syndromes and stand densification from long-standing fire suppression efforts

Global Change Stress Factors

The primary climate change and air pollution stress factors to be considered in this paper are: nitrogen deposition, ozone, changing temperature and precipitation patterns, increasing CO_2, drought, forest pest outbreaks, and fire (table 1). Nitrogen and ozone air pollution have been impacting forest ecosystems in southern California for the past 50 years and we know something of their effects (Fenn and others 2003b). Carbon dioxide concentrations have been gradually increasing over this same time period and severe drought periods have also occurred. From 1999 to 2004, drought has been particularly severe in southern California and the southwestern U.S. (Piechota and others 2004), and insect outbreaks and fire severity in forests of southern California increased dramatically in 2003 (Westerling and others 2004). These and other changes in southern California forests may portend future impacts on western forests under future air pollution and global change scenarios. However, much of our understanding of air pollution and climate change impacts on ecosystems are based on studies of single or possibly two factors. Multiple air pollution interactions are relatively poorly understood, and predictions of the combined effects of air pollutants within the context of increasing CO_2, and climate change are even more uncertain.

The extent of forested areas in the West that will be exposed to phytotoxic levels of ozone is on the increase. Projected increased temperatures will likely contribute to higher rates of ozone formation (Beedlow and others 2004). On a worldwide basis, the percentage of temperate and subpolar forests exposed to damaging levels of ozone (> 60 ppb) is predicted to increase from 29 to 60 percent by the end of this century (Fowler and others 1999). Nitrogen deposition is also expected to affect increasing acreages of forest in the West as urbanization and population growth continue in this fast growing region. The recent development of reliable passive monitors for measuring concentrations of gaseous pollutants (Bytnerowicz and others 2002) such as ozone, nitric acid vapor, nitrogen oxides, ammonia, and sulfur dioxide now makes it feasible to determine air pollution exposure patterns over large forested areas. For example, from a network of passive ozone monitors throughout a large extent of the Sierra Nevada range in California, it was surprising to discover high summertime ozone concentrations in the Mammoth Lakes and Owens Valley regions of the eastern Sierra Nevada, approximately 165 to 250 km from any major pollutant sources (Frączek and others 2003). These findings demonstrate that elevated ozone concentrations can occur in unexpected areas and that passive monitoring networks are effective in characterizing pollution exposures over broad forested areas. Throughfall deposition of nitrogen and sulfur, a surrogate measure of total dry and wet deposition, can also be measured more routinely in a large number of remote sites because of the recent development of ion exchange resin collectors that require infrequent sample collection (for example, every six months; Fenn and Poth 2004). These monitoring tools, along with the ongoing development of portable active monitors of ozone and other pollutants, will continue to improve our capacity to relate air pollution exposures in the field to ecosystem effects.

We consider that in areas where drought severity increases significantly, this factor will override the impacts of other factors. Drought stress leads to tree mortality, either directly or due to predisposition of trees to pests and diseases. The end result is greater fire risk. Wildfire is the most important natural ecological disturbance in western North America (McKenzie and others 2004). In areas where soil moisture is only moderately reduced, increased atmospheric CO_2 may compensate by reducing evapotranspiration fluxes. However, if ozone levels are high, stomatal control can be disrupted (Grulke 1999), thus counteracting any CO_2-induced decrease in evapotranspiration. Ozone has also been shown to counteract the growth-stimulating effects of CO_2 (Isebrands and others 2003). The combined effects of ozone and N (or either pollutant alone) results in lowered root production (Fenn and others 2003b), which is likely to increase drought stress as well. These examples illustrate the complexity involved in attempting to predict ecosystem responses to changes in multiple air pollution and climate change factors, particularly because the many interacting factors are expected to elicit dynamic patterns of ecosystem responses based on evolving atmospheric, environmental, and biological conditions.

Climate Change Scenarios for the Western United States

We base our discussion of future climate change scenarios on simulations from the two primary global climate models used by the National Assessment Synthesis Team (NAST 2000) of the US Global Change Research Program: the Canadian Climate Centre (CGCM1) and the Hadley Centre, United Kingdom (HadCM2) global climate models. Hereafter, they will be referred to as the Canadian and the Hadley models. Projected warming in the United States in the 21st century is 2.9ºC for the Hadley model and 5.0ºC for the Canadian model. Recently, results of models and expert opinion seem to be reaching a consensus on estimates for increased global temperature at the end of the century when CO_2 concentrations are expected to double. Although, uncertainty remains high, projections are converging on a projected global warming of 3ºC (Kerr 2004). Murphy and others (2004) reported a five to 95 percent probability range for a 2.4 to 5.4ºC temperature increase with CO_2 doubling and a most probable warming of 3.2ºC.

Average warming over the Pacific Northwest is projected to reach 1.7ºC by the 2030s and 2.8ºC by the 2050s (table 2). Winter temperatures may rise 4.5 to 6.0ºC by the 2090s (NAST 2000). Precipitation is expected to increase in most areas of the Pacific Northwest, mainly in the winter, with little change or a decrease in summer. The projected result of wetter winters and drier summers is decreasing water availability, especially in the Hadley model. By the 2090s, precipitation is projected to increase from a few percent to 20 percent in the Hadley model and from 20 to 50 percent in the Canadian model (NAST 2001).

In the Southwest (California, Nevada, Arizona, New Mexico, Utah, and western Colorado), average temperature is projected to increase 2ºC by the 2030s and 4.5 to 6ºC by the 2090s (table 2). The models project increased precipitation in winter, especially over California where runoff is expected to double by the 2090s. In much of the Pacific Northwest and in California, the Mediterranean climate characterized by warm dry summers, already creates conditions of seasonal drought stress, making these ecosystems prone to periodic pest outbreaks and fire. These conditions may worsen with climate change. Some areas of the Rocky Mountains are projected to get drier, possibly resulting in loss of alpine meadows (NAST 2000), but both models project more extreme wet and dry years. Because of greater precipitation in winter, possibly more as rain, and because of greater runoff (less water storage) and more extreme dry years, increased drought stress must also be considered as a likely scenario, notwithstanding predictions of an overall increase in precipitation. Likely scenarios for the West indicate increases in forest cover in the West and that desert areas will decrease with a wetter climate, resulting in increased coverage by woody species (NAST 2000). Due to uncertainties about regional precipitation, projections also include the possibility of generally warmer and drier

Table 2. Projected climate change scenarios for the western United States[a].

Region	Temperature increase	Precipitation pattern	Ecosystem impacts
Pacific Northwest[b]	1.7ºC by the 2030s; 2.8ºC by the 2050s	Projections for the region range from a 7% decrease to a 13% increase; increases are mainly in winter while decreases or small increases are in summer	Decreasing water availability and presumably greater drought stress, particularly over the longer term as temperatures increase
Southwest[2]	2.0ºC by the 2030s; 4.5 to 6.0ºC by the 2090s	Projected to be wetter and warmer; increased precipitation projected in winter, especially in California; runoff may double in California by the 2090s; some areas of the Rocky Mountains may get drier; more extreme wet and dry years; there is also a chance that climate may get drier over much of the West during the 21st century	Likely increase in biomass; reduction in desert areas and increase in woodlands and forests; if climate becomes drier opposite responses are likely; fire frequency expected to increase in either scenario

[a] Climate change scenarios are mainly based on the two primary global climate models used by the National Assessment Synthesis Team (NAST 2000, 2001) of the US Global Change Research Program; the Canadian Climate Centre (CGCM1) and the Hadley Centre, United Kingdom (HadCM2) global climate models.

[b] Pacific Northwest as here defined, includes Washington, Oregon and Idaho. The Southwest includes the states of California, Arizona, Nevada, Utah, New Mexico, and western Colorado.

conditions in the West (NAST 2000, 2001). Simulated projections provide a consensus that fire severity and incidence in the West will increase whether precipitation increases or decreases in the region (McKenzie and others 2004; NAST 2001).

Predictions of Ecosystem Responses to Global Change

A consensus finding of the NAST report suggests that over the short term increased temperature, moisture, and CO_2 is expected to result in C gains in most forest ecosystems in the coterminous United States (Aber and others 2001; NAST 2000, 2001). However, this partially depends on whether the fertilization effect of CO_2 is sustained or whether downregulation or acclimation occurs after a period of increased CO_2. Many initial studies of plants cultivated in pots in exposure chambers indicated that CO_2 growth stimulation would be transitory. Long and others (2004) reviewed results from FACE experiments which suggest that the stimulatory growth response to CO_2 may not be transitory. Mickler and others (2003) also reviewed several field studies that suggest that the CO_2 response may be long lasting. However, this yet remains an open question. In a recent review, Beedlow and others (2004) concluded that increases in C sequestration by forests as a result of CO_2 fertilization are unlikely because of other limiting factors such as soil N, air pollution, and water availability. Projections of forest growth increases in the next few decades of climate change must be tempered by the possibility or likelihood that increased drought stress may occur in some regions; a response that will counteract predictions of forest growth increase. Greater year to year variability in precipitation patterns are predicted, which suggests that severe drought years will also be more common. Furthermore, in a warmer climate, if more winter precipitation in montane regions of the West occurs as rain as opposed to snow, runoff will be more rapid, likely reducing soil water retention and further contributing to drought stress.

A complete analysis of forest ecosystem response to global change will, in many cases, require that ozone and N deposition also be included along with the other factors commonly considered in global change scenarios. Responses to N deposition and ozone can be on the same order as responses to climate change (Aber and others 2001), which further illustrates the importance of considering these global change factors when evaluating ecosystem responses to changing atmospheric conditions. To date, no rigorous evaluations have been done of the combined effects of the primary climate change and air pollution factors such as increased temperature and CO_2, N deposition and elevated ozone exposure, and changing precipitation patterns that may lead to greater drought stress. The effects of these interacting factors on disturbance factors such as changes in pest or pathogen outbreaks and fire frequency and severity also must be considered. Clearly these are complicated scenarios, and simulation modeling will be needed to address these myriad interactions and complexities. Combined biogeography-biogeochemistry models have been developed (referred to as dynamic general vegetation models) to evaluate ecosystem response to the interacting effects of temperature, precipitation, and CO_2 (Aber and others 2001). However, ozone and N deposition effects are not included in these models. Ozone exposure can disrupt stomatal control (Grulke 1999), and has been shown to cancel out the growth-promoting effects of CO_2 (Isebrands and others 2003). Similarly, tree responses to global change factors may depend on whether N is deficient, or in sufficient or excess supply. These examples of ozone and N availability illustrate how the addition of an additional stress factor can completely change the net ecosystem effect of global climate change and demonstrate why all relevant factors must be considered as we seek to improve our capacity to predict future ecosystem effects of global change.

As reviewed by Aber and others (2001), interacting effects of various combinations of two or three of these factors (CO_2, O_3, precipitation, or temperature) have been simulated for representative eastern regions and interactive effects of increased CO_2 and ozone have been studied in FACE experiments (Percy and others 2002), but direct investigations of higher level interactions including the primary global climate change factors in combination with N deposition and ozone have not been reported. Because of the absence of model evaluations of ecosystem responses to these multiple stress factors associated with global climate change, in the following section of this paper we will make a preliminary attempt at predicting some of the possible Western forest responses to global change/air pollution by reviewing a case study in the San Bernardino Mountains in Southern California where many of these stress factors have impacted these forests to various degrees.

San Bernardino Mountains Case Study of Multiple Stress Impacts

The San Bernardino Mountains (SBM) case study in Southern California is the best empirical field study in the Western United States indicating forest ecosystem responses to major global change stress factors. Nitrogen deposition and ozone exposure have presumably been affecting the forest ecosystem in the SBM for at least the last 50 years. Ozone injury on ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), a major component of the mixed conifer forest in the SBM, was first reported in the early 1950s (Miller and others 1963, Parmeter and others 1962). Summer drought stress is a natural condition in this Mediterranean climate. Drought becomes particularly severe when successive unusually dry years occur, such as is the case since 1999. Over the past 50 years CO_2 concentrations have also been increasing and global warming is also underway, but these gradual increases have not yet exerted the effects that are expected to occur in future decades. Nitrogen deposition has caused major changes in biogeochemical cycling, and in conjunction with ozone, has caused significant physiological perturbations in ponderosa pine and California black oak (*Quercus kelloggii* Newb.). Because ozone exposure and N deposition are both high in the more exposed areas of the SBM, it is sometimes difficult to separate the effects of these two pollutants.

In the Western SBM, the physiological functioning of ponderosa pine trees has been dramatically altered in ways that are believed to increase its sensitivity to the main ecosystem stressors common to this region – drought and insect outbreaks (Fenn and others 2003b). Fine root production in ponderosa pine is dramatically reduced as is the number of annual foliage whorls that are retained. At Camp Paivika, the westernmost site in the SBM, little more than one annual whorl of foliage is retained on average. In essence, the pine trees function as "deciduous conifers" (Grulke and Balduman 1999). As a result of ozone-induced premature needle fall and N-induced greater foliar growth, litter accumulates to a much greater degree in the highly polluted sites. Nitrogen enrichment of the litter also inhibits long term litter decomposition. Nitrogen and ozone also result in a greater shoot:root ratio, resulting in greater C storage in bole and branches (Fenn and Poth 2001). The net result is that as long as fires are suppressed, air pollution exposure enhances fuel accumulation as litter on the ground and more dense forest growth aboveground. The increased fuel accumulation is expected to increase the already high fire risk. Reduced root growth and denser aboveground growth is also expected to increase drought stress and susceptibility to pests, which eventually leads to tree mortality and increased fire risk.

Widespread tree mortality and wildfire became a vivid reality in the SBM in the fall of 2003, during which time hundreds of thousands of trees were affected by the most severe drought conditions in the SBM in recorded history. Hundreds of thousands of trees died from drought, bark beetle infestations, and rampant forest fires. However, unusually high tree mortality, bark beetle outbreaks, and fire losses occurred throughout the SBM regardless of the level of ozone exposure or N deposition. This illustrates the key point that when drought stress becomes overly severe and prolonged, this stressor overrides other factors, including air pollution impacts. However, ozone and N deposition have been shown to further predispose trees to bark beetle attack in the SBM (Pronos and others

1999, Jones and others 2004), and as hypothesized above, decades of physiological air pollution impacts appear to worsen drought stress effects. Over the years, tree mortality in the SBM has been attributed to a multiple stress syndrome in which some or all of the following factors contribute to mortality: drought, ozone injury, N deposition and bark beetles (Fenn and others 2003b; Jones and others 2004). As tree mortality spreads over an area, this in turn increases the risk of severe fire losses. Fire risk is already high in many western forests as a result of nearly a century of successful fire suppression efforts, reminding us that projections of global change impacts must be made within the context of land use history.

Conclusions

Projections of climate change effects on forests over the first several decades of this century generally indicate increased forest growth in the United States. Precipitation is expected to increase over most of the West, although years of extremely high or low precipitation are also projected to increase. However, if assumptions of the fertilization effect of increased CO_2 are incorrect or overestimated, projections of increased forest growth may be at least partially nullified. Furthermore, these projections do not include the effects of ozone and N deposition. Forest responses to climate change can be significantly modified in areas where these pollutants are elevated.

A high degree of uncertainty in projections of future forest responses to global change (here defined to include climate change and air pollution effects) is inevitable based on our current knowledge base and technological tools for evaluating these complex scenarios. Complexity is high because the effects of many interacting factors must be considered over large spatial and temporal scales. These interactions cannot be tested experimentally because all the requisite factors cannot be adequately manipulated or controlled, and because of the long time frame needed to observe patterns of forest ecosystem responses. Thus, simulation modeling approaches, bolstered by experimental data on the effects of single factors or various stressor combinations, are needed to evaluate future impacts.

Evaluation of effects will be simplified for areas not significantly affected by air pollution. For example, in the western U.S., air pollution impacts mainly occur in "hotspots" near or downwind of urban or agricultural emissions source areas, with relatively large areas of little apparent pollution effects. However, sensitive indicator organisms such as diatoms and lichens are affected over larger areas than previously expected, including areas with N deposition loadings as low as 3 to 8 kg ha^{-1} yr^{-1} (Fenn and others 2003a). The extent of forested areas in the West affected by ozone and N deposition is expanding because of rapid urbanization and increasing emissions from urban and agricultural emissions sources. Many of these emissions sources are also encroaching further onto lands adjacent to forested areas. Some areas, such as the Central Valley of California, are becoming more of a regional air pollution problem that affects the adjacent montane ecosystems (in this case the Sierra Nevada range). Realistic simulation model scenarios of future ecosystem responses to global climate change will be needed that include scenarios of high and low levels of ozone and atmospheric N deposition.

Common knowledge and empirical field results suggest that under conditions of prolonged or severe drought, this stress factor will override other global change factors. Thus, future drought conditions will be a major driver of ecosystem condition. Drought is projected to increase in some parts of the West, such as the Pacific Northwest. In the Northwest and in California where summer drought is typical, drought can become more common or severe even with a long term trend of greater precipitation. This is particularly true if extreme wet and dry years increase in frequency and if more precipitation in montane regions occurs as rain, resulting in rapid runoff and lower water retention. Increases in drought conditions will also lead to greater pest outbreaks, severe stand mortality and increased fire severity.

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Critical Loads and Levels: Leveraging Existing Monitoring Data

D. G. Fox, Cooperative Institute for Research in the Atmosphere, Colorado State University, Ft. Collins, CO
A. R. Riebau, USDA Forest Service, Research and Development, Washington, D.C.
R. Fisher, USDA Forest Service, Air Resources Program, Washington, D.C.

Abstract—*A snapshot of current air quality in the National Parks and Wilderness areas of the US is presented based on data from the 165 site Interagency Monitoring of Protected Visual Environments, or IMPROVE program, and other relevant air quality monitoring programs. This snapshot is provided using the VIEWS web service, an on-line web-based data warehouse, analysis, and delivery system for visibility and atmospheric aerosols. The relevance of these data to inform development of a proposed new program of Critical Loads and Levels will be discussed.*

Introduction

In the United States, land management agencies such as the USDA Forest Service and various Department of Interior agencies (National Park Service, National Fish and Wildlife Service, Bureau of Land Management, and others) have responsibility to manage the country's natural resources. These land managers are authorized through specific legislation to monitor various aspects of the resources they manage. However, monitoring the potential effects of air pollution on these natural resources is a relatively new challenge and one that invokes a shared responsibility between land managers, and state and federal environmental agencies. One result of this is uneven monitoring with variable coverage and quality between components. A recent National Research Council (NRC) report, Air Quality Management in the United States (National Research Council 2004, p. 11), identified "Protecting Ecosystem Health" as one of seven major air quality challenges facing the United States in the coming decade. Specifically the NRC report states:

"Although mandated by the Clean Air Act, the protection of ecosystems affected by air pollution has not received appropriate attention in the implementation of the act. A research and monitoring program is needed that can quantify the effects of air pollution on the structure and function of ecosystems. That information can be used to establish realistic and protective goals, standards, and implementation strategies for ecosystem protection."

In this paper we review some of our experiences in protecting ecosystems from air pollution effects over the past 27 years since passage of the 1977 Amendments to the Clean Air Act. These Amendments formally addressed protection of some of the nation's ecosystems by designating 156 mandatory Class 1 Areas (federally managed wilderness and national parks above certain minimum sizes that existed when the Act passed). For Class 1 areas, federal land managers are given an "affirmative responsibility" to protect their "air quality related values (including visibility)." Land managers have responded with a number of different monitoring activities. Many involve inventory of the resources and are site, region, and agency specific. Only one monitoring network, IMPROVE, collects national, multi-agency, quality controlled data actually used in the regulatory process. As such IMPROVE represents an example of the type of monitoring the NRC report requests. However, before reviewing IMPROVE and its data, we will briefly review air pollution effects on ecosystems identifying the components needed to develop critical levels and loads for their protection.

Conceptual Models of Air Pollution Impacts on Ecosystems

The USDA Forest Service, in response to the Clean Air Act, developed a conceptual model of air pollution impact on the Class 1 areas they manage (Fox and others 1989). This included an early effort to identify key monitoring activities needed for identifying and documenting the condition of Class 1 area "air quality related values" (Fox and others 1987). Recently, an interagency Federal Land Manager Air Quality Related Values WorkGroup (FLAG) reviewed, revised, and updated the early conceptual model (http://www.fs.fed.us/r6/aq/natarm/Flag_final.pdf).

The conceptual model of Class 1 area air pollution impacts, as originally conceived, focused on:

- *visibility* (aerosol concentrations in and around the Class 1 areas);
- *ozone*, the only one of the nationally established "criteria" pollutants known to impact vegetation at concentrations routinely measured in Class 1 areas, and;
- *sulfur and nitrogen deposition* because of both their potential for acidifying surface waters and soils as well as their nutrient value.
- Certainly there are additional aspects of air pollution that have an impact, particularly deposition of metals and concentrations of "toxic" air pollutants; however, they tend to be isolated and site specific and so require special attention on a case by case basis.
- At any rate the original conceptualization has proven robust. It is similar to the framework developed by the UNECE Convention on Long-range Transboundary Air Pollution and the International Cooperative Programme (ICP) it has spawned (ICP 2004). The ICP has taken the concept further by developing and mapping so called *critical levels* and *critical loads*. *Critical levels* and *critical loads* are determined on an ecosystem basis, considering ecosystem specific biology and biogeochemistry as well as sensitivities in conjunction with ambient concentrations and deposition levels. Critical values are defined as threshold levels above which significant aspects of the ecosystem may not be sustainable. Obviously, there are mixes of both science and value judgment that must go into quantifying *critical loads* and *critical levels*. Setting these numerical values is not the subject of this paper.

Here we wish to consider a general procedure that has been used in Europe (fig. 1, IPC 2004.) In this procedure, there are clear needs for data capable of providing statistically accurate spatial and temporal patterns of air

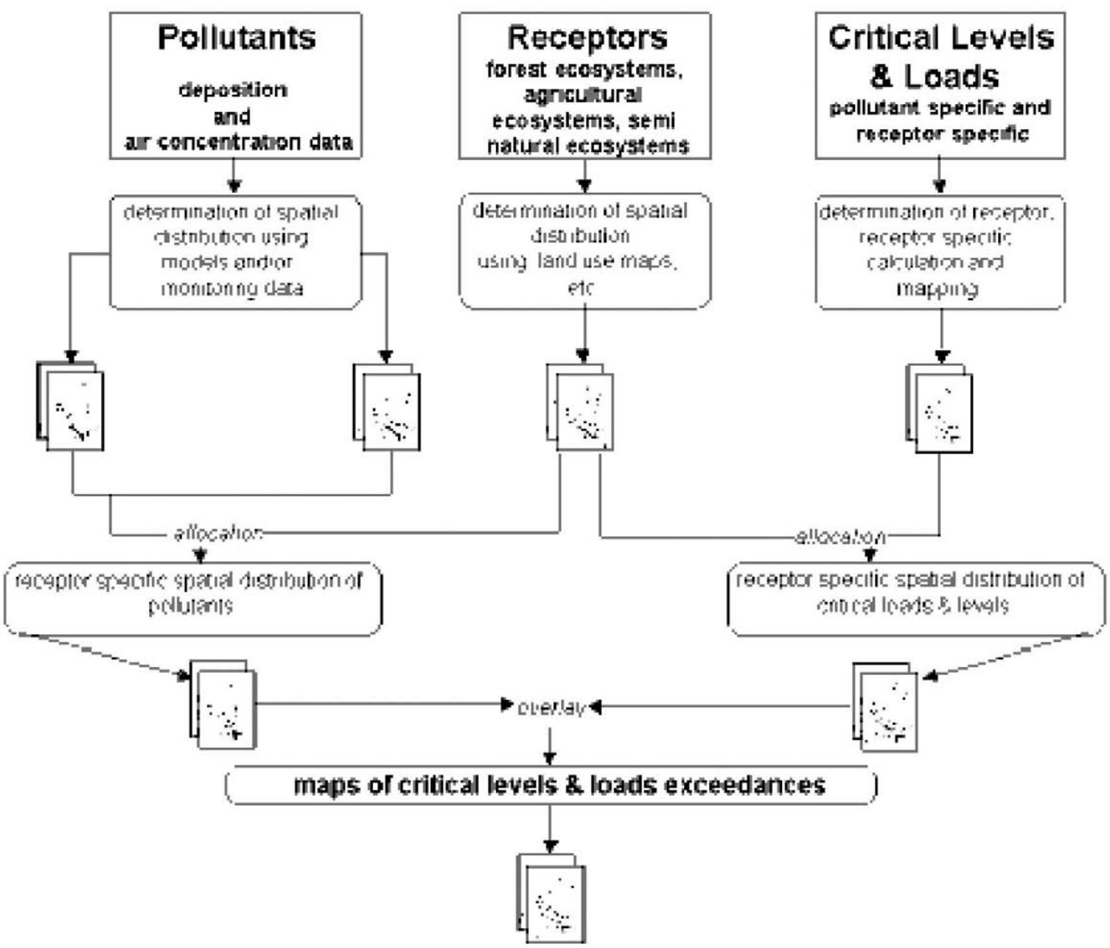

Figure 1. The steps in constructing critical loads and levels as employed by the UNECE's ICP (ICP 2004).

pollution, data providing equivalently accurate spatial maps of ecosystems and land cover, and conceptual models able to link pollution levels with specific ecosystems impact mechanisms.

In this paper we will focus only on the first of these three requirements, namely the air quality monitoring data that are currently available in the United States. We will briefly review the current status of rural air quality in the United States, presenting a snap shot of present data from the IMPROVE, NADP, and ambient air quality networks. But first, to provide this snap shot, we will use the capabilities and resources of the VIEWS, which will be presented in some detail. Finally we will present a brief discussion of the relevance of this type of data to enhanced ecosystem impact monitoring and specifically, to the implementation of a US version of the ICP critical loads monitoring.

Views

The Visibility Information Exchange Web System (VIEWS) mission is to facilitate the analysis and use of aerosol and atmospheric pollution data in a public web-based environment to improve understanding and knowledge about air quality and its improvement. VIEWS is supported collaboratively by five RPOs that assist regional bodies of states and tribes in their efforts to address regional air quality problems in general and the EPA's Regional Haze Rule in particular. VIEWS provides custom data products based primarily on IMPROVE data and designed to assist states in the regulatory process. Also available from VIEWS are supporting datasets of general interest to regional haze impacting National Parks, Wilderness areas, and other scenic areas.

To support the RPOs data requirements, the VIEWS web site is designed to provide organized, comprehensive, and convenient access to data and data products relevant to the Regional Haze Rule and general visibility issues. This information can be accessed by users in an ad-hoc manner and can be returned in a variety of formats, including graphically and as formatted text files. Most data products obtained from the VIEWS web site are generated dynamically from the VIEWS database.

Behind the scenes VIEWS supports a robust and efficient SQL database system designed to acquire and manage large amounts of air quality data. To date, datasets from IMPROVE and over 20 other monitoring programs are included. All data in VIEWS have undergone a series of integrity checks and are described by common metadata and data structure. This 'data homogenization' process produces a truly integrated database optimized for efficient retrieval and meaningful comparisons.

The Visibility Information Exchange Web System (VIEWS) home page, http://vista.cira.colostate.edu/views, is shown in figure 2. Below the VIEWS logo are quick links to data resources and information, such as user's guides, news and bulletins, and a current dataset inventory. The left-hand navigation bar provides links to the main web site sections. Descriptions of the content and capabilities of the main VIEWS sections are presented following the top-down organization of the left hand navigation bar.

Data and Metadata

The data and metadata section provides access to the integrated air quality datasets and related metadata in VIEWS. These resources are available via links from the *All Data* section or via the interactive *Metadata* and *Query Wizard* tools. The *Metadata Browser* is an interactive graphical browser used to display monitoring site locations and land features in a web-based Geographical Information System (GIS). This tool provides a map with zoom and pan capabilities, high-resolution geographical layers, and provides tabular metadata for single or multiple monitoring sites. The Metadata Browser incorporates the *active layer* concept common to GIS applications in which the user can select monitoring sites from an active geographical layer. For example, if the active *Counties* layer is selected, clicking on the map within a given county will select metadata for all sites in that county. Unique to VIEWS is the ability to select a Class I area and display metadata for the representative IMPROVE monitoring sites, even if that site is not physically within the Class I area boundaries. In its tabular output, the Metadata Browser provides links to the *Site Browser* tool. The Site Browser contains detailed monitoring site metadata, links to topographic maps, and photographs of many IMPROVE sites.

The *Query Wizard* tool allows users to retrieve data by selecting a subset of monitoring sites, measured parameters, and time ranges from the VIEWS integrated database. Users are provided options to download data and metadata from multiple monitoring programs and select from a variety of output formats, including text files and charts.

The *ASCII Data* page provides links to a variety of files containing raw IMPROVE aerosol data and associated metadata. These data are provided in simple text format to allow easy access to relevant information.

The *Annual Summary* section of VIEWS provides access to data products in support of states' requirements to comply with the Regional Haze Rule. These

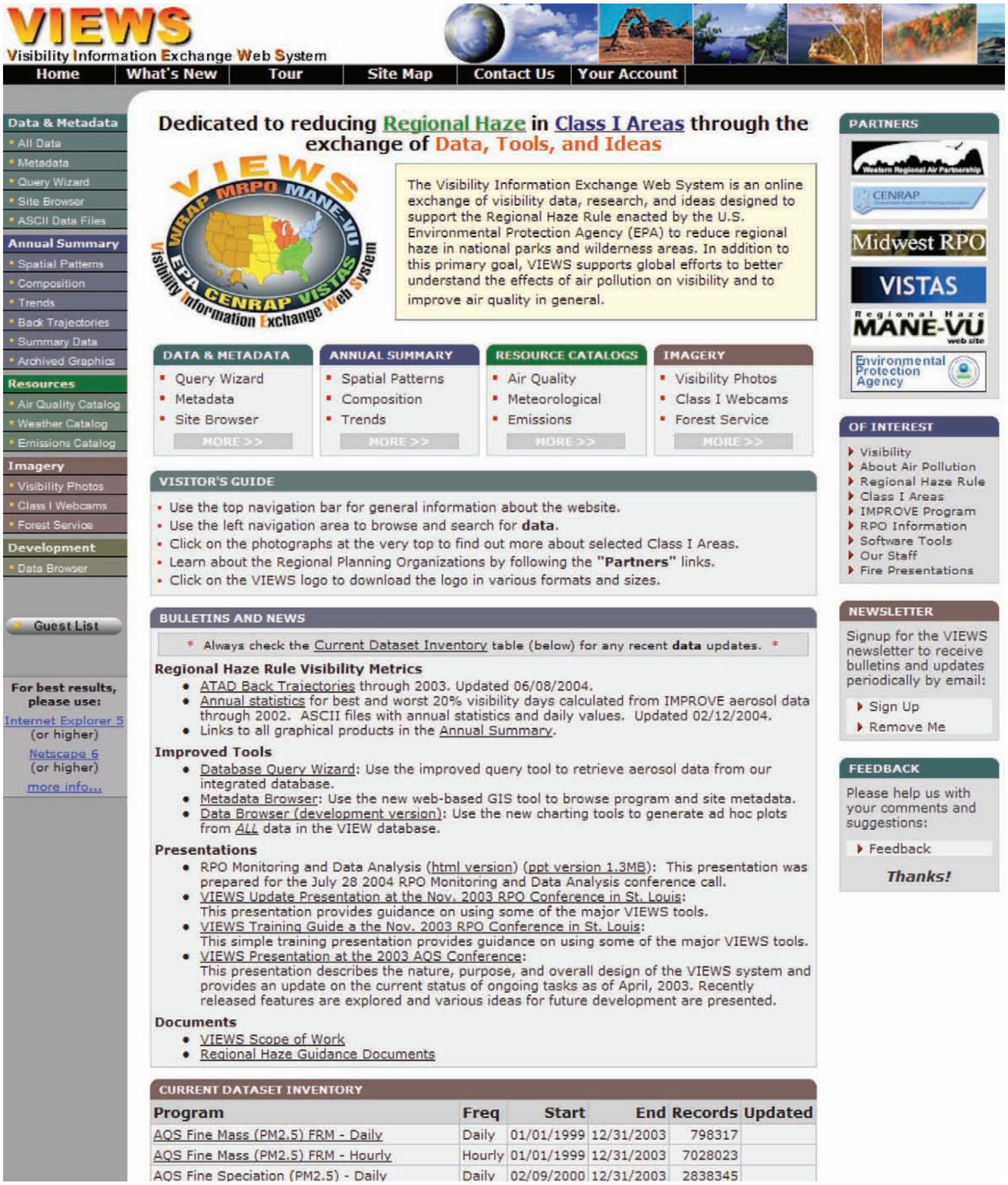

Figure 2. VIEWS home page.

data products include graphical summaries based on IMPROVE aerosol data. The *Annual Summary* data products are updated on a yearly basis as each complete year of IMPROVE data become available. Calculated visibility metrics catered to the Regional Haze Rule include the annual and 5-year mean of the best and worst 20 percent visibility days expressed in deciviews. Other parameters available from the Annual Summary are annual and seasonal means and a host of measured and calculated parameters based on IMPROVE aerosol data. Annual Summary data products are available via a series of graphical interfaces. These interactive web pages display visualizations of aerosol spatial patterns, composition information for specific data aggregations, trend lines of annual and multi-year time periods, and back-trajectories to indicate air mass source regions during specific days and haze events.

Rural Air Quality in the US

The primary data resource for VIEWS is the IMPROVE network. IMPROVE, the Interagency

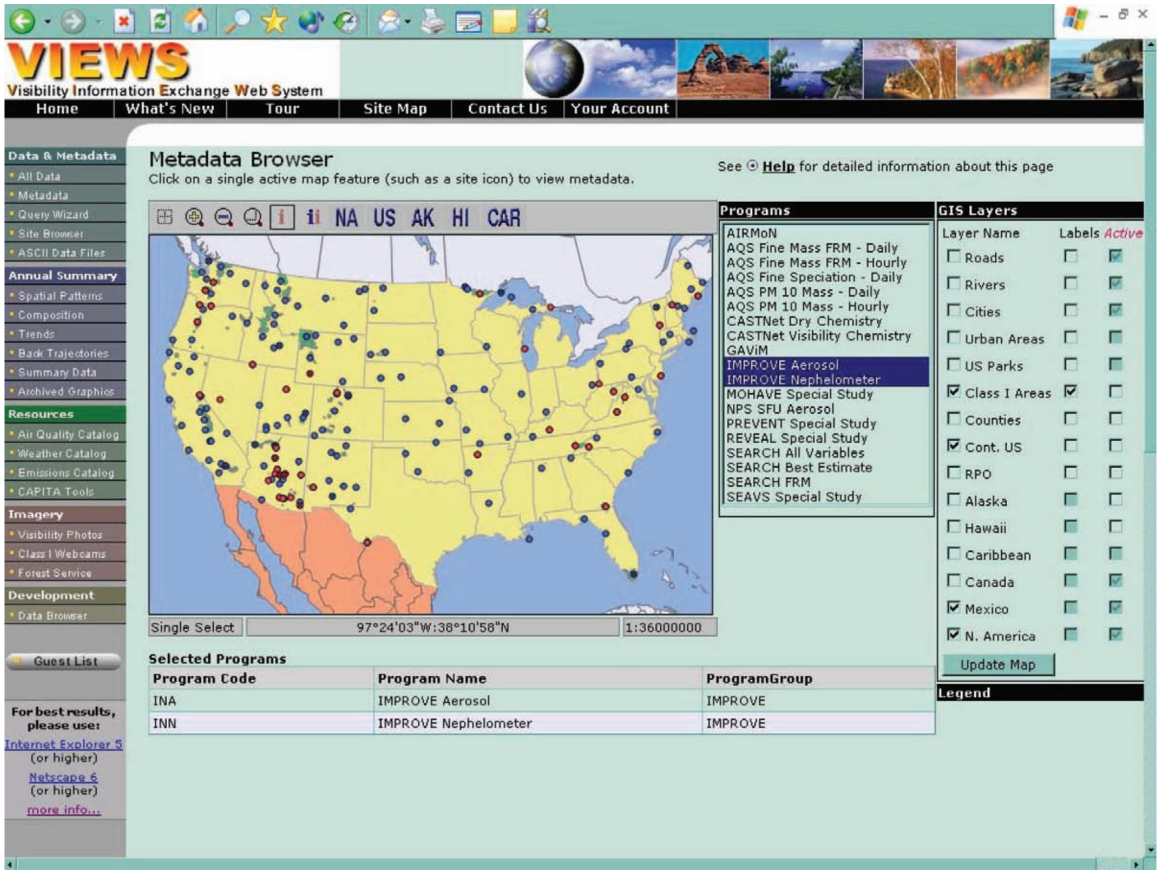

Figure 3. Class 1 areas and IMPROVE aerosol and visibility monitoring sites as presented in the VIEWS metadata browser.

Monitoring of Protected Visual Environment program, is a comprehensive monitoring program, supported by the EPA and federal land managers, to assess visibility and the chemical aerosols that degrade it at the 156 Clean Air Act Class 1 areas in the United States. Details about the IMPROVE program can be found on the VIEWS web site. The network includes 165 sites measuring fine particle aerosols and their chemical speciation every third day through out the year. Optical monitoring is also conducted at a subset of the aerosol sites facilitating the linkage between aerosol measurements and visibility. IMPROVE has been operating since 1988, but has only expanded to its current 165 sites since 2002. Figure 3 taken from the VIEWS metadata browser illustrates the current IMPROVE network along with the Class 1 areas in the continental US. The IMPROVE data include over 40 measured chemical components of the measured aerosol and some 17 calculated values based on the measurements. These data, all coming from rural locations selected to be representative of Parks and wilderness, represent a unique resource to provide information about the status of rural air quality in the US.

Without going into the details of how visibility is related to the concentration of aerosol chemical species, a simple view of visibility quickly indicates the Class 1 areas that are most likely impacted by air pollution. Figure 4 illustrates visibility from the latest year for which full data are available (2002). The current average, best (the best 20 percent of measured days) and worst (the worst 20 percent) standard visual ranges are mapped. The pattern of pollution displayed by these maps suggests that the worst rural air quality in the US is expected in the eastern central US and on the southwestern coast. The cleanest air is anticipated in the western interior regions of the country.

In addition to visibility, the conceptual impact model mentioned above addresses the deposition of sulfur and nitrogen. While IMPROVE does not measure deposition, it does measure concentrations that are related to dry deposition through often complex aerodynamic considerations. A simplified approach, that has been widely used, is to relate the concentration to dry deposition through a parameter called deposition velocity. While deposition velocity ranges from zero to quite high numbers on a diurnal basis, nevertheless dry deposition is at least expected to correlate with concentration. The IMPROVE network measures sulfur and nitrogen as their ammoniated aerosol components because it is as ammonia sulfate and

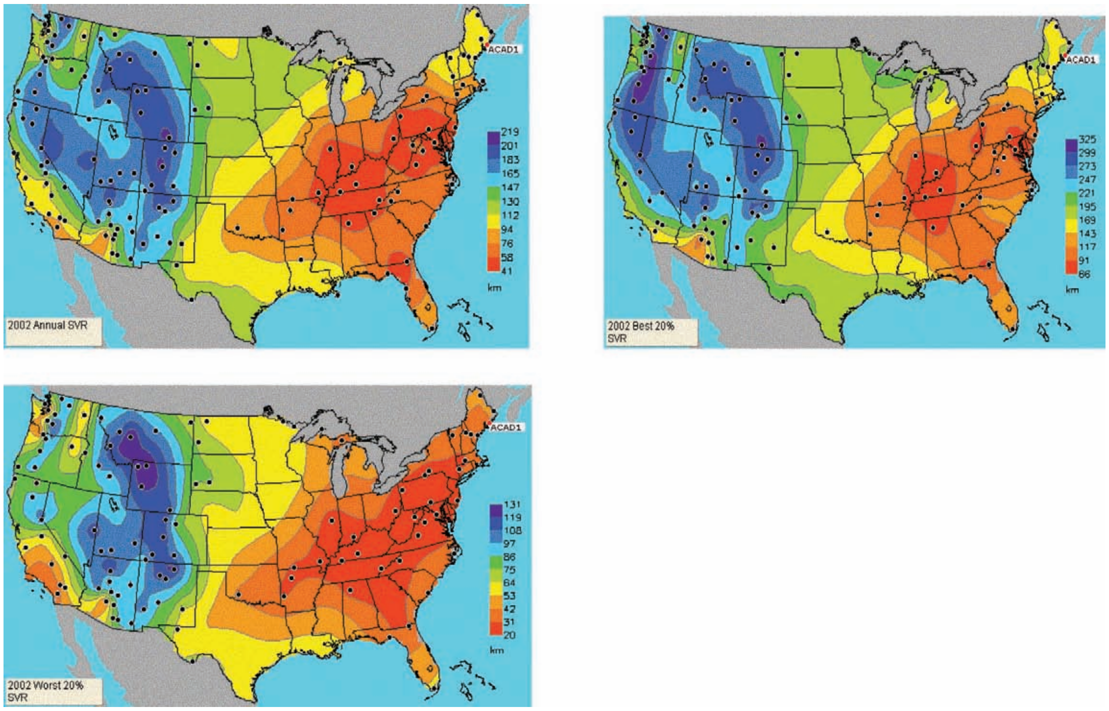

Figure 4. Visibility reported in kilometers of standard visual range (SVR) indicates how far one can see in each location. SVR has an inverse relationship with the extinction coefficient which is related to aerosol chemical concentrations and humidity.

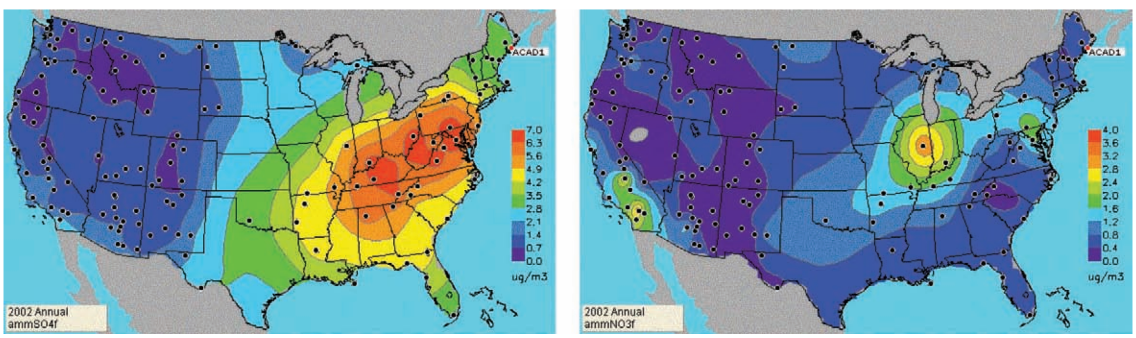

Figure 5. IMPROVE average measured ammonia sulfate and ammonia nitrate aerosol concentrations from 2002.

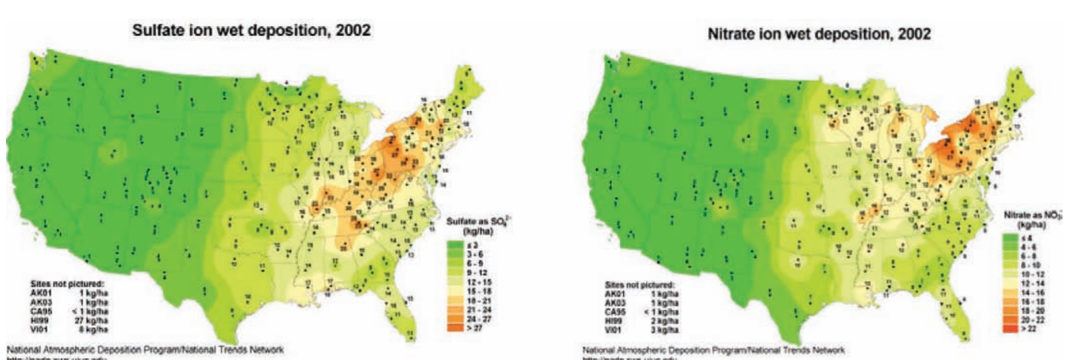

Figure 6. NADP measured sulfate and nitrate wet deposition in 2002.

ammonia nitrate that they generally are found in rural areas. Figure 5 shows the 2002 annual average concentrations of ammonium sulfate and ammonium nitrate.

A second component of deposition is so called wet deposition. Again while there are complex relationships with precipitation and wet deposition, it is reasonably approximated by measuring the chemistry of rain and snow collected in buckets. This is precisely what the National Atmospheric Deposition Program does at over 200 sites located around the US (http://nadp.sws.uiuc.edu/). Figure 6 presents wet deposition data from 2002 for sulfate and nitrate ion. There is also a network of dry deposition measurements, the Clean Air Status and Trends (CASTnet) network, that measures in rural areas, ambient aerosol, and gaseous concentrations, as well as relevant meteorological parameters to calculate dry deposition. CASTnet data are available for download from VIEWS. Figure 7 presents sulfur and nitrogen total deposition based on NADP and CASTnet data at National Park sites around the country for 2002 (http://www2.nature.nps.gov/air/Monitoring/drymon.htm).

Ozone is monitored by a large network of samplers in support of the EPA's National Ambient Air Quality Standard for that pollutant. There are over 4,000 State and Local Air Monitoring Stations(SLAMS) in this network; however, primarily monitors are sited to measure impacts on human health and are thus strongly biased toward urban areas. More characteristic of natural resources, the National Park Service monitors ozone in a number of National Parks (http://www2.nature.nps.gov/air/data/current/index.htm) and these results are displayed on the National Park Service web site in real time (fig. 8). A comprehensive picture of current and forecast air quality is available from EPA's AirNow web site (http://www.epa.gov/airnow/index.html). Figure 9 illustrates AirNow's presentation by showing the peak ozone concentrations that occurred on August 11, 2002.

Forest Service researchers have deployed networks of passive ozone samplers in forest areas, especially in California (Byterowicz and others 2003). These monitors have the capability of providing a more integral picture of ozone impacts on ecosystems.

Relevance to Critical Loads and Levels

The monitoring data that we have briefly outlined is needed before it will be possible to estimate critical loads. This is one, and only one component, of the critical steps in developing critical loads and levels. However, we hope we have illustrated that air quality monitoring data are available although not necessarily available in one location. The VIEWS web service has significant potential to display and allow manipulation of the data resources needed to project current air quality, the first of the three sets of knowledge displayed in figure 1 as being needed.

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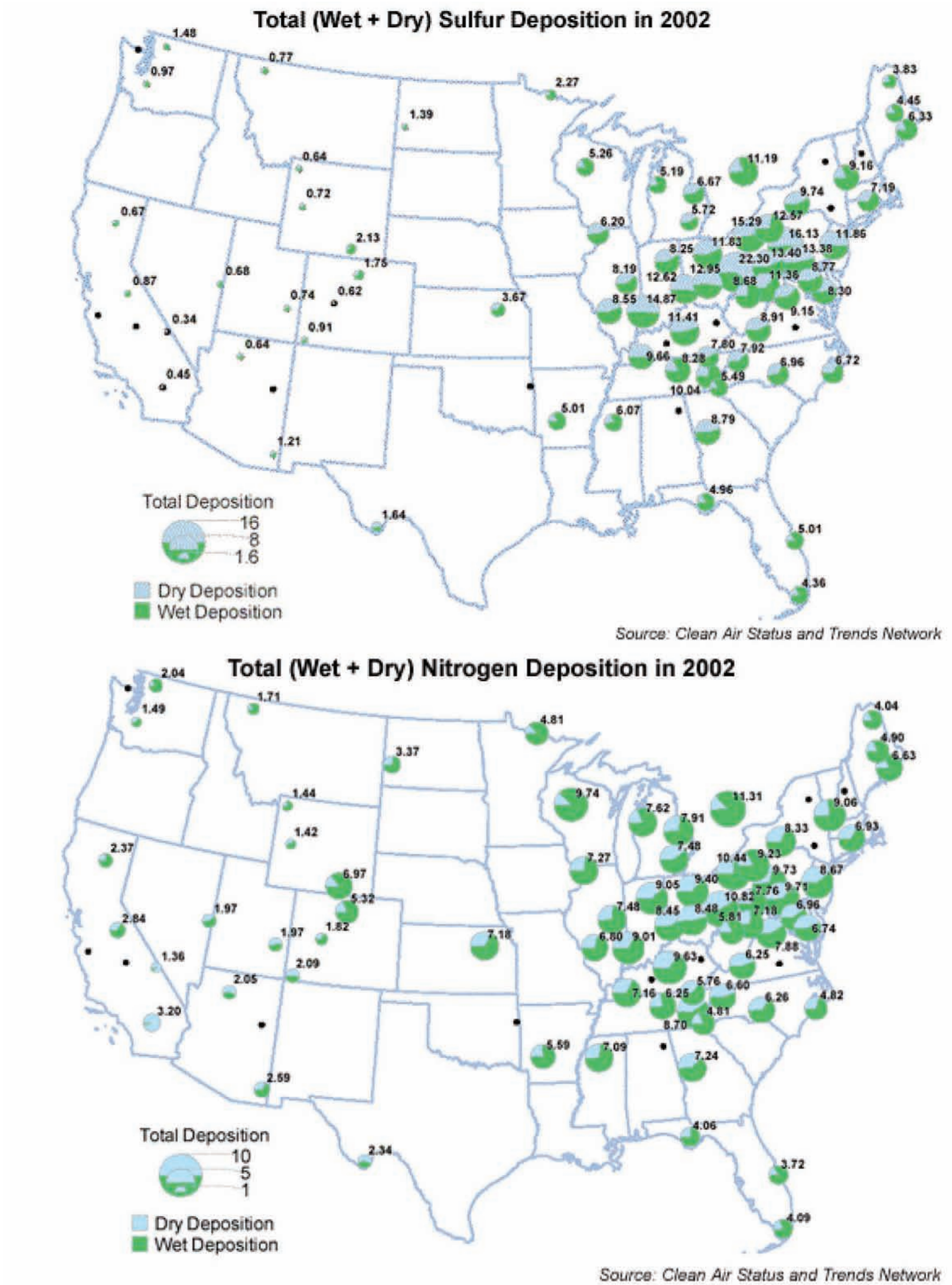


Figure 7. Total (wet-green and dry-blue) deposition at CASTnet sites in the US. Data are kilograms per hectare per year of sulfur and nitrogen deposition (from NPS web site http://www2.nature.nps.gov/air/Monitoring/drymon.htm).

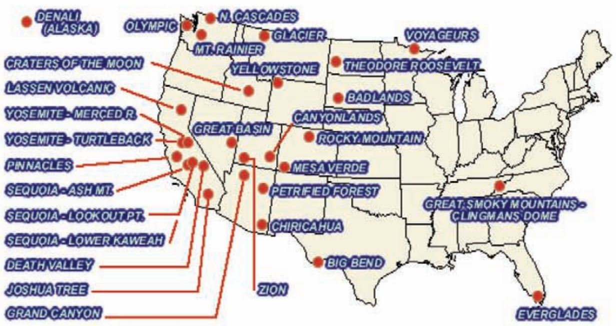
National Park Service
Nature & Science

National Park Service
U.S. Department of the Interior

Air Resources NPS >> Nature & Science >> Air >> Data >> Current

Current Ozone and Weather Data in National Parks

Select a Monitoring Site from the Map or List Below



AIR QUALITY WEB CAMS | EPA AIRNow | OZONE HEALTH ADVISORY | OZONE STANDARD EXCEEDANCES | OZONE DATA

Thursday August 19, 2004		
Monitoring Site	Current Hour of Data (Local Standard Time)	Current 1-Hour Average Ozone (ppb)
Badlands National Park, SD	1 PM	43
Big Bend National Park, TX	2 PM	50
Canyonlands National Park, UT	11 AM	63
Chiricahua National Monument, AZ	1 PM	47
Craters of the Moon National Monument, ID	1 PM	52
Death Valley National Park, CA	12 PM	77
Denali National Park, AK	11 AM	15
Everglades National Park, FL	2 PM	13
Glacier National Park, MT	1 PM	39
Grand Canyon National Park, AZ	1 PM	55
Great Basin National Park, NV	12 PM	53
Great Smoky Mountains Nat'l Park - Clingmans Dome, TN	3 PM	56
Joshua Tree National Park, CA	12 PM	71
Lassen Volcanic National Park, CA	11 AM	61
Mesa Verde National Park, CO	12 PM	53
Mount Rainier National Park, WA	12 PM	33
North Cascades National Park, WA	6 AM	1
Olympic National Park, WA	12 PM	20
Petrified Forest National Park, AZ	12 PM	58
Pinnacles National Monument, CA	11 AM	36
Rocky Mountain National Park, CO	12 PM	43
Sequoia National Park - Ash Mountain, CA	12 PM	86
Sequoia National Park - Lower Kaweah, CA	12 PM	81
Theodore Roosevelt National Park, ND	1 PM	44
Yellowstone National Park, WY	1 PM	43
Yosemite National Park - Merced River, CA	11 AM	67
Yosemite National Park - Turtleback Dome, CA	11 AM	77
Zion National Park, UT	12 PM	59

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Figure 8. The National Park Service ozone monitoring network presents the current status of ozone in the National Parks on their web page (http://www2.nature.nps.gov/air/data/current/index.htm).

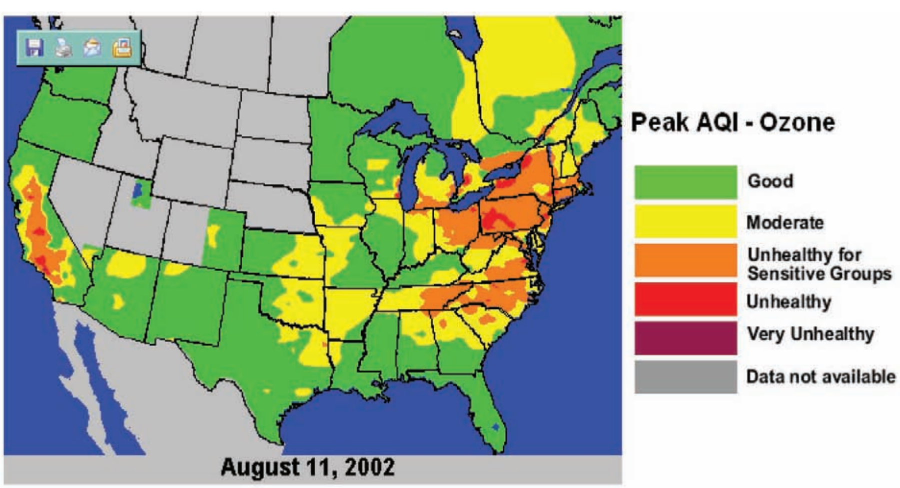

Figure 9. EPA's AirNow web site presents archived ozone data. Here a single day in August, 2002 is selected to show the peak Ozone concentrations that occurred on that day. Details are available at the web site (http://www.epa.gov/airnow/index.html).

Monitoring Forest Condition in Europe: Impacts of Nitrogen and Sulfur Depositions on Forest Ecosystems

M. Lorenz, G. Becher and V. Mues are forest scientists at the Federal Research Centre for Forestry and Forest Products, Leuschnerstr. 91, D-21031 Hamburg, Germany
E. Ulrich, soil scientist, Office National des Forêts, Boulevard de Constance, F-77300 Fontainebleau, France

Abstract—*Forest condition in Europe has been monitored over 19 years jointly by the United Nations Economic Commission for Europe (UNECE) and the European Union (EU). Large-scale variations of forest condition over space and time in relation to natural and anthropogenic factors are assessed on about 6,000 plots systematically spread across Europe. This large-scale monitoring intensity is referred to as "Level I." Causal relationships are studied in detail on about 860 intensive monitoring plots covering the most important forest ecosystems in Europe. This intensive monitoring is referred to as "Level II." Crown condition shows a very high spatial and temporal variation which is explainable mainly by tree age, weather extremes, biotic factors, and air pollution. At open field stations close to Level II plots, results of wet deposition measurements indicate that sulfate and nitrate concentrations decreased from 1996 to 2001, whereas ammonium concentrations fluctuated during the same measuring period.*

Introduction

Forest condition in Europe received increasing attention in the early 1980s as a response to growing concern that defoliation in parts of the forests in Europe could be caused by air pollution (Ulrich 1981, Schütt 1982). Since then forest condition has been a subject of scientific, political, and public debate, today being discussed within the wider context of sustainable forest management. The European-wide monitoring of forest condition was started 19 years ago by the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) under the Convention on Long-range Transboundary Air Pollution (CLRTAP) under the United Nations Economic Commission for Europe (UNECE) in close cooperation with the European Union (EU). Today, 38 European countries as well as Canada and the United States of America are participating, rendering the monitoring program one of the greatest of its kind worldwide. Canada and the United States of America do not use the same monitoring methods as the countries in Europe. However, they contribute national reports and are increasingly involved in the further development and joint application of monitoring methods in some fields of the program. The main objectives of the program are:

- to provide knowledge of the spatial and temporal variation in forest condition on the European scale and their relationships to environmental factors
- to contribute to a better understanding of the relationships between the condition of forest ecosystems and both natural and anthropogenic stress factors (in particular, air pollution) throughout Europe using a network of sample plots

The infrastructure, data base, and results created by ICP Forests and EU permit increasingly contributes to forest policy at national, pan-European, and global level on the effects of climate changes on forests, sustainable forest management, and biodiversity in forests.

The Monitoring System

The above mentioned two objectives are implemented by means of a systematic large-scale monitoring network and an intensive forest monitoring program. The large-scale monitoring (Level I) aims to assess the spatial and temporal variation of forest condition across Europe. It is therefore pursued on a large number of monitoring plots. Given the large number of plots, only a limited set of parameters can be assessed and hence little evidence of cause-effect relationships can be expected at Level I. Cause-effect relationships are the target of the intensive monitoring program (Level II) with its much larger set of monitoring parameters. The labor and cost intensive monitoring restricts the number of Level II plots. The numbers and the locations of the Level II plots were chosen by each country according to international guidelines

Table 1.

Surveys conducted	Level I	Level II
Crown condition	Annually (5,942 plots)	Annually (866 plots)
Foliar condition	Once (1,497 plots)	Every 2 years (855 plots)
Soil chemistry	Once (5,289 plots)	Every 10 years (865 plots)
Soil solution chemistry	-	Continuously (243 plots)
Tree growth	-	Every 5 years (859 plots)
Ground vegetation	-	Every 5 years (730 plots)
Atmospheric deposition	-	Continuously (499 plots)
Ambient air quality	-	Continuously (133 plots)
Meteorological condition	-	Continuously (202 plots)
Phenology (optional)	-	According to phenophases (59 plots)
Remote sensing (optional)	-	(157 plots

and national priorities. The intensive monitoring aims at the ecosystem scale rather than at the European-wide scale.

At Level I, approximately 6,000 permanent plots are systematically arranged in a 16 x 16 km transnational grid. In a small number of countries the plots are arranged randomly instead of systematically, but the plot density corresponds to that of the 16 x 16 km grid. In parts of Scandinavia even the density of the plots is smaller, which results in an under-representation of this part of Europe in the total Level I plot sample. On all Level I plots, annual crown condition assessments are carried out. Also, soil surveys were conducted on 5,289 plots, most of them in the years 1993 to 1995. A repetition of the soil survey is planned for 2006. Moreover, foliage surveys were conducted on 1,497 plots, most of them in the years 1992 to 1997.

For the intensive monitoring more than 860 Level II plots were selected in the most important forest ecosystems of the participating countries. The intensive monitoring aims at crown condition, soil condition, soil solution chemistry, foliage chemistry, tree growth, tree phenology, ground vegetation, meteorological condition, ambient air quality, and deposition. Not all of the respective monitoring activities are conducted on all Level II plots (table 1). The crown condition surveys on the Level II plots and on about half of the Level I plots include the assessment of several identifiable damage types such as insects, fungi, game, fire and abiotic agents. For Level II also the assessment of litterfall is foreseen and the respective method has been developed. All surveys within the program are based on harmonized methods documented in a regularly updated manual (Anonymous 2001). Since the establishment of the program, a comprehensive data bank on a wealth of monitoring parameters has been built up. In each participating country, the responsibility for the surveys lies with the national forest services. All countries are represented in the Task Force of ICP Forests, which is chaired by Germany. For the coordination of parts of the monitoring, data management, evaluation, and reporting, Germany hosts the Programme Coordinating Centre (PCC) at the Federal Research Centre for Forestry and Forest Products (BFH) in Hamburg, Germany.

Crown Condition

Approach

Crown condition is a fast reacting indicator for numerous environmental factors affecting tree vitality. It is assessed by means of visual assessments of defoliation and discoloration. This is an inexpensive method permitting about 135,000 sample trees to be assessed annually on the approximately 6,000 plots at Level I. The drawback of this approach is that the assessment results are influenced by the subjectivity of different observers. Several data quality assurance measures were therefore introduced. At the national level, observer bias is estimated by analyzing training and test results as well as results of control assessments (Schadauer 1991, Köhl 1991 and 1992). A high standard of training of the assessors can reduce observer bias. For individual species, the possibility to reach reliable results of the defoliation assessments at the national level has been shown (Eichhorn and Ackerbauer 1987, Dobbertin and others 1997). At the international level, the assessment results show systematic inconsistencies between different countries (Innes and others 1993). Several efforts are undertaken to identify and reduce such systematic inconsistencies by means of cross-calibration and inter-comparison courses as well as by means of photographic techniques.

Spatial and Temporal Variation

Trees of the six most frequent species having been assessed continuously at Level I between 1989 and 2002 reveal in general increasing defoliation; however, with great differences between individual species (fig. 1). The increase is very obvious for maritime pine (*Pinus pinaster*), as well as for holm oak (*Quercus ilex* and *Quercus*

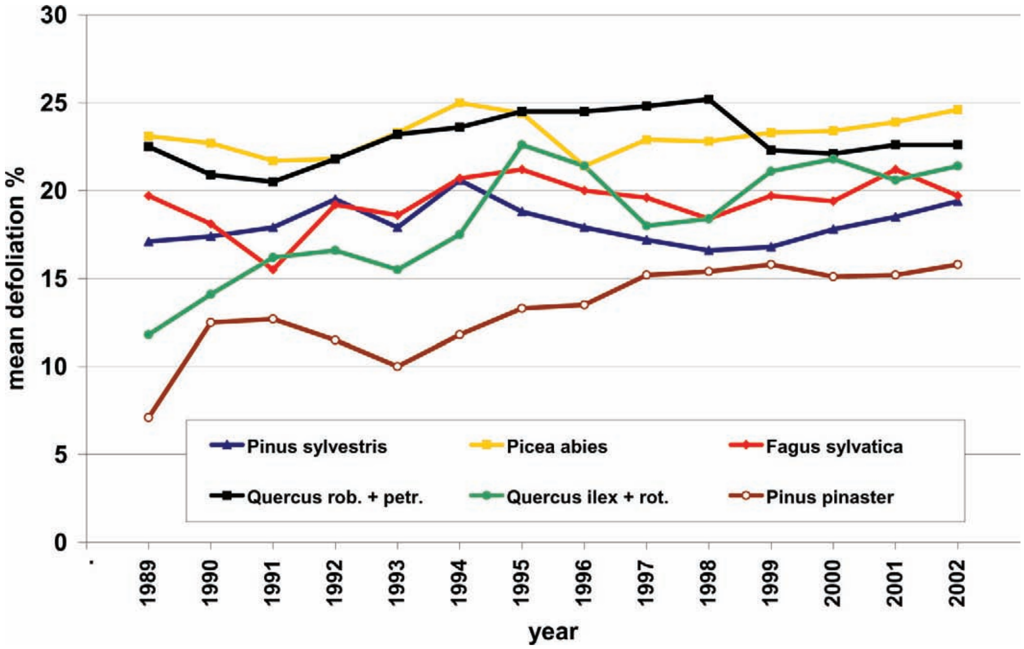

Figure 1. Development of mean defoliation of the six most frequent species. Number of trees: Scots pine (*Pinus sylvestris*), 2521; Norway spruce (*Picea abies*), 2988; pedunculate oak (*Quercus robur)* and sessile oak (*Q. petraea*), 1237; common beech (*Fagus sylvatica*), 2620; maritime pine (*Pinus pinaster*), 1360; and holm oak (*Quercus ilex* and *Q. rotundifolia*), 2243.

rotundifolia). Defoliation of Scots pine (*Pinus sylvestris*) and Norway spruce (*Piceas abies*) was higher in 2002 than in 1989; however, showed large annual fluctuations over the period of observation. Scots pine recovered markedly from its high defoliation in 1994; however, its defoliation has been increasing again after 1998. No trend at all is revealed for the defoliation of common beech (*Fagus sylvatica*), as well as for pedunculate oak (*Quercus robur*) and sessile oak (*Quercus petraea*). The latter two species reveal an obvious recovery from a high of defoliation in 1998 (Lorenz and others 2003). The mean development of defoliation across Europe (fig. 1) does not reflect the high spatial variation of defoliation and its development, or any causes related to it.

In recent multivariate and geostatistical studies (Lorenz and others 2002), both the temporal and the spatial trends in mean plot defoliation of Scots pine (1,313 plots) and common beech (399 plots) were evaluated in relation to:

- the presence of biotic agents (insects and fungi) according to crown condition assessments
- the amount of precipitation from January to June provided by the Global Precipitation Climatology Centre (GPCC)
- the deposition of S, NOx, and NHy as modeled by the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP)

The only significant – but weak ($r^2 = 0.44$) – statistical relationship found is the positive correlation between defoliation of Scots pine and sulfur deposition. This is explained by the high number of Scots pine plots in areas of previously high defoliation and sulfur depositions particularly in parts of Poland, the Czech Republic, Slovak Republic, and Baltic States. Figure 2 shows the decrease in defoliation of Scots pine in these areas from 1994 to 1999. Comparatively small areas of increasing defoliation in Bulgaria and Norway were explained by weather extremes and *Gremmeniella abietina* attacks, respectively, by the national forest services. The temporal trends in the defoliation of common beech show a more heterogeneous spatial pattern with several spots of improvement and deterioration scattered across Europe. Frequently reported stressors influencing the condition of common beech are drought and frost. The spatial variation of defoliation of both Scots pine and common beech was largely explained by stand age and by the variable "country." The correlation with the latter variable reflects partly the above mentioned systematic methodological differences or differences in forest history between countries. The correlation between defoliation and stand age has been recognized since the first crown condition surveys. It seems plausible that this reflects at least partly the natural thinning of the crown with increasing tree age.

Nitrogen and Sulfur Depositions

Approach

In accordance with its political mandate under CLRTAP, ICP Forests is paying particular attention to the effects of air pollution on forests, among the multitude of other factors affecting forest condition. Indirect effects of

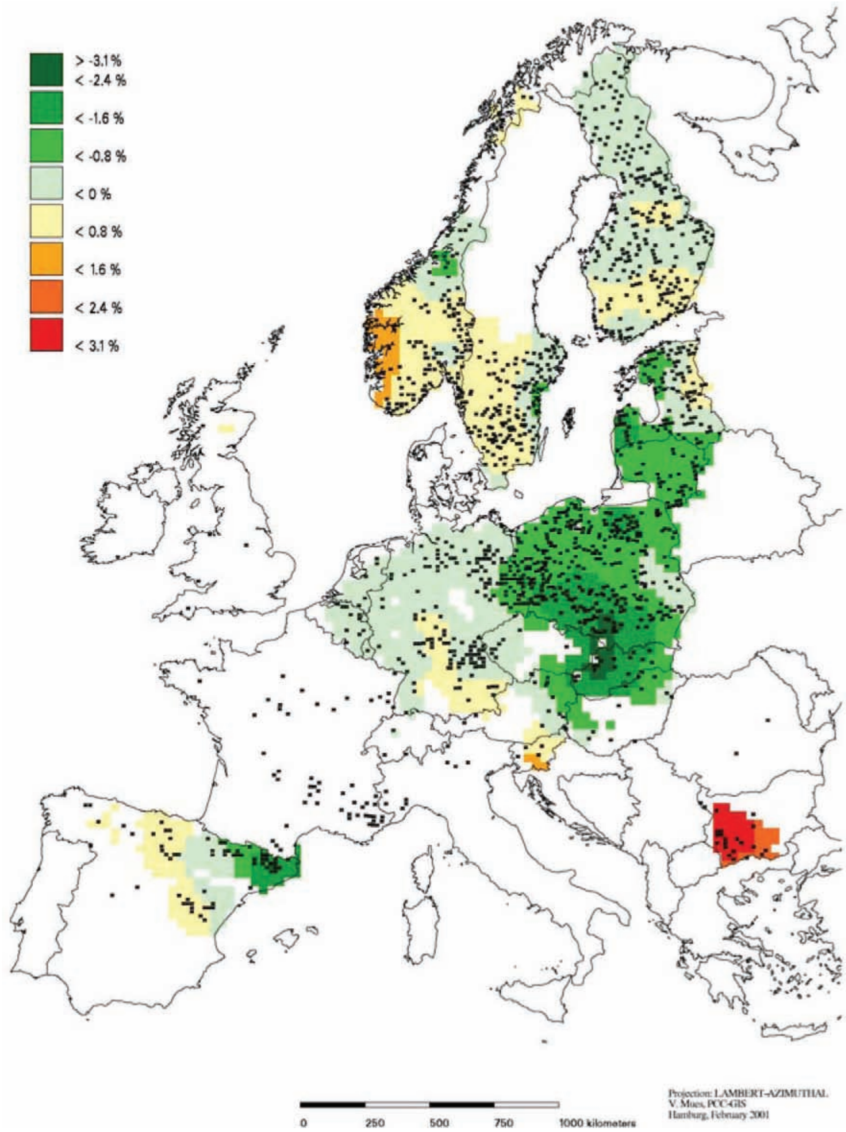

Figure 2. Kriged temporal trends of defoliation (changes in defoliation in percent points) of Scots pine (*Pinus sylvestris*) from 1994 to 1999 (from Lorenz and others, 2002).

nitrogen and sulfur depositions via the forest soils have been described both by forest damage research (Ulrich 1981) and by forest condition monitoring (De Vries and others 2001). On Level II plots, total atmospheric deposition under canopy is derived by adding throughfall and (for common beech because of its smooth bark) stemflow, while correcting for the effects of element interactions with the canopy (uptake and leaching) using bulk deposition. Bulk deposition is measured in the open field close to the Level II forest plots. It reflects the local air pollution situation and provides a reference for the measurements under canopy. The methods and results of a study of the temporal development and the spatial variability of nitrate (N-NO_3), ammonium (N-NH_4), and sulfate (S-SO_4) are described, based on the Level II bulk-deposition data expressed in terms of annual mean concentration. Results of an estimation of critical loads for nitrogen and acidity follow.

Concentrations of Sulfur and Nitrogen in Bulk Deposition

Bulk deposition expressed in terms of annual mean concentration in deposition samples was calculated as the volume weighted average in mg/l (Farmer and others 1987). For mapping concentrations across Europe, mean plot-wise ion concentrations over the years 1999 to 2001 were calculated. For tracing and mapping trends, a trade-off had to be made between the length of the time span on the one hand and the amount of data (number of countries having contributed to the data pool) on the other hand. Taking into account these two aspects, the time period 1996 to 2001 was rated as most suitable. For the quantification of temporal changes, linear regression was used. With the years of assessment as predictor and annual mean ion concentration as target variable for each plot, linear relationships were obtained. The slopes of the linear equations were statistically tested and depicted in maps according to the following classification:

- negative slope, error probability 5% and less
- negative slope, error probability more than 5%
- positive slope, error probability 5% and less
- positive slope, error probability 5% and more

It must be stressed that conclusions about temporal changes in ion concentration based on such short time series can only be made with great reservations. Nevertheless, there is no doubt about temporal changes in annual concentration of nitrate, ammonium and sulfate in bulk precipitation. Likens and Bormann (1977) showed their evidence for watershed ecosystems in New England. Ulrich and Lanier (1999) developed a national indicator based on national volume-weighted mean concentrations, which was used by Ulrich (2003) for the French intensive monitoring network "RENECOFOR." They found linear trends in nitrogen, sulfur, calcium, and magnesium concentration between 1992 and 2002.

In central Europe, there is an obvious cluster of plots with high volume weighted nitrate ($N\text{-}NO_3$) concentrations ranging from > 0.5 to 0.65 mg/l. On about one-third of the plots in Poland and northern Germany, concentrations are > 0.65 to 2.6 mg/l. In the other parts of Europe, the concentrations are clearly lower, showing concentrations between 0.1 and 0.5 mg/l (fig. 3). The concentrations of ammonium ($N\text{-}NH_4$) and sulfate ($S\text{-}SO_4$) show similar spatial patterns as those of nitrate, for example, a cluster of high concentrations in central Europe, with particularly high concentrations in Poland.

The temporal development of nitrate concentrations reflects the statistical uncertainties inherent to the short time series. Most plots do not show statistically significant changes in concentrations between 1996 and 2001. However, the share of plots with no significant decrease (69.0%) and the share of plots with significant decrease (15.3%) in concentrations sum up to 84.3%. This may be cautiously interpreted as indicating an overall decrease in nitrate depositions. The temporal development of ammonium is affected by similar statistical uncertainties resulting from the short observation period (Fischer and others 2004). Compared to nitrate and ammonium, the temporal development of sulfate concentrations shows a much more pronounced decrease from 1996 to 2001 (fig. 4). Decreases in sulfate concentrations were found on 89.4% of the investigated plots. On 44.8% this decrease is statistically significant. These plots do not reveal a pronounced spatial pattern. However, those plots showing increasing sulfate concentrations are clustered in Poland. The obvious decrease in sulfate concentrations is also evident in the graph of the temporal development of mean plot concentrations on all plots for each year from 1996 to 2001 (fig. 5). This reflects the successful reduction of sulfur emissions over more than two decades under CLRTAP of UNECE. Nitrate concentrations are also decreasing, but the decrease is less obvious than for sulfate. Linear regressions of the time series yield stable statistical parameters for both sulfate and nitrate. In contrast, this is not the case for ammonium concentrations. They show a fluctuating development over the period of observation.

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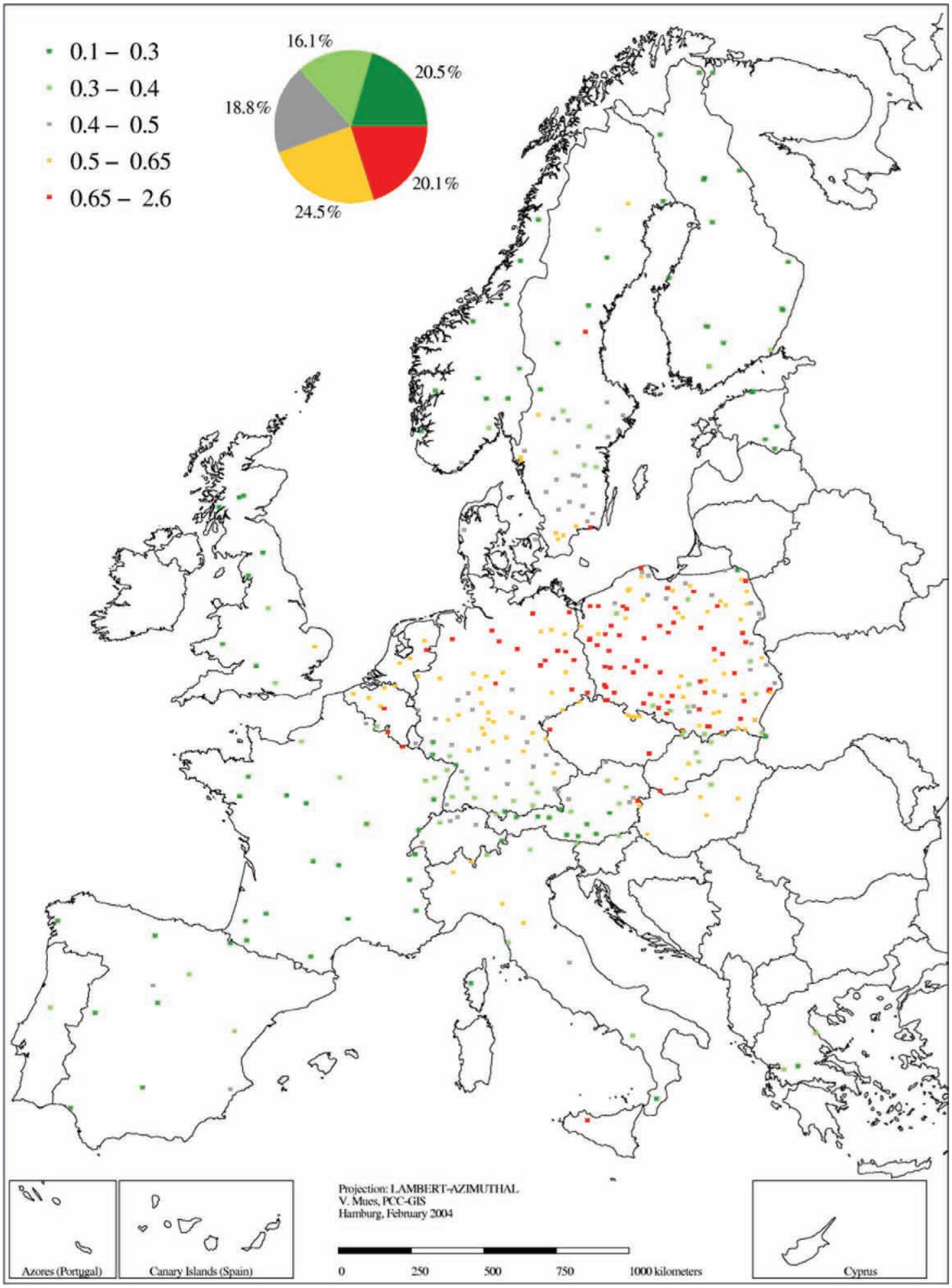

Figure 3. Geographic variation of the volume weighted mean N-NO_3 concentrations in mg/l between 1999 and 2001 on 409 Level II plots.

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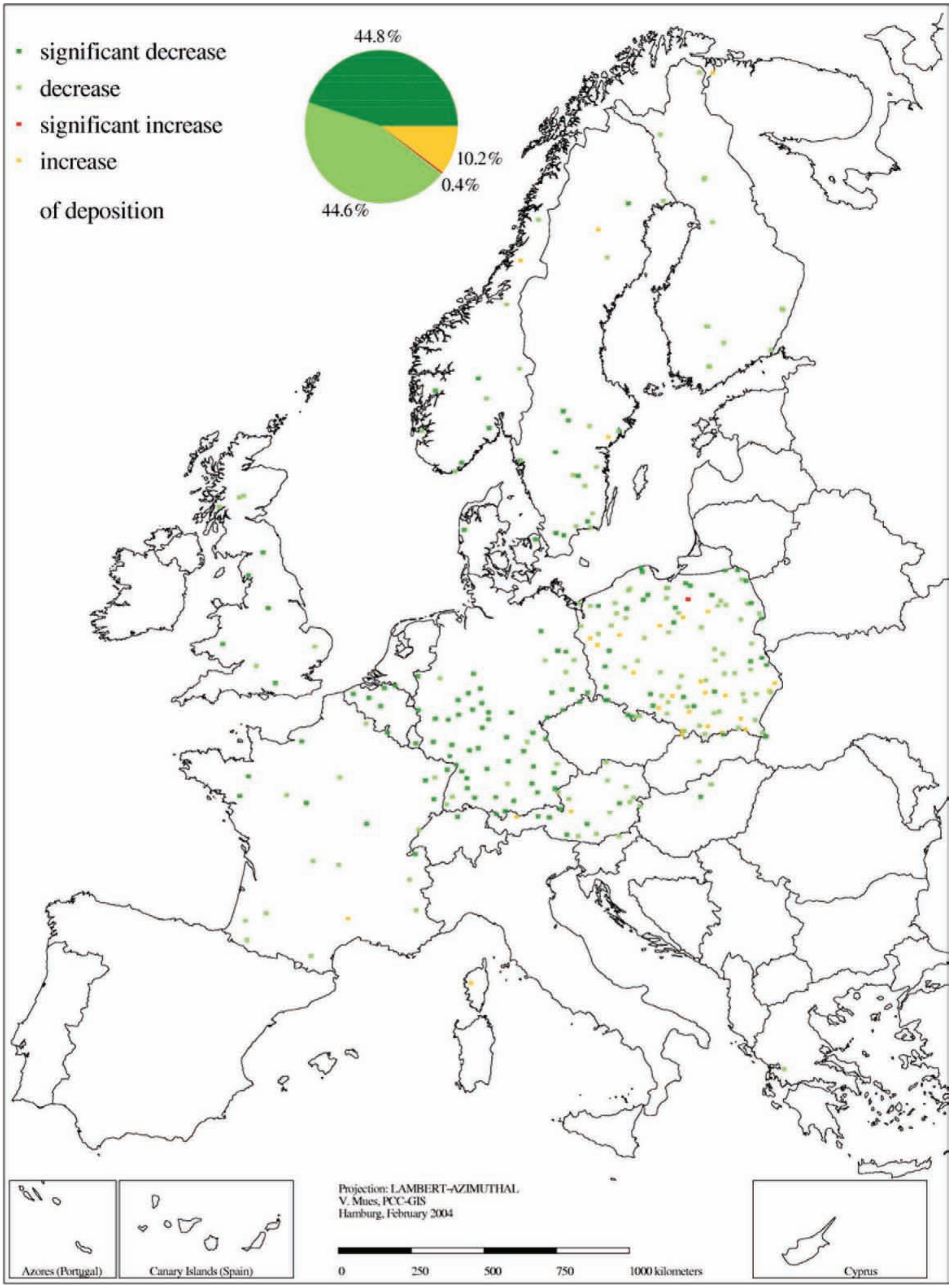

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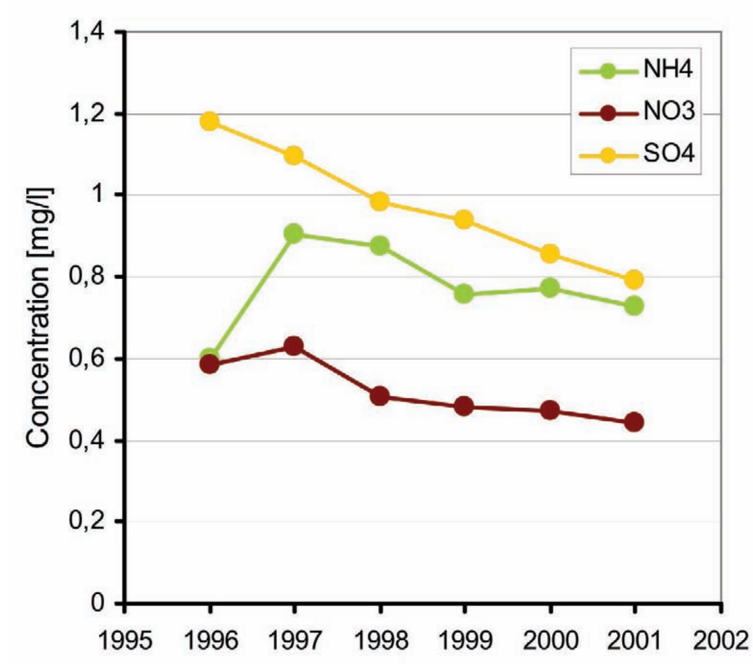

Figure 5. Development of the volume weighted mean concentrations in mg/l between 1996 and 2001.

Critical Levels as Applied to Ozone for North American Forests

Robert C. Musselman, Plant Physiologist, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO

Abstract—*The United States and Canada have used concentration-based parameters for air quality standards for ozone effects on forests in North America. The European critical levels method for air quality standards uses an exposure-based parameter, a cumulative ozone concentration index with a threshold cutoff value. The critical levels method has not been used in North America, but efforts are now being initiated in the United States and Canada to use the critical loads concept for nitrogen and sulfur deposition to forest and aquatic ecosystems. It is expected that if this effort is successful, the critical levels approach might also be used for ozone effects on forests in North America. Although the European exposure-based or the newer flux-based critical levels standard may seem to be an improvement over the concentration-based United States and Canadian standards in relating plant response to ozone, the most appropriate ozone critical level index for plant response includes a flux-based parameter that incorporates plant defensive mechanisms. Forest plots and monitoring protocols are operational in Europe to obtain data used in determining critical levels for ozone. Similar plots should be established in the United States and Canada to begin collection of field data needed for determining critical levels for ozone in North America. The plots should be established in coordination with current Forest Health Monitoring (FHM) plots in the United States and long-term forest health plot networks in Canada. Current North American ozone monitoring networks should be expanded to obtain initial ozone data for these forest health monitoring plots.*

Ozone and Plant Response

Ozone is recognized as the air pollutant most harmful to vegetation (de Vries and others 2003, Krupa and others 2001, US EPA 1996). Yet it has been difficult to identify metrics that relate ambient ozone exposure to plant response. Active monitoring using EPA equivalency protocols for continuous ozone monitoring summarizes continuous data observations as hourly averages. Since almost all of the routine ozone monitoring of ozone in the US and Canada is recorded and/or summarized as hourly averages, it seems logical that these values have been used in the determination of a metric for the air quality standards. Various metrics of the one-hour average ozone concentrations have been used to summarize ozone to relate to vegetation response. Research has determined (Musselman and others 1994, Musselman and Massman 1999, US EPA 1996) that the ozone parameters most closely related to vegetation response are those that:

- Are cumulative throughout the growing season,
- Preferentially weight the higher concentrations, and
- Include time periods when stomata are open and ozone is taken up into plant tissue, and when the plant tissue is most sensitive to ozone.

The hourly ozone values can be used in calculation of cumulative ambient exposure of ozone to vegetation throughout a growing season. Also, the hourly ambient ozone concentration database can be used to quantify the high concentrations of ozone that impact vegetation. This is often accomplished by using a threshold value and considering concentrations equal to and above or only above that value in the index. Determination of stomatal response of vegetation requires stomatal conductance data not associated with ambient ozone concentrations but important for ozone flux into plant tissue. Stomatal conductance data are known only for a few plant species, and the data were mostly obtained from controlled environment experiments rather than from plant growing under natural conditions in the field. Thus, it is difficult to estimate ozone flux for a large diversity of vegetation and changing environmental and ozone conditions across the United States. An additional factor in the usefulness of ozone flux and its relationship to plant response is that defensive mechanisms within plant tissue must be considered in formulating a flux-based standard.

It is important to clarify the definitions of concentration, exposure, flux, and dose when discussing ozone and plant response, since these terms have been given different meanings over the past few decades (Fowler and Cape 1982, Grünhage and others 1999, Runeckles 1974). The definitions here have recently been adopted by the US EPA (2004).

- Concentration of ozone is the number of moles of ozone per unit volume of air.
- Exposure is the product of the concentration of ozone and the length of time that vegetation is exposed to that pollutant.
- Stomatal flux is the rate of uptake of ozone through stomata.
- Dose is the instantaneous stomatal flux of ozone integrated over time, or the total amount of pollutant taken into plant tissue through stomata over time.
- Effective flux is the balance between flux and defense, since detoxification mechanisms are present in leaf tissue resulting in not all the ozone being taken up being associated with vegetation injury or damage.
- Effective dose is the integral over time of the effective flux.

As one moves down this list of ozone parameter indices, the relationship of the parameter to plant response increases. Therefore, it is desirable to utilize ozone metrics for air quality standards to protect vegetation that use parameters nearer the bottom than nearer the top of the list.

Current U.S. Air Quality Standard

The United States has implemented the Clean Air Act (CAA) amendments of 1970 (Public Law 91-604) and the Environmental Protection Agency is required to promulgate primary and secondary National Ambient Air Quality Standards (NAAQS). The primary NAAQS is to "protect the public health, allowing an adequate margin of safety;" and the secondary NAAQS is to "protect the public welfare from any known or anticipated adverse effects associate with the presence of such air pollutant in the ambient air." According to the CAA, "public welfare" includes, but is not limited to "soils, water, crops, vegetation, manmade materials, animals, wildlife, visibility and climate."

NAAQS are required to be reviewed every five years. A summary document called the Air Quality Criteria Document (AQCD) is prepared based on the latest scientific knowledge and is extensively peer reviewed and open to public review. From the background AQCD document, the EPA Office of Air Quality Planning and Standards prepares an analysis (OAQPS Staff Paper) that is reviewed by an independent review board, the Clean Air Scientific Advisory Committee (CASAC). CASAC provides a "closure letter" to the EPA Administrator stating their recommendation for the ozone standard.

The first NAAQS for ozone was in 1971. Additional AQCDs for ozone have been prepared in 1978, 1984, 1993, and 1996 with subsequent NAAQS determined based on the scientific information in the AQCDs. Based on the latest scientific information in the 1996 AQCD for ozone "Air quality criteria for ozone and related photochemical oxidants" (http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=2831), the EPA prepared a OAQPS Staff Paper published in 1996 that recommended an exposure-based secondary standard of the SUM06, 12 hr/day, 3-month index based on vegetation response to ozone. This index incorporates a cumulative exposure based ozone parameter using a threshold ozone concentration, and it accounted for the time period during the day when stomatal flux is expected to be at its maximum. This recommended secondary standard was different from the recommended concentration-based primary standard.

The CASAC reviewed the 1996 AQCD and the 1996 OAQPS Staff Paper, but could not reach a consensus and "come to closure" on the form of a secondary standard for ozone. Therefore, the EPA Administrator's decision in 1996 was that the secondary standard for ozone should be the same as the primary standard; reasoning that the new more stringent primary standard for public health would provide sufficient protection for public welfare (vegetation). Thus, the current United States primary and secondary ozone NAAQS (promulgated July 1997) is 0.08 parts per million (ppm) for an 8-hr average. The standard is exceeded when the fourth highest daily 8-hr average for ozone over the last three years is greater than 0.08 ppm (0.084 effective when rounded). This United States NAAQS for ozone is not an exposure-based standard, since it is not cumulative. Nor does it preferentially weight the higher concentrations or consider stomatal uptake. Thus, the relationship between the concentration based NAAQS and vegetation response is weak. Nevertheless, improving air quality by reducing ozone to become compliant with the current NAAQS will likely reduce ozone impact on vegetation, since control strategies will likely reduce the higher hourly ozone concentrations.

For areas in non-compliance with NAAQS, the responsible local, tribal, or state air quality regulatory agencies develop "State Implementation Plans" (SIPS) which identify air pollution control strategies that will be implemented to reduce concentrations of the pollutant below NAAQS. The CAA also requires the "Prevention of Significant Deterioration" (PSD) to "protect the public health and welfare from any actual or potential adverse effect from… air pollution…not withstanding attainment and maintenance of NAAQS." The PSD section of the CAA provides protection of Air Quality Related Values (AQRVs) for certain national parks, wildlife refuges, and wilderness areas, through establishment of ceilings on additional amounts (increments) over baseline levels in these areas (called Class I). The New Source Review (NSR) process is used to evaluate the potential affect of pollutant sources on primary and secondary receptors.

Although the US has not adopted an exposure-based NAAQS, some federal agencies in the US are utilizing exposure-based parameters to evaluate ozone effects on Class I areas in their NSR analysis of ozone effects on forest vegetation, in response to the requirements of the National Environmental Protection Act (NEPA). A web based software tool (http://216.48.37.155/calculator/calculator.htm) has been developed to summarize ambient hourly ozone data to determine the W126 and N100 (as recommended by FLAG 2000), SUM06, maximum daily 8-hour averages values, percentile distributions, average concentration for each hour of the day, and frequency distributions for use in this evaluation. Using results from experimental studies in open top chambers, the W126 and N100 values are used as inputs to estimate biomass reductions of key forest species from ozone exposures.

A new External Review Draft AQCD for ozone will be available in October 2004 (http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=22411). The 2004 AQCD again documents that vegetation is very sensitive to ozone and that plant response shows a closer relationship to cumulative indices that preferentially weight the higher concentrations. The document also discusses ozone flux, effective flux, and effective dose in detail, and reviews a growing number of literature citations that now recognize that ozone taken up into plant tissue is more closely related to vegetation response than is ambient ozone concentration, regardless of how the ambient ozone concentrations are summarized (Karlsson and others 2003, Massman and others 2000, Musselman and Massman 1999). Nevertheless, the United Sates has always used a concentration basic metric to determine air quality standard for ozone, and the primary and secondary NAAQS for ozone have always been the same. Whether the forthcoming summary EPA Staff Paper and CASAC review recommends an exposure, dose, or effective dose-based secondary NAAQS for ozone that is different from the current concentration-based primary standard, and whether the EPA Administrator agrees, remains to be determined. However, changing from a concentration-based standard to an exposure, dose, or effective dose-based standard seems unlikely.

Current Canada Air Quality Standards

Canada-Wide Standards (CWSs) are established by the federal government and provincial and territorial Environment Ministers working together under the framework of the "Canada-wide Accord on Environmental Harmonization" (http://www.ccme.ca/ccme). CWSs are developed using sound scientific foundation and a risk-based approach. The CWSs developed are presented to the Provincial Ministers. The "Canada-wide Environmental Standards Sub-agreement" sets standards for the provincial governments to jointly agree on priorities to develop standards and to prepare complementary work plans to achieve those standards. Current ozone Canada-Wide Standards (CWSs) for human health and the environment, established in 2000, is 65 ppb, fourth highest daily maximum 8-hour average concentration, three-year average. Compliance is required by 2010, with a review scheduled for 2005. Note that the Canadian standard is similar to that for the United States, demonstrating that the two countries closely coordinate their ozone air quality standards. It is expected that Canadian regulators will also retain concentration-based CWSs based on ambient hourly ozone concentration data. As with the United States NAAQS, the CWSs for Canada are concentration based. They are not cumulative nor do they preferentially weight higher concentrations, and they do not consider stomatal uptake into plant tissue.

Current Europe Air Quality Standards

The European Union uses critical levels or critical loads as a basis for evaluating pollutant effects on vegetation and the subsequent setting of exceedance levels. The basis for the critical levels/loads concept is the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) that provides international cooperation for air pollution abatement in the European Union. CLRTAP provides a framework for scientific cooperation and policy formulation and identifies specific obligation of the participating parties. Both the United States and Canada are parties of CLRTAP, but their participation has been inactive. CLRTAP established a Working Group on Effects (WGE). The WGE established a number of International Cooperative Programmes (ICPs), Working

Group Task Forces for providing a scientific basis for determination of critical levels/loads of pollutants for Europe. Critical loads are mapped by the ICP Modeling and Mapping Task Force based on scientific input from the various specialty ICP Work Group Task Forces, such as ICP-Forests and ICP-Vegetation. The information provided by the ICP Work Groups provides a sound scientific basis for the Co-operative Program for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe to formulate regulatory protocols for Europe.

European protocols use critical loads and/or critical levels to evaluate plant response to pollutants. The term critical level is generally used for gaseous air pollutants such as ozone which do not accumulate in plant tissue or ecosystems, while the term critical loads is used for pollutants such as nitrogen and sulfur which are deposited in ecosystems and accumulate over time to result in a cumulative loading on vegetation and ecosystems. Although the effects of ozone are cumulative, the pollutant itself is not cumulative in plant tissue or on non-plant surfaces. The critical loads and critical levels standards are exposure based, since they consider loading of a pollutant concentration over a period of time such as a growing season.

A critical load is defined as "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (UNECE 2004, chapter 5). Critical levels have been defined as "the atmospheric concentrations of pollutants in the atmosphere above which adverse effects on receptors, such as human beings, plants, ecosystems, or material may occur according to present knowledge (Karenlampi and Skarby 1996, UNECE 1996). Critical loads for pollutants have been defined similarly in the US by Federal Land Managers as "the concentration of air pollution above which a specific deleterious effect may occur" (FLAG 2000). More recently, the critical levels definition in Europe has been modified for vegetation to "concentration, cumulative exposure, or cumulative stomatal flux of atmospheric pollutants above which direct adverse effects on sensitive vegetation may occur according to present knowledge" (UNECE 2004, chapter 3). Note that "cumulative stomatal flux" could be called "dose" as defined above.

It is recognized that ozone is the most important regional air pollutant in Europe (de Vries and others 2003). Although the United States, Canadian, and European air quality standards all use hourly ambient ozone as a basis for calculation the ozone metric, the European critical loads concept is different from the ambient air quality standard used in the United States and Canada. The Europeans have adopted the AOT40 parameter as the index to determine critical levels for exposure of vegetation to ozone. The AOT40 is the sum of differences between the hourly ozone concentrations in ppb and 40 ppb in each hour when the ozone concentration exceeds 40 ppb. Since the AOT40 parameter is exposure based, utilizes a threshold, and is accumulated over the season for determination of critical levels, an AOT40 critical level should be more closely related to vegetation response than a concentration-only based standard like that used in the United States and Canada.

The European International Cooperative Programme (ICP) on Effects of Air Pollution on Natural Vegetation and Crops currently uses three different cumulative exposure methods to evaluate critical loads for ozone for crops, forests, and natural vegetation (http://icpvegetation.ceh.ac.uk). All three methods use hourly ambient ozone concentrations at the top of the canopy as the basis for quantifying the ozone critical loads for the evaluation. Plant response data for determining effects of critical levels of ozone are collected at or near ICP plots, or from controlled fumigation experiments. The three cumulative exposure based methods used for ozone are the Level I (AOT40) concentration based critical level, the VPD-modified concentration based critical level, and the Level II stomatal flux based critical level (UNECE 2004, chapter 3). The flux-based approach is used only for wheat and potato crops, since flux data are lacking for other crops and for forest trees and semi-natural vegetation. The concentration-based approach is used for all other agricultural crops, horticultural crops, semi-natural vegetation, and forest trees. For forest trees, the critical level for ozone is an AOT40 of 5 ppm-h, using the hourly concentration means at the top of the canopy (20m) from 1 April to 30 September. The VPD-modified concentration-based critical level is used only for injury for selected crops.

It is important to distinguish between injury and damage to vegetation from ozone. The definitions listed here have been adopted by the US EPA (2004).

- Injury is leaf necrosis, premature leaf senescence, reduced photosynthesis, reduced carbohydrate production and allocation, reduced growth, and/or reduced plant vigor.
- Damage is all effects that reduce the intended value or use of the plant. Included in this definition are reductions in economic, ecologic, or aesthetic value (US EPA 2004). Damage can be either yield loss or crop loss:
  - Yield loss is reduction in quality or quantity of the harvestable portion of a agricultural or forest crop from ozone.

- Crop loss is the reduction in the monetary value of the forest or agricultural crop due to ozone.

The European Level I assessment of ozone effects on vegetation is an exposure based analysis of injury. It is not appropriate to use the Level I assessment for yield loss, but it only should be used as an indication of relative risk of vegetation to ozone (Fuhrer and others 1997, Grunhage and others 1999, Karenlampi and Skarby 1996, Karlsson and others 2003). Level II assessment is designed to estimate effects of ozone on vegetation based primarily on ozone uptake and yield response models (Karlsson and others 2003). Stomatal flux data are used for this assessment. This dose-based critical level is beginning to be used in Europe to determine yield reductions for wheat and potato crops. However, the AOT40 exposure based critical level is now being used in Europe to determine yield loss (but not crop loss) for agricultural and horticultural crops, and for growth reductions in forest trees and semi-natural vegetation (UNECE 2004).

Although the dose-based approach would be expected to provide a better relationship between ozone and plant response and provide information to determine yield loss, limited data are currently available to implement this method. The Europeans are beginning to utilize stomatal flux and dose but not effective flux nor effective dose to determine critical levels for wheat and potato crops. Even where data are available for wheat and potato, the usefulness of this approach will be limited by lack of data on defensive mechanism that can greatly affect plant response once ozone uptake has occurred. Defensive mechanisms within plant tissue determine whether or not ozone taken into leaves is detoxified before it can injure plant tissue. Efforts have begun to quantify the defensive mechanisms in ozone plant flux response models (Barnes and other 2002, Massman and others 2000, Massman 2004, Plöchl and others 2000), but these defensive algorithms are not utilized in the current critical level models, and European efforts have concentrated on stomatal flux and dose when not using exposure-based ozone parameters, but not on effective flux or effective dose-based models.

Linking European ICP-Forests Plots and Forest Health Monitoring Plots in the United States and Canada to Critical Levels

Extensive networks of plots for forest health monitoring exist in the US, Canada, and in Europe. An extensive network for monitoring ambient ozone also exists in North America and Europe. Many of these monitors are in urban or suburban areas away from forested ecosystems, and may not be representative of ozone in remote forest ecosystems. Nevertheless, urban areas are continuing to expand in rural forested areas and the number of rural ozone monitoring stations has increased. Using statistical techniques, urban and rural ozone monitors can be used in combination to provide reasonable ozone exposure estimates across the landscape (Fraczek and others 2003, Lee and Hogsett 2001, Lefohn and others 1997).

It is important to obtain ozone data as near each forest health monitoring plot as possible, or to develop reasonable statistical estimates of ozone exposure at those sites. This is especially important in complex terrain where ozone can vary considerably over a short geographic area. Ozone monitors should be place in open areas exposed to prevailing winds to accurately determine ambient ozone levels. Samplers placed within a canopy will not be monitoring ozone to which the forest ecosystem is exposed, since ozone will already be absorbed by plant or non-plant surfaces before it reaches the sampler.

Protocols for air quality monitoring in North America and Europe require continuous monitoring, but only hourly averages of the continuous data are utilized for calculating ozone statistics for air quality standards. The hourly average ambient ozone concentrations are summarized as an 8-hr average for the concentration-based air quality standards in North American and as an AOT40 for the exposure-based critical levels in Europe. The hourly average concentrations are also utilized in the dose-based critical loads model used in Europe.

Canada has supplemented their urban active monitoring network with an extensive network of passive ozone samplers located in remote areas (Cox and Malcolm 1999). Similarly, extensive passive ozone networks have been established in California (Arbaugh and Bytnerowicz 2003) and in the Carpathian Mountains of Central Europe (Bytnerowicz and others 2002, 2004). The Carpathian network samplers were installed near forest health monitoring plots to assess ozone effects on forest health. The passive samplers are also being tested in Western Europe, and these have been installed at or near intensive monitoring plot locations (de Vries and others 2003). The advantages of the passive networks are low cost and no requirements for electric power allowing remote installation. The major disadvantages are 1) plants are sensitive to peak ozone concentrations (Musselman and Massman 1999) that are not captured in the cumulative passive ozone data, and 2) that since determination of exceedances of air quality standards and critical levels utilize hourly ozone data, passive data, which only calculates average concentration over a period of time, cannot be used to determine these exceedances.

Attempts have been made to calculate or model hourly average ozone data based on cumulative passive data (de Vries and others 2003, Krupa and others 2001, Tuovinen, 2002). It is generally understood that these models must be calibrated using active sampling data at each sampling site (Krupa and others 2001, Tuovinen 2002). This is because of the large amount of spatial (latitude, altitude, terrain) and temporal (seasonal, diurnal, meteorological) variability in ozone between sites. Relating active to passive data is particularly problematic in complex terrain. The models also do not account for the technical errors inherent with operation and analysis of the passive samplers (Tuovinen 2002). Nevertheless, some limited success has been made to determine ozone exposure dynamics based on passive sampling data when on-site calibration with active samplers and meteorological data has been deployed. The samplers can be placed in or near forest health plots to determine ozone loading at these sites. In areas where passive monitors suggest that ozone loading is high, active ozone monitors should be installed to relate forest condition and/or ozone symptomology to the dynamics of ozone exposure.

The European CLRTAP and ICP-Forests has been relatively successful in determining exposure-based critical levels for ozone effects on forest ecosystem in Europe. A basis for this success is the establishment of a network of field plots for monitoring ecosystem functioning and the effects of air pollution on the forest condition. The approach has been to describe spatial and temporal variation in forest condition (Level I), and to understand the relationship between forest ecosystem condition and air pollutants (Level II) (Haussmann and Lorenz 2004). The objective of these data is to provide information to ICP Modelling and Mapping for formulate policy to respond to air pollution stress.

The ICP-Forests network of monitoring plots has proven to be a valuable resource for determination of critical loads of nitrogen and sulphur in Europe. Consequently, Federal Land Managers in the United States and Canada are actively evaluating the critical loads approach for nitrogen and sulphur in North America. Researchers are beginning to develop critical loads for the northeast United States and southeast Canada (http://www.ecosystems-research.com/fmi/index.htm) based on model input data from various sources. It is expected that data available from ICP-Forest type plots would enhance this database. A series of demonstration plots is being explored to provide data for critical loads mapping in other regions of the United States. If these protocols are established for N and S in North America, protocols for determining critical levels for ozone could be implemented in North America. Although it appears that the United States and Canada currently will not be adopting a European Level II approach for determining ozone critical levels, the establishment of the ICP Forest monitoring plots would provide a valuable database to enable this possibility in the future.

Initial European Level I assessment of ozone-induced specific visible injury symptoms can be evaluated in or near forest health monitoring (FHM) plots if these plots provide open exposure to ambient ozone and if ozone sensitive plant species are present. Efforts have been made in the United States to establish specific plots near FHM plots that are more suitable for ozone biomonitoring, where visible oxidant stipple symptoms are recorded on up to three open grown ozone sensitive plant species. Data available from the nearby FHM plots, including biological and physiological information for individual sensitive species, and information on ecosystem structure and function, with accompanying ancillary ambient hourly ozone or extrapolated ozone data, will allow critical levels assessment of ozone effects on forest health in North America.

Air quality standards in the United States and Canada are based on concentration, and those in Europe are based on exposure with some new effort to base European standards on stomatal flux. Any effort in the United States and Canada to move beyond a concentration-based standard and beyond the European exposure and dose-based standard toward an effective dose-based standard will allow a more meaningful air quality standard for vegetation. Information provided from ICP plots and forest health monitoring plots, along with controlled fumigation experimental data, will facilitate this transition to an effective dose based standard.

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Canadian Experiences in Development of Critical Loads for Sulphur and Nitrogen

Shaun Watmough, biogeochemist, Department of Environmental and Resource Studies, Trent University, Peterborough, Ontario K9J 7B8, Canada
Julian Aherne, biogeochemist, Department of Environmental and Resource Studies, Trent University, Peterborough, Ontario, Canada
Paul Arp, Professor, Faculty of Forestry and Environment Management, University of New Brunswick Fredericton, NB, Canada
Ian DeMerchant, GIS specialist, Canadian Forest Service, Atlantic Forestry Centre, Fredericton, NB, Canada
Rock Ouimet, forest soil science scientist, Direction de la recherche forestière, Forêt Québec, Ministere des Ressources Naturelles du Québec, Sainte-Foy, QC, Canada

Abstract—*Critical loads are a broad-scale modelling approach designed to assess the potential risk of pollutants to ecosystems. A description of the methodology for estimating critical loads (sulphur and nitrogen) for acid deposition (CL(A)) for upland forests in eastern Canada is presented, using a case study in central Ontario. In eastern Canada, CL(A) have been calculated for upland forests, with the objective of maintaining the molar ratio of base cations to aluminium in soil solution above 10. In the current approach, nitrogen (N) dynamics including N fixation, N immobilisation and denitrification have been set to zero. Further, critical load estimates presented in this study do not include nutrient removals through harvesting, and dry deposition input is estimated to be 20 percent of wet (1994 to 1998) deposition. Critical loads were calculated separately for Ontario, Québec and the Maritime Provinces (New Brunswick, Nova Scotia and Newfoundland) using the same methods, but using different soil and forest databases. Mean area-weighted critical loads among provinces are similar, ranging between 273 eq ha^{-1} yr^{-1} (Newfoundland) and 512 eq ha^{-1} yr^{-1} (Ontario). Preliminary estimates indicate that more than 50 percent of the upland forest area in Ontario and Québec and between 10 (Newfoundland) and 33 percent (Nova Scotia) of upland forest in the Maritimes receive acid deposition in excess of the critical load. Current efforts are being directed toward improving the accuracy of critical load estimates and current exceedances using better estimates of dry deposition and harvesting removals, and investigating the linkage between exceedance of the critical load and adverse biological effects.*

Introduction

In Europe and increasingly in other parts of the world, the concept of critical loads has been applied to estimate acceptable levels of acid deposition (Posch and others 2001). A critical load is defined as "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt 1988). Critical loads have been most commonly applied to sulphur and nitrogen deposition, although critical loads for trace metals, ozone and organic chemicals are also being developed (Posch and others 2001). Critical load models have been an important and successful tool for the development of control strategies for transboundary air pollution in Europe (Gregor and others 2001), and critical loads for acid deposition (sulphur (S) and nitrogen (N)) have recently been calculated for regions in eastern North America (Arp and others 1996, Ouimet and others 2001, Watmough and Dillon 2003a). The most common method for calculating steady state critical loads of acidity for forest soils is the Simple Mass Balance (SMB) model (Posch and others 2001).

Upland forests in the Northeastern United States and Eastern Canada are particularly sensitive to acidic deposition because of high local S and N deposition rates, and because shallow and poorly-buffered upland soils are common throughout the region. Critical loads for upland forests in eastern Canada were estimated under the

NEG/ECP (New England Governors/Eastern Canadian Premiers) working group on critical loads (Québec and Maritime Provinces) or through a complimentary project funded by Environment Canada. In this paper we present a description of the methodology adopted for critical load calculations using a case study in Ontario. Preliminary critical load estimates for Eastern Canada are summarised also.

Methods

The Simple Mass Balance Model

The simple mass balance model assumes a simplified, steady state input-output description of the most important biogeochemical processes that affect soil acidification. Potential ecosystem inputs include: 1) atmospheric deposition of S, N, calcium (Ca), magnesium (Mg), and potassium (K); 2) soil base cation weathering rate; and 3) N fixation. Ecosystem outputs and consumption include: 1) net nutrient accumulation in the soil; 2) net nutrient storage in above-ground biomass by uptake; 3) net removal of nutrients by forest harvesting or other disturbance; 4) nutrient loss through soil leaching; and 5) denitrification or N immobilisation.

$$CL(S+N)=BC_{dep}-Cl_{dep}+BC_{w}+N_{i}+N_{u}+N_{de}-ALK_{le(crit)} \quad (1)$$

Equation (1) describes the critical load calculation (units are in eq ha^{-1} yr^{-1}), where BC_{dep} = base cation (Ca + Mg + K + sodium (Na)) deposition, Cl_{dep} = chloride deposition BC_w = base cation weathering, Bc_U = net base cation (Ca + Mg + K) uptake by trees, N_i = net nitrogen immobilisation rate in soil, N_u = net nitrogen uptake by trees, N_{de} = net denitrification rate, and $ALK_{le(crit)}$ = critical alkalinity leaching rate. In the current assessment, harvesting removals were excluded, in other words, Bc_u and N_u were set to zero. In addition, N_i and N_{de} were assumed to be negligible. Further details on the SMB model are given by (UBA 1996) and the NEG/ECP Forest Mapping Group (NEG/ECP Environment Task Group 2001).

A key component of the critical load calculation is the critical alkalinity leaching rate. This critical chemical criterion ultimately determines the acceptable level of base saturation in forest soils. Among the many chemical criteria proposed in the European modelling exercise, the UN-ECE developed a model to calculate the critical ALK_{le} for forest soils based on two criteria: the molar Bc:aluminium (Al) ratio in soil leachate; and the gibbsite dissolution constant which controls Al solubility (UBA 1996). The following equation summarises the calculation:

$$ALK_{le(crit)} = 1.5\times\left(\frac{Bc_{dep}+Bc_{w}-Bc_{u}}{(Bc/Al)_{crit}}\right)+Q^{2/3}\times\left(1.5\times\frac{Bc_{dep}+Bc_{w}-Bc_{u}}{(Bc/Al)_{crit}\times K_{gibb}}\right)^{1/3} \quad (2)$$

where Bc = K + Ca + Mg (*dep, w*, and *u* represent deposition, weathering, and net uptake, respectively; eq ha^{-1} yr^{-1}), Na is excluded since it provides no protection against Al toxicity for plants, $(Bc/Al)_{crit}$ = molar soil solution threshold criterion, Q = water flux from the bottom of the rooting zone (m^3 ha^{-1} yr–1), and K_{gibb} = gibbsite dissolution constant criterion (m^6 eq^{-2}). A range of threshold values have been proposed for Bc/Al and K_{gibb}; the current assessment is based on Bc/Al = 10 and $log_{10}(K_{gibb}$ in $(L\ mol^{-1})^2)$ = 9.0. These values were chosen with the overall objective of maintaining soil base saturation at an acceptable level for forest health and productivity.

Data Requirements

Critical loads for upland forests and related exceedances were compiled and mapped separately for Newfoundland, Nova Scotia, New Brunswick (Balland and others 2004), Québec (Ouimet 2004), and Ontario (Watmough and others 2004) following the same methodology, but using different data sources. Input data for critical load calculations (table 1) were collected from multiple sources although the majority of the data were obtained from the Canadian Soil Information System (CANSIS) and Environment Canada. More detailed land polygon (CANSIS) data were available for the Maritimes compared with Québec and Ontario. All atmospheric wet deposition data were provided by Environment Canada (Ro and Vet 2002), and represent the average wet deposition (1994 to 1998), multiplied by a constant weighting factor of 20 percent to account for dry deposition. Updated estimates of dry deposition are currently being included into revised critical load maps.

Table 1. Input parameters for calculation of critical loads.

Theme	Map attribute (units)
Climate	Runoff or soil percolation (m)
	Mean annual temperature (°C)
	Atmospheric deposition Ca, Mg, K, Na, Cl, SO_4, NO_3, NH_4 (eq ha^{-1})
Land polygons	Ecological region, CANSIS soil landscapes, etc.
Soil data	Substrate acidity type: acid, intermediate or basic
	Average soil depth (m)
	Average clay content (percent)

Base Cation Weathering Rate

Base cation weathering rates for each soil polygon were estimated based on the weighted clay content of soil, parent substrate, soil depth and temperature (Sverdrup and others 1990):

Acid substrate: $W=(56.7 \times \%clay)-(0.32 \times \%clay^2)$ (3)

Intermediate substrate: $W=500+(53.6 \times \%clay)-(0.18 \times \%clay^2)$ (4)

Basic substrate: $W=500+(59.2 \times \%clay)$ (5)

where W = base cation weathering rate (eq ha^{-1} yr^{-1}) for 1 m soil depth. Weathering estimates were corrected for differences in mean annual temperature:

$$W_c = W \times e^{((A/(2.6+273))-(A/(273+T))} \quad (6)$$

where W_c is the temperature-corrected weathering rate (eq ha^{-1} yr^{-1}) for 1 m soil depth; A is the Arrhenius constant (3600 °K) and T is the mean annual temperature (°C). The maximum soil depth used in the calculations was 0.75 m, base on the assumption that this represented the maximum rooting depth for upland forests.

The application of this steady state model within the geographic mapping context has been described in detail by the (NEG/ECP Environment Task Group 2001) and (Arp and others 2001). The case study presented here, describes the calculation of critical load and current exceedance for 10 soil mapping units situated in the Manitoulin Island region, central Ontario (fig. 1). Preliminary critical load estimates for eastern Canada, that are included in the 2004 Canadian Acid Rain Assessment report to be released in early 2005 (Environment Canada in prep), are summarised also.

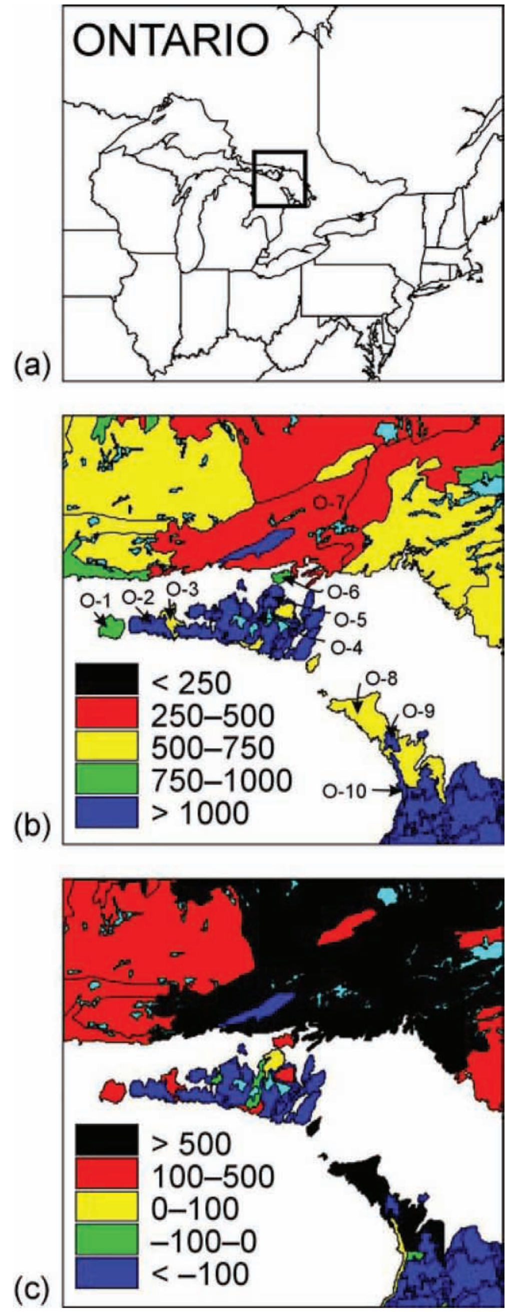

Figure 1. (a) Case study location, centred around Manitoulin Island and the Bruce peninsula (b) critical loads for acid deposition (eq ha^{-1} yr^{-1}) and (c) current exceedance (eq ha^{-1} yr^{-1}) based on average 1994 to 1998 deposition.

Results

Case Study: Manitoulin Island

The weighted percent clay content of the 10 land polygons centered around Manitoulin Island was between 2.5 and 33.4 percent; soil depth for all polygons was set to the maximum depth of 0.75 m (table 2). By incorporating substrate type and average annual temperature for each land polygon, mean annual base cation weathering rates were estimated to be between 113.9 and 2303.7 eq ha^{-1} yr^{-1} (table 2). Higher weathering rates are associated with higher clay content (table 2) and substrate acidity. Annual base cation deposition was generally higher in the southern part of the region, reflecting the closer proximity to industrial activities in southern Ontario and the greater dominance of calcareous soils. Base cation deposition ranged from a low of 145.9 eq ha^{-1} yr^{-1} at the north-west tip of Manitoulin Island, to a high of 214.5 eq ha^{-1} yr^{-1} at the most southerly land polygon on the Bruce Peninsula (table 2; fig. 1). Base cation inputs from deposition represented between 8 (O-9) and 60 percent (O-7) of the total annual base cation weathering inputs for each land polygon.

Table 2. Selected land polygon characteristics (percent clay, weathering rate, base cation deposition, critical alkalinity leaching, and sulphur and nitrogen deposition) for critical load calculations and estimates of current exceedance (negative values indicate no exceedance).

ID	Clay (percent)	W_c [1]	BC_{dep}	$ALK_{le(crit)}$ (eq $ha^{-1}y^{-1}$)	S_{dep}	N_{dep}	CL(A)	Exceedance
O-1	15.6	528.8	145.9	–165.9	334.2	495.9	869.8	126.3
O-2	19.4	1045.2	163.2	–287.1	364.6	543.9	1528.2	–438.0
O-3	11.1	290.4	163.2	–113.0	364.6	543.9	599.3	490.9
O-4	10.8	783.6	178.1	–230.7	389.8	576.0	1228.0	–69.1
O-5	14.8	704.3	187.6	–207.5	416.8	613.0	1137.0	98.7
O-6	12.1	552.2	187.7	–172.7	417.1	613.3	950.1	286.4
O-7	2.5	113.9	176.2	–73.6	393.2	577.7	398.8	766.2
O-8	13.1	278.6	207.4	–118.6	443.9	656.8	646.1	674.7
O-9	33.4	2303.7	205.3	–574.7	439.5	648.7	3124.7	–1818.8
O-10	7.8	774.8	214.5	–231.8	454.5	671.8	1264.0	87.5

[1] Wc: temperate corrected weathering rates were normalized to a maximum depth of 75 cm.

Land polygons with higher base cation inputs (and no harvesting) will have a greater $ALK_{le(crit)}$ (equation 2). In this example, annual $ALK_{le(crit)}$ was between –73.6 (O-7) and –574.7 eq ha^{-1} yr^{-1} (O-9). All N dynamic parameters (fixation, immobilisation and denitrification) were set to 0 and we assumed that there was no forest harvesting. Critical loads for acid deposition for each land polygon are simply a function of the base cation weathering rate, base cation deposition, and the $ALK_{le(crit)}$ (equation 1). Critical loads for acid deposition are between 398.8 (O-7) and 3124.7 eq ha^{-1} yr^{-1} (O-9) (table 2; fig. 1).

Sulphate deposition is between 334.2 and 454.5 eq ha^{-1} yr^{-1} (table 2) and follows a similar pattern to base cation deposition with higher values occurring in the southern part (O-10) of the study region. Similarly, N (nitrate + ammonium) deposition follows the same spatial pattern as both sulphate and base cations and ranges from 495.9 to 671.8 eq ha^{-1} yr^{-1} (typically ~60 percent of total acid deposition), with the highest values occurring in the southern region of the island. Acid deposition exceeds the critical load at 7 of the 10 land polygons, with exceedance values ranging between 87.5 (O-10) and 766.2 eq ha^{-1} yr^{-1} (O-7), indicating that reductions in acid (S + N) deposition of up to 78 percent (O-7) are required to prevent the Bc:Al molar ratio in soil solution from falling below 10 (table 2).

Eastern Canada

Approximately half of the mapped area in Ontario and Québec currently receives acid deposition in excess of the critical load (table 3). Newfoundland has the lowest areal exceedance, with 10 percent of the mapped area exceeding the critical load. The percentage area of exceedance in New Brunswick and Nova Scotia is intermediate between Newfoundland and Québec/Ontario. Comparison between the provinces, however, should be made with caution, since the mapping units (polygon area) in Ontario and Québec are much larger (≥ 300 km^2 on average) than in the Maritime provinces (1.5 km^2 on average). On average, almost 48 percent of the mapped region of eastern Canada exceeds the critical load of acidity. The greatest exceedance occurs where atmospheric acid deposition rates are high and where the critical soil acidification loads are calculated to be low, and occur in central and eastern Ontario, southern Québec, especially in the Lower-Laurentide region north of the St. Lawrence River, and southeastern Nova Scotia.

Table 3. Summary statistics for critical load estimates and current exceedances in eastern Canada (2004 Canadian Acid Rain Assessment [Environment Canada, in press]).

Province	Mean critical load[1] (eq $ha^{-1}y^{-1}$)	Mean exceedance[1]	95^{th} percentile exceedance[1]	Terrestrial area in exceedance (percent)
Newfoundland	273	153	292	9.9
Nova Scotia	429	192	296	33.1
New Brunswick	459	148	426	10.6
Ontario	512	202	602	50.6
Québec	416	353	736	51.5
Total	439	265	427	48.3

[1] Area-weighted.

Discussion

Steady state critical loads for acid deposition calculated using the SMB model provide a method of estimating the potential risk from acid deposition over a large geographical area. They highlight areas that are potentially most at risk from acid deposition, but do not provide an indication of when adverse effects will occur. The current approach also assumes that N immobilisation is zero, which does not generally reflect the present situation (Watmough and Dillon 2003b), but assumes that "at steady state" there will be no net N immobilisation (or denitrification and fixation). Critical load estimates are also based upon the assumption that molar Bc:Al ratios in soil solution below 10 will result in adverse effects on forest health. In this study we have adopted a precautionary approach with respect to both the critical chemical limit and N dynamics. However, the critical chemical limit in soil, soil weathering rates, and particularly N dynamics in forest soils are areas of active research, so it is possible that critical load maps will be updated as new information becomes available.

In general, the greatest exceedance of the critical load occurs in regions that are estimated to have the lowest weathering rates and are therefore likely to have the lowest exchangeable base cation pools in soil. Recent studies in eastern Canada have provided evidence for a link between exceedance of the critical load and adverse biological effects (Ouimet and others 2001; Moayeri 2001; Watmough and others 2004), although a causal relationship between poor forest health and exceedance of the critical load has yet to be established. Current research efforts are being directed toward improving the accuracy of critical load estimates and current exceedance calculations by using more accurate estimates of dry deposition and soil weathering rates, and by including land-use changes (for example, harvesting and fire).

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Biosphere Systems and Processes

Putting Adaptive Management into Monitoring: Retrospective and Prospective Views of Northwest Forest Plan Monitoring

David E. Busch, Senior Biologist, U.S. Geological Survey Western Region, Regional Ecosystem Office, Portland, OR
Jon R. Martin, Northwest Forest Plan, Interagency Monitoring Program Manager, U.S. Forest Service, Portland, OR

Abstract—*Based on ten years of Northwest Forest Plan implementation, we focus on key scientifically-oriented questions relating to improving Plan monitoring. The questions, which fall into groups concerning issues of scale, integration, and efficiency, have applicability to monitoring programs being designed and implemented throughout the world. Progress toward answering such questions is evidence of a functioning adaptive management paradigm, specifically an important subcomponent of such an approach dealing with adaptive change within monitoring programs themselves.*

Introduction

The Northwest Forest Plan (NWFP or Plan) represents one of the preeminent ecoregional initiatives implemented in North America. Plan implementation utilizes an adaptive management strategy (Walters 1986) wherein monitoring is a key step in evaluating ecosystem and socioeconomic status and trends. Monitoring for the Plan has been reinforced by a Federal court decision mandating the implementation of a scientifically-valid monitoring program (Dwyer 1994). Monitoring has been actively discussed, debated, and supported by the Regional Interagency Executive Committee, the set of Federal executives in the Pacific Northwest whose agency missions involve various aspects of NWFP implementation.

While monitoring is central to adaptive ecosystem management, the monitoring process can itself be evaluated as it is implemented (Ringold and others 1996). NWFP monitoring has been implemented using alternative approaches employing scientifically-derived experimental design. The NWFP monitoring program is also subject to decisions regarding continuation or change in the system by which status and trends are estimated. Thus, data about monitoring and possibilities for course correction in monitoring program implementation mean that opportunities for "adaptive monitoring" within the NWFP are possible (fig. 1).

After over a decade of design, planning, review, implementation, and reporting the results of NWFP monitoring, it is timely to assess the program put in place to evaluate the status and trend of Plan indicators. While resource

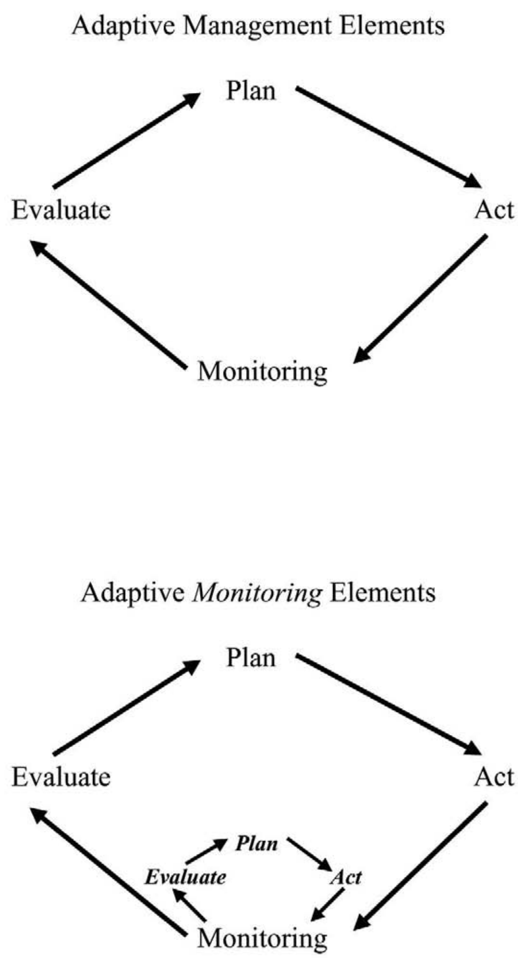

Figure 1. A simple depiction of the adaptive management cycle (top), with superimposition of an internal "adaptive monitoring" loopv to facilitate continuous evaluation, planning, and action improvements in monitoring programs (bottom).

managers' reviews of monitoring tend to emphasize cost savings, increased efficiency, tighter focus on management issues, and the potential for enhanced information yield, the need for monitoring programs to be structured around fundamental ecological factors playing out across multiple spatial and temporal scales must also be considered. Additionally, the tendency to create "orphan" databases has been detrimental, not only to monitoring programs themselves, but also to the decision-making processes that they serve (Palmer 2003). Benefits and risks of continuation or change in the monitoring of populations and ecosystems are being used to help structure alternatives for NWFP monitoring.

Planning, design, and pilot testing resulted in an overall strategy for NWFP monitoring (Mulder and others 1999), as well as the implementation of monitoring plans covering resources of interest to decision makers (for example, Hemstrom and others 1998, Lint and others 1999, Madsen and others 1999, Reeves and others 2003). By 2004, the monitoring program was able to report on trends occurring in the NWFP region over a decade or more for forest vegetation ("late-successional old growth" or LSOG) and for the threatened northern spotted owl. In other cases, the time series for monitoring were much shorter or could more realistically be considered initial inventory or baseline data. All monitoring modules have produced results that permit at least preliminary examination of underlying assumptions, conceptual models, analytical tools, development of descriptive or predictive models, and efficiency of protocols used for NWFP monitoring. Monitoring results are being summarized in a series of reports authored by interagency monitoring program leads. Experience with NWFP reporting of status and trends has lead us to pose a range of questions, the answers to which are likely to prove productive for future monitoring program implementation both for the NWFP as well as for programs that are being planned or conducted elsewhere. We have grouped questions about monitoring program implementation into those related to scale, those related to integration, and those related to efficiency.

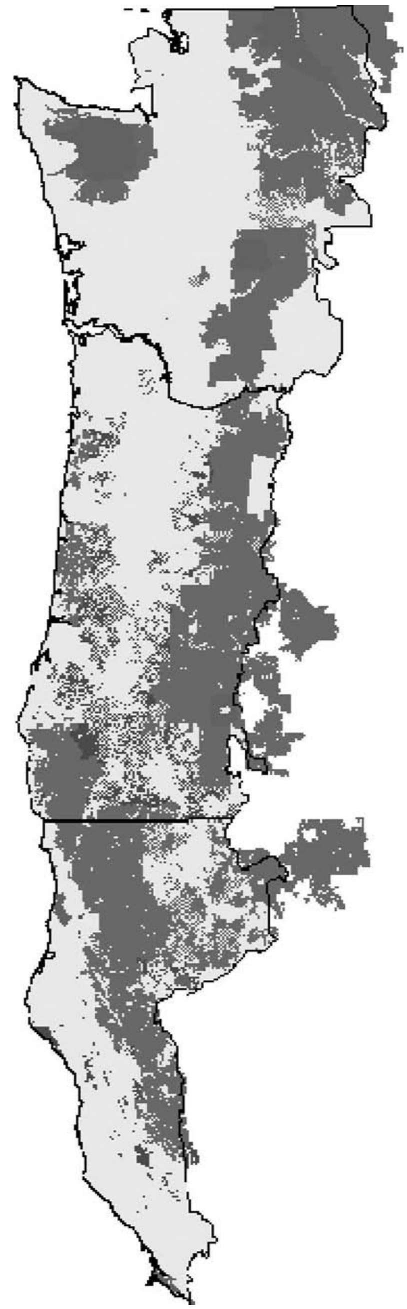

Figure 2. The Northwest Forest Plan region in the states of Washington, Oregon, and California. Federal lands managed by the U.S. Forest Service, the U.S. Bureau of Land Management, and the U.S. National Park Service are shown in gray.

Scale

The NWFP embodies conservation goals and implementation standards for approximately 9.7 million ha of forest and associated aquatic systems under federal ownership in the Pacific Northwest (fig. 2). At the finest level of resolution, the NWFP is implemented via management decisions that can affect as little as a few ha or restricted (<1 km) stream segments. Between geographic extremes are multiple levels of ecological (for example, watersheds, river basins, biophysical provinces) and institutional (for example, land management units, designated reserves, stream buffers) hierarchy upon which both monitoring program design and natural resource management are focused. Given that the resources are never likely to be available to provide robust depictions of systems operating at all scales, there are persistent questions about how to allocate effort to most effectively meet information needs at multiple levels. Ideally, aggregation of monitoring information from smaller scales should contribute to the ability to assess higher hierarchical levels, while monitoring at greater scales should, at a minimum, provide valuable context for more localized questions (Morrison and Marcot 1995, Trexler and Busch 2003). After 10 years of NWFP implementation, both monitoring data and implementation experience are available to help address some issues pertaining to scale. Principal questions include:

- What are the primary scales of interest to decision makers and how firm must inferences be at these scales; what are the opportunities for aggregating data or increasing sampling frequency or density in areas of special interest?
- Given that NWFP monitoring provides good examples of both statistically rigorous sample design as well as designs utilizing scientific consensus, are there needs to adjust monitoring program elements toward one approach or the other?
- What do we need to know about the influence of non-federal lands on federal resources and what are the possibilities for developing contextual information using data derived across a spectrum of land ownerships?
- Considering the temporal dimension anticipated for responses to NWFP management actions, is the intensity of data collection adequate to detect projected trends?
- Has new information about dynamic environments been incorporated into monitoring design, and are information needs about disturbance at odds with monitoring of the NWFP reserve system or agency land allocations?

Integration

A dominant theme within the literature on monitoring and adaptive ecosystem management is one of integration (Walters 1986, Karr 1987, Davis 1993, Silsbee and Peterson 1993, Woodward and others 1999). This theme carries through to assumptions and design principles employed for NWFP monitoring (Mulder and others 1999, Noon 2003). One dimension of this theme can be seen in the presumption that systems will be managed adaptively based at least partly on information developed in monitoring programs. As with other major ecoregional monitoring programs, there is also a prevalent expectation that monitoring programs will be well-integrated internally. In the case of the NWFP monitoring program, this implies that Implementation Monitoring (evaluating status and trends of NWFP Standards and Guides implementation), Effectiveness Monitoring (assessing status and trends associated with the effects of Plan implementation on systems of interest), and Validation Monitoring (evaluation of underlying assumptions and cause-effect relationships in the NWFP) will have well-developed interconnections within the general monitoring program. Another expectation is for monitoring modules evaluating Plan effects on the status of specific resources to be well-integrated. For example, utilizing vegetation data from the LSOG module in all of the other ecologically-oriented monitoring modules is a key provision of the general monitoring program design. Perhaps less explicit but important nonetheless, is the idea that NWFP monitoring and related research programs would be integrated and would further the ability to infer causative relationships in relation to system responses to management. Among questions pertaining to integration are the following:

- Is monitoring program information proving effective in making necessary adaptations to the NWFP?
- Are procedures in place to integrate information from NWFP Implementation Monitoring, Effectiveness Monitoring, Validation Monitoring, and related data sources so that thorough analyses of the Plan can be conducted?
- How is the program developed to monitor status and trends of NWFP-affected resources contributing to the ability to evaluate cause and effect relationships relating to anthropogenic or natural factors?

Efficiency

In concept, one can think of the efficiency of a monitoring program as the information yield per unit of resource invested to produce that information. However, managers and scientists are rarely interested in the amount of raw data produced from monitoring, and instead are more focused on the trends that are pertinent to the policy questions facing them (Urquhart and others 1998). Thus, the concept of monitoring efficiency also must incorporate a theme relating to how well-targeted monitoring information is in relation to the resource management decisions being made. Unfortunately, scientific and management questions themselves are not stable over time and space since they respond to societal factors as well as information produced external to that developed in monitoring programs. A number of mechanisms were incorporated in NWFP monitoring program design with the prospect of making the program operate efficiently and to become more efficient as implemented (Mulder and others 1999). An assessment of NWFP monitoring relative to program cost or to management questions is beyond the scope of this paper. However, a number of questions are important from the perspective of the NWFP monitoring program's performance relative to several scientific themes:

- Does new information accumulated since NWFP inception provide a basis for making adjustments to the assumptions or conceptual models underlying the NWFP monitoring program?
- Does information developed on wildlife populations, or preliminary models developed to project population trends based on habitat, validate a habitat modeling approach for NWFP monitoring?
- Given that system baseline condition and targets for ecosystem restoration were not fully-articulated initially, does monitoring program information provide the means to further define baselines or targets?
- Do power analyses based on time series of NWFP monitoring data indicate a need to refine efforts to determine population trends?
- Have scientific information and scientists continued to be effectively utilized with NWFP monitoring implementation?

Conclusion

Although making progress toward answers for the questions posed about NWFP monitoring will benefit immensely from information available from the monitoring program itself, collectively the questions pose a daunting challenge. Solutions will be aided by those conducting scientific monitoring and research, but policy and cost information will also be of critical importance. Most of the questions we articulate have been posed in an isolated or adhoc manner over the course of NWFP implementation. It is anticipated that this synthesis of higher level questions will catalyze productive dialogue about potential adaptive adjustments to the NWFP monitoring program.

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Conceptual Frameworks for Monitoring of High-altitude Andean Ecosystems

David E. Busch, Senior Biologist, U.S.Geological Survey Western Region, Regional Ecosystem Office, Portland, OR
Xavier Silva is Director, IDB-TNC Ecoregional Project for South America, Teacher & Lecturer, San Francisco de Quito University, Quito, Ecuador

Abstract—*The Ecuadorian government and its partner organizations in the international conservation community share an interest in developing monitoring programs for Andean protected areas to help support management for recreation, education, and ecological sustainability. To accomplish this goal, the U.S. Agency for International Development and the Department of the Interior are providing assistance to establish a system of ecological monitoring. Assistance was focused on Parque Nacional Cotopaxi, a protected area centered on a 5911m active stratovolcano and an ecosystem dominated by the paramo vegetation association. A number of issues complicate the development of monitoring and management systems for such protected areas. Among these are uncertainty about the roles and interactions of ecosystem drivers, the relative importance of various anthropogenic factors, and a need for clarity about how individual protected areas function within larger ecological and socioeconomic contexts of Andean landscapes. Changes in factors of management interest can be viewed as progression along, or deviation from, pathways of ecological succession. A simple conceptual model integrating physical and anthropogenic factors has been developed to help describe a basic Andean successional template. Elevation gradients are well-established as fundamental ecosystem determinants in montane ecosystems throughout the world. Further articulation of this concept makes it clear that proximity to volcanic activity in space or time can be considered a primary driver. Similarly, spatiotemporal proximity to glaciation is another clear determinant of successional status. In addition to physical ecosystem factors, human perturbation is proposed as a cause for deviations (altered trajectories, novel stable states or cycles) from "normal" successional gradients. Monitoring of Andean ecosystem status and trend should be designed and implemented taking into account this physical system/perturbation template. In addition to stratification along lines of zonal and azonal ecological communities, sample design for monitoring ecosystems should first be stratified along lines of volcanic and glacial disturbance, as well as human perturbation.*

Introduction

The Ecuadorian Ministry of the Environment and the US Agency for International Development are working toward the development of a system to support the conservation and beneficial uses of recreation, education, and ecological scientific understanding at Parque Nacional Cotopaxi (PNC) and other Andean protected areas. There also is interest in the development and establishment an ecological monitoring system for PNC.

- Monitoring system development is crucial because:
- PNC is a magnet for domestic and foreign visitors; plans for future ecotourism are likely to increase visitation pressure.
- No basic inventory of PNC's resources has been conducted.
- Changes to PNC have accelerated over the last 50 years.
- Reports on PNC resources are available, but also problematic because many of the reports are not readily accessible to managers in Ecuador; past investigations have also employed different methods making comparison and integration difficult.
- There is a need to determine status and trends for PNC ecosystems, flora, and fauna.
- Patterns of ecological succession have not been identified, nor have potential positive or negative deviations from "natural" successional trajectories.

- Stream and lake systems in PNC are not well-understood with respect to their value as habitat for wildlife and aquatic biota, water quality, or water supply
- Interactions of ecological and anthropogenic factors through time have not been described.
- Ecological conditions within PNC need to be better integrated with past and future volcanism affecting the Cotopaxi region.
- PNC administrators do not have information needed to deal with Park visitation, use of Park resources, and adjacent land uses.
- It is unclear how PNC fits within the larger context of Andean ecosystems, as well as surrounding land uses, cultures, and economies.

In the face of such extensive needs, funding to implement a system of PNC monitoring is in short supply and the Park staff is burdened with ongoing commitments that preclude implementation of a viable monitoring program. Given similar situations in many of the protected areas of the Andes, it is important that monitoring program development and implementation be initiated using technologies that are inexpensive, simple, and robust with respect to the information yield for a given level of effort. However, this does not imply that the easiest or most obvious monitoring protocols should have the greatest priority for implementation. A step-wise process for monitoring program development (Noon 2003) becomes critical when implementation efficiency is so important. A key initial step in monitoring protocol development is agreement about system processes and resource states. Such agreement is best reached through the development of system conceptual models.

Monitoring Design Process

Monitoring at Andean protected areas should not planned or conducted independently at individual sites. A number of resources are available for the development of a coordinated ecological monitoring system for such areas (Busch and Trexler 2003, Elzinga and others 2001, Feinsinger 2001).

A useful way to view monitoring is in the context of an adaptive assessment, or adaptive ecosystem management, framework (Holling 1978). This type of framework is helpful in showing how monitoring can influence management actions, but it is also essential to understand that monitoring data alone are not sufficient to complete the adaptive management cycle supporting productive natural resource decision making. Proper analysis and evaluation of data from a variety of sources is critical, as are formats for communicating and developing planning options to put well-founded alternatives in front of natural resource managers (Palmer 2003). Data management and the conversion of data into useful information and knowledge are important steps in a properly functioning adaptive management process. For monitoring of the system of Andean protected areas, including PNC, it is important that the responsible organizations develop sustainable networks capable of aggregating, storing, and distributing data for analysis and report writing.

Various versions of a stepwise process to develop monitoring plans have been presented. In general, approaches used in different monitoring programs are comparable with each other utilizing a step-wise process similar to that recommended by Noon (2003):

1. Specify goals and objectives
2. Characterize system stressors
3. Develop conceptual models of the system
4. Select monitoring indicators
5. Establish sampling design
6. Define response criteria
7. Link monitoring results to decision making

For PNC and related Andean protected areas, steps 1 and 2 were at least partially articulated in advance by policy makers. In spite of this, the development of scientifically-valid monitoring plans often requires a re-articulation of goals and objectives using the principles of the technical disciplines involved (Reeves and others 2004). Meetings with Ecuadorian scientists and PNC management staff helped to reaffirm goals and objectives and characterize system stressors in an ecological context. Using information from the literature, from field visits to Andean protected areas, and from the aforementioned meetings, a first-generation conceptual framework for monitoring is proposed here. Agreement about basic ecosystem stressors and drivers permitted the derivation of a preliminary set of indicators and sampling design (Busch and Jorgenson 2004). Although much has been accomplished, all of these steps, particularly those toward the end of the sequence, should be revisited to evaluate what additional measures will be necessary to assure the success and sustainability of a monitoring program for PNC and related Andean protected areas.

Conceptual Framework

Monitoring in the Cotopaxi area must be integrated within the context of neighboring land uses as well as monitoring at greater spatial scales. Although monitoring in North American systems has not enjoyed total success in integrating information between fine and coarse scales, paradigms for making such connections have been derived (Trexler and Busch 2003). Such models can be helpful in thinking about how monitoring at a single unit such as PNC, may contribute to monitoring in ecologically-related parts of a region (for example, The Nature Conservancy multi-national Condor Bioreserve), or throughout Ecuador's system of protected areas.

The missions of individual Park units and systems of protected areas are diverse. Consistent with this, the needs for monitoring are similarly diverse (fig. 1). There may be a species or community of interest (for example, a keystone, umbrella, or emblematic species) that is considered to be the monitoring focus. Alternatively, aggregations of species, as indicated by various measures or estimates of biodiversity, may be the primary interest. Given adequate understanding or assumptions about environmental parameters that support species requirements, there may be a focus on habitat, or there may be understanding and interest in various physical dimensions adequate to catalyze an ecosystem-based approach. Brainstorming ("Lluvia de Ideas") meetings with Ecuadorian specialists about potential needs for PNC and related areas produced a list of potential categories incorporating important processes, drivers, stressors, and resources:

- Vegetation and plant succession
- Climate change, C & N cycles, photosynthesis, ET
- Invasive and exotic species
- Rare or biotically rich environments (wetlands, etc.)
- Hydrology and water quality
- Visitor use and abuse
- Threatened and endangered species (listed species)
- Land use – fire, grazing, forest management
- Social factors (park visitation and indigenous cultures)
- Endemic, flagship, keystone species
- Economic factors (ecotourism and extractive economies)

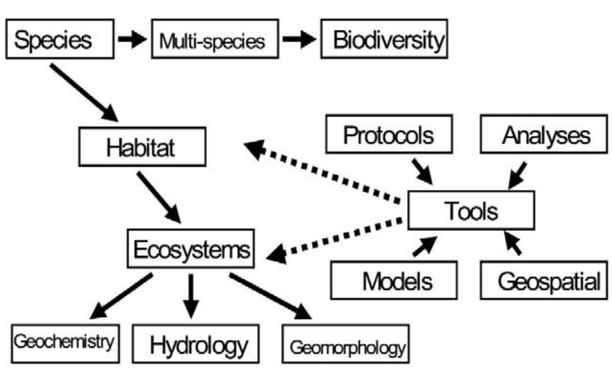

Figure 1. Potential dimensions of interest for monitoring ecosystems; tools for making monitoring efficient and integrating across dimensions.

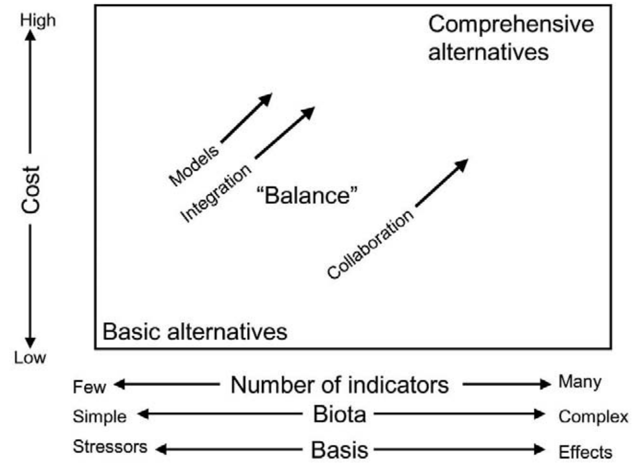

Figure 2. Concept for outlining monitoring alternatives at varying levels of complexity and cost.

As can be seen from lists such as this, monitoring interests in the Ecuadorian system of protected areas are many and varied. Caution must be exercised to temper the expectations about the level of monitoring that can actually be implemented. A concept for developing monitoring alternatives ranging from those that are low in complexity and cost to those of increasing sophistication is presented in figure 2. Obviously, the information yield is greater as more staff and financial resources are added to the monitoring program. However, another important implication is that there are a number of analytical mechanisms for making monitoring more efficient and effective, potentially at relatively little additional cost. Crucial to the development of such efficiencies is the growth of collaborative mechanisms between those with a stake in field-level sampling and those possessing the capability and interest in aggregating, archiving, analyzing, modeling, and communicating based on the information collected.

Changes in factors of management interest can be viewed as occurring upon a physical ecosystem template. For example, elevation gradients are well-established as fundamental ecosystem drivers in montane ecosystems throughout the Andes (Humboldt and Bonpland 1807). Further articulation of ecosystem drivers in ecosystems of the Ecuadorian Andes is clearly possible. From our observations at PNC and neighboring Andean systems, it is proposed that the proximity to volcanic activity in space or time is one primary driver (fig. 3, top). Relatively recent volcanic activity at Volcan Cotopaxi has affected PNC ecosystems more profoundly than those at nearby montane systems where volcanic activity is spatially or temporally more distant. Proximity to features of intense volcanic activity (e.g. lahars) also has clear effects on successional status of sites within PNC. Glaciation is

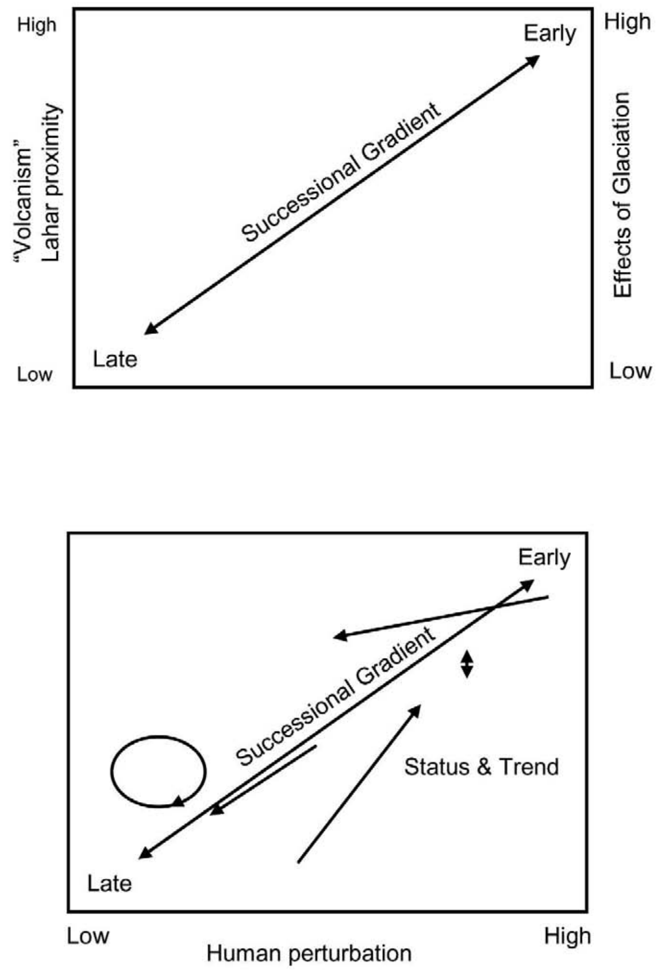

Figure 3. Monitoring of ecosystems in relation to successional gradients. Status and trend of ecosystem as successional trajectories with proposed "drivers" for Andean ecosystems

proposed as another important dynamic in such systems. Similar to volcanic activity, the proximity to active glaciers, morainal deposits, etc. in space or time also appears to be a clear determinant of successional status.

In addition to physical ecosystem factors, human disturbance is proposed as a determinant of ecosystem successional status (fig. 3, bottom). However, whereas volcanism and glaciation can generally be viewed as primary drivers of other ecosystem processes in more or less "natural" patterns, perturbation of ecosystem processes by humans is likely to be a cause for deviations (altered trajectories, novel stable states or cycles, etc.) from normal successional gradients. While the focus of this model is ecological, fuller incorporation of a perturbation axis into the conceptual framework for PNC and related Andean protected areas will require the development of parallel socio-economic systems of factors and drivers.

Conclusion

Monitoring of Andean ecosystem status and trend should be designed and implemented taking into account a physical system/disturbance template. In addition to stratification along lines of Andean zonal and azonal ecological communities (for example, puna, paramo, pajonal, mattoral, quebradas humedales, lagos, etc.), sample design for monitoring ecosystem subsystems should first be stratified along lines of volcanic disturbance, glaciation, as well as human perturbation. Once a basic level of understanding has been developed about cause and effect relationships between the most important Andean ecosystem stressors and their ecological consequences, selection of the most effective and efficient monitoring indicators will be possible.

Acknowledgments

Fruitful discussions with a number of specialists who have studied Andean ecosystems and society were essential to our work. We especially wish to thank Janet Jorgenson and Marc Weitzel (U.S. Department of the Interior, Fish and Wildlife Service); Darwin Hernandez, Marco Encalada, and Rocio Bastadas (Corporacion OIKOS); Rocio Cedeno (U.S. Agency for International Development), and the staff of Parc Nacional Cotopaxi.

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Remote Sensing of Saltcedar Biological Control Effectiveness

Ray Carruthers, Ecologist and Research Leader, USDA-ARS, Exotic and Invasive Weed Research Unit, Albany, CA
Gerald Anderson, Ecologist and Remote Sensing Specialist, USDA-ARS Northern Plains Agricultural Research Lab in Sidney, MT
Jack DeLoach, Research Entomologist and Lead Scientist, Saltcedar Biological Control Project at the USDA-ARS, Grasslands Soil and Water Research Laboratory, Temple, TX
Jeff Knight, State Entomologist, Nevada Department of Agriculture, Reno, NV
Shaokui Ge, Research Affiliate, University of California Berkeley, CA
Peng Gong, Professor and Co-Director, Remote Sensing Lab, University of California, Berkeley, CA

Abstract—*Saltcedar (*Tamarix *spp.) is a major invasive weed found throughout the Western United States and Mexico. Introduced into North America in the 1800s, this shrub to small tree, now infests many riparian areas where it displaces native vegetation, increases fire hazards, uses extensive amounts of water, increases flooding during high water events and thus has caused extensive damage to urban, agricultural and natural areas. In 2001, scientists from the United States Department of Agriculture released a Chinese leaf beetle (*Diorhabda elongata*) into test areas in six states to initiate and evaluate a new biological control program for saltcedar. A combination of ground-based sampling and remote sensing has been used to monitor impacts caused by this biological control program. Both color aerial photography and hyperspectral remote sensing were used to successfully classify and quantify saltcedar populations and the effectiveness of the biological control program, including beetle spread and defoliation within monotypic stands of saltcedar and in areas where saltcedar is mixed with native vegetation.*

Introduction

Saltcedar (*Tamarix* spp.) is an exotic weed that has invaded many riparian areas across western North America. In the absence of natural enemies and disease causing organisms, saltcedar grows very aggressively (DeLoach and others 2000) and is highly competitive with native vegetation (Smith and others 1998, Sala and others 1996, Shaforth and others 1995). Therefore, many of the nation's most productive and diverse ecological regions are being negatively affected by the invasion of this exotic invasive plant (Lovich and DeGouvenain 1998). Common methods used to control saltcedar include herbicide application, burning and bulldozing, all of which are expensive and highly detrimental to non-target flora and fauna. Although these approaches may be successful in the short run, they do not provide permanent control of the problem as the saltcedar often grows back or reinvades from surrounding areas.

Over the past decade, biological control of saltcedar has been a major research effort within the USDA-Agricultural Research Service. A consortium of scientists and land managers has recently field tested the use of this new technology in several western states including CA, CO, MT, NM, NV, OR, TX, UT, and WY (DeLoach and others, this proceedings). A leaf beetle from Eurasia, *Diorhabda elongata*, has now been tested at several locations, where it has established reproductive populations, increased dramatically in numbers and spread extensively across saltcedar infested areas where the beetles have caused extensive defoliation of saltcedar for multiple seasons (fig. 1). In these test locations, the leaf beetles are significantly impacting saltcedar growth and development, while no non-target plants have been negatively affected (DeLoach and others, this proceedings).

Ground sampling of beetle populations and their impact on target saltcedar and adjacent beneficial species was conducted at all of the release sites for several years; however the scale of impact quickly made ground-based field sampling both difficult and expensive. Previous studies (Everitt and DeLoach 1990) have documented

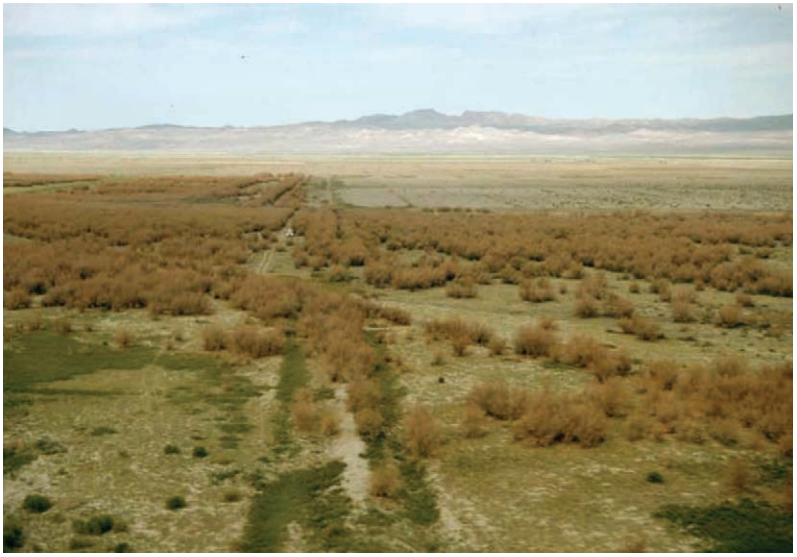

Figure 1. Saltcedar defoliation caused by *Diorhabda elongate* in Lovelock, Nevada (September 2003).

the effective use of remote sensing for the assessment of saltcedar infestations. In support of the overall project monitoring and assessment efforts (DeLoach and others, this proceedings), further remote sensing was conducted to characterize saltcedar infestations, to follow beetle establishment, impact and spread, and eventually to document the return of beneficial vegetation into areas where saltcedar has been controlled.

Methods and Materials

The Study Areas

Saltcedar biological control release sites were located in nine different western states including California, Colorado, Montana, New Mexico, Nevada, Oregon, Texas, Utah, and Wyoming (DeLoach and others 2004). Some states such as California, Nevada, and Texas included three or more different release sites while the other states only had a single test site. In this paper, we will present results from two of over a dozen specific research sites examined. We will discuss detailed assessments of aerial photography from Cache Creek, CA and hyperspectral imagery form Lovelock, NV. However these two types of remote sensing technology, along with videography and satellite imagery are being used to assess saltcedar infestations and biological control impacts at most of our research locations in all of the states where *Diorhabda elongata* has been released.

Cache Creek is a small river that is located north and west of Woodland, CA (38° 40' 02''N latitude and 128° 45' 30''W longitude). The stream course is highly infested with *Tamarix parviflora* intermixed with a diverse combination of native flora including many species of willows, cottonwood, and other common riparian plant species. This area is also infested with other exotic plant species of interest to our research team, including *Arundo donax*, *Lepidium latifolium* and *Centaurea solstitialis* that are also being assessed using remote sensing. Cache Creek is of primary interest to us as *T. parviflora* blooms in distinctive purplish-red blossoms (fig. 2) early in the spring prior to leaf-out of saltcedar and most other riparian vegetation. Thus, the saltcedar is easily identified visually on the ground and in the air, making it possible for us to separate it from other vegetation at this time of the year. During mid-season, however it is difficult to separate *T. parviflora* from other green vegetation as the plants are then without flowers and are often intermixed and hard to see due to visual barriers caused by adjacent plant canopies. This area was chosen as one of our primary study sites because an extensive historical record of aerial photography exists for this location.

The saltcedar infestation on Cache Creek runs along approximately 50 miles of river channel, much of which is hard to access and thus is very difficult to map and manage. The use of remote sensing to assess and develop comprehensive distributional maps would better allow local land managers to implement saltcedar removal,

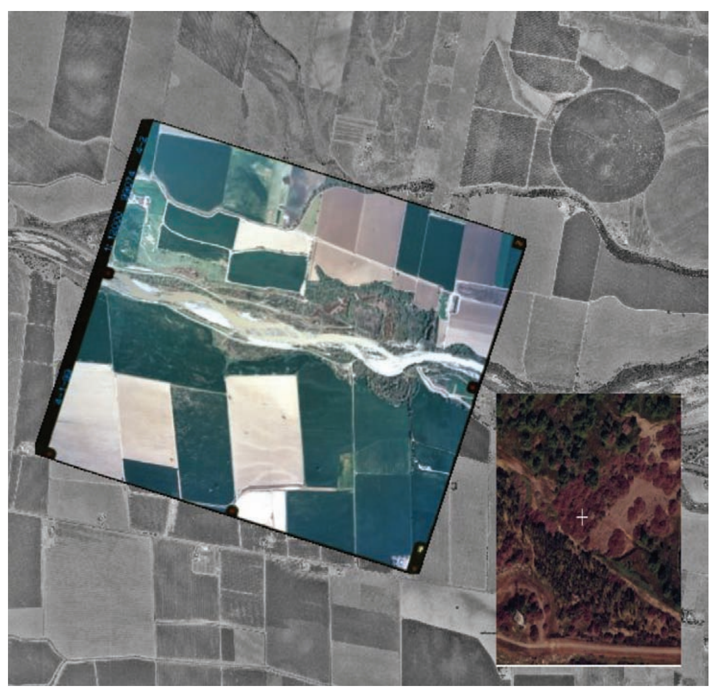

Figure 2. An orthorectified color aerial photograph of a saltcedar infested portion of Cache Creek, CA. Inset shows blowup with individual purple colored saltcedar (*Tamarix parviflora*) in bloom.

allow our team to better assess biological control impacts, and would additionally provide a saltcedar base-map for future midsummer saltcedar assessments using hyperspectral imagery. Hyperspectral image collection has already been conducted in this area but has not yet been analyzed. We are conducting this additional research in Cache Creek (where we now have accurate saltcedar base maps) as new methods of aerial identification of saltcedar using midsummer foliage would be very helpful in the development of identification and separation techniques for other species of saltcedar. This is important as most *Tamarix* spp. (other than *T. parviflora*) do not have such a temporally concentrated bloom period and thus, need to be recognized with or without flowers.

Assessment of the use of remote sensing to characterize beetle defoliation has concentrated on the use of hyperspectral imagery that was collected at insect releases sites near Lovelock, Nevada (40° 1' 20''N latitude and 118° 31' 24"W longitude). The Lovelock site is near the Lovelock and Oreana Valleys and adjacent to the Humboldt River, just upstream from the Humboldt Sink. The Lovelock Valley is one of Nevada's primary agricultural areas where alfalfa is grown primarily for seed production. Saltcedar heavily infests the Humboldt River and side irrigation channels in this area, where it extend up-stream for approximately 100 miles. Saltcedar is especially damaging in this drainage, as it both reduces available water for agriculture and blocks channel flow during times of heavy runoff. Local agricultural producers have been fighting saltcedar all along the Humboldt River channel for the past two decades and are losing the battle. Saltcedar leafbeetle releases in this area have been extremely successful. The beetles have highly defoliated the saltcedar, and have now spread many miles from the release site over the past four years. Beetle impact now can be easily evaluated only by using aerial reconnaissance.

Remote Sensing Data Acquisition

Aerial Photography—A total of 42 natural color aerial photographs were taken at a scale of 1:12,000, along Cache Creek in April of 2001 and 2002. At the time of photography, the saltcedar was in full bloom and was purplish-red in color, making it distinctive from other associated riparian vegetation and the physical background in the study area (fig. 2). However, because the photographs were taken in response to flowering, it is possible to confuse saltcedar with some blooming fruit trees in adjacent agricultural orchards and thus careful analysis between riparian zones and agricultural fields was conducted. For analysis, the photos were scanned at a 1-foot resolution (1000 dpi) using full color with three (blue, green, and red) digital channels. These digital images were then resampled at 1-meter resolution using a nearest neighbor algorithm. Once processed for analysis, images were orthorectified and georeferenced to 1-meter resolution DOQs from USGS using a second order polynomial function. Each individual digital image was then evaluated for saltcedar (see subsequent section on image analysis), classified then mosaiced to provide an area-wide map of the saltcedar infestation.

Hyperspectral Imaging—Hyperspectal aerial imagery was acquired over study areas using a CASI II hyperspectral imaging system on 2 July 2002, 29 August 2002, 18 July 2003, and 10 September 2003 (2004 images have also been acquired but not yet analyzed). The CASI II is a line scanner covering 545 nm, between 400 to 1000 nm. The system can be modified to acquire different spatial and spectral resolutions. CASI records calibrated radiance values, which were used in this study. Conversion to reflectance using ground targets is possible; however, the objectives of the project could easily be achieved using radiance alone.

Spectral and spatial coverage were changed over the course of the study to best accommodate biological control damage assessment. On 2 July 2003, imagery was acquired at an altitude of 1,500 m above ground level (AGL) obtaining a 2 m pixel resolution and 48 bands, with band centers ranging from 426.7 nm to 965.1 nm with a 5.9 nm bandwidth. The area covered was approximately 1,697 ha along the Humboldt River release site. Imagery collected on 29 August 2002 was acquired at an altitude of 750 m AGL, producing a 1 m resolution. Spectral resolution was dropped from 48 to 36 bands with a 7.9 nm band-width to accommodate the additional data (band centers ranged from 4.286 to 963.2 nm) and the area covered was 1,212 ha. On 18 July 2003 the area flown was reduced to focus in on the damage detected in August of 2002. Approximately 610 ha were imaged near the release site using the same band configurations and imaging altitude as the August 2002 flight. Spectral bands for the September 2003 flight were again reduced (to 32 bands) to accommodate the need to image a much larger area. Band centers ranged from 422 nm to 954 nm with an 8.8 nm band-width. Images were again taken at 750 m AGL, which produced a 1 m pixel resolution over approximately 3,170 ha.

Geographic coordinates for each line of the CASI images were recorded in real time using a differential global positioning system (GIS) coupled with the systems inertial momentum unit (IMU).

Image Analysis

Aerial Photography—Based on the color similarity and relationships among various types of native vegetation and the invasive species, vegetation was initially divided into eight types: *T. parviflora*, evergreen trees, non-evergreen trees, shrubs, crops, bare fields (including agriculture and rangeland), water bodies (including wetlands), rocks and roads. Initially, color patterns alone were used to separate and classify the saltcedar from the other categories of habitat. This provided inaccurate identification of saltcedar along the stream channel and thus more complex methods of analysis were required. Thus, the image processing to distinguish saltcedar from associated vegetation and background required four distinct steps beyond just the use of color differentials. The following analysis used: (1) Texture extraction using six texture measures; (2) Texture subset selection based on separability measured by Bhattacharya distances (BD); (3) Best texture determination based on classification accuracy; and (4) Post-classification processing based on invasive habitats. After these classification procedures were applied, the original eight categories were reduced to six categories by merging rocks and roads with bare fields and bare hills. Finally, ground-truthing was conducted from the up-stream, middle reach, and down-stream segments along the creek, to assess classification accuracy. For more details on the analysis and classification procedure, see Ge and others (2004).

Hyperspectral imagery—Image to image registration was performed to compensate for much of the spatial registration error that confounds temporal difference analysis. Images were then transformed to the normalized difference vegetation index (NDVI) and a change detection algorithm was used to determine differences between images collected over the period of study. Areas showing change were photo-interpreted and matched to ground observations on beetle occurrence to ensure the change was the result of *Diorhabda elongata* feeding damage to saltcedar. All areas of saltcedar that had been defoliated were subsequently masked as a region of interest (ROI) and the impacted area was quantified (ha).

Results and Discussion

Aerial Photography of Saltcedar Infestations

Based on the scanned images, all eight covers were compared based on their quantized numerical values of color (pixel by pixel), using analysis of variance. Although we found significant differences overall, tonal confusion existed among some covers, including saltcedar. For example, saltcedar sometimes was confused with water and other shrub-like plants because of their similar color and the variability caused by shading. Bhattacharya distance (BD) was applied to represent the separability between class pairs of samples. BD values range between 0 and 2.00. If it is less than 1.00, the two cover classes are very similar and thus hard to separate. A BD value between 1.00 and 1.9 means that the two classes might be classified as two different cover types. A BD value between 1.90 and 2.00 indicates very good separation between the two classes. The separability of saltcedar with other shrub covers using color alone was only 1.88. *Tamarix* separability with water was even less with a BD of only 1.03. Therefore, using color alone, it was not possible to accurately separate saltcedar from the surrounding habitats, even though it was easily recognizable using the human eye due to large-scale pattern recognition. Pattern recognition was then evaluated using four different window sizes (3x3, 5x5, 7x7, and 9x9 pixel dimensions) focused around each one meter pixel. This was done to evaluate the effectiveness of patterning or texture as an added component in the analysis. After significant comparative analyses, a window size of 5x5 pixels was found to provide the best overall accuracy in correctly classifying saltcedar. Using this window size, the overall average separability was improved from a BD of 1.87 to 1.99, and even more significantly, the separability of saltcedar from adjacent water was increased from a BD 1.03 to 1.96, which approaches the maximal BD value of 2.0. Based on this improved separability, habitat classification errors were minimized and covers compared to actual observed plant distributions (fig. 3). Comparisons made between this automated saltcedar recognition process and human interpretation of the photos

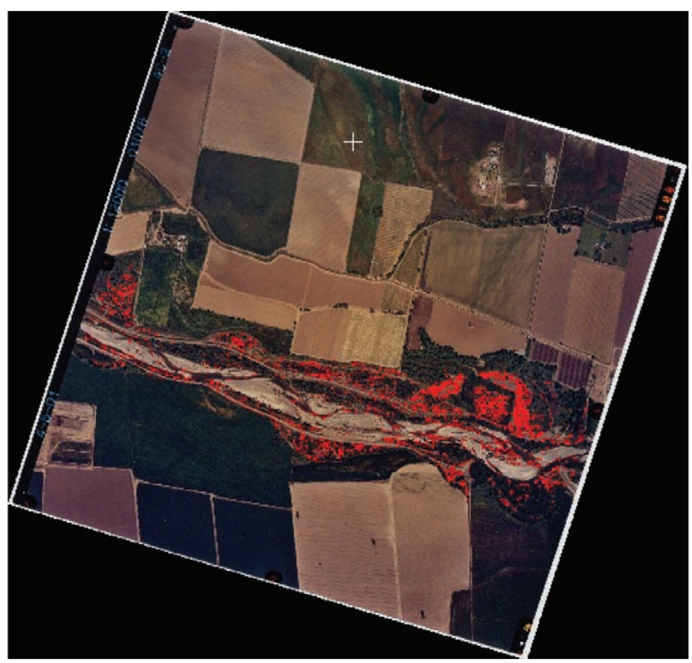

Figure 3. Classified image showing saltcedar infested areas highlighted in red. A combination of color and texture analysis was necessary to identify the saltcedar.

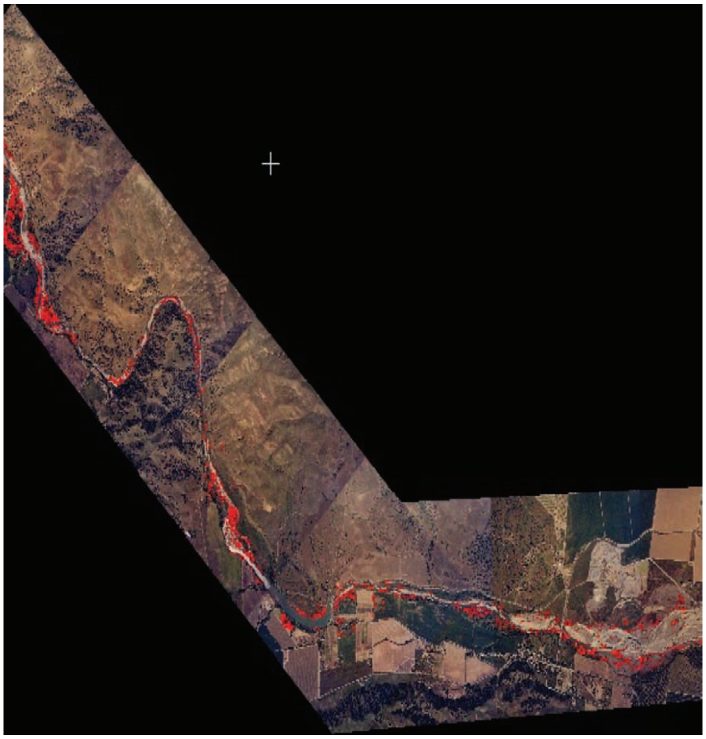

Figure 4. A mosaiced series of saltcedar classified images showing infestation areas along Cache Creek.

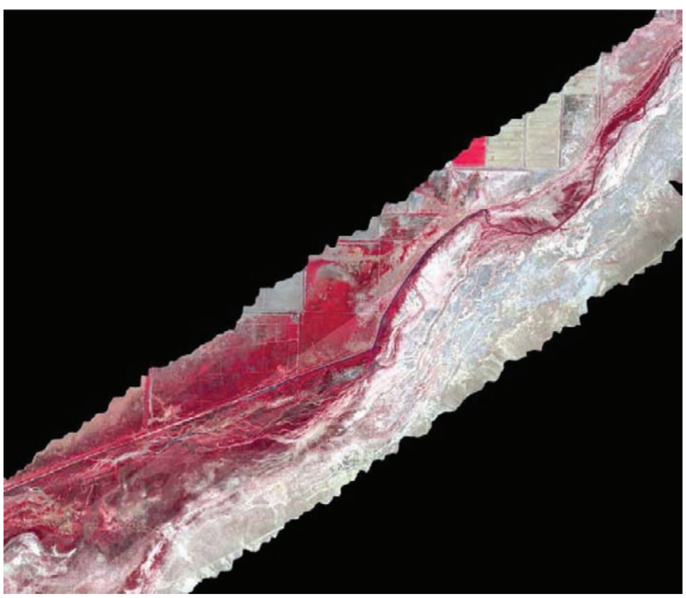

Figure 5. The entire area near Lovelock, Nevada that was imaged in July 2002 (1,697 ha). This monoculture of health saltcedar (depicted in red) showed no signs of beetle defoliation from the air.

resulted in an approximate 90 percent accuracy. Although full field validation is still underway, this classification also provided an approximate 90 percent accuracy in preliminary field assessments.

Finally, these classified images were mosaiced across the study area in order to provide comprehensive infestation maps and to estimate the invasive saltcedar cover in a 40 km subset of the Cache Creek drainage. The total area of saltcedar infestation for this single 40 km section of stream was estimated to be 398 ha. These maps (fig. 4) are now being used by local land managers in their saltcedar control programs and as a basis for comparison against more detailed hyperspectral analyses being conducted during the summer of 2004.

Hyperspectral Image Analysis

Analysis for the 2 July 2002 imagery indicated a total imaged area of approximately 1,697 ha (fig. 5). During this sample period there was no visible saltcedar damage. Significant defoliation of saltcedar was identified by ground crews prior to the August 2002 flight. The area was relatively small and localized, so adjustments were made to increase spatial resolution to 1 m by reducing the number of bands from 48 to 36 and decreasing the image area (1,697 ha to 1,212 ha) and the flight altitude. Change detection between the July 2002 and August 2002 image pairs (figs. 5 and 6, respectively) indicated that the biological control agents had defoliated approximately 0.35 ha over the two-month period (fig. 6). This measure represents only the actual area of canopy cover of the saltcedar trees, not the larger surface area (open ground) infested by saltcedar. In July of 2003 the total canopy area of saltcedar defoliated increased to 4.3 ha (fig. 7), and in the interval between the 18 July 2003 flight and the 10 September 2003 flight (62 days) *Diorhabda elongata* had defoliated (or mostly defoliated) approximately 76.7 ha (fig. 8). Between the initial flight, 2 July 2002, and the last flight, 10 September 2003, the defoliation progressed approximately 2.8 km from the original release site and produced an impact span of approximately 5.2 km (southwest to northeast). The beetles themselves have actually spread much further along the Humboldt drainage. Results indicate an exponential rate of beetle population growth and saltcedar defoliation (fig. 1). A total of nine other sites are being monitored using the same technique (not reported here). These areas are more typical of riparian vegetation with a mixture of saltcedar and other plants. Defoliation rates in these areas indicate that impacts to saltcedar are somewhat slower across most of the plant's range, but that insect establishment has occurred, that the beetle populations are building and saltcedar is being negatively impacted at almost all of the test locations (DeLoach and others, this proceedings).

Summary

A comprehensive assessment program has used a combination of color aerial photograph and hyperspectral

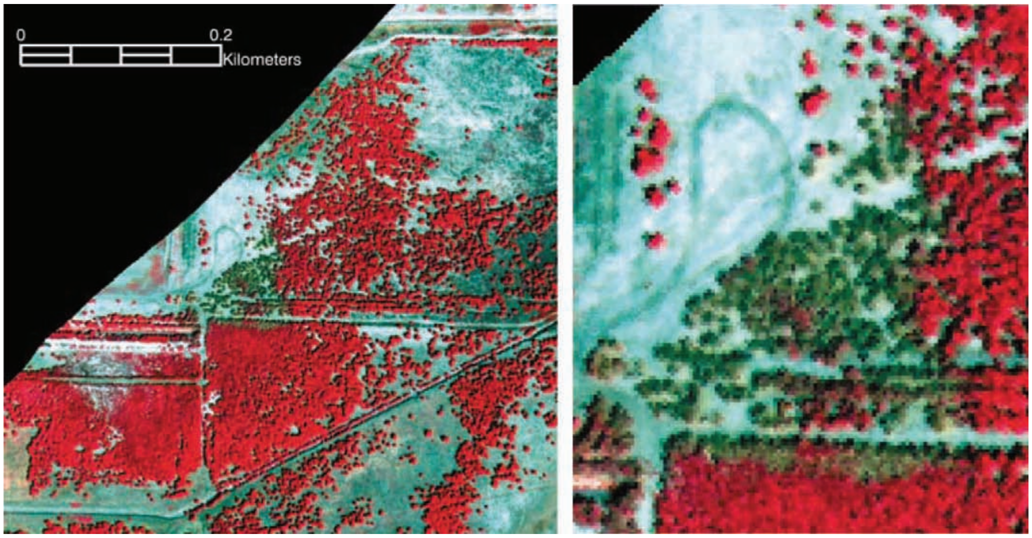

Figure 6. Beetle defoliation in August 2002 is shown in green in this false color simulated infrared image. The healthy saltcedar is shown in red. The enlarged section of the defoliation revealed an approximate 0.3 ha impacted by the beetle when it was first noted using aerial reconnaissance.

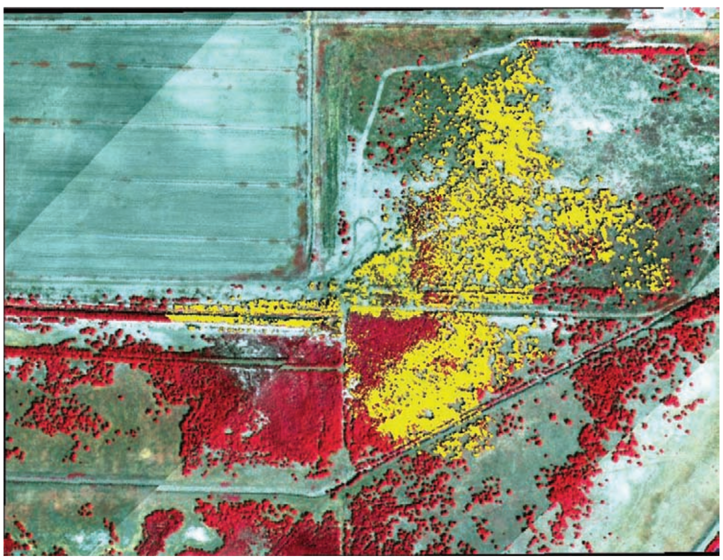

Figure 7. Areas appearing bright yellow are the saltcedar plants defoliated by the biological control agents in July 2003. The red areas are the healthy non-defoliated plants. The approximate area defoliated was 4.3 ha.

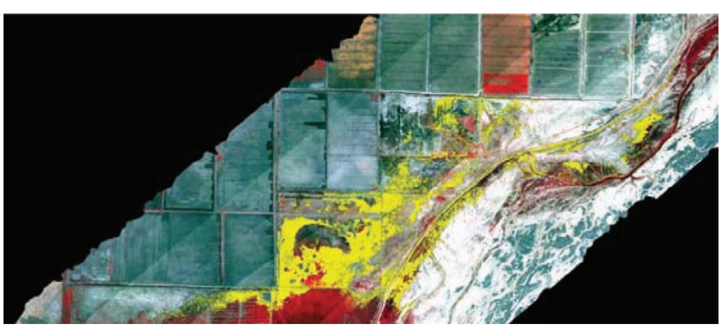

Figure 8. The yellow highlight indicates the area of saltcedar defoliation occurring between the first flight (2 July 2002) when no defoliation was detected and the 10 September 2003 flight when approximately 76.6 ha of saltcedar had been defoliated

imagery to assess saltcedar populations prior to beetle release and to follow beetle defoliation patterns from the original release sites across wide areas of impact. A combination of color and texture analysis was used to identify, classify, and map invasive *Tamarix parviflora* during spring bloom, along a 50 mile segment of Cache Creek in central California with an estimated 90 percent accuracy. An on-going effort is further evaluating the use of hyperspectral imagery during mid-summer to identify saltcedar interspersed with other background native vegetation in this and other infested areas. Additional use of hyperspectral image assessment and GIS mapping has allowed biological control specialists to track and evaluate beetle performance at many pilot release sites where the beetles have spread across thousands of acres. A combination of aerial and ground sampling has clearly documented the success and safety of this project in multiple study areas; however, due to the scope of the beetle defoliation, aerial reconnaissance seems to now be the only practical method of assessing the full magnitude of impact. Based on these trials and remote sensing assessments, several State and Federal agencies are highly enthusiastic about saltcedar biological control and have initiated efforts to use this technology over wide areas. Remote sensing is expected to play a major role in the continued assessment of this beneficial invasive species management project.

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Herpetological Communities of the Middle Rio Grande Bosque: What Do We Know, What Should We Know, and Why?

Alice L. Chung-MacCoubrey, Research Wildlife Biologist, USDA Forest Service, Rocky Mountain Research Station, Albuquerque, NM
Heather L. Bateman, Graduate Student, Department of Biology, University of New Mexico, Albuquerque, NM

Abstract—*Amphibians and reptiles (herpetofauna) play important roles within ecosystems. Similar to many birds and mammals, they are major consumers of terrestrial arthropods. However, amphibians and reptiles are more efficient at converting food into biomass and are a higher quality food source for predators. Recent declines in some herpetofaunal populations have stimulated a greater overall interest in the monitoring of these populations. Although studies have examined the use of exotic plant-invaded ecosystems by birds and mammals, few have focused on the herpetofaunal community. Specifically, there is little information on the ecology and management of reptiles and amphibians within riparian cottonwood forest (bosque) along the Middle Rio Grande in New Mexico. Invasion by exotic plant species and accumulation of woody debris have led to high fuel loadings and thus the risk of catastrophic fire in the bosque. Thus, land managers are interested in removing exotics and reducing fuels by various techniques. To effectively manage habitat and make sound decisions, managers must understand how various fuels reduction treatments affect wildlife communities, including the distribution, abundance, and ecology of amphibian and reptile populations. In 1999, the U.S. Forest Service- Rocky Mountain Research Station initiated a study to monitor and evaluate the response of vegetation and wildlife to three fuel reduction treatments in the Middle Rio Grande bosque. This component of the study will evaluate the impact of treatments on herpetofauna. Using pre- and post-treatment capture data from pitfall and funnel traps, we will analyze species-specific and community level responses to the treatments. Specifically, we will address how these treatments affect survivorship, species richness, abundance, diversity, reproduction, and community energy flow.*

Importance of Herpetofauna Within Ecosystems

Amphibians and reptiles, which we will refer to as herpetofauna, play important roles within ecosystems. Many consume insects, serve as food for birds, mammals, and other predators, and may be indicators of environmental health. Compared to birds and mammals, amphibians and reptiles are less mobile, have smaller home ranges, and thus may be affected to a greater degree by alterations to their habitat (Burton and Likens 1975). Yet, herpetofauna have long been overlooked by managers, biologists, and researchers.

Herpetofauna as Consumers, Predators, and Prey

Amphibians and reptiles eat a wide variety of foods, including plants, arthropods, birds, and small mammals. Many feed solely on arthropods. Whiptail lizards are active foragers and eat mostly moths and moth larva (Lepidoptera), beetles (Coleoptera), crickets and grasshoppers (Orthoptera), and termites (Isoptera, Medica 1967, Degenhardt and others 1996). Amphibian species such as toads eat bees and ants (Hymenoptera), beetles, insect larvae (Hemiptera), and spiders (Arachnida, Degenhardt and others 1996).

Relative to birds and mammals, amphibians and reptiles are more efficient at transferring energy up the food chain and thus retaining energy within ecosystems. Because they are ectotherms, amphibians and reptiles expend little energy toward metabolic thermoregulation (using 7 to 10 times less energy per unit body mass than endotherms) and are more efficient at converting food into new tissue. This conversion efficiency is approximately 50 percent in ectotherms and only 2 percent in endotherms (Pough and others 2001). In a New Hampshire forest, salamanders collectively consumed less food than birds and mammals, but produced more animal mass per year than the birds and mammals combined (Burton and Likens 1975). Consuming smaller invertebrates on the forest floor, salamanders harvested energy unavailable to birds and mammals and returned it to the food chain as salamander biomass. Salamanders were also a higher-quality food source because they contained a greater percentage of protein than birds and mammals (Burton and Likens 1975).

Herpetofauna as Indicators

Amphibians and reptiles also serve another valuable role as indicator species of environmental and ecosystem health. Since the 1980s, herpetologists have reported worldwide declines in amphibian populations and species extinctions (Collins and Storfer 2003). These declines have prompted extensive investigations by government agencies to identify the causes of these abnormalities and if there is any potential risks to human health (Van der Schalie and others 1999). Hypotheses to explain these global amphibian declines include exotic species invasions, habitat alteration, exploitation, global climate change, and disease (Collins and Storfer 2003). Recent population declines have focused more attention on amphibians and reptiles, which have historically been overlooked. Managers and biologists are more concerned and aware of the potential effects of human activities on amphibian and reptile populations and their habitats. This paper focuses on effects of human activities on herpetofauna in the Middle Rio Grande bosque, a highly managed and altered southwestern riparian forest ecosystem.

The Middle Rio Grande Bosque Ecosystem

The Middle Rio Grande supports the most extensive, remaining gallery of cottonwood forest (*Populus deltoides* subspecies *wislizeni*) in the southwest (Hink and Ohmart 1984). This forest, or bosque, hosts a rich assemblage of vertebrates, particularly birds (Hink and Ohmart 1984). In the past century, humans have dramatically altered the vegetative structure and composition of the bosque through damming, channelization, irrigation, urbanization, and restoration. Much of the previous extent of the bosque has been converted for agricultural or urban use, and the remaining bosque primarily exists between levee roads paralleling the river (Hink and Ohmart 1984, fig. 1). In the 20th century, engineers dammed and channelized the river to reduce the frequency and severity of flooding and to facilitate agriculture and water management. As a result, many natural processes in the bosque ecosystem have been disrupted or altered. For example, spring floods historically scoured forests of woody

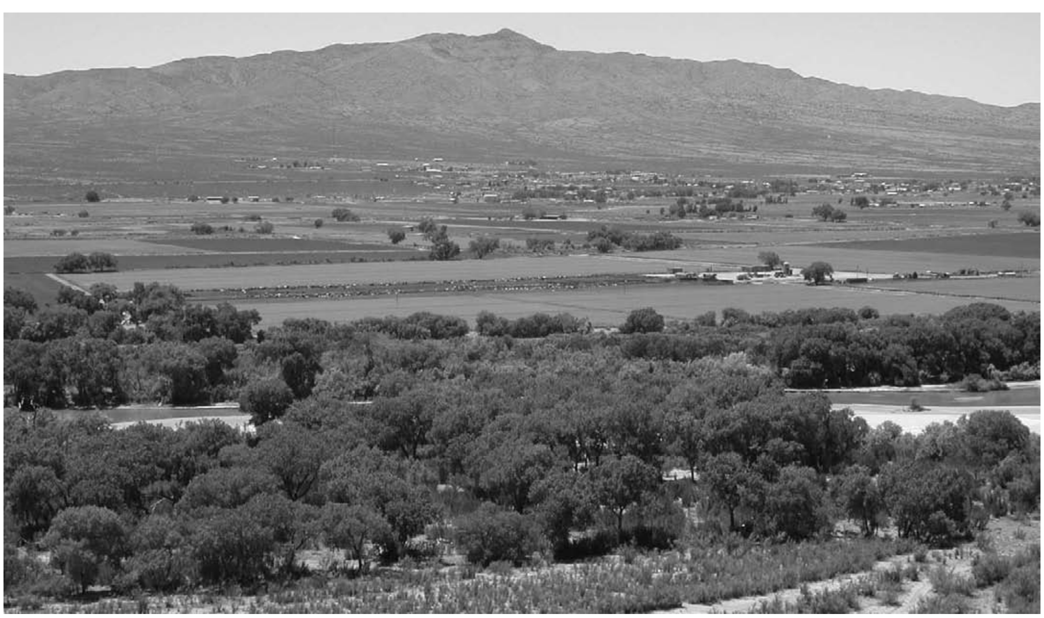

Figure 1. Cottonwood forests of the Middle Rio Grande bosque are largely confined to areas immediately adjacent the river. Surrounding floodplains have been converted for agricultural or urban use.

debris and deposited new sediments on which cottonwood seedlings germinated (Howe and Knopf 1991, Taylor and others 1999). The absence of spring flood events has reduced recruitment in cottonwood populations and allowed invading plants, such as saltcedar (*Tamarix ramosissima*) and Russian olive (*Elaeagnus angustifolia*), to establish on sites formerly available to cottonwood (Howe and Knopf 1991). The quantities of woody debris in many areas of the bosque have also increased substantially due the lack of scouring floods (Ellis and others 1999). Accumulation of these woody debris, combined with dense stands of saltcedar and Russian olive in the understory, lead to fuel loadings capable of supporting catastrophic wildfires (Stuever 1997).

To reduce fire risk, restore cottonwood dominance, and increase groundwater availability, land managers have used herbicide, prescribed fire, chaining, ripping, and other mechanical manipulations to remove saltcedar and other invasive woody plants (Taylor and McDaniel 1998, Taylor and others 1999, Dello Russo and Najmi, this proceedings). Vegetative structure and composition affect food, shelter, cover, and other resources available to wildlife. Thus, anthropogenic changes in the bosque have likely altered wildlife communities of these forests (for example, species composition, abundance, and interactions). Managers must understand the effects of various restoration treatments on wildlife communities and individual wildlife species to make sound decisions that balance management objectives (for example, reducing fire risk) with other considerations such as the Endangered Species Act, recreational use, aesthetic value, and ecosystem integrity.

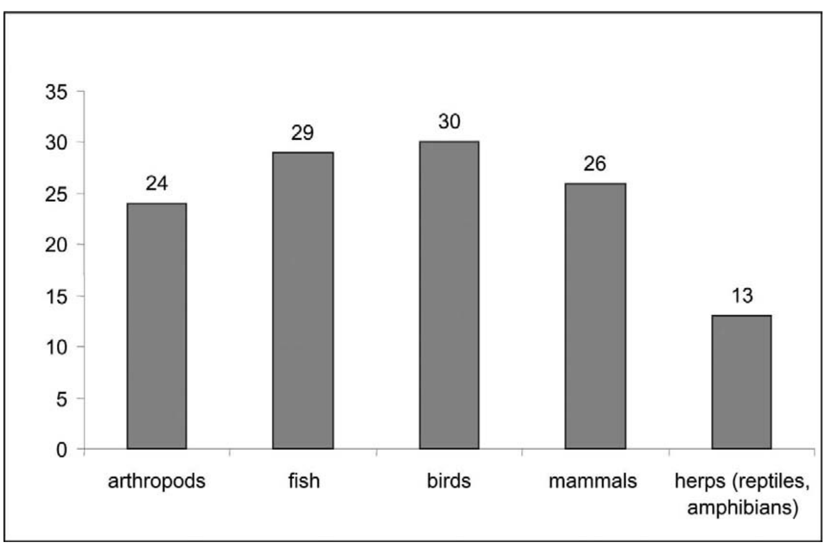

Figure 2. Results of a literature search of the BIOSIS Database (1969-2004) for studies of vertebrates and arthropods that occurred along the Rio Grande in New Mexico.

What Do We Know About Herpetofauna in the Bosque?

Information on the herpetofaunal community of the Middle Rio Grande bosque is limited. A literature search of the BIOSIS Database revealed that only 10 percent of studies published on animals associated with the Rio Grande in New Mexico have focused on herpetofauna (fig. 2). Most studies focused on fish, birds, arthropods, or mammals. Because there are no studies of amphibians and reptiles in the bosque prior to channelization and damming of the river, it is difficult to characterize the herpetofaunal community of native, undisturbed cottonwood forest.

A list of expected species may be assembled from recent studies, historic and museum records, and habitat associations from Degenhardt and others (1996). More recently, Hink and Ohmart (1984) characterized herpetofauna associated with riparian vegetation of the Middle Rio Grande based on results of their pitfall surveys, museum records, and other field observations. Stuart and others (1995) reported herpetofauna captured at two sites within the Bosque del Apache National Wildlife Refuge (BDANWR) near Socorro, NM. Several studies have examined the lizard communities of desert riparian areas in Arizona. However, data from these studies are not comparable to Middle Rio Grande bosque because mesquite (*Prosopis velutina*) was the major overstory tree/shrub in the Arizona study areas, and cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*) had only a scattered or occasional presence (Vitt and others 1981, Jakle and Gatz 1985, Jones and Glinski 1985, Szaro and Belfit 1986).

Based on available literature, cottonwood forests and associated habitats of the Middle Rio Grande (including ditches, canals, ponds, sandbars, and drier peripheral riparian habitats) are used by at least 50 reptile and amphibian species. Species that were captured (Hink and Ohmart 1984, Stuart and others 1995) and species with other types of records in the Middle Rio Grande bosque (Hink and Ohmart 1984, Degenhardt and others 1996, Bailey and others 2001) are listed in table 1. The Eastern Fence Lizard (*Sceloporus undulatus*), New Mexico Whiptail (*Aspidoscelis neomexicana*, formerly genus *Cnemidophorus* from Reeder and others 2002), and Woodhouse's Toad (*Bufo woodhousii*) were frequently captured from Española to Socorro, NM (Hink and Ohmart 1984). Fifteen other species of lizards, snakes, amphibians, and

Table 1. Species list of herpetofauna observed or captured in the Middle Rio Grande bosque and associated habitats (including ditches, canals, ponds, sandbars, and drier peripheral riparian habitat). Reference codes are as follows: HC = captures by Hink and Ohmart (1984), HM = museum records and other observations reported in Hink and Ohmart (1984) Appendix 2, D = habitat associations from Degenhardt and others (1996), B = Bailey and others (2001), S = captures by Stuart and others at BDANWR (1995).

Taxa	Scientific Name	Common Name	Reference
Amphibians	*Ambystoma tigrinum*	Tiger Salamander	HC, D, B, S
	Bufo cognatus	Great Plains Toad	HC, D, B
	Bufo punctatus	Red-spotted Toad	HM
	Bufo woodhousii	Woodhouse's Toad	HC, D, B, S
	Pseudacris triseriata	Western Chorus Frog	HC, D, B
	Rana blairi	Plains Leopard Frog	B
	Rana catesbeiana	American Bullfrog	HC, D
	Rana pipiens	Northern Leopard Frog	HM, D, B
	Scaphiopus couchii	Couch's Spadefoot	HM, D, B
	Spea bombifrons	Plains Spadefoot	HC, B
	Spea multiplicata stagnalis	New Mexico Spadefoot	HM, D, B
Turtles	*Apalone spinifera*	Spiny Softshell Turtle	HC, D, B
	Chelydra serpentina serpentina	Eastern Snapping Turtle	D
	Chrysemys picta	Painted Turtle	HM, D, B
	Terrapene ornata	Ornate Box Turtle	HM, D, B
	Trachemys gaigeae gaigeae	Big Bend Slider	D, B
	Trachemys scripta elegans	Red-eared Slider	D
Lizards	*Aspidoscelis exsanguis*	Chihuahuan Spotted Whiptail	HC, D, S
	Aspidoscelis inornata	Little Striped Whiptail	HC, D, S
	Aspidoscelis neomexicana	New Mexico Whiptail	HC, D
	Aspidoscelis tesselata	Common Checkered Whiptail	HM, D
	Aspidoscelis tigris	Tiger Whiptail	HM
	Aspidoscelis uniparens	Desert Grassland Whiptail	HM, D, S
	Aspidoscelis velox	Plateau Striped Whiptail	HC
	Cophosaurus texanus	Greater Earless Lizard	D
	Crotaphytus collaris	Eastern Collared Lizard	D
	Eumeces obsoletus	Great Plains Skink	HC, D, B
	Holbrookia maculata	Common Lesser Earless Lizard	HC
	Phrynosoma hernandesi	Greater Short-horned Lizard	HM
	Phrynosoma modestum	Round-tailed Horned Lizard	HC, D
	Sceloporus magister	Desert Spiny Lizard	HM, D, B
	Sceloporus undulatus	Eastern Fence Lizard	HC, D, S
	Urosaurus ornatus	Ornate Tree Lizard	D
	Uta stansburiana	Common Side-blotched Lizard	HC, D
Snakes	*Arizona elegans*	Glossy Snake	HC
	Coluber constrictor	Eastern Racer	HM, D, B
	Crotalus atrox	Western Diamond-backed Rattlesnake	HM, B
	Crotalus viridis	Prairie Rattlesnake	HM, B
	Heterodon nasicus	Western Hog-nosed Snake	HM
	Lampropeltis getula	Common Kingsnake	HM, D, B, S
	Leptotyphlops dissectus	New Mexico Threadsnake	D, B
	Masticophis flagellum	Coachwhip	HM, B
	Pituophis catenifer	Gophersnake	HM, D, B
	Rhinocheilus lecontei	Long-nosed Snake	HM
	Sistrurus catenatus	Massasauga	HM
	Tantilla nigriceps	Plains Black-headed Snake	HM, B, S
	Thamnophis cyrtopsis	Black-necked Gartersnake	HM, D, B
	Thamnophis elegans	Terrestrial Gartersnake	D, B
	Thamnophis marcianus	Checkered Gartersnake	HM, D, B
	Thamnophis sirtalis	Common Gartersnake	HC, D, B

turtles were captured infrequently, at a limited number of locations, or both (Hink and Ohmart 1984, table 1). An additional 23 species of reptiles and amphibians were occasionally sighted or otherwise documented in the Middle Rio Grande Valley (Hink and Ohmart 1984, table 1). In two mixed stands of mature cottonwood and saltcedar at BDANWR, Stuart and others (1995) detected eight amphibian and reptile species (table 1).

Most of the species captured are typically associated with upland habitats (for example, desert grasslands, shrublands, and arroyos) rather than mesic riparian forest (Degenhardt and others 1996). Hence, capture rates were highest in open vegetation types with sandy soils and sparse ground cover and lowest in stands with dense understories (Hink and Ohmart 1984). Species captured more frequently in open, sandy habitats with sparse vegetation (for example, open stands of intermediate aged cottonwoods) included Eastern Fence Lizards, New Mexico Whiptails, Chihuahuan Spotted Whiptails (*A. exsanguis*), Woodhouse's Toads, Great Plains Toads (*Bufo cognatus*), and Plains Spadefoots (*Spea bombifrons*, Hink and Ohmart 1984). However, Great Plains Skinks (*Eumeces obsoletus*) were captured frequently in stands with densely vegetated understories.

Species associated with wetter habitats within the bosque (for example, near permanent water) included Gartersnakes (*Thamnophis* spp.), Spiny Softshell Turtles (*Apalone spinifera*), Tiger Salamanders (*Ambystoma tigrinum*), Western Chorus Frogs (*Pseudacris triseriata*), and American Bullfrogs (*Rana catesbeiana*, Hink and Ohmart 1984). Although once abundant in the bosque, Northern Leopard Frogs (*Rana pipiens*) were rarely captured by Hink and Ohmart (1984) and are considered extirpated from Bernalillo, Socorro, and Sierra counties (Applegarth 1983, Bailey and others 2001). The absence or low numbers of these species captured likely reflect the loss of suitable wetland habitat along the river. From 1935 to 1989, surface area covered by wet meadows, marshes, and ponds declined by 73 percent along 250 miles of Middle Rio Grande floodplain (Roelle and Hagenbuck 1995).

What Should We Know and Why?

Cottonwood forests of the bosque exist in a variety of states (for example, minimally-invaded, highly-invaded, or 'restored') as a result of initial alterations (for example, dams and channelization), subsequent changes (for example, invasive plants and accumulation of debris), and restoration efforts (for example, removal of invasive plants, herbicide application, and prescribed fire). Amphibian and reptile populations respond to changes in abiotic factors, such as structural heterogeneity and substrate moisture (Cunningham and others 2002, James and M'Closkey 2003), as well as biotic factors such as insect availability and predation (Sabo and Power 2002). Simply detecting changes in herpetofaunal populations is not adequate for guiding management activities. Rather, understanding the causes of observed population changes is necessary to design appropriate management responses (Gibbs and others 1999). Thus, questions arise regarding how changes in forest structure and composition have affected herpetofaunal diversity, community ecology, and species distributions, abundances, and interactions.

What Can We Learn From Other Taxa?

Answers to these questions are difficult due to the lack of information on amphibians and reptiles in native bosque prior to recent anthropogenic changes. Although there is no published literature on the effects of these changes on herpetofaunal communities, researchers have compared arthropod, bird, and rodent communities in cottonwood and saltcedar habitats, and results of these studies may provide insight into herpetofaunal community responses.

Ellis and others (2000) described arthropod richness, abundance, and composition in cottonwood and saltcedar sites at BDANWR. Cottonwood sites had a greater abundance of abundance of exotic isopods (Isopoda), which are leaf macrodetritivores. Spider richness and abundance were greater in saltcedar sites. The abundance of other insect taxa was similar or greater in saltcedar sites than cottonwood sites. Thus, although saltcedar has altered riparian ecosystems, it does support a varied and abundant surface-dwelling arthropod community which in turn, support amphibians, reptiles and other vertebrates.

The bosque hosts a rich assemblage of birds in both cottonwood and saltcedar habitats (Hink and Ohmart 1984). Cottonwood and saltcedar habitats were similar in number of species during spring, summer, and fall, although species composition differed seasonally (Hunter 1985, Ellis 1995). During the spring breeding season, more neotropical migrant species were found in cottonwood habitats than saltcedar (Hunter 1985, Ellis 1995).

Ellis and others (1997) described rodent communities in cottonwood and saltcedar sites. White-footed mice (*Peromyscus leucopus*) were the most abundant species in the bosque. Whitethroat woodrats (*Neotoma albigula*) occurred only in cottonwood sites. Overall, rodent species richness was greater in saltcedar sites than cottonwood sites. Similar to the herpetofaunal community, most rodents were upland and grassland species, not riparian specialists.

Effects of Habitat Loss

Damming, channelization, and water diversion have resulted in the loss of wetlands and meadow habitats along the Middle Rio Grande (Hink and Ohmart 1984, D. McDonnell, University of New Mexico, personal communication 2004). Biologists and managers must understand how the loss of these unique habitats has impacted amphibians and other aquatic-associated species in the bosque and whether urban areas, agricultural fields, and irrigation canals provide alternative, quality habitats for these species.

Effects of Fuels Reduction Treatments

Treatments to decrease fuel loadings in the bosque are needed to reduce the risk of catastrophic wildfire to people, their homes, and businesses in surrounding urban and rural areas (Taylor 2001). Information is needed on the impacts of various treatments on herpetofaunal species and communities and opportunities for mitigating adverse effects. For example, in pinyon-juniper woodlands of western Colorado, spiny lizards (genus *Sceloporus*) prefer standing dead trees for shelter, perching, foraging, and other activities. Loss of these trees through fuels reduction treatments would reduce habitat for spiny lizards (James and M'Closkey 2003). However, these negative effects may be mitigated by leaving a percentage of dead standing trees after treatment. Information on the life history and specific habitat requirements of amphibian and reptile species within the bosque is required to answer these questions as they pertain to fuels management along the Middle Rio Grande. Species adapted for open environments may respond favorably to fuels reduction, whereas species requiring more cover or moist habitats may be negatively affected. The challenge facing managers, researchers, and biologists is to identify treatment alternatives that will achieve as many management objectives as possible (for example, fuels reduction, control of exotic plant species, endangered species habitat improvement, improved water management and delivery, restoration of native plant species, biodiversity, and positive or neutral effects on wildlife).

Other Considerations

Many management decisions are often weighed by their impacts on biodiversity, and a high species richness is often favored. However, community productivity and desired species composition are also important considerations when evaluating management activities. The number of animals supported in an area depends on the amount of energy available, and amount of energy available is determined by plant primary productivity (Damuth 1987). Will removal of exotic plant biomass temporarily decrease energy available and thus the number of insects, birds, mammals, amphibians, and reptiles supported on treated sites?

Ernest and Brown (2001) found that abundance, biomass, and energy use mirror fluctuations in primary production, whereas species composition may not follow the same pattern. For example, two sites may have the same number of species, but could differ in the size, abundance, and density of those animals, which is measured by population-level energy use. Therefore, by tracking changes in population-level energy use rather than solely species composition or diversity, we can assess fluctuations in ecosystem function, or resource supply, caused by fuels reduction treatments.

Managers may also be required to make value judgments as to whether changes in species composition and abundance are favorable or unfavorable. All-female, or parthenogenic, lizard species are common in marginal, ecotonal, or disturbed habitats and consequently, have been called 'weedy species' (Wright and Lowe 1968). Parthenogenic species such as the New Mexico Whiptail, Desert Grassland Whiptail (*A. uniparens*), and the Chihuahuan Spotted Whiptail are the most frequently captured whiptails in the Middle Rio Grande bosque (Hink and Ohmart 1984, Stuart and others 1995). However, populations of the Little Striped Whiptail (*A. inornata*), a nonparthenogenic species, were found in the bosque of BDANWR (Stuart and others 1995). Would it be considered a negative consequence if management activities fostered populations of this bisexual, nonparthenogenic grassland species at the cost of other parthenogenic whiptail species and a decline in species diversity? Are managers interested in maximizing biodiversity, restoring native species to bosque, or enhancing habitat for declining species? Research cannot answer these questions, but it can provide information helpful to making decisions.

The Fuels Reduction Project

In 1999, scientists with the U.S. Forest Service Rocky Mountain Research Station initiated an interagency, collaborative project to evaluate the effectiveness of three fuel reduction treatments at sites in the Middle Rio Grande bosque and monitor their effects on groundwater, vegetation, soils, and wildlife. Cooperators on this project include Middle Rio Grande Conservancy District, BDANWR, City of Albuquerque Open Space Division, Bureau of Land Management, New Mexico Department of Environment, Texas Agriculture Experiment Station, and the NRCS Plants Material Center. This project attempts to identify the most effective fuels reduction and exotic plant removal method that will preserve native plants, reduce fire risk, and have a positive or least-negative impact on native wildlife species (Finch and others 2002).

Project Area

The project area encompasses approximately 129 km of riverside bosque from Albuquerque to the BDANWR.

Twelve sites were selected along this stretch of the river, each with relatively homogeneous vegetation, approximately 20 hectares in size, and composed of a mature cottonwood overstory and an exotic woody understory (specifically, saltcedar and Russian olive). To achieve a randomized block design, the 12 sites were subdivided into three blocks of four sites each, and each of the four sites was randomly assigned a treatment type. Treatment 1 consists of mechanical removal of dead and down wood and exotic trees and shrubs followed by spot application of herbicide to cut stumps. Treatment 2 consists of procedures in treatment 1 followed by a light, prescribed fire. Treatment 3 consists of procedures in treatment 1 followed by revegetation with native shrubs. Treatment 4 is the control and consists of no treatment.

Monitoring

To evaluate effects of treatments on herpetofaunal communities, we are monitoring populations (primarily lizards and amphibians) via drift fence arrays, pitfalls, and funnel traps. Drift fences, pitfalls, and funnel traps are being used simultaneously because multiple techniques result in a more complete sampling of amphibian and reptile communities (Jorgensen and others 1998, Crosswhite and others 1999). Each of the 12 sites has three arrays. Each array consists of six pitfalls and six funnel traps positioned along a set of fences. There are a total of 216 pitfalls and 216 funnel traps at the 12 study sites. Each year, traps are open continuously from the first week of June to mid September and are checked three times per week from 0600 and 1400 hrs. Snout-to-vent length, tail length, age (hatchling or adult) and weight of all animals are recorded. Individuals of all lizard species and Woodhouse's Toads are uniquely identified via toe clipping for mark-recapture analysis. Other amphibians and snakes are not captured in sufficient numbers to warrant marking.

Herpetofaunal Research Questions

Habitat Relations

Using pre- and post-treatment trapping results and associated vegetation data (such as vegetation structure, plant species composition, density, canopy cover, litter depth, and woody debris), we will address several of the questions posed. Data from this study will provide insight into the natural history of many species, some of which are little studied to date. For species that are more commonly found in upland habitats, these data will provide specific information regarding their habitat use in riparian cottonwood forests. For example, parthenogenic whiptail species have been studied in upland and riparian habitats of the Lower Rio Grande in Texas and Mexico (Walker 1987, Walker and others 1990), but little is known about their behavior and habitat use along the Middle Rio Grande. Our study will help describe how these populations respond to habitat disturbance and the degree to which they overlap with sexual whiptail species.

Species-specific Responses

Pre- and post-treatment information collected on animals and vegetation will allow us to describe how treatments impact amphibians and reptiles at different life stages and whether new species colonize after different treatments. In particular, we will address species-specific responses to treatments, how populations of parthenogenic species respond to treatment-related habitat changes, and how populations of aquatic or mesic-associated species respond to treatments.

Species Diversity

Avian and lizard diversity are typically greater in complex, heterogeneous environments (MacArthur 1958, Pianka 1967, Farley and others 1994). We will describe diversity with rank-abundance curves and examine whether differences in spatial heterogeneity among or within sites are associated with changes in herpetofaunal diversity.

Ecosystem Function

We are interested in linking species and population-level responses to changes in the ecosystem. To assess energy availability for each site, we will evaluate population-level energy use (Ernest and Brown 2001) by amphibians and reptiles in sites before and after treatment. Population-level energy use is calculated from species density, species-specific metabolic rate, and body mass. This will estimate the amount of energy in the herpetofaunal community.

Project Status

Although data collection for this project began in summer 2000, initial phases of treatments have only recently been completed. Mechanical removal and herbicide phases of treatments occurred at five sites during fall and winter of 2002-2003 and at three sites during fall and winter of 2003-2004. Mechanical removal will occur at the remaining site in fall 2004, and final phases of treatments (prescribed fire and revegetation) will completed by spring 2004. The first season of post-treatment data was collected this summer 2004 at 11 of the 12 sites.

Table 2. Species list of herpetofauna captured in the Middle Rio Grande bosque during the RMRS fuels reduction project (2000 to 2003), ordered within taxa by total number of captures.

Taxa	Scientific Name	Common Name	Number
Amphibians	*Bufo woodhousii*	Woodhouse's Toad	617
	Bufo cognatus	Great Plains Toad	58
	Scaphiopus couchii	Couch's Spadefoot	40
	Spea multiplicata stagnalis	New Mexico Spadefoot	13
	Ambystoma tigrinum	Tiger Salamander	2
	Rana catesbeiana	American Bullfrog	2
	Spea bombifrons	Plains Spadefoot	2
	Pseudacris triseriata	Western Chorus Frog	1
Turtles	*Apalone spinifera*	Spiny Softshell Turtle	1
Lizards	*Sceloporus undulatus*	Eastern Fence Lizard	2755
	Aspidoscelis neomexicana	New Mexico Whiptail	2569
	Aspidoscelis exsanguis	Chihuahuan Spotted Whiptail	2034
	Aspidoscelis uniparens	Desert Grassland Whiptail	1139
	Eumeces obsoletus	Great Plains Skink	397
	Sceloporus magister	Desert Spiny Lizard	73
	Uta stansburiana	Common Side-blotched Lizard	35
	Aspidoscelis tigris	Tiger Whiptail	29
	Aspidoscelis tesselata	Common Checkered Whiptail	12
	Aspidoscelis inornata	Little Striped Whiptail	1
	Phrynosoma cornutum	Texas Horned Lizard	1
Snakes	*Lampropeltis getula*	Common Kingsnake	24
	Pituophis catenifer	Gophersnake	15
	Heterodon nasicus	Western Hog-nosed Snake	9
	Thamnophis sirtalis	Common Gartersnake	8
	Tantilla nigriceps	Plains Black-headed Snake	7
	Thamnophis marcianus	Checkered Gartersnake	4
	Masticophis flagellum	Coachwhip	3
	Thamnophis elegans	Terrestrial Gartersnake	2
	Arizona elegans	Glossy Snake	1
	Crotalus viridis	Prairie Rattlesnake	1
	Leptotyphlops dissectus	New Mexico Threadsnake	1
	Rhinocheilus lecontei	Long-nosed Snake	1
	Crotalus atrox	Western Diamond-backed Rattlesnake	0[a]

[a] Observed at study site, but not captured.

Preliminary Results

A total of 9,857 individuals of 32 species (8 amphibians, 11 lizards, 12 snakes, and 1 turtle) have been captured during the 2000 through 2003 seasons (table 2). Because the arrays are less effective at capturing amphibians and snakes, the majority of individuals captured were lizards. Four species, including the Eastern Fence Lizard, New Mexico Whiptail, Chihuahuan Spotted Whiptail, and Great Plains Skink, were present at most or all sites (11 or 12 sites). Fewer aquatic or moist habitat species are represented. Similar to previous studies, the majority of species captured were upland species. For example, the New Mexico Whiptail is typically associated with open, sparse vegetation (Christiansen and others 1971). The large number of captures of this and other species is surprising considering the high degree of canopy cover, and therefore shading, at our sites (x = 83.3 + 3.3 percent S.E.). At least 3 years of posttreatment data (2004-2006) will be collected at all sites, and data analysis will begin at the close of the field season in mid September 2004.

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Relevance of the Sustainable Rangelands Roundtable Criteria and Indicators for Sustainable Rangeland Management to Conditions in Patagonia (Argentina)

Andrés F. Cibils, Assistant Professor, Range Science, Department of Animal and Range Sciences, New Mexico State University, Las Cruces, NM

Gabriel E. Oliva, Research Scientist, INTA-EEA Santa Cruz and Professor at the Universidad Nacional de la Patagonia Austral, Casilla 332, (9400) Río Gallegos, Argentina

Abstract—*Patagonia's rangelands are similar to those in western United States in terms of climate, topography, and vegetation physiognomy. However, differences in environmental, economic, and societal values do exist between regions. We assessed the usefulness of C&I (Criteria and Indicators) developed in the United States for other countries, and identified indicators not included in the SRR (Sustainable Rangelands Roundtable) set that would be important for monitoring the sustainability of Patagonia's rangelands. Most of SRR's C&I were relevant to conditions in Patagonia (Argentina). Less than half the indicators were applicable, however, due to the relative paucity of data and validated models. This exercise suggested that a shorter list of essential indicators may be necessary to realistically conduct regional long-term assessments of overall sustainability of rangeland ecosystems in developing countries.*

Introduction

Rangelands of western North America and Patagonia (Argentina) share important physical and productive characteristics. Such similarities should allow a meaningful assessment of the relevance and applicability of the Sustainable Rangeland Roundtable (SRR) monitoring framework to rangelands outside North America. Differences in land use regulations and land tenure regimes between regions, on the other hand, are sufficient to make this comparison an interesting and worth-while endeavor.

The objective of this paper is to assess the relevance and applicability of the criteria and indicators (C&I) proposed by SRR to conditions in Patagonia (Argentina). We will first describe Patagonian rangelands and briefly compare them to rangelands in western North America. We will then give a concise overview of the social, economic, and environmental conditions in Patagonia, followed by an account of current rangeland monitoring efforts in the region. The last and most important section of this paper will deal with the relevance assessment itself. In this section we will summarize the main results and conclusions of this exercise.

Rangelands of Patagonia (Argentina) in Relation to Their North American Counterparts

Rangelands occupy over 90 percent of the land area of Patagonia, a region of cold semi-arid deserts on the southernmost end of the South American continent (Lat 39° to 55° S). In this paper we will focus mainly on Patagonia's grazing lands East of the Andes in southern Argentina (approximately 750 000 km^2).

Most of Patagonia lies in the rain shadow of the Andes. Mean annual precipitation rarely exceeds 250 mm except in the forested foothill ranges where rainfalls can exceed 1,000 mm. (Soriano 1983). Rainfall occurs mainly during winter across most of the region (Paruelo and others 1998). Mean annual temperatures range from 15.9°C in the North to approximately 5.4°C in the far South of Tierra del Fuego (Soriano 1983). Strong persistent westerly winds are one of the most distinctive characteristics of Patagonia's climate; gusts of 100 km/h, or more, are common in spring and summer (Paruelo and others 1998). Over 70 percent of Patagonia's topsoil is coarse-textured, and almost 90 percent of soils in the region exhibit some degree of degradation, mostly as a consequence of improper land use. Severe desertification affects about a third of Patagonia (Del Valle 1998); some of its most dramatic expressions are the lenguas medanosas (sand dunes) that covered an area of approximately 85 000 km^2 in the early 1970s. Many of these accumulations are about 100 years old, suggesting that the rate of wind-driven erosion processes may have been accelerated by the introduction of domestic livestock in the region (Soriano 1983).

Patagonian rangelands are primarily treeless shrub and grass steppes that give way to dwarf-shrub semi-deserts in the drier areas of the central plateaus (Roig 1998). Vegetation is mostly made up of xerophytic species that have evolved remarkable adaptations to cope with severe water stress conditions (León and others 1998). Blended in the steppe landscapes are riparian areas (*vegas* or *mallines*) associated with rivers and other permanent water sources. Although mallines are a very small proportion of the total land area of Patagonia, they frequently play a key role in livestock production and, in many instances, are the ecosystems most severely affected by improper land management decisions (Golluscio and others 1998).

Patagonian and western North American rangelands exhibit a number of geomorphologic, edaphic, botanical and land use similarities. Both regions share genera of important grasses (*Stipa*, *Festuca*, *Poa*), sedges (*Carex*), and shrubs (*Larrea*, *Prosopis*, *Lycium*, *Atriplex*). Forage production and grazing capacity of areas with similar annual rainfall are analogous. Commercial livestock and sheep grazing enterprises are a fundamental element of rangeland livelihood of both Patagonian and western North American rangelands. Ranch management practices, animal handling skills, and educational background of operators in both regions are also comparable. Furthermore, tensions between multiple rangeland use alternatives, particularly in the case of oil and gas production, have been well documented in both regions.

Rangelands of Patagonia and western North America also exhibit a number of important differences, the most significant of which is possibly associated with land ownership regime. In stark contrast to western North America, almost all of Patagonian rangelands are privately owned and, therefore, grazing use is virtually unregulated. In addition, rangeland science and management tradition is fairly young in most of Patagonia; widespread application of range survey methods to determine grazing capacity of commercial ranches did not begin until the late 1980s. Most of Patagonia's rangelands have been (and still are) grazed by sheep rather than cattle. Wool production-driven grazing management is thought to have greatly contributed to desertification in the region. Surprisingly, invasive noxious weeds are not a widespread problem on Patagonia's rangelands.

Social, Economic, and Environmental Sustainability of Rangelands of Patagonia (Argentina)

Social aspects: Pastoral use history of rangelands in Patagonia is relatively recent; even today there are less than 2.3 inhabitants per square kilometer (INDEC 2001). Colonization of this vast land took place in the late 1880's, after military "desert" campaigns subjugated native peoples and the country offered land for colonization, mainly to Argentine and Chilean "criollos" but also to settlers of European or Middle-Eastern descent, including Spaniards, English, Scottish, Italians, Syrian-Lebanese and Yugoslavians. Native peoples were mainly hunters and gatherers: the Tehuelche in the south did not endure the cultural impact of colonization and are now severely reduced in number, while the Mapuche people, in the north, recovered after an initial descent. Both groups add up to 23 to 50 thousand people, about 1.4 to 3.5 percent of the residents of the region. Early (1880-1900), colonization was actively encouraged by the government and settlers were given access to pastoral leases in large areas of the most productive or readily accessible land. At the turn of the 19th century, poorer settlers took part in the colonization of arid or inaccessible areas. The land was divided geometrically into allotments of about 10 to 20 thousand hectares without considering environmental factors or the balance of range types, water points, or wintering areas within the properties (Barbería 1995). Native Americans remained on the land in small subsistence allotments of about 500 to 2500 hectares or in a few reservations. Freehold rights consolidated land tenure of most of the big "estancias" at the turn of the 20th century, but small allotments remain mostly with informal or traditional occupation, a great number of them unfenced.

Economic Aspects

The sheep industry flourished until 1920, while prices of wool were high and undisturbed grasslands could take heavy grazing pressures. Sheep numbers peaked by 1937, (fig. 1), and remained stable for almost 50 years (Oliva and others 1995, Escobar 1997, Mendez Casariego 2000). In the 1980's, a generalized stock reduction process was triggered by a combination of lower international wool

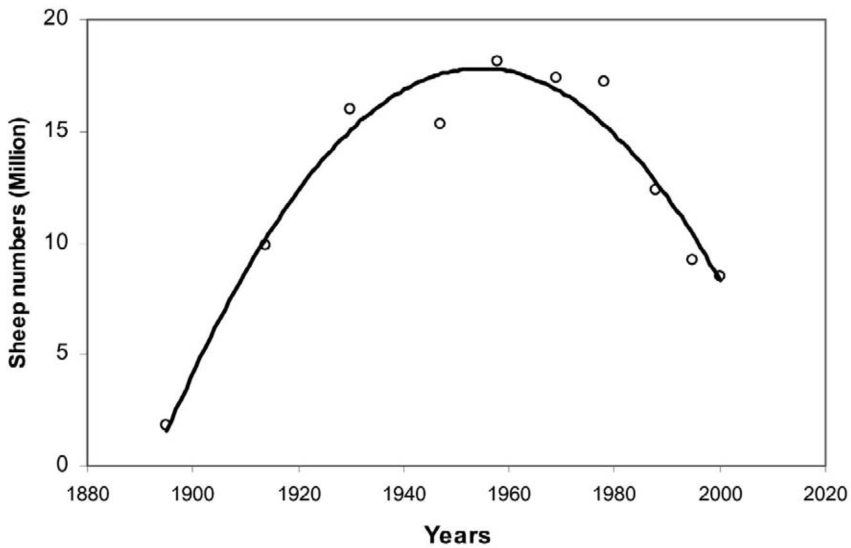

Figure 1. Sheep numbers in Patagonia (From Borelli and Cibils 2004).

and meat prices, loss of productivity due to rangeland degradation, and macroeconomic policies that inflated the value of local currency (Borrelli and others 1997, Mendez Casariego 2000). These factors put most sheep ranching enterprises in a difficult financial position; by the end of the 20th century most ranchers had become heavily indebted and had drastically reduced their work force. This crisis primarily affected mid-sized (20.000 hectares) family-owned ranches in the Central Plateau of Santa Cruz, where about 440 (40 percent of the total) estancias have been abandoned or remain occupied by caretakers with no pastoral activities. Rural population in Santa Cruz fell from 24.500 in 1960 to 13.700 in 1991 (Mendez Casariego 2000). Changes in macroeconomic policies implemented in 2002 have increased the profits of the sheep ranching industry (Teran and Claps 2002), and there is currently a strong predisposition to re-colonize vacant lands.

Environmental Aspects

Heavy grazing-induced degradation processes were described early on by Bailey Willis (1914, as cited in Castro (1983), Morrison (1917), Auer (1951), Soriano (1953), Soriano (1956a, b) and Movia and others (1987). Soil erosion was treated using dune control techniques as early as 1950 (Castro 1983). Nevertheless, the underlying causes of degradation were not addressed, and heavy stocking rates remained in place until the 1980's. Regional evaluation of desertification using satellite imagery began in the early 1990's and showed that severe or very severe desertification had affected approximately 34 percent of Patagonia (Goergen 1995, Del Valle and others 1998).

The Role of Government Administration

According to the Argentine constitution, natural resources, including rangelands, are under the jurisdiction of provincial governments. Sadly, environmental consequences of improper grazing have rarely been addressed by provincial or national government policies due to the fact that most of the land is under freehold tenure and there is no constitutional mandate to monitor the state and management of rangelands. Grazing has therefore, gone unregulated and conservative management has depended mostly on the perceptions and goodwill of landowners. Due to social and political influence of traditional rancher associations, significant amounts of public funds have frequently been directed towards the maintenance and expansion of the sheep industry through subsidies and financial support regardless of the grazing capacity of rangelands. Joint desertification projects sponsored by the Instituto Nacional de Tecnología Agropecuaria (INTA, Argentina) and the Deustche Gesellschaft fur Technische Zusammenarbeit (GTZ, Germany) from 1989 to 2002 helped increase public awareness regarding the threat that desertification posed to the region, and stimulated the design and fairly extensive application of rangeland survey and monitoring techniques. The trend of public fund allocation has changed in recent years since the passing of a Sheep Act in 2002 (Poder_Legislativo_Nacional 2004) that assigns about $7 M yearly to projects that can demonstrate ecological sustainability through certified range evaluation. Rancher associations participate in the distribution of these funds that support the development of a regional-scale monitoring system. A project with funding currently under consideration by the Global Environment Facility Program of the World Bank (GEF) will address three aspects that the Sheep Act of 2002 does not include, namely: 1) rangeland monitoring; 2) education; and 3) diversity conservation through public and private protected areas. Such recent developments allow moderate optimism regarding a change in long-term government rangeland conservation policies.

Rangeland Monitoring in Patagonia

Rangeland management in Patagonia emerged as a scientific discipline in the 70's as a product of region-wide projects funded by FAO (Food and Agriculture Organization of the United Nations), INTA, and BID (Inter-American Development Bank). During the early 80's researchers began applying traditional range-condition analysis and developing range condition guides for a few sites in the region (Borrelli and others 1984, Borrelli and others 1988, Bonvisutto and others 1993, Nakamatsu and others 1993, Paruelo and others 1993). Considerable effort was later put into transforming range condition guides into state and transition models (Paruelo and others 1993). However, ecological status guides were soon almost totally replaced by practical methods to assess forage availability at the scale of individual pastures in expeditious and cost effective ways.

Two separate approaches were developed to survey grazing capacity of rangelands. The first, known as "Pastoral Value Method" (PVM) (Elissalde and others 2002), calculated cover of all plant species with step transects and transformed cover data into forage availability estimates using coefficients that considered plant species palatability and nutritional value. The second technique known as "Santa Cruz Method" (SCM) (Borrelli and Oliva 1999, Borrelli and others 1999, Borrelli and Oliva 2001), included estimates of shortgrass and forb biomass (by clipping cuadrats) and stubble heights of key shortgrass species. The PVM has been used to determine grazing capacity of shrublands in northern Patagonia whereas dwarf shrublands and tussock grasslands of southern Patagonia (including the island of Tierra del Fuego) have been mostly surveyed using the SCM. Both methods rely on previous site inventories using Landsat TM satellite imagery and on-the-ground GPS sampling to produce ranch maps as base cartography of natural resources is very scarce in most of the Region.

Both the PVM and SCM are now officially recognized by provincial governments in Patagonia. Provincial governments sponsor annual training courses and keep official registries of certified rangeland surveyors. Over 6 percent of rangelands (1.4 million hectares) of southern Patagonia (Santa Cruz and Tierra del Fuego) have been surveyed; approximately 60 percent of the ranches in the most productive areas have been surveyed with the SCM at least once. A somewhat smaller but similarly important area has been surveyed using the PVM in the provinces of Chubut, Río Negro and Neuquén. Because the Sheep Act of 2002 requires producers to submit certified rangeland surveys to qualify for government subsidies and loans, the area of surveyed rangelands is expected to increase steadily in the years to come.

Although the PVM and SCM give valuable rangeland management information, they have not been designed to monitor regional ecological trends through time. The SCM estimates yearly forage biomass at a ranch scale relying on the "take half, use half" rule of thumb for a few key species assuming that this rate of utilization will not have detrimental effects on rangeland condition. The PVM includes an estimate of cover for all plant species in addition to the percent of bare soil, but is usually performed only once in order to obtain an initial forage assessment; subsequently stocking rates are adjusted following rain patterns (Rimoldi and Buono 2001).

The need for an independent method to establish rangeland state and trend at the scale of range types (from 0.4 to 14.3 M ha) and at relevant time scales (decades) has been acknowledged recently, and an INTA-GTZ project has enabled range scientists of Patagonia to discuss an initial methods to monitor vegetation and soil. This monitoring system, known as MARAS (Monitoreo Ambiental de la Región Arida y Semiárida de Patagonia, (Oliva and others 2004) is based on Australia´s WARMS method (Western Australia Monitoring System), and includes point intercept transects or frequency samples to evaluate herbaceous vegetation and Camfield lines to monitor shrubs. Soil surface sampling and shake tests are also performed to monitor topsoil integrity. Monitoring stations will be set up at a rate of 1: 20.000 hectares and will be measured every five years. MARAS has received funding from the Sheep Act of 2002 to train field personnel, install the first monitoring sites, and design a web-based data bank that will be accessed by government agencies and NGOs. In the future, MARAS could supply information to monitor vegetation cover, species composition, forage biomass and soil condition of rangelands in Patagonia. To date, there are no plans in place to incorporate social or economic variables into this monitoring system.

Table 1. Relevance of SRR C&I to conditions in Patagonia.

Criteria	Number of indicators	Indicators important to conditions in Patagonia	Indicators that can be monitored with existing data and models	Indicators that can be reported adequately over time	Indicators that will be monitored in the future
			----------- **Soil – based indicators**-----------		
1. Conservation and maintenance of soil and water resources of rangelands	5	5	2	2	2
			-----------**Water-based indicators**-----------		
	5	5	0	0	1
2. Conservation and maintenance of plant and animal resources on rangelands	10	8	4	2	
3. Maintenance of productive capacity on rangelands	6	6	4	4	
4. Maintenance and enhancement of multiple economic and social benefits to current and future generations	28	20	12	12	
5. Legal, institutional, and economic frame-work for rangeland conservation and sustainable management	10	9	4	4	
Totals	**64**	**53**	**26**	**24**	**3**

Relevance of SRR C&I to Conditions in Patagonia (Argentina)

To asses the relevance of SRR C&I to conditions in Patagonia we followed the overall framework developed by SRR to refine the Sustainable Forest Roundtable's list of C&I. Specifically, we asked: 1) Is this indicator important to conditions in Patagonia?; 2) Can it be monitored with current data and models?; 3) Can it be monitored adequately over time?. In cases where the answer to our second question was "no" we added a fourth question: 4) Is there a feasible plan in place to monitor this indicator in the future?

Most of the SRR criteria were classified as being relevant to conditions in Patagonia (table 1). Only a few indicators, mostly within criterion 2, were classified as not being applicable to Patagonian rangelands. For example, area of land in rangelands is fairly stable and is not threatened by urban growth or agriculture. Therefore, fragmentation of rangeland habitat is possibly not a major concern either. In a small number of other cases, mostly with indicators grouped within criteria 4 and 5, we could not tell whether they applied to social, economic or legal sustainability of rangelands in Patagonia, and therefore excluded them from the list.

Our catalog of 53 relevant indicators was severely reduced when actual monitoring feasibility was considered (table 1). Available data or models could only assess 26 of the 53 relevant indicators for sustainable rangeland management proposed by the SRR (table 2). In most cases, available data and monitoring capabilities would be able to address less than half the indicators classified as potentially relevant. In the case of indicators of productive capacity of rangelands (Criterion 3) almost all indicators could be readily applied. Most disturbingly, however, indicators to monitor water resources of rangelands (Water-based indicators under Criterion 1) were totally absent from our short list.

Relative lack of quality data and scarcity of validated models were the factors that limited the applicability of SRR C&I to Patagonian rangelands the most. Plans to expand and improve rangeland monitoring data collection are limited and can be expected to have a very small impact on our assessment of current conditions.

Table 2. List of relevant indicators that could be monitored in Patagonia.

Criteria	Indicators
1. Conservation and Maintenance of Soil and Water Resources of Rangelands	**Soil –based Indicators:** 4. Area and percent of rangeland with significant change in extent of bare ground 5. Area and percent of rangeland with accelerated soil erosion by water or wind
2. Conservation and Maintenance of Plant and Animal Resources on Rangelands	12. Rangeland area by plant community (*) 15. Density of roads and human structures 17. Extent and condition of riparian systems (*) 18. Area of infestation and presence/absence of invasive and other nonnative plant species of concern (*)
3. Maintenance of Productive Capacity on Rangelands	21. Rangeland aboveground biomass 22. Rangeland annual productivity 23. Percent available rangeland grazed by livestock 24. Number of domestic livestock on rangeland
4. Maintenance and Enhancement of Multiple Economic and Social Benefits to Current and Future Generations	29. Number of visitor days by activity and recreational land class 32. Rate of return on investment for range livestock enterprises 36. Poverty rate (general) 37. Poverty rate (children) 38. Income inequality 41. Federal transfers by categories (individual, infrastructure, agriculture, etc.) 45. Agriculture (ranch/farm) structure 46. Years of education 47. Value produced by agriculture and recreation as a percent of total 48. Employment, unemployment, underemployment, and discouraged workers by industrial sector 49. Land tenure, land use, and ownership patterns by size classes 50. Population pyramid and population change
5. Legal, Institutional, and Economic Framework for Rangeland Conservation and Sustainable Management	56. Institutions and Organizations 59. Professional Education and Technical Assistance. 63. Measuring and Monitoring. 64. Research and Development.

(*) Not all plant communities can be monitored through time with current available technology.
(**) Invasive nonnative plant species are only important locally in certain areas of Patagonia.

Our assessment exercise may be indicative of the kinds of challenges associated with applying the SRR C&I to rangelands in developing countries. Application of rangeland monitoring assessments in developing countries following the framework proposed by SRR may require a shorter bare-bone list of essential criteria and indicators. Our short list of indicators (table 2) could possibly serve as a starting point in that direction. The development of a condensed list of essential indicators could serve as a guide to help land managers and local enforcement authorities in developing countries prioritize the use of scarce funds allocated to monitoring efforts.

There are a few additional indicators not considered in the SRR C&I that would be pertinent and feasible in Patagonia:

1. Wind is the most widespread erosion and degradation agent on grazed rangelands of Patagonia. Because soils are predominantly coarse-textured, some studies suggest that the loss of fine particles (lime) and the increase in heavier particles that cannot be transported by wind (sand) is a good indicator of ongoing erosion processes (Oliva and others 2000). A simple topsoil texture test would allow fairly straightforward monitoring of early degradation processes.
2. Overgrazing can modify structural patterns of the vegetation, subdividing sink areas that are associated with shrubs (in the order of 1-2 meters diameter), and hummocks associated with tussocks (10-30 cm in diameter). These processes are difficult to monitor, although some initial efforts are underway using vertical photography or Camfield lines. Monitoring of vegetation structural patterns may prove to be important to evaluate ecosystem integrity and the risk of unfavorable transitions.
3. From the social point of view the proportion of abandoned ranches, could be a good indicator of the sustainability of the ranching industry.

Conclusions

Most of the C&I for sustainable rangeland management proposed by the SRR are relevant to conditions in Patagonia (Argentina). Less than half the indicators are applicable, however, due to the relative paucity of data and validated models. This exercise suggested that a shorter list of essential indicators might be necessary to realistically conduct regional long-term assessments of overall sustainability of rangeland ecosystems in developing countries.

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Groundwater, Vegetation, and Atmosphere: Comparative Riparian Evapotranspiration, Restoration, and Water Salvage

J. R. Cleverly, Research Assistant Professor of Biology, Department of Biology, University of New Mexico, Albuquerque, NM
C. N Dahm, Professor of Biology, J. R. Thibault, Riparian Ecologist, and D. McDonnell, Graduate Student, Department of Biology, University of New Mexico
J. E. Allred Coonrod, Associate Professor of Civil Engineering, Department of Civil Engineering, University of New Mexico

Abstract—*As water shortages persist throughout the Western U.S., a great deal of money and effort is directed toward decreasing riparian water loss, thereby enabling continued water use by irrigators, industry, and municipalities. This study focuses upon long-term measurement of evapotranspiration (ET) by native and non-native riparian species along the Middle Rio Grande (MRG) in New Mexico where riparian ET has been estimated to be 20 to 50 percent of water budget depletions. Leaf area index (LAI) was most strongly related to average ET rates, irrespective of species composition. Decreased LAI caused by crown dieback in native cottonwood was found at sites where the drought has also resulted in groundwater decline. Saltcedar ET, on the other hand, increased from 6 to 9 mm/day during groundwater declines of up to 7.5 cm/day. Atmospheric conditions that influence ET rates include vapor pressure deficit, net radiation, precipitation, friction coefficient, and the relative contribution of winds that are tangential and transverse to the riparian corridor. Some of these conditions interact to affect ET rates. For example, precipitation events are associated with lower net radiation, vapor pressure deficit, and ET. Potential water salvage following removal of non-native vegetation was predicted by comparing ET and LAI rates in various vegetation types. Lowest LAI and ET are found in a saltcedar/saltgrass non-overlapping mixed stand. In contrast, a dense monospecific saltcedar stand frequently consumes up to 11.5 mm/day, especially when flooded. ET from other vegetation types along the Middle Rio Grande seldom spikes so high. Conversion from dense monospecific saltcedar to sparse saltcedar/saltgrass woodland is predicted to save 0.2 m per year, based upon both ET and LAI changes in such a conversion. Previous studies of water salvage place this value between positive or negative, for unsuccessful removal of saltcedar may result in increased ET.*

The Middle Rio Grande: A Case Study

The Middle Rio Grande (MRG) passes through semi-arid and arid landscapes as it descends from Otowi to Elephant Butte, New Mexico (fig. 1). With average annual precipitation declining over these 372 km, most of the water resources available to riparian vegetation is supplied from upstream through the shallow alluvial aquifer that surrounds the Rio Grande. Historically, the MRG floodplain hosted small Rio Grande cottonwood (*Populus deltoides* ssp. *wislizennii*) copses, riverbank cottonwood and Goodding willow (*Salix gooddingii*) individuals, riverbank coyote willow (*S. exigua*) thickets, and wide expanses of grasses such as saltgrass (*Distichlis spicata*) (Scurlock 1998). These riparian areas have become dense with native and non-native vegetation, where monospecific and mixed xeroriparian saltcedar (*Tamarix chinensis*) thickets dominate the bosque to the south of the Rio Puerco confluence and dense cottonwood, saltcedar, and Russian olive (*Elaeagnus angustifolia*) forests dominate in the northern MRG. In either case, this dense vegetation presents a fire hazard and is potentially responsible for a great deal of water loss to the atmosphere.

The Rio Grande Compact dictates how much water may be legally lost between official river discharge gauges. In the MRG, the upstream and downstream gauges of record were changed to Otowi and Elephant

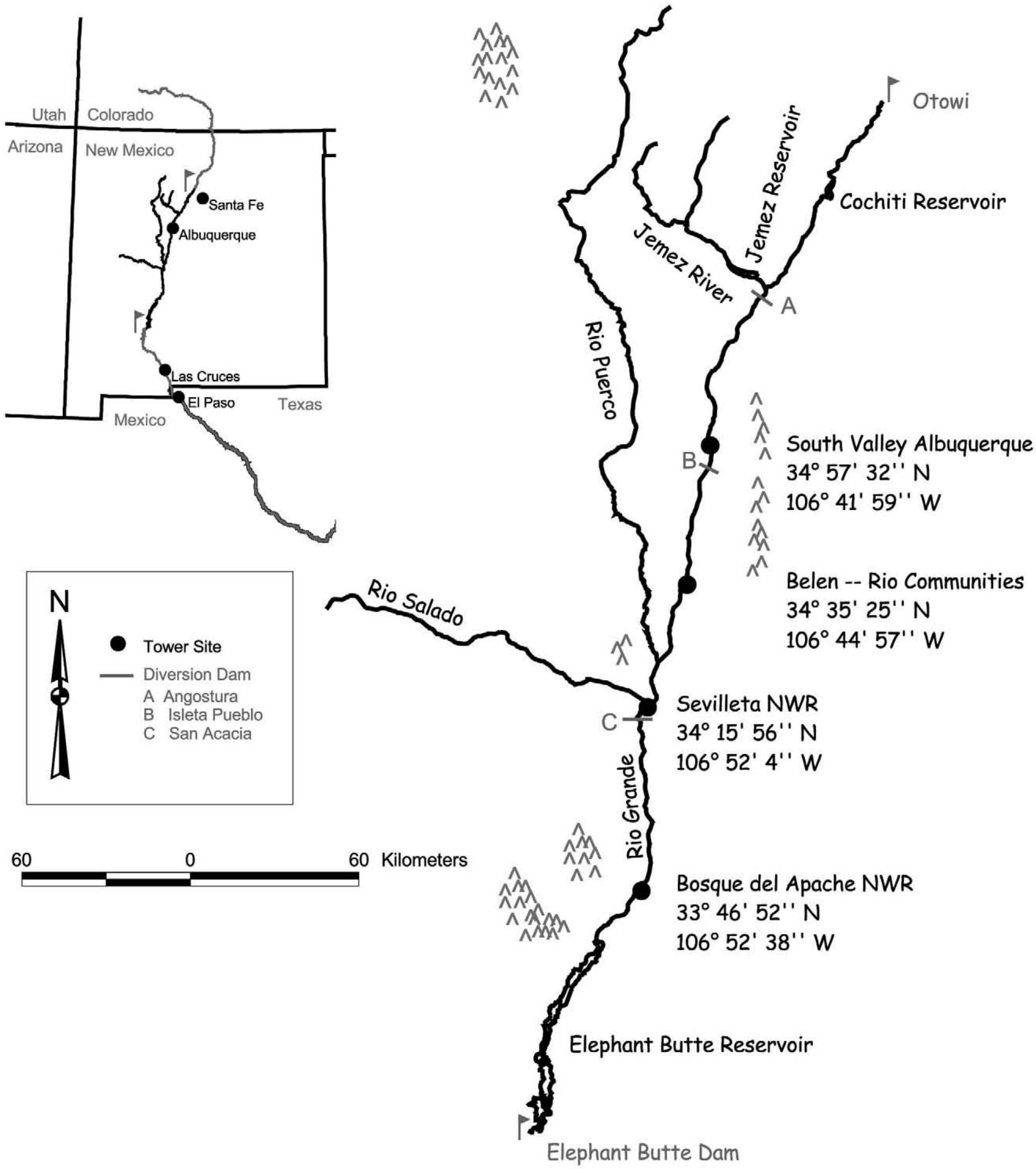

Figure 1. Map showing significant features and location of eddy covariance towers in the Middle Rio Grande evapotranspiration case study.

Butte in 1948 (fig. 1). Between these two points, various economic interests compete with riparian ET for the limited water budget depletions that are allowed. If phreatophytic vegetation, which draws water directly from the shallow alluvial aquifer surrounding the MRG, transpires an excessive amount of water into the atmosphere, fewer diversions from the river are allowed for agricultural, municipal, and industrial uses. A water budget is often constructed to provide the best accounting of water sources and demands, but the utility of water budgets is constrained by incomplete knowledge of key components in the water budget (Cleverly and others 2002, Dahm and others 2002).

Better understanding of riparian corridor ET is crucially important for managing water resources and predicting water availability. Open water and riparian water loss to the atmosphere is believed to be the greatest single depletion of water from the MRG, ranging between

30 and 75 percent of the total inflow at Otowi (Cleverly and others 2002). Discounting reservoir evaporation, water losses from the riparian corridor is thought to be between 20 and 50 percent of the total inflow at Otowi (Dahm and others 2002). However, these evaporation and evapotranspiration rates are theoretical in nature, while direct measurements have recently contributed a great deal to ensuring that the most accurate ET estimates are obtained (Goodrich and others 2000).

When considering the large volumes of water potentially escaping the riparian corridor, as well as our uncertainty regarding the accuracy of this estimated ET, a central question regarding our ability to manage riparian ET has arisen. Specifically, managers wish to know whether certain vegetation can be removed from the ecosystem to decrease depletions. In particular, can non-native species be removed to both improve habitat for endangered species as well as reduce ecosystem ET. The culprit in the southwestern United States is saltcedar (*Tamarix* spp.), a plant from Eurasia that has been accused of extravagant, and often unrealistic, ET rates. However, a great deal of controversy remains surrounding the issue of saltcedar ET: whether ET is greater than that for native vegetation such as dense cottonwood forests, and whether gains in gauged stream flow will result from removal of saltcedar (Weeks and others 1987).

The MRG provides a background for addressing these issues and improving our ability to predict riparian ET, where we have been using state-of-the-art three-dimensional eddy covariance (3SEC) systems arrayed at various locations along the MRG to elucidate the roles of vegetation, hydrology, and atmospheric conditions in controlling riparian ET.

Riparian Evapotranspiration

Riparian evapotranspiration is the process by which open water and soil water is translocated to the atmosphere as vapor. Interactions between groundwater, vegetation, and atmospheric conditions can either restrict or enhance actual ET, depending upon the conditions themselves. As the term evapotranspiration implies, evaporation from open water or soil and transpiration from vegetation are combined into a single water loss term. This composite flux is measured directly using the 3SEC system, which is considered to be the standard by which wetland ET is evaluated (Drexler and others 2004).

The vegetation along the MRG is phreatophytic, meaning that its roots are connected directly to the capillary fringe of the water table (Smith and others 1998). Some of these plants are facultative phreatophytes, meaning that they may obtain water from both the capillary fringe and the vadose zone. Examples of such plants are saltcedar and mesquite (*Prosopis* spp.), both of which are able to maintain function soil water potentials intermediate between obligate riparian species and upland species (Busch and others 1992, Pockman and Sperry 2000). Conversely, cottonwood is extremely vulnerable to soil drying, allowing partial crown dieback under water table drawdown (Cooper and others 2003, Rood and others 2003). In one instance, among a population of young cottonwood along a drying ephemeral reach, has cottonwood shown any proclivity toward use of soil water in addition to groundwater (Snyder and Williams 2000).

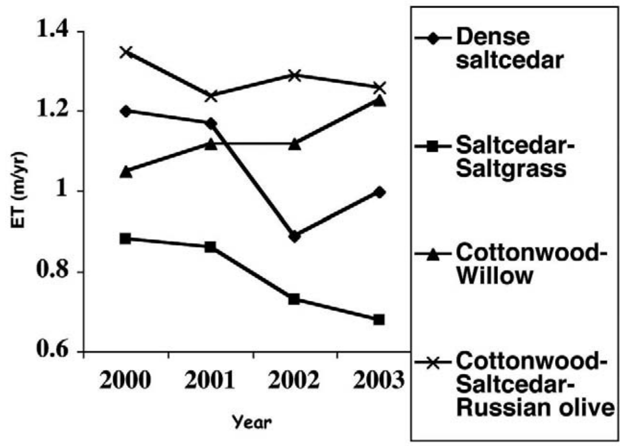

Figure 2. Annual ET from each of the sites illustrated in figure 1 over the years 2000 through 2003.

Variability in annual ET rates along the MRG is very high (fig. 2). Before the current drought, ET rates were highest from cottonwood forests with a thick saltcedar understory—1.35 m/yr (4.4 acre-ft/acre-yr)—and from dense saltcedar stands—1.2 m/yr (3.4 acre-ft/acre-yr). As the drought developed, ET rates fell to below 0.7 m/yr (2.2 acre-ft/acre-yr) at the saltcedar/saltgrass site. Seemingly, cottonwood forests are unaffected by drought--maintaining ET rates up to 1.3 m/yr (4.2 acre-ft/acre-yr). However, groundwater levels have remained shallow at these sites due to Albuquerque wastewater amendments and irrigation delivery structures.

Groundwater

Transpiration by cottonwood is uninhibited by groundwater accessibility whenever the water table is within three meters of the surface (Horton and others 2001). When groundwater is drawn down deeper, transpiration declines with increasing crown dieback (Scott and others 1999, Rood and others 2000). Goodding willow is found in habitats similar to those where cottonwood is more likely to be located, preferentially occupying sites with shallow water table, high soil water content, and

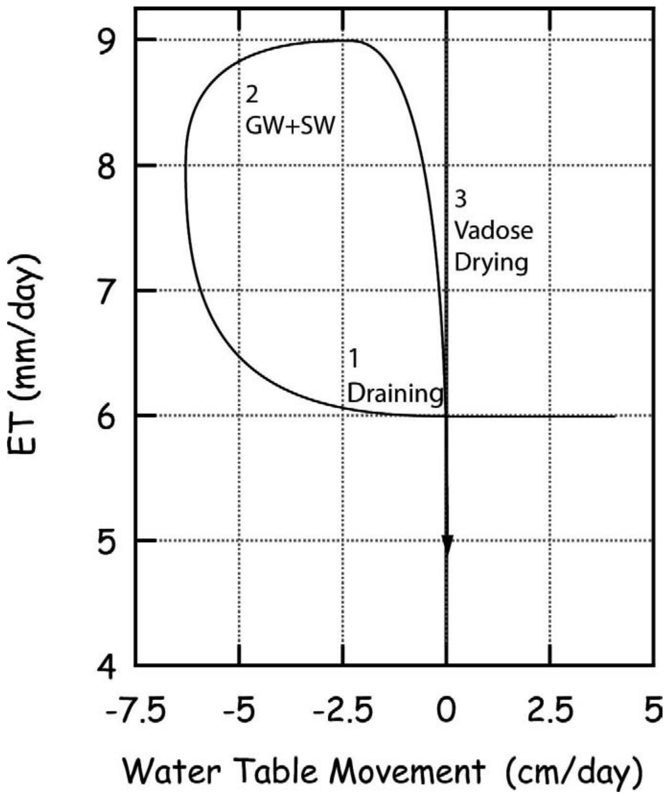

Figure 3. Daily average ET during a period of extended groundwater decline indicated by negative changes in the water table depth. ET does not initially increase, showing a lag between decline of the water table and dewatering of the capillary fringe (1). As roots are taking up water at the deepened capillary fringe and the vadose zone, ET increases (2), until the upper layers are emptied and saltcedar returns to predominately groundwater sources (3).

low salinity (Busch and Smith 1995). Conversely, coyote willow can tolerate dryer conditions, much like saltcedar or mesquite (Busch and Smith 1995). The hydrologic conditions under which these species are found have implications for predicting how willows might respond to groundwater decline, in which Goodding willow ET is expected respond to groundwater depth as does cottonwood, while ET from coyote willow is expected to respond more like saltcedar.

Saltcedar transpiration is not restricted by depth to groundwater as it is in cottonwood. In Arizona, saltcedar was unaffected by groundwater depths of up to 10 meters (Horton and others 2001). In China, from where one common species of non-native saltcedar originates, transpiration was found to remain unchanged, even when the water table was dropped to 25 meters below the surface (Gries and others 2003). Even though saltcedar ET is not dependent upon depth to the water table, saltcedar ET does respond to changes in water table depth, increasing while the groundwater is falling (fig. 3).

Figure 3 illustrates the mutual effects of drought resistant xylem (Pockman and Sperry 2000), facultative phreatophytic habits (Busch and others 1992), and a combination of drought tolerance and spendthrift stomatal conductance depending upon the conditions (Cleverly and others 1997). Hysteresis is generated in this relationship between groundwater changes and saltcedar ET due to the time lag between groundwater decline and soil water desaturation, during which time tap root elongation is negligible. Increased ET rates in association with sustained groundwater decline occur because active roots left behind by the elongating taproot continue to exploit soil water resources left behind by the retreating groundwater (fig. 3).

Vegetation

A very general relationship between average ET and leaf area index (LAI) along the MRG was observed in 2000 (Dahm and others 2002). LAI is a measure of the leaf surface above a unit area of ground. Along the MRG, LAI ranges from 1.7 ± 0.1 in a saltcedar/saltgrass mosaic to 3.7 ± 0.1 at a dense saltcedar site. Monthly ET-LAI observations during 2001 through 2003 illustrate that this relationship is curvilinear—ET increases rapidly with increases at low LAI, and ET and comes to a plateau near LAI values of three and above. This upper plateau indicates the limiting effect of self-shading; in which upper canopy leaves completely shade lower leaves and sub-canopy layers. Deep shading of lower canopy layers severely restricts the energy available to evaporate water from within the leaf.

Remote sensing technology that can discriminate LAI above three holds the best promise for deriving basin-wide scaled ET estimates. One metric that matches LAI closely when LAI is less than three is the normalized difference vegetation index (NDVI), computed as

$$NDVI = \frac{NIR - Rd}{Rd + NIR} ,$$

where Rd and NIR are pixel reflectance of red and near infrared light, respectively (Pearcy and others 1991). The utility of NDVI declines rapidly when LAI is greater than three because absorbance of red light by chlorophyll is complete in the upper few leaf layers. Middle-frequency infrared (MIR), like NIR, is not as effectively absorbed by chlorophyll. ET, LAI, and species composition maps were developed using spectral fingerprints for forests of varying species composition along the MRG. From this analysis, the leaf area transpiration index (LATI) was developed (LATI-ET $r^2 = 0.93$).

Ground reconnaissance of LATI method was performed by collection of LAI and groundwater chemistry data at multiple sites along the MRG. High concentrations of chloride in groundwater result in higher LAI and ET from saltcedar-dominated sites, but high groundwater chloride levels at cottonwood-dominated sites resulted in reduced LAI and ET. Saltcedar ET is not strongly affected by nitrate or ammonium concentrations in the groundwater, but cottonwood ET is enhanced by high concentrations of these nitrogen-containing nutrients. At one cottonwood site downstream from the Albuquerque wastewater treatment plant (fig. 1), LAI, ET, and groundwater concentrations of nitrate and ammonium are all high.

Table 1. Results from stepwise multiple regression between ET anomalies and micrometeorological conditions.

Dominant vegetation	Variables[a]
Saltcedar	q*, u*, VPD, Temperature, Precipitation
Cottonwood	H, R_n, v, v X u

[a]q*: Surface scale for vapor flux
u*: Friction velocity
H: Sensible heat flux
R_n: Net radiation
v: Wind speed tangential to the riparian corridor
u: Wind speed along the riparian corridor

Atmosphere

An analysis of ET anomalies was performed at each site to determine those conditions that were greater or lesser than average ET (Mo and Juang 2003). Stepwise general linear regression can then be used to analyze the role of micrometeorological conditions on large, multi-seasonal datasets (n ~ 20 per year). While time series data contains observations that are neither independent nor identically distributed (i.i.d.), computed anomalies are statistically derived observations that do not violate the i.i.d. assumptions of general linear regression.

Topography was most directly related to differences in ET covariances. For example, the northern two sites illustrated in figure 1 show ET spikes and dips in response to heat stress effects due to heat transfer from the nearby mesa (table 1). Boundary layer stability typically results from such mesoscale conditions, and ET declines in response to such lateral winds because these winds expose stress intolerant cottonwoods to higher vapor pressure deficit (VPD). As VPD increases, stresses upon tissue water increases due to the enhance vapor gradient between the leaf's interior and the surrounding air.

The southern sites are located near large mountains that are associated with greater cold air drainage. Warmer daytime temperatures are moderated by cooler nighttime temperatures in this area, and ET anomalies are related to local turbulence, VPD, and the range of diel temperature extremes (table 1) (Cooper and others 2003). It is at these sites where precipitation events lead to a sharp decline in ET. On days with measurable precipitation, (1) net radiation dips due to cloud-shading, (2) daytime high temperature dips, (3) atmospheric humidity increases, (4) vapor pressure deficit dips due to two and three, and (5) turbulence is high due to the convective nature of typical monsoon storms that develop of mountain ranges.

Additional cold air drainage at the southern sites serves to shorten the growing season, further restricting annual ET. The final hard freeze in the spring at the southern site is about one week later than at the northern site. Likewise, the first autumnal freeze in the south precedes senescence in the north by one week. Comparison of ET from these cottonwood and saltcedar sites can be achieved by considering differences in season length—cottonwoods in the south would experience similar shortening of the growing season and saltcedars in the north leaf-out and senesce earlier than in the south.

Considering all of these conditions that reduce annual ET from the saltcedar stands along the MRG, it is surprising that dense saltcedar has had peak water use exceeding 10 mm/day on 17 days from between 2000 through 2004. Although water use by saltcedar stands may be limited for much of the year, the vegetation itself is able to maintain extremely high ET rates for short periods when VPD is high, surface flooding is occurring in which floodwaters are perched above a clay lens, or the water table is rapidly declining.

Potential Water Salvage

The potential to save water by manipulating vegetation characteristics is dependent upon changes in leaf area index that are achieved by a given restoration project. If saltcedars are thinned, in combination with replacement by saltgrass, sacaton grass, or rabbitbrush (*Chrysothamnus nauseosus*), LAI and ET will be potentially decreased by up to 0.2 m/yr (0.7 acre-ft/acre-yr) (fig. 2). The reverse is also true—LAI and ET would increase if a low LAI saltcedar site were converted to a dense cottonwood site by cottonwood pole planting in high density. Increases in water use would also be observed in those all-too-common restoration attempts that do not successfully kill saltcedar, allowing the vegetation to resprout in greater density than before the restoration attempt. In any case, coordinated restoration efforts that successfully achieve historical grassland/cottonwood/willow mosaics would reduce ET rates while maintaining habitat resources for species that are now endangered.

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Monitoring to Protect the Character of Individual Wildernesses

David N. Cole, Research Biologist, Aldo Leopold Wilderness Research Institute, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT

Abstract—*A primary goal of wilderness stewardship is to protect individual wilderness areas from most anthropogenic change. Numerous agents of change threaten to degrade wilderness character. These agents of change are both internal (for example, grazing) and external (for example, polluting industries) to wilderness. They can be activities (for example, recreation use) or the indirect effects of activities (for example, invasion of exotic species), and can also be management actions (for example, fire suppression). Wilderness managers need information about both these agents of change (or threats) and the attributes of wilderness character that they threaten. They need monitoring data about (1) the magnitude of threats and (2) changes in wilderness attributes caused by these threats (impacts), in order to be in a better position to protect the wilderness character of the areas that they steward. This paper uses a matrix approach to provide a comprehensive overview of wilderness protection monitoring. It describes the current state-of-the-art. It identifies substantial knowledge and technological gaps, as well as research needs.*

Introduction

Public lands that have been officially designated as wilderness have many different values (McCloskey 1990, Noss 1991). Some of these values are readily apparent and easy to describe; others are not. The most commonly recognized wilderness values are ecological and experiential values. Wildernesses have ecological value because, at least ideally, they preserve lands in a natural condition and allow for the free play of natural processes. They provide refuge for plants and animals, are source areas for clean water and are available as reference areas for science. The experiential values of wilderness stem from their availability for appropriate recreational use. Although different people seek and find diverse experiences in wilderness, wilderness offers some of the most outstanding opportunities for experiencing solitude and a sense of freedom and spontaneity within large natural environments. For many, wilderness provides therapeutic, educational, and spiritual values (Hendee and Dawson 2002).

A third set of wilderness values might be termed the symbolic values of wilderness. These values are more difficult to articulate and are less readily apparent than the ecological and experiential values of wilderness, but they are perhaps the values most unique to wilderness. These are the values most frequently articulated in the language of those most influential in passing the Wilderness Act (Zahniser 1956-57). Perhaps the most important symbolic value of wilderness is wilderness as a symbol of restraint and humility. This value is well-captured in the definition of wilderness, contained in the Wilderness Act, as "an area where the earth and its community of life are untrammeled by man." "Untrammeled" is simultaneously the most important and the most misunderstood word in the Wilderness Act. "Synonymous with unconfined, unfettered and unrestrained," untrammeled suggests "freedom from human control rather than lack of human influence" (Cole 2000, p. 78). Much of the symbolic value of wilderness derives from its being land that humans do not mold to their purposes. Wilderness is a place that humans should not intentionally manipulate for any reason—even to enhance the ecological or experiential values of wilderness.

Although wilderness lands have additional values (such as economic benefits), it is largely the ecological, experiential and symbolic values that constitute the wilderness character of these lands and the primary legislative mandate for wilderness managers is to protect the wilderness character of the lands they steward. Where these values are threatened, wilderness managers must act to protect them. An important element of any protection program is the identification of threats and the monitoring of impacts to wilderness values. Therefore, in order to protect the wilderness character of the individual wilderness areas that they steward, managers need monitoring programs related to ecological, experiential and symbolic values. This paper provides an overview of the breadth of monitoring needed to adequately protect the wilderness character of individual wildernesses. It also reviews the types of wilderness monitoring that are best developed and suggests priorities for further work.

Protecting the Ecological and Experiential Values of Wilderness

There are numerous threats to the ecological and experiential values of wilderness. These threats are both internal and external to wilderness. They include human activities, the indirect effects of activities and also management actions. Managers must be concerned about the impacts that potential threats have on attributes of wilderness character.

The Threats Matrix

Figure 1 shows a conceptual model of the most significant threats to and attributes of wilderness that can be applied to wilderness protection (Cole 1994). As the numerous lines radiating from each individual threat suggest, any single threat will impact many different wilderness attributes and values. Therefore, the impacts of any single threat will differ depending on the attributes

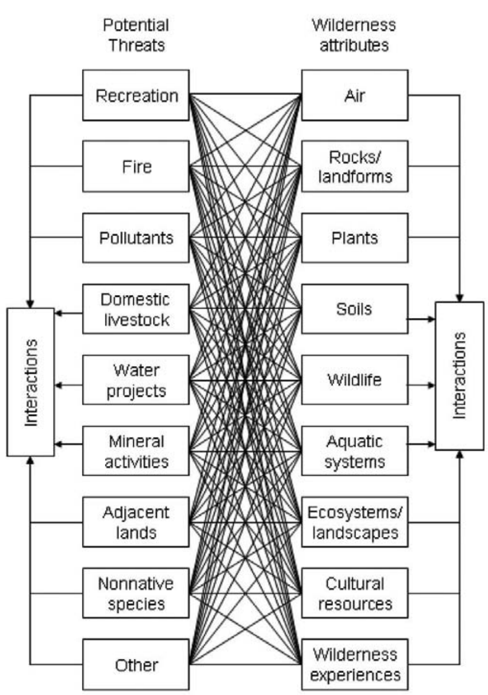

Figure 1. Linkages between important potential threats and the wilderness attributes they impact.

the threat impacts. For example, the effects of fire suppression on vegetation are very different from the effects of fire suppression on wilderness experiences. Similarly, the effects of different threats on a single attribute are highly variable. The implication of this is that managers need to understand the linkages between each significant potential threat and each individual wilderness attribute. If this was not challenging enough, these potential threats and impacts interact synergistically. Therefore, managers need to also understand the cumulative impacts of multiple threats. Separating individual attributes is even more artificial than separating threats because impacts occur at all temporal and spatial scales.

Despite the artificiality of separating individual threats and wilderness attributes, the matrix that results by combining threats and attributes is a convenient way to depict the breadth of topics that might be included in a wilderness monitoring program (fig. 2). In this matrix, threats form columns and attributes form rows. Each cell consists of the various impacts that each threat causes to each attribute. Figure 2 includes most of the common wilderness threats. While this matrix was developed for a generic wilderness, individual wilderness units might adapt it to their specific needs by either adding additional threats or attributes or by deleting ones that are not relevant to their situation.

Monitoring Threats and Impacts

These threats and impacts vary in terms of their significance, our knowledge about them and the availability of monitoring protocols and programs. Most monitoring programs aim to assess either the threat or changes in wilderness attributes; a few assess impacts directly. Cole and Landres (1996) review knowledge about the most common threats and impacts to wilderness ecosystems. Hendee and Dawson (2002) provide a good overview of concerns related to wilderness experiences.

Most attention within wilderness has been devoted to understanding, monitoring and mitigating the threat posed by recreation use and the impacts that it causes. Nevertheless, surprisingly few wilderness areas have reliable estimates of the amount of recreational visitation they receive. The most reliable data are for overnight visitors to wildernesses managed by the National Park Service, because permits are usually required for overnight stays in those areas.

Monitoring data on campsite conditions (impacts of camping on soil and vegetation) are also relatively common. As of 2000, about one-half of the 628 wildernesses in the United States had some type of baseline data on campsite conditions (Cole and Wright 2003). However, only about one-third had data on campsites for the entire wilderness.

POTENTIAL THREATS
(Agent of change and associated management)

ATTRIBUTES OF WILDERNESS CHARACTER	Recreation	Fire	Pollutants	Domestic Livestock	Adjacent Lands	Water Projects	Mineral Activities	Non-native Species	Other*
Air									
Rocks, Landforms									
Plants, Soil									
Wildlife									
Aquatic Systems									
Ecosystems, Landscapes									
Cultural Resources									
Wilderness experiences									

*Includes scientific uses, overflights, other laws and mandates, inholdings, subsistence uses, previous uses, wildlife extirpations, and future threats

Figure 2. The threats matrix in which cells represent the impacts that each potential threat has on each attribute of wilderness character.

There are several explanations for the prevalence of campsite monitoring programs in wilderness. First, campsite impacts are among the more obvious adverse effects of recreation use and represent problems that wilderness managers spend considerable time and resources trying to "fix." Second, campsite impacts provide one of the few situations where it is possible to directly assess and monitor the impact of concern. The impacts of camping on vegetation and soil are intensive, stationary and highly localized. This makes it possible—by comparing campsite conditions to adjacent undisturbed controls—to quite precisely measure the effects of camping. For most other impacts, including the effects of recreation on animals or on visitor experiences, this cannot be done. For these threat-attribute combinations, inferences about impacts must be drawn from data on the threat and the attribute. For example, we can count visitors and we can monitor wildlife populations, but we generally cannot measure wildlife impacts directly. We can attempt to attribute changes in wildlife populations to visitation but this is often highly speculative.

Beyond recreation, assessment of atmospheric pollutants in individual wildernesses is perhaps the best developed monitoring program. This program emphasis is clearly the result of legislative mandates imposed by the Clean Air Act of 1970. Federal land managers are responsible for protecting air quality-related values in parks and wilderness from air pollution damage or impairment. Monitoring efforts are focused primarily on the wilderness attribute (air), rather than the threat (source of pollution) or impact. Some of the most common attributes being measured include visibility (which is reduced by fine particles), ozone, and deposition of sulphur and nitrogen compounds (Tonnessen 2000). However, because there is substantial consensus about what air quality should be like under "natural" conditions and because substantial research has been conducted on the adverse effects of pollutants on flora, fauna and aquatic systems, these data can be used to estimate the impacts of atmospheric pollutants.

Increased awareness of problems resulting from the introduction of nonnative species has led to improved monitoring efforts recently. Most often these efforts are confined to plants deemed to be "noxious." Programs to monitor the effects of livestock grazing also exist. Monitoring range conditions is probably more common where the grazers are cattle or sheep than where the grazers are recreational pack stock.

The impacts associated with fire and how fire is managed are probably the least adequately monitored but among the most significant impacts to wilderness character. For these, not only is it impossible to directly monitor impacts, it is also impossible to monitor the threat very precisely. The threat is not fire itself; nor is it the suppression of fire. The magnitude of threat is the degree to which the fire regime differs from a "natural" fire regime, something that cannot be estimated very precisely given climate change, definitional problems related to appropriate spatial and temporal scales, and unresolved issues such as the past role and influence of native Americans. Most often, vegetation structure and composition are assessed, from which inferences about impacts of fire management are drawn.

Protecting the Symbolic Values of Wilderness

Less attention has been given to articulating threats to the symbolic values of wilderness and how impacts to such values might be monitored. For the values of humility and restraint, as suggested by the concept of "untrammeled" wilderness, the primary threats are intentional manipulations of wilderness ecosystems and other ecological attributes. Manipulations of wilderness ecosystems can be intentional or unintentional. They can be undertaken with the intent of altering conditions within wilderness or they can be the consequence of an attempt to control conditions outside of wilderness. Manipulations can be undertaken to enhance other wilderness values (most commonly naturalness) or not. The symbolic values of restraint, humility and untrammeled wilderness are most compromised by intentional manipulations undertaken to alter conditions within wilderness.

I know of no attempts to monitor threats to or loss of the symbolic values of wilderness. However, in the effort to develop a national assessment of trends in wilderness character (see Landres in this proceedings), protocols are being developed that might prove useful in individual wildernesses as well. The general approach being advocated is simply to report the prevalence of actions designed to manipulate the biophysical environment. These might include anything from igniting prescribed fires to planting fish to placing radio collars on wolves. The more manipulative actions that are taken, the more symbolic values are at risk.

Priorities for Improving Wilderness Monitoring

When it comes to monitoring to protect the values of individual wildernesses, the needs are huge and current efforts are meager to non-existent. The paucity of resources available for wilderness stewardship generally and monitoring specifically probably reflects a belief that the job of wilderness is a simple one. Conversely, I have argued that there is no other responsibility given to land managers that is more difficult to do well than wilderness stewardship (Cole 1990). Given the likelihood that available resources will continue to be scarce, careful consideration of monitoring priorities is critical.

Opinions regarding monitoring priorities are diverse, depending to a great degree on one's value system. For many (certainly most ecologists), the ecological values of wilderness are considered most significant, leading them to assert that priority should be given to the most pervasive ecological impacts in wilderness. Others, however, may consider experiential or symbolic values to be most significant, leading them to different conclusions about the most important attributes to monitor.

Three criteria that might be applied to priority setting include: (1) the ability of managers to mitigate impacts, (2) the pervasiveness of impacts, and (3) the uniqueness of what is threatened. Recreation impacts are probably the impacts that managers can most readily control. Although intense, many recreation impacts are highly localized and recreation use is subject to managerial control. Among the most pervasive impacts are likely to be those associated with fire and its management, atmospheric pollutants and the effects of adjacent lands and their management on wilderness. In contrast to recreation, the impacts of these threats are not nearly as intensive but are much more extensive, sometimes affecting most of the wilderness. From the perspective of protecting ecological values, the impacts of these threats are likely to be highly significant but difficult to assess with much precision. Development of more precise methods for assessing and interpreting impacts is a high priority research need. Finally, the most unique values at risk are likely to be the symbolic values of wilderness. No lands other than wilderness are likely to be declared off-limits to intentional manipulation out of a sense of restraint and humility. In fact, it is unlikely that we will even show this restraint in wilderness. Therefore, more attention needs to be given to monitoring trends in these values. Impacts to rare and endangered plant and animal populations also demand high priority, based on the criterion of uniqueness. They typically are receiving substantial attention.

Conclusions

More personal and financial resources need to be devoted to wilderness stewardship if agencies are to redeem their responsibility to protect wilderness character. Much of this could be achieved if wilderness received the attention that it deserves within land management agencies. In the Forest Service, for example, 18 percent of lands are designated wilderness. However, the agency spends less than 1 percent of its annual budget on wilderness stewardship. In the past, most attention within wilderness has been devoted to recreation management. Other issues need more attention—not at the expense of recreation management, which continues to be underfunded, but as a complement. More attention needs to be devoted to understanding and monitoring the effects of pervasive threats such as fire and its management and the influence of management and development of adjacent lands. More attention also needs to be given to understanding the symbolic values of wilderness and how they might be monitored and protected. Finally, every individual wilderness is unique. This means that the wilderness character of each wilderness is unique and is often better understood holistically than when reduced to cells in a matrix. Considerable ingenuity is needed to better incorporate holism and uniqueness in our attempts to monitor and steward wilderness.

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Planning for Large Scale Habitat Restoration in the Socorro Valley, New Mexico

Gina Dello Russo, Ecologist at the Bosque del Apache National Wildlife Refuge and a U.S. Fish and Wildlife Service representative to the Socorro Save our Bosque Task Force, Socorro, NM
Yasmeen Najmi, Planner at the Middle Rio Grande Conservancy District and Vice-Chairperson of the Socorro Save Our Bosque Task Force, Albuquerque, NM

***Abstract**—One initiative for large scale habitat restoration on the Rio Grande in central New Mexico is being led by a nonprofit organization, the Save Our Bosque Task Force. The Task Force has just completed a conceptual restoration plan for a 72-kilometer reach of river. The goals of the plan were to determine the potential for enhanced biological diversity through improved management of river processes. The specific river issues addressed in the plan include endangered species habitat improvement, fire management, and increased biodiversity through exotic species control and native plant establishment. Important water issues addressed by this plan include existing and potential use by the mosaic of habitats along the river and potential savings through improved management and delivery. Restoration of river processes coupled with exotic species control, bank destabilization, wetland enhancement, sand bar maintenance, grassland reestablishment, and other techniques could improve the diversity of native riparian plants on approximately 8,500 hectares of active floodplain under the jurisdiction of federal, state, local government agencies and private landowners. Areas where flooding occurs less frequently are designated as suitable for reestablishment of grasslands and more open forest/savannas. These areas are predicted to provide the greatest water savings. Restoration projects in areas where flooding occurs more frequently would focus on reestablishment and maintenance of cottonwood/willow forests of different age classes, wet meadows, and permanent wetlands. In this way, the diverse mosaic of habitat that occurred on the Rio Grande could be restored and maintained while addressing important socioeconomic issues, such as water use and fire. This plan is presently being used by water and land managers, private landowners, and other local interests to guide implementation of large scale resource management efforts.*

Introduction

The importance of river processes such as flood pulses, connectivity between the channel and adjacent floodplain, and groundwater recharge to the long-term viability of river ecosystems has been documented by a number of researchers (Ellis and others 2002, Molles 1998, Crawford and others 1993, Sparks 1995, Auble and others 1994). The Save Our Bosque Task Force's (Task Force) Conceptual Restoration Plan for the Rio Grande from San Acacia to San Marcial, New Mexico (plan), was developed in a five phase process to evaluate the potential to restore river processes and thereby increase biological diversity on a 72 kilometer (45 mile) reach of Rio Grande in central New Mexico, the Socorro valley. The importance of riparian systems in the overall biodiversity of the planet, particularly in arid regions has also been well-documented (Naiman and others 1993, Briggs 1996, Crawford and others 1996). The Task Force planning effort is meant to serve as a tool to landowners and management agencies interested in improving the health of the Rio Grande ecosystem within current constraints.

This valley is a unique blend of small communities, agricultural fields, the Rio Grande, and its associated habitats. Economic interests in the valley include agriculture, science and research interests, a state university, private businesses, and ecotourism of which the Bosque del Apache NWR and Sevilleta NWR are a part. Stakeholder involvement through an oversight committee and a series of public meetings improved the final product by incorporating the issues and expertise of those involved in land and water management and private interests.

The Rio Grande of the Socorro valley now occupies approximately one third of its original floodplain. It is confined by a flood control levee along its western bank. There is no levee on the eastern bank, which allows the river at high flows to spread out on a floodplain of approximately 6,900 ha (17,000 acres). There is an extensive drainage and water delivery system associated with agriculture and water management interests.

Table 1. Suggested San Acacia flood frequency in cfs.

Probability	Return Period	Post Cochiti 1974-2002	Entire Record 1936-2002	Suggested Flood Peak Discharge
0.8	1.25	3700	3750	3700
0.5	2	5660	4140	5660
0.2	5	8480	6280	8480
0.1	10	10400	9740	10400
0.04	25	12800	14200	14200
0.02	50	14600	22800	22800
0.01	100	16400	32500	32500
0.002	500	20500	64900	6490

Methods

Data Collection and Analysis

One of the purposes of the plan was to review the available information on historic Rio Grande hydrology, channel morphology and vegetation composition. Historically, the Rio Grande's most dramatic physical and biological changes occurred during flood and avulsion events (Carter 1953, Lee 1907). The scouring of the floodplain, movement of sediment through the system, plant establishment, and recharge of wetlands and shallow groundwater all related to some extent to these events. The resulting forests, wetlands, wet meadows, scrublands, alkali flats and savannas were a significant portion of the floodplain community when Europeans arrived (Scurlock 1998). Understanding these river processes and the changes to physical and biological aspects of the system tied to water and related land resource development since the 1800s were a part of the initial analysis for plan preparation.

The Rio Grande of the past century has been used to support agriculture and growing human settlements (Clark 1987, Simmons 1972). The infrastructure established in the floodplain limited the floodplain available for river flows and riparian habitats, altered the flood pulses and disrupted the sediment supply (Crawford and others 1993). The responses of the river to this altered regime have included narrowing of the active channel, degradation and in some areas accelerated aggradation, and limited overbank flooding within this "active floodplain" (Bullard 1993, LaGasse 1981). Earlier in the 20th century, the introduction of exotic plant species, primarily saltcedar (*Tamarix* sp.), altered the plant community throughout much of the river's length as well (Everitt 1998).

Extensive data collection in the Socorro valley by a number of federal and state agencies informed the analysis of past channel and floodplain dynamics, predicted trends in hydrology and geomorphology, and vegetation community alterations and succession. Fluvial geomorphology including bed slope analysis, sediment analysis and predicted yield, and the delineation of subreaches (upstream to downstream: Escondida, San Antonio and Refuge) based on these characteristics was included in this phase of the planning effort. A flood frequency analysis was completed using the San Acacia gauge at the upstream end of the plan area (table 1). The vegetation classification system originally used (Hink and Ohmart 1984) in this plan has now been updated and a plan revision includes this more recent information (BOR 2004). This evaluation of river processes and historic biological diversity informs the subsequent discussions on the feasibility of restoring these processes in this reach of river and possible benefits from that restoration.

Specific River Issues

A number of issues including threat of wildfire, channel conveyance capacity and flood potential, and the present condition of terrestrial and aquatic habitats and their use of water are important to the local stakeholders of the valley (Task Force unpublished information). Important institutional constraints and resource management goals were also considered in conjunction with these issues.

To evaluate the channel capacity and flood potential, the bankfull discharge of each subreach, spring flushing flows, areas of inundation and a flood frequency analysis were developed for restoration designs. Calibration of a two dimensional flood routing model (FLO2D; Tetra Tech ISG 2000) for this reach had been accomplished earlier by other entities. This method of predicting overbank flows (fig. 1), area of inundation, velocity, and depth of water was used throughout the plan development for addressing issues of flooding, water use, and predicted plant community establishment and viability. Sediment loading and sand bar dynamics through the reach were considered in terms of channel capacity, vegetation establishment, as well as aquatic habitat diversity.

To characterize the existing habitat value and determine possible future conditions in riparian habitats,

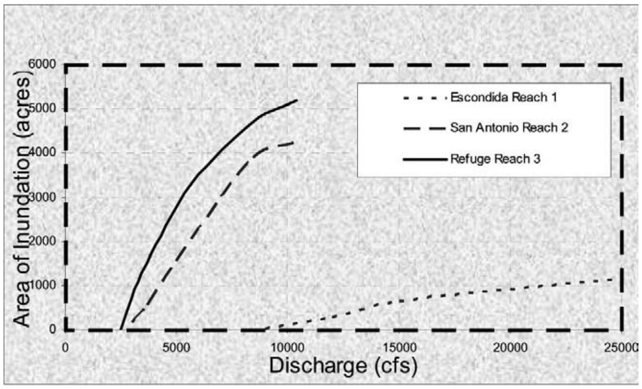

Figure 1. Area of overbank flooding by subreach.

recent vegetation maps and historic descriptions of the plant community "mosaic" of the valley floodplain were used (BOR 2002, Crawford and others 1993, Campbell and Dick-Peddie 1964). Biologically diverse habitat areas attract a more diverse fauna than monotypic saltcedar stands (Bosque del Apache NWR unpublished data, Ellis 1995, Naiman and others 1993). Native woodlands were characterized by an overstory of cottonwood (*Populus deltoides*) and Goodding's black willow (*Salix gooddingii*) with an understory of coyote willow (*Salix exigua*), New Mexico olive (*Foresteria pubescens*), screwbean mesquite (*Prosopis pubescens*), and seepwillow (*Baccharis* sp.). The resulting mapping products were used to distinguish sensitive areas for protection from wildfire and to calculate estimates for current water use without restoration.

The potential for water savings through the reach was calculated using the vegetation and predicted flood area maps and the most recent information on evapotranspiration estimates for the area (Cleverly and others 2001, King and Bawazir 2000). A comparison of pre-restoration and predicted future condition without restoration water use was compared with water use associated with improved habitat diversity and restored river processes. An initial description of the groundwater/surface water dynamics through the reach was attempted but existing information on this important aspect of the ecosystem is limited. Research currently underway will inform and improve the analysis of this interaction and become part of future updates to the plan (Bowman and others 2002).

The basic premise for evaluating appropriate plant community reestablishment at this conceptual level and relating that to potential water savings was to assume that riparian plant establishment will be determined by connectivity to the channel, shallow groundwater table and flood frequency. The occasional very high flows through the reach could establish patches of dense vegetation at higher elevations, but the ability of those plants to

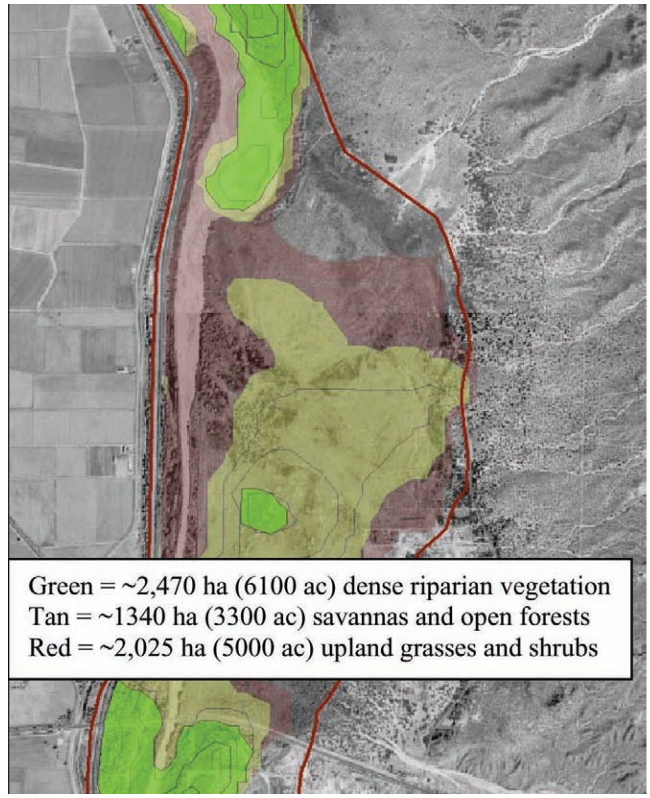

Figure 2. Flood frequency related to present and reestablished plant communities.

survive could be limited by the local groundwater gradient to the west. Areas currently vegetated with exotic tree species that were flooded only at infrequent flood intervals would be reestablished as open grasslands. Those areas that were more closely associated with the channel and groundwater would most likely be vegetated with riparian habitats of dense structure. Estimated area of grassland, savanna, wetland, and forest were calculated and used in subsequent evaluation of biological diversity and water use (fig. 2).

Institutional constraints on the system were evaluated as well. The Middle Rio Grande of New Mexico has commitments for water delivery to sovereign tribal nations and downstream users (Rivera 1999). The current delivery of water to legal users is based on prior appropriations but the Middle Rio Grande has not been adjudicated. The river channel through the Socorro valley and the Low Flow Conveyance Channel have served as delivery systems to downstream water users. Management alternatives within current authorities were reviewed as a part of plan formation.

Development of the Restoration Concepts and Strategies

An exercise to determine the initial ranking of proposed restoration components was accomplished through a series of workshops with oversight committee members, local professionals in the fields of hydrology, geomorphology, engineering and biology, and interested citizens. A video of the Rio Grande through the reach was available during discussions. A decision-making matrix was developed to aid in determining qualitative values to the physical and biological attributes, resource use and benefits, possible adverse impacts, potential techniques and final ranking of restoration technique and purpose. Definitions and instructions for matrix components were developed and distributed to participants as well. The matrix resulted in an initial prioritization of restoration by subreach to assist in restoration plan development.

Results

Development of the Conceptual Restoration Plan

Results of the decision-making exercise showed that restoration of periodic higher flows, restrictions on floodplain development and other "passive" restoration techniques are considered essential to the enhancement of biological diversity through this reach of river. This is similar to results of other larger scale evaluations of the Rio Grande completed recently (Tetra Tech, Inc. 2002, Crawford and others 1993). The importance of controlling exotic vegetation and diversifying the habitats along the river were reflected in ranking as well. Hard engineering techniques such as rip rap placement and channel gradient control structures ranked very low in terms of benefit to this reach of river. Restoration project areas were selected based on improved river-floodplain connectivity, environmental compatibility, likelihood of success, consistency with other restoration activities in the subreach, cost, construction feasibility, long-term sustainability, potential response to adaptive management, potential water salvage, and potential conflicts.

A series of maps focusing on the different river issues and the recommended techniques to address these issues was produced. The "Restoration Lyte Plan" was developed to present implementation focusing on fire protection, exotic species removal and minimal habitat diversification. This version was envisioned to address immediate needs with limited costs. The Water Salvage Plan and the Drought Reduction Plan have been combined into a Drought Impacts Plan that addresses the critical issues during prolonged dry periods. Opportunities for water savings through exotic species control, fire management, endangered species habitat protection, and limiting vegetation encroachment in the main channel are included in this mapping product. Some of the restoration projects have been designed to enhance or restore habitat for both the endangered Rio Grande silvery minnow and Southwestern willow flycatcher. These projects are highlighted in the Habitat Diversity and Endangered Species Habitat Plan and the River Dynamics Plan. The Long Term Comprehensive Plan consists of all the selected projects from each theme. This mapping product provides a tool to discuss long term trends in biodiversity, water use, channel dynamics, endangered species habitat availability, and fire protection along the 72-hectare river reach with a look at balancing these priorities. Different versions were developed to aid a number of diverse resource managers in the area. The Task Force, in conjunction with interested floodplain landowners and management agencies, are prioritizing restoration projects based on a phased implementation strategy and available budget.

Monitoring and Adaptive Management Strategy

The Adaptive Management Plan includes coordination with other stakeholders in the valley through the formation of a work group. There is an urgent need to understand the ecological effects of restoration as implementation moves forward and to develop new management options to sustain these projects. The first priority of the work group will be to evaluate channel and riparian changes and propose priorities for addressing undesirable trends in biological diversity. While it is recommended that restoration components be sustained by prescribed flow recommendations, the success of some restoration activities will be contingent on an adaptive management plan that has an appropriate maintenance response when flows are not available. Successful adaptive management of this reach of river will depend on agency cooperation and public involvement.

The second priority will be to implement a monitoring program to identify the monitoring needs in terms of baseline hydrographic, biological, vegetation and geomorphic data and long term monitoring of trends in the ecosystem. As a part of this monitoring program, information to assess restoration success or failure would be gathered. It is envisioned that the monitoring program developed by the work group will build from the existing programs of resource agencies and researchers working in the Socorro valley (BOR unpublished data, Bestgen and Platania 1989, Hildebrandt and Ohmart 1982, Muldavin and others 2000, Coonrod and others 2002, Massong and others 2002, Stromberg and others 1991, FLO Engineering 1999). The plan outlines suggested focus areas, parameters, and schedules for monitoring the abiotic and biotic components of Rio Grande ecosystem.

The third priority is to develop a set of guidelines for responding to ecosystem changes observed through implementation of the monitoring program. Recommended responses to undesirable conditions in terms of flood frequency and duration, vegetation encroachment, levee instability, bank erosion and channel migration, failure to induce overbank flooding, river desiccation, sediment plugs, and high soil salinity are proposed in this Plan.

Other Products of the Plan

A list of Rio Grande water resource projects, cross section plots, a database index, and review comments and responses are included in the appendices along with an extended bibliography. This bibliography is broken down by topics including endangered species, general data, geology, geomorphology, history and culture, hydrology, general categories, groundwater, surface water, legal and administrative, maps, riparian habitat, river restoration, sediment load, vegetation, and wildlife.

Discussion

Plan updates will be necessary as new monitoring information, current research and new techniques become available. The Task Force has plans to evaluate recent groundwater information and a draft surface water/groundwater model for the area (Bowman and others 2002) for inclusion in future drafts. Current copies are available at the Middle Rio Grande Bosque Initiative website (www.mrgbi.fws.gov). This information will improve restoration selection and feasibility in the valley. It will also improve the analysis of current water use by the natural system in this reach and the potential for water savings. The FLO2D model will need to be calibrated during the next large sustained flood event to improve the accuracy of this flood routing model in the Socorro valley.

The Task Force is working with private landowners to develop restoration plans for their particular parcels based on general information derived from the plan and proposed site specific monitoring. The Task Force hopes to convene the Adaptive Management Work Group in early 2005 to begin establishing the monitoring program.

Since this effort was accomplished to address issues on the active river floodplain (east of the flood control levee), the Task Force did not include evaluation of water use, land ownership or other important concerns in the valley west of the levee. It is the Task Force's intention to use this CRP as a planning tool for its work in the valley and to make it available to other agencies for their use. Quantifying potential water savings and improved land management opportunities adds information to a larger discussion on Rio Grande water issues.

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Overview of Saltcedar Biological Control

C. Jack DeLoach, Research Entomologist and Lead Scientist, Saltcedar Biological Control Project
Lindsey R. Milbrath, Research Entomologist, USDA-ARS, Grasslands Soil and Water Research Laboratory, Temple, TX
Ray Carruthers, Ecologist and Research Leader, USDA-ARS, Exotic and Invasive Weed Research Unit, Albany, CA
Allen E. Knutson , Professor and Extension Entomologist, Texas A&M University Research & Extension Center, Dallas, TX
Fred Nibling and Debra Eberts, Research Botanists, U.S. Department of Interior, Bureau of Reclamation, Ecological Research & Investigations Group, Denver, CO
David C. Thompson, Research Entomologist, Department of Entomology, Plant Pathology & Weed Science, New Mexico State University, Las Cruces, NM
David J. Kazmer, Research Entomologist, USDA-ARS, Northern Plains Agricultural Research Laboratory, Sidney, MT
Tom L. Dudley, Research Entomologist, University of Nevada, Department Environmental & Resource Science, Reno, NV
Dan W. Bean, Research Entomologist, Department of Vegetable Crops, University of California at Davis, Albany, CA
Jeff B. Knight, State Entomologist, Nevada Department of Agriculture, Reno, NV

Abstract—*Biological control has successfully controlled 10 exotic, invasive weeds of rangelands and natural ecosystems in the United States since 1945, and control of others is in progress. We initiated biological control of saltcedar (*Tamarix *spp.) in 1987, using host-specific insect herbivores that regulate saltcedar populations in the Old World. We did a risk analysis, including the possible effects of biological control on the endangered southwestern willow flycatcher, (*Empidonax trailii extimus*) which had begun nesting extensively in saltcedar in Arizona. Our cooperators in France, Israel, Kazakhstan, China, and Turkmenistan tested 20 candidate control insects. Then, after quarantine testing, we released the first of these, the leaf beetle Diorhabda elongata Brullé from China and Kazakhstan, into field cages at 10 approved sites in 6 states in 1999 and into the open environment in May 2001. These beetles established at five sites in Nevada, Utah, Colorado and Wyoming and defoliated from 40 to 600 ha at each site by late June 2004. However, these beetles failed to establish in Texas and southern California because short summer daylengths stimulated premature diapause and failure to overwinter. In 2002, our overseas cooperators sent Diorhabda biotypes from four southern latitudes. After quarantine testing, we released some of these biotypes into field cages and then into the open environment at 5 sites in Texas, 2 in New Mexico, and 2 in California during late 2003 and 2004. They overwintered well, are increasing in population, and have begun defoliating saltcedar at 2 sites but have encountered heavy predation in some areas; intensive monitoring is underway. Biological control can provide self-sustaining, permanent, safe, and low cost control of saltcedars. This will allow recovery of native riparian plant communities, improved wildlife and fish habitat, reduced wildfires, increased availability of water, and increased recreational usage of parks and natural areas.*

Introduction

The invasion of river bottoms and lakeshores of the western United States by exotic, saltcedars is producing one of the worst ecological disasters in the recorded history of that region. Saltcedars, introduced in 1823, spread rapidly after the 1920s and today occupy over 800,000 ha of highly valuable land along streams and lakeshores from the central Great Plains to the Pacific and from Montana into northern Mexico. They often completely displace native plant communities, degrade wildlife habitat, and contribute to the population decline of many species of birds, fishes, mammals, and reptiles, including many threatened or endangered species (Wilcove and others 1998). They increase wildfires and soil salinity, lower water tables and reduce recreational usage of parks and natural areas. Saltcedar thickets typically use 4 to 5 acre feet of water per year that in the present drought severely reduces water available for agricultural irrigation, municipal and environmental use. They contribute to default of water agreements between states and between the U.S. and Mexico and damage parks and natural area reserves bordering the Rio Grande (Reviewed by DeLoach and others 2000).

Taxonomy and Distribution

Saltcedars (Tamarix: Tamaricaceae: Tamaricales) are a genus of 54 species of small trees or shrubs native only in the Old World. The genus evolved in riparian habitats in arid, saline areas of Central Asia, with a secondary center of speciation in the eastern Mediterranean area (Baum 1978). Ten species have been introduced into the United States since 1823 as ornamentals and to control streambank erosion in the West. Four species and their hybrids have become serious pests in the West: *T. ramosissima*, *T. chinensis* (both widespread), *T. canariensis* (Gulf of Mexico coast), and *T. parviflora* (California) (Gaskin and Schaal 2002). All are deciduous, deep rooted, facultative phreatophytes, with pink flowers and with foliage of juniper (cedar) – like bracts. The large, evergreen tree, *Tamarix aphylla* (athel), that is a common shade tree of the Chihuahuan and Sonoran deserts, is less aggressive and is not a target for biological control.

Conventional Controls

Saltcedars are difficult to control by mechanical methods, fire or many herbicides because of their ability to resprout from underground buds and to reinvade from their windblown seeds. Recently, "arsenal" (imazapyr) used as an aerial spray and "garlon" (triclopyr) as a cut-stump treatment provide good control (Duncan and McDaniel 1998). However, both are expensive and arsenal also kills many native plants. These controls are unsatisfactory in natural areas of mixed vegetation where the objective is to kill the invading weed and preserve the beneficial and native plants.

Biological Control

Biological control of weeds is best suited to control exotic, invasive weeds in relatively stable ecosystems such as natural areas and rangelands, by the introduction of the natural enemies (insects or sometimes plant pathogens) that regulate the weed's abundance in its native region. The objective is to permanently reduce the weed's abundance below the damage level, but not to eradicate it. The philosophy and methodology of biological control of weeds has been developed and reviewed by many workers (Huffaker 1957, Nechols and others 1995). This method has been used worldwide since 1865 against 133 weed species in 51 countries (Julien and Griffiths 1999). In North America, it began in 1945 and has been used against 40 exotic weeds of rangelands and natural areas. It has been highly successful in a third of the attempts (often with no additional control ever needed over wide areas) and partially successful in another third. The method also has been very safe, with only eight reported cases of non-target feeding worldwide (seven minor and temporary and one of moderate damage with stand reduction), all from agents released before testing protocols, reviews and authorization were tightened in 1965 and all predicted in the pre-release testing. The low beneficial values of saltcedar, its lack of closely related plants in the Western Hemisphere, and the large number of host-specific and damaging insects that attack it within its native distribution in the Old World, make saltcedar well suited for biological control.

Progress in Biological Control

A program of classical biological control for saltcedar, by the introduction of the *Tamarix*-specific insects that regulate its populations in its area of natural distribution in Asia and the Mediterranean area, was initiated in 1987 by one of us (DeLoach) at USDA-ARS, Temple, TX, supported from the beginning by the USDI Bureau of Reclamation. The project was joined in 1998 by the new ARS Exotic and Invasive Weeds Research Unit (ARS-Albany) organized by one of us (Carruthers).

Discovery and Testing of Control Insects

Surveys of the natural enemies of saltcedar have been made in its native geographical range for many years, as a part of the studies of the natural resources of the Soviet Union, summarized by Kovalev (1995). We began overseas exploration and testing in 1991 with our collaborators at ARS European Biological Control Laboratory (EBCL), France (Alan Kirk and Rouhollah Sobhian); Tel Aviv University, Israel (Dan Gerling); ARS Sino-American Biological Control Laboratory, Beijing and Urumqi, China (Ren Wang, Qing Guang Lu, Hongyen Chen, and Bao Ping Li); Almaty, Kazakhstan (Roman Jashenko and Ivan Mityaev); and Ashkhabad, Turkmenistan (Svetlana Myartseva). Those studies together have revealed over 300 highly specific and damaging insect species as potential biological control agents (DeLoach and others 1996).

After completing a literature review and a risk analysis, we began testing in quarantine at ARS-Temple in 1992, and at ARS-Albany in 1998. From the 20 candidate control insects investigated overseas, we tested 7 species and selected the leaf beetle Diorhabda elongata Brullé, from Fukang, China and Chilik, Kazakhstan as the first and most promising candidate for complete testing and release (DeLoach and others 2000).

Both adults and larvae of *D. elongata* (fig. 1a,b,c), feed on the foliage of saltcedar and the large larvae also de-bark small twigs causing the distal foliage to die. Several years of laboratory and outdoor cage testing demonstrated that *D. elongata* is unlikely to attack any non-target plants except for possibly causing slight damage to the related, native *Frankenia salina* in California but not *F. jamesii* or *F. johnstonii* in Colorado and Texas. It also might cause moderate damage to exotic athel trees (*T. aphylla*), which have some value as shade trees and windbreaks in the southernmost United States and northern Mexico; however, athel also is becoming invasive in some areas (DeLoach and others 2003, Lewis and others 2003a, John Herr, Albany and Lindsey Milbrath, Temple, manuscripts in progress).

The adults overwinter and the larvae pupate under litter beneath the trees. Laboratory tests showed that beetle populations can double each 6.2 days. Field cage studies showed a range of population increases but a 30-fold increase per generation was not uncommon. In Colorado and Wyoming, overwintered adults become active in late-April and produced two generations before they began overwintering in September. In the more southern areas, the saltcedar growing season appears to be long enough to allow completion of 4 or possibly 5 generations (Lewis and others 2003b).

Clearances and Permits

In March 1994, we submitted a petition to the Technical Advisory Group on Biological Control of Weeds (TAG) of the USDA Animal and Plant Health Inspection Service (APHIS) asking their recommendation for release of *Diorhabda elongata* into the open field.

However, the listing of the southwestern willow flycatcher as federally endangered in February 1995 required consultation with the USDI Fish and Wildlife Service (FWS). We submitted a Biological Assessment, to FWS Region 2, Albuquerque, NM in October 1997. This risk analysis revealed that the flycatcher had begun nesting extensively in saltcedar in some areas of Arizona since saltcedar had replaced the native willow habitat, but little in other areas. The effect of biological control on the other 50 threatened or endangered (T&E) species reviewed was expected to be beneficial or cause no effect. However, the harmful effects of saltcedar reduced reproductive success of the flycatcher to half of that in its native willow habitat, in heavily infested areas along the lower Colorado River and at Roosevelt Lake, AZ (DeLoach and others 2000). Recently, flycatcher populations have increased dramatically, but only in areas where the willows have increased.

In June 1998, we, with staff from several other agencies, met with FWS to discuss their requirements for approving release of the Diorhabda beetles. We then submitted a Research Proposal to FWS on 28 August 1998 for release of the beetles. This document included specifications as follows: a research phase in which; 1) *D. elongata* could be released only into secure field cages at 10 specified sites in different climatic zones in Texas, Colorado, Wyoming, Utah, Nevada and California, all more than 200 mi from where the flycatcher nested in saltcedar. The beetles would be monitored in the cages for one year to determine their survival, developmental biology, rate of increase, and observed damage to saltcedar and non-target plants in the cages. 2) The beetles then were to be released into the open field for a 2-year period, during which the degree and rapidity of control, rate of natural dispersal, and effects on native plant and wildlife communities would be monitored. After this combined 3-year research period, FWS and APHIS would review the research results and determine the conditions under which an Implementation Phase could be carried out in which unlimited releases could be made in specified areas. The Letter of Concurrence issued by FWS on 28 December 1998 (revised 3 June 1999), the Environmental Assessment prepared by APHIS in February 1999, the Finding of No Significant Impact (FONSI) issued on 7 July, and the APHIS permits to release in the field cages during July 1999, all contained these restrictions.

The Saltcedar Biological Control Consortium had been organized in December 1997 by one of us (DeLoach), and is co-chaired by three of us (Carruthers, Nibling, DeLoach) to help guide this process and to provide coordination between agencies and input, guidance and oversight in the research program from user and environmental organizations (Stenquist 2003). It has met annually since then and now has representatives from ca. 50 federal and state agencies, universities, and private user and environmental groups. The sister Tamarix Coalition in Grand Junction, CO and the Rio Grande Institute in western Texas were organized more recently.

Experimental Releases and Results in Field Cages: July 1999 to May 2001

After receiving FWS concurrence and FWS permits, we placed the beetles into field cages during the summers of 1999 and 2000 at 10 sites in six states. This research was coordinated by some of us at each site: for Fukang, China beetles: DeLoach at Seymour, TX; Eberts at Pueblo, CO; Kazmer at Lovell, WY and Lake Ft. Peck, MT; Knight at Lovelock, Stillwater and Schurz, NV; and Carruthers and Dudley at Bishop, Hunter-Liggett and Cache Creek, CA; and for Chilik, Kazakhstan beetles, by Greg Abbot, APHIS at Delta, UT. These beetles successfully overwintered in the cages at the eight most northern sites, all north of the 38th parallel, although only weakly so at Stillwater and Cache Creek. At the five sites where strong overwintering occurred (Pueblo, Lovell, Delta, Lovelock and Schurz), the beetles increased to large numbers during the summer and completely defoliated the plants inside the cages during both 1999 and 2000. They failed to overwinter at the two sites south of the 38th parallel, at Seymour and Hunter-Liggett. Here, they ceased feeding and egg laying, and began overwintering in early July but did not survive the winter (Lewis and others 2003b).

In laboratory and outdoor cage tests, Lewis and others (2003b) at Temple and Dan Bean at Albany showed that these beetles entered premature overwintering diapause at daylengths less than 15 h 45 min, then starved during the 8 to 9 months of often warm temperatures before spring. Maximum daylength at Seymour is only 14 hr 21 min and is even less farther south, which caused the failure to overwinter.

Releases and Results in the Open Field in Northern Areas: May 2001 to Late Summer 2004

Based on the field-cage results and additional host specificity testing (Lewis and others 2003a), we requested and received release permits from APHIS. We released adults into the open field during May 2001 at the 6 sites where the beetles had overwintered, plus at Seymour. We released approximately 27,000 adults and larvae at Lovell, WY; 6900 adults plus many larvae at Pueblo, CO; 15,000 at Delta, UT; 3,500 at Schurz and 1,400 at Lovelock, NV; 4,400 larvae and 2000 adults at Bishop, CA; and 498 adults at Seymour, TX.

During the remainder of the summer, we found a few to moderate numbers of eggs, larvae, and adults and dispersal of only about 10 m. When large larvae of the second generation developed in mid-August 2002, we saw extensive damage at some sites. At Lovelock on 28 August, the larvae had destroyed 95 to 98 percent of the foliage of all trees within an area 100 m in diameter (1 ha), centered at the release cage. Heavy feeding but not total defoliation had occurred in an additional concentric ring 50 m wide outside the affected core area. We saw a similar area of defoliation at Pueblo. We observed heavy predation by ants at Lovell and by birds at Delta. The beetles failed to establish at Seymour.

During 2003, the beetles at Lovelock had defoliated 3.2 ha in early July, and by early September about 200 ha (total area of land infested by saltcedar, not canopy cover of the trees), along a 5 km reach of the Humboldt River (Carruthers and others, this proceedings). By September 2003, several plants had resprouted profusely from the base and occasionally from the upper branches but enough beetles had remained in the stand to defoliate this regrowth. At Schurz (Fig. 1d), the beetles had defoliated ca. 12 ha along the Walker River and at Pueblo ca. 40 ha. At Delta and Lovell, the beetles overcame bird and ant predation in 2002 to defoliate 40 ha and 6 ha, respectively by September 2003.

By the end of 3 ½ growing seasons after release (late June 2004), defoliation by the Fukang/Chilik beetles at the five northern sites had increased 3 to 5 fold over the amount in August 2003, to an estimated 600 ha at Lovelock, 200 ha at Delta, 120 ha at Schurz and Pueblo, and 40 ha at Lovell. As of late 2004, few trees have been completely killed, but we expect to see increasing whole tree death during 2005 and 2006. However, the defoliation has been 95 to 100 percent, which has reduced water usage to a very low level and has opened the canopy cover and allowed other plants to begin increasing in growth and number. Bird populations have increased at least temporarily at Lovelock, apparently because of the increased food supply (the Diorahbda beetles). In 2003, additional releases of the Fukang/Chilik beetles were made at Lake Fort Peck, MT by one of us (Kazmer, site manager) and at Owyhee, OR by one of us (Dudley) and E.M. Coombs, Oregon Department of Agriculture (site managers).

Short-Daylength Beetles Discovered and Released in Southern Areas

One of us (Carruthers) discovered Diorhabda biotypes at lower latitudes in Crete and mainland Greece, and through our cooperators at EBCL France in Tunisia and Uzbekistan and through cooperators in China at Turpan. Some of these biotypes have the potential to establish south of the 38th parallel and perhaps throughout the southern range of saltcedar in the southwestern U.S. and northern Mexico. The Crete beetles, placed in a large outdoor cage at Temple during August 2002, overwintered with little mortality and began feeding and reproducing vigorously on the plants by early April. Additional host specificity testing of these four new biotypes of *D. elongata* from the Old World demonstrated that they also are safe to release (Lindsey Milbrath, ARS-Temple and John Herr, ARS-Albany, manuscripts in preparation), although they may feed slightly on native Frankenia salina in California, and they probably will moderately damage the exotic athel (*T. aphylla*) trees (fig. 1e, f) in the southern areas.

The southern-adapted Crete beetles were placed in field cages and in the open field in the southern areas during the summer of 2003 and 2004 (table 1). Populations are increasing near Big Spring, TX and at Artesia, NM and they were beginning to defoliate several saltcedar trees, as of late August 2004. However, these beetles

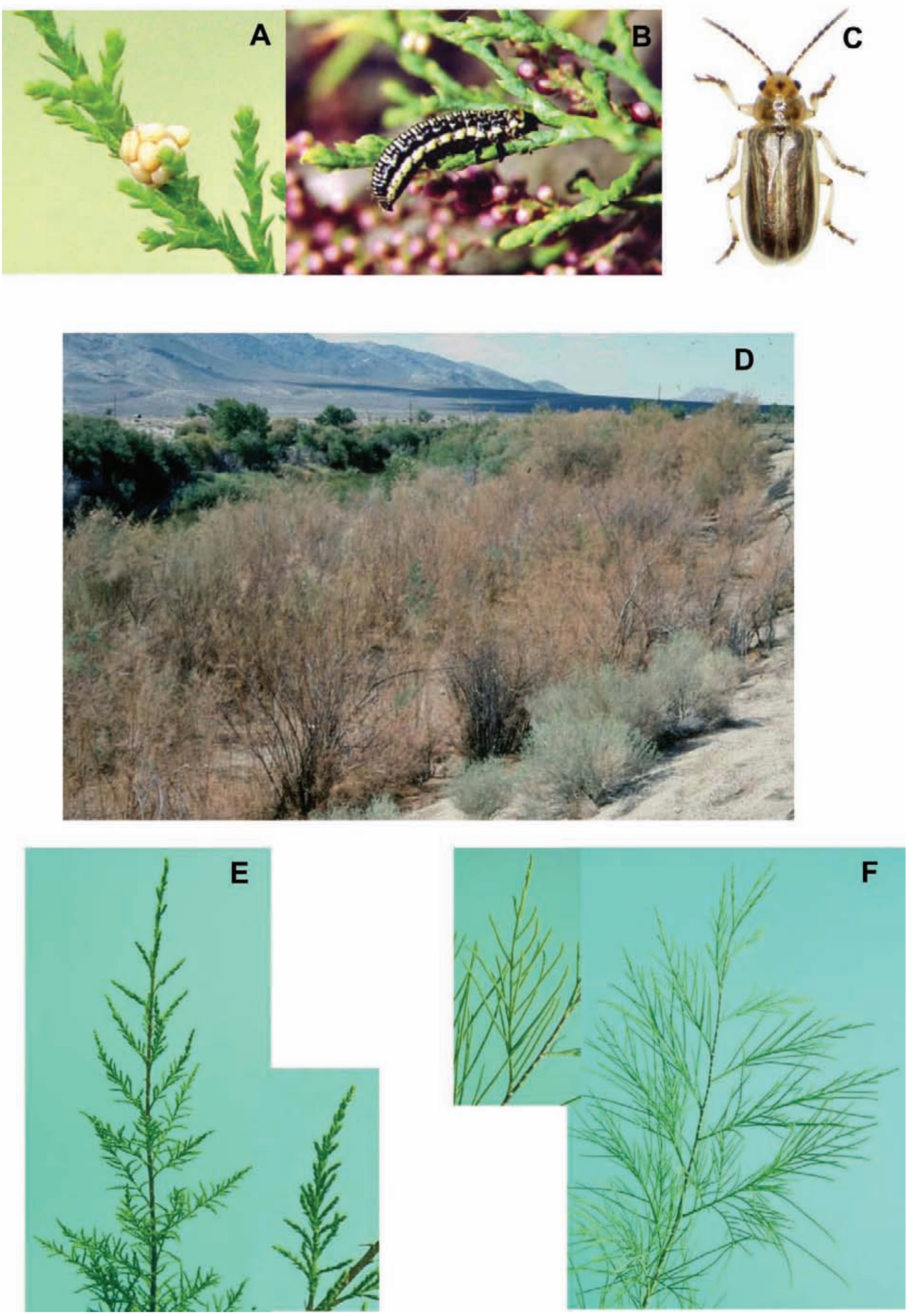

Figure 1. *Diorhabda elongata* egg mass-A; third instar larva-B; adult-C; defoliated plants at Schurz, NV, August 2003-D; foliage of *Tamarix ramosissima* or hybrid-E and foliage of *Tamarix aphylla*-F.

Table 1. Field release of southern adapted *Diorahbda elongata* biotypes in 2003 or 2004.

Approved release site	°N latitude	Crete (35°20´)	Tunisia (34°46´)	Uzbekistan (39°55´)	Turpan, China (42°57´)	Posidi, Greece (39°58´)
		Origin (and latitude) of beetles: date released				
		Released in field cages				
Cache Creek, CA	38°56´	22 Aug				
John Martin, CO	38°6´				May 2004	
Bishop, CA	37°5´				May 2004	
Hunter-Liggett, CA	35°57´	18 Sep 03				
Lake Merideth, TX	35°29´					May 2004
Seymour, TX	33°43´	24 Jun			20 Mar	
Artesia, NM	33°9´	13 Aug				
Lake Thomas, TX	32°36´	10 Jul			31 Jul	
Big Spring, TX	32°15´	10 Jul		20 Aug		
Brantley, NM	32°5´					May 2004
Ft. Stockton, TX	30°50´					
Candelaria, TX	30°8´					
San Jacinto SP, TX	29°45´					
Kingsville, TX	27°25´	27 Aug	13 Aug			
Zapata, TX	26°58´	5 Nov	26 Aug			
		Released in open field				
Cache Creek, CA	38°56´	29 Oct				
John Martin, CO	38°6´				July 2004	
Hunter-Liggett, CA	35°57´	7 Sept				
Lake Merideth, TX	35°29´					July 2004
Seymour, TX	33°43´	14 Aug			31 Jul	
Artesia, NM	33°9´	28 Aug				
Lake Thomas, TX	32°36´	21 Aug				
Big Spring, TX	32°15´	16 Sept				
Brantley, NM	32°5´					July 2004
Kingsville, TX	27°25´	10 June 2004				

have experienced heavy predation by ladybird beetles at Cache Creek and Lake Thomas and by assassin bugs at Artesia. We are releasing large numbers into nearby subplots in an attempt to avoid or overwhelm the predators. The vigorous feeding and reproduction by these beetles, and the longer growing season allows three to five generations a year, and could result in even better control in the south than observed in the north.

Monitoring

An intensive monitoring program is being carried out as required (see Clearances and Permits, above), under monitoring plans developed by the Saltcedar Biological Control Consortium by Juli Gould for the control insects and damage to saltcedar, by Tom Dudley for saltcedar and native plant recovery, and by Larry White for bird populations (Gould and others 2000).

The basic monitoring plan specifies a 10 ha sampling circle centered at the beetle release point with 100 (now reduced to 40) permanently marked sentinel saltcedar trees within 3 concentric rings of 1, 2 and 7 ha. Diorhabda and other insect populations, percent defoliation, plant growth and condition are measured periodically on four marked 40 cm long branch terminals on each saltcedar tree. Once or twice annually, the vegetation is sampled by measuring tree height and diameter, percent healthy, yellowing or dead branches, and the distance, species identification and size of three nearest neighbor trees. Also, low vegetation is measured in two 1 m^2 quadrats, one under and one outside the tree canopy, in which present cover of all species and of litter and bare soil is estimated. This sampling plan now seems inadequate because the beetles rapidly overflow and completely defoliate the entire sampling circle. Modifications, such as the inclusion of long transects, are being discussed.

The beetles disperse beyond the defoliated area, and are difficult to find at low densities. Our cooperators, Bob Bartelt and Allard Cossé, ARS-Peoria, IL have developed a beetle pheromone and a saltcedar extract that are very attractive to Diorhabda beetles over distances of 10 to 20 m. These have been effective in monitoring the dispersal of the Fukang beetles at Lovelock. (Earl Andress, APHIS, Barstow, CA, personal communication).

For monitoring birds, two riparian sampling areas are selected, one with near monotypic saltcedar and one with nearly pure native vegetation. In each area, 10 permanent point-count areas are located, each 100 m in diameter and separated from each other by 100 m. Three or more times annually during the breeding season, the numbers of each bird species seen or heard during 5 min are counted from the center point of each circle. This allows a direct comparison between saltcedar and native vegetation, and also of populations in saltcedar before and after biological control with the native plots as a statistical control. Procedures also have been developed for monitoring butterflies, all insects, bats, other small mammals, and reptiles.

Previous and continuing research on remote sensing promises a good and less expensive method of monitoring the degree and extent of control (Everitt and DeLoach 1990) and of the recovery of native riparian plant communities following control although some ground truthing will still be needed. (Carruthers and others, this proceedings).

Expectations From Control

We expect biological control to gradually (over a period of 3 to 5 years) and permanently to reduce the abundance of saltcedar to below the level of economic or environmental damage, but not to eradicate it. In this situation, both saltcedar and the beetles would remain at fluctuating low population levels, the beetles always would be present to control regrowth or reinvasion, and 100 percent control (never obtained by biological or any other method) is not needed.

Under these conditions, we expect the native plant communities to reestablish naturally in most areas where depth to water table and soil salinity are not too great. This should improve wildlife habitat and allow the recovery of many species of birds and fish and some mammals and reptiles, including several threatened and endangered species. Control of saltcedar is expected to increase the amount and quality of water available for irrigated agriculture, municipalities, and the environment and to help fulfill the water rights agreements between states and between the United States and Mexico. Control also is expected to increase recreational usage of parks and wildland areas and to reduce wildfire and salinity levels.

Large-scale revegetation projects are under development by the USDI Bureau of Reclamation for areas where natural revegetation may be insufficient. Several other biological control insects are also being developed by our overseas cooperators for use in fringe climatic areas when the Diorhabda beetles may not provide sufficient control or where predators may limit control, or where their release may not be allowed.

Saltcedar also has invaded large areas in northern Mexico, where it is damaging natural areas and contributing to the acute water shortages along the Rio Bravo and in other areas. The U.S. program easily can be extended into Mexico at very low cost, through the participation of Mexican scientists. However, the large, exotic, athel trees (fig. 1e, f) are valued to some degree in northern Mexico for shade trees, hedges, and windbreaks. The Diorhabda beetles are expected to damage athel to some extent, based on our cage studies (Lindsey Milbrath, ARS-Temple, manuscript in preparation). Open-field tests are underway at Kingsville, TX and Artesia, NM to quantify this (Patrick Moran, ARS-Weslaco, site manager). Approval of the Mexican scientists, natural areas managers, and authorities is being sought before releases are made along the Rio Grande, Texas.

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The Laws of Diminishing Yields in the Tropics

R. Derpsch, Ing. Agr. MSc., Senior Advisor to MAG-GTZ Soil Conservation Proyect, Casilla de Correo 1859, Asunción, Paraguay
M. Florentín, Ing. Agr. MSc., DIA, Campo Experimental de Choré, Proyecto Conservación de Suelos MAG-GTZ, Casilla de Correo 1859, Asunción, Paraguay
K. Moriya, Ing. Agr. MSc., DEAG, Coordinador Contraparte, Proyecto Conservación de Suelos MAG-GTZ, Casilla de Correo 1859, Asunción, Paraguay

Introduction

The key problem of conventional agriculture in the tropics and subtropics is the steady decline in soil fertility, which is closely correlated with the duration of soil use. The reason for this can be found primarily in the occurrence of soil erosion, the loss of organic matter, leaching of nutrients into deeper soil layers, and soil physical degradation associated with conventional tillage practices that leaves the soil bare and unprotected in times of heavy rainfall and heat (Derpsch and Moriya 1998). The result of soil degradation is not only that farm land has to go out of the production process, but also that there is an increasing need for more inputs and investments to maintain high levels of productivity. In the United States for instance, 50 percent of fertilizer needs is applied only to compensate for the losses in soil fertility due to soil degradation, and in Zimbabwe, soil nutrient losses by erosion are three times higher than the total quantity of fertilizers applied (Stocking 1988, cited by Steiner 1996). The GLASOD project (Global Assessment of Soil Degradation), which is a United Nations program for the environment (UNEP) that aims to determine worldwide soil degradation, distinguishes four processes of degradation caused by man: degradation by water erosion, by wind erosion, chemical and physical soil degradation (Oldeman and others 1990). According to this study, the major cause of soil degradation is water erosion (56 percent), followed by wind erosion (28 percent). In other words, erosion is responsible for 84 percent of soil degradation worldwide (Oldeman and others 1993). The following major factors are mentioned as causing degradation by water erosion: deforestation (43 percent), overgrazing (29 percent), and bad soil management (24 percent). However, soil preparation, which is the major factor causing soil degradation, is not mentioned, and is probably confused with bad soil management and deforestation. According to Oldeman and others (1993), the most important forms of chemical soil degradation are the loss of nutrients and organic matter in South America, and salinisation in Asia. Under the main causes of chemical soil degradation, bad soil management (56 percent) and deforestation (28 percent) are mentioned. Similar results are reported by FAO (1984). In this case also, the influence of soil preparation on soil degradation is not considered. It appears that most professionals avoid using the term "soil preparation" as a factor responsible for soil degradation and prefer to use terms like "bad soil management," where various factors, one of which is soil preparation, are involved.

There is evidence that conventional soil tillage, which leaves the surface of the soil bare and unprotected, is one of the major causes of erosion and soil degradation on agricultural land. Maximum sediment amounts as well as phosphorus and nitrogen content in the water of the Itaipú dam (shared by Paraguay and Brazil), were measured in times of soil preparation for winter and summer crops (Derpsch and others 1991).

The Laws of Diminishing Yields in the Tropics and Subtropics

In nature there are laws ruling the diminishing productivity of soils which have to be taken into account in agricultural and livestock production. Disregard of these laws promotes the degradation of soils and the loss of soil productivity. Respect for these laws is indispensable if we aim to obtain sustainable agricultural production.

1. Any agricultural or livestock production system that contributes to constantly reducing the organic matter content of the soil is not sustainable and results in poor soils and farmers.
2. Under tropical and subtropical conditions intensive and repeated tillage will generally mineralize (reduce) organic matter at rates higher than the potential for repositioning. This results in a decreasing organic matter content of the soil and diminishing crop yields over time.

3. High rainfall and wind intensities prevailing in the tropics and subtropics are generally associated, under intensive and repeated tillage, with soil loss rates (due to wind or water erosion) that are higher than natural soil regeneration. This results in loss of nutrients and organic matter and in diminishing yields over time.
4. Under tropical and subtropical conditions, intensive and repeated tillage will generally damage the soil structure and lead to excessively high soil temperatures. This will have negative effects on root growth, soil flora, and fauna (soil biological processes) and on soil moisture resulting in diminishing yields over time.
5. Any agricultural or livestock production system in which important losses of nutrients occur through extraction without reposition (for example, soil exploitation) through volatilization (for example, regular burning), and/or through leaching (for example, fallow periods without crops), is not sustainable and results in poor soils and farmers.

Additionally soil carbon is lost very fast to the atmosphere (as carbon dioxide) after the soil is intensively tilled. This results in unacceptable CO2 emissions into the atmosphere, and instead of carbon being deposited in the soil, improving its fertility, tillage contributes to the greenhouse effect and to the global warming of the planet. (Kern and Johnson 1993 a and b, Reikosky 2000).

In summary, the unavoidable negative effects of intensive and repeated soil tillage in the tropics and subtropics on organic matter content, soil erosion, soil structure, soil temperature, soil moisture, water infiltration, soil flora and fauna (soil biological processes) and loss of nutrients, result in chemical, physical and biological soil degradation. This results in diminishing yields over time and in productivity losses of the soil and leads to poor soils and farmers.

As a consequence of the laws of diminishing productivity of tropical soils, sustainability of agricultural or livestock production cannot be achieved as long as repeated and intensive soil tillage is performed in the tropics and subtropics. Nor can sustainability be achieved as long as the soil is exploited without reposition of nutrient losses through leaching and/or extractions that occur with harvests, and as long as frequent burning of fields is performed.

Analysis of the Laws of Diminishing Yields

1. Any agricultural or livestock production system that contributes to constantly reducing the organic matter content of the soil is not sustainable and results in poor soils and farmers.

   Soil organic carbon is the soil attribute most consistently reported in long-term studies and is a keystone soil quality indicator, being inextricably linked to other physical, chemical, and biological soil quality indicators (Reeves 1997). Soil organic matter may be one of the most important soil quality characteristics in relation to tillage because of its influence on other soil physical, chemical and biological properties (Cannel and Hawes 1994).

   Due to the fact that the cation exchange capacity of most tropical soils is very low (Sánchez 1976), organic matter is much more important for storing nutrients in the tropics than in temperate regions. Therefore the efficiency of mineral fertilizers is greatly reduced if organic matter is not added at the same time. On the other hand, it is necessary to consider that organic matter is mineralized about five times more rapidly in the tropics than in temperate regions. Consequently, the organic matter content of the soil is of overriding importance in relation to soil fertility in the tropics and subtropics.

   Therefore we can state that any agricultural production system that does not add sufficient organic matter and/or gradually reduces the organic matter content of the soil below an adequate level is not site-appropriate, will result in soil degradation, and is not sustainable.
2. Under tropical and subtropical conditions intensive and repeated tillage will generally mineralize (reduce) organic matter at rates higher than the potential for repositioning. This results in a decreasing organic matter content of the soil and diminishing crop yields over time.

   Soil tillage results in rapid mineralization of organic matter stored in the soil, liberating nitrogen that will be available for plants. This can lead to an increase in yield for a few years. However, when soil tillage is performed under favorable conditions for mineralization of organic matter (heat, humidity, good aeration) leaving the soil under fallow (bare), valuable nitrate reserves are lost by lixiviation (washing into deeper soil layers), without crops being able to utilize them.

   Once organic matter has been consumed, more nitrogen cannot be liberated and crop yields remain low. The result is a depleted soil, where the indispensable organic matter is missing.

   The long-term influence (100 years) of soil preparation on the organic matter content in the Argentinean Pampas is described by Yamada (1999). Over this period a reduction in the organic matter content of the soil from 6.0 to 2.5 percent could be observed.

   Here it is necessary to remember that in warmer climates organic matter reduction is processed much more quickly, and reductions below 1 percent, sometimes as low as 0.2 percent can be reached in only one or two decades of intensive soil preparation.

Recent research by USDA Agricultural Research Service (ARS) shows that soil carbon is lost very fast – as carbon dioxide – within minutes after the soil is intensively tilled (plowed). After 19 days, total losses of carbon from plowed wheat fields were up to five times higher than for unplowed fields. In fact, the loss of carbon from the soil equaled the amount that had been added by the crop residue left on the field the previous season (Reikosky 2000). For the first time, scientists now know with certainty how tillage reduces the organic matter in the soil. It is the loss of carbon (as carbon dioxide – CO2) from the soil during tillage that lowers levels of organic matter (CTIC, 1996)

3. High rainfall and wind intensities prevailing in the tropics and subtropics are generally associated, under intensive and repeated tillage, with soil loss rates (due to wind or water erosion) that are higher than natural soil regeneration. This results in loss of nutrients and organic matter and in diminishing yields over time.

   Occurrence of erosion can be considered the most important factor causing soil degradation. Under the concept of sustainability, the first negative factor in relation to productivity and profitability, and the major aggressor of the environment is soil erosion. Consequently, sustainability can only be achieved if soil erosion is stopped completely.

   When agriculture is practiced on slopes in undulating topography, and rains of a certain intensity occur, soil preparation, especially with disc implements, results in bare soil, and this results in water erosion, or - in regions of heavy winds - in wind erosion.

   It is estimated that soil losses in cropland in Latin America reach 10 to 60 t/ha/year (Steiner 1996, Derpsch and others 1991). Average soil losses in the State of Paraná, Brazil, where good soil conservation is practiced, are as high as 16 t/ha/year. In Paraguay, on 4000 m^2 plots with 6 percent and 8 percent slope on high clay content Oxisols, average soil losses of 21.4 t/ha were measured in conventional soil preparation, while only 633 kg/ha of soil loss were measured in no-tillage (Venialgo 1996). For the same experiment after extreme precipitation of 186 mm on June 9 and 18, 1995, soil losses of 46.5 t/ha were measured under conventional tillage, as compared to soil losses of only 99 kg/ha under no-tillage (both plots on 8 percent slopes). This resulted in 470 times higher soil losses when soil was prepared. (Venialgo 1996)

   The high losses from agricultural soils have to be compared with consideration given to the annual rates of soil regeneration that are estimated to be not more than 250 to 500 kg/ha/year. Some scientists accept that natural soil regeneration may reach 1000 kg/ha/year. When soil losses are higher than natural soil regeneration rates, sustainable agriculture is not possible.

   Recent studies show that soil erosion is a selective process, with the most fertile soil particles taken away. Eroded soil sediments usually contain several times more nutrients than the soils they originated from (Stocking 1988).

   Research has shown that soil cover is the most important factor that influences water infiltration into the soil, thus reducing runoff and erosion (Mannering and Meyer 1963). Under conventional tillage, lower infiltration rates have been measured by comparison with no-tillage (Roth 1985), and this results in a drastic increase of erosion when the soil is tilled.

4. Under tropical and subtropical conditions, intensive and repeated tillage will generally damage the soil structure and lead to excessively high soil temperatures. This will have negative effects on root growth, soil flora, and fauna (soil biological processes) and on soil moisture resulting in diminishing yields over time.

   In conventional tillage, lower soil moisture content and higher soil temperatures as well as lower aggregate stability have been measured (Kemper and Derpsch 1981, Sidiras and Pavan 1986, Derpsch and others 1991).

   Research shows enough evidence that lower biological activity occurs when the soil is intensively tilled by comparison with a field that is not tilled. Microorganisms will die because of famine under a bare soil system because they will not find organic substances at the surface to supply them with food. In addition, the less favorable soil moisture and temperature conditions under conventional tillage have a negative effect on microorganisms of the soil. For these reasons fewer earthworms, arthropods, (acarina, collembola, insects), fewer microorganisms (rhyzobia, bacteria, actinomicetes), and also fewer fungi and micorrhyza are found under conventional tillage conditions than under no-tillage conditions (Kemper and Derpsch1981, Kronen 1984, Voss and Sidiras 1985).

5. Any agricultural or livestock production system in which important losses of nutrients occur through extraction without reposition (for example, soil exploitation) through volatilization (for example, regular burning), and/or through leaching (for example, fallow periods without crops), is not sustainable and results in poor soils and farmers.

   When high amounts of nutrients are exported from fields with harvested crops (or animals), without reposition, depletion of nutrients will occur in the medium or long term. Regular burning is another reason for nutrient depletion from fields, because nutrients are lost through volatilization. Major nutrient losses also occur from tilled fields which are left fallow without a crop in the short, medium, or long term. As no roots are present that could prevent the downward movement of nutrients, these are lost through leaching into deeper soil layers, where they are out of reach of annual crops.

What Do We Conclude From the Laws of Diminishing Yields?

First of all we conclude that plowing and soil tillage are in opposition to sustainable land use in the tropics and subtropics.

Secondly, we conclude that we have to change the traditional farming practice of tilling the soil. We need a new production system that does not show the negative consequences of tilling the soil.

Thirdly, we can conclude that conservation tillage and especially no-tillage appear to be the production systems that can replace the traditional practice in small, medium, and large-scale agriculture. Why?

There is enough scientific evidence from warmer and increasingly also from temperate areas showing: a) that tillage is not necessary to produce a crop, b) that no-tillage has positive effects on chemical, physical and biological soil properties in comparison with conventional soil preparation, improving soil fertility over time, c) that no-tillage and conservation tillage save time, labor and fuel, and show higher economic returns than conventional tillage, and d) that no-tillage is a very efficient tool for controlling erosion and therefore it is environmentally and socially desirable.

It is now generally accepted that conservation tillage systems offer numerous benefits that intensive tillage systems cannot match. These advantages have been summarized as follows (ISTRO, 1997):

1. Reduced labor requirements
2. Time savings
3. Reduced machinery wear
4. Fuel savings
5. Improved long-term productivity
6. Improved surface water quality
7. Reduced soil erosion
8. Greater soil moisture retention
9. Improved water infiltration
10. Decreased soil compaction
11. Improved soil tilth
12. More wildlife
13. Reduced release of carbon gases
14. Reduced air pollution

Adoption of No-tillage

The superiority of no-tillage over conventional tillage practices is mirrored in high rates of adoption of this new technology. No-tillage is now being practiced on more than 16 million ha in Argentina, on 21.8 million ha in Brazil, on 23.7 million ha in the USA and on approximately 90 million ha worldwide. In the MERCOSUR countries (Argentina, Brazil, Paraguay, and Uruguay) the technology has seen a 59-fold increase between 1987 and the year 2004 (from 670,000 ha to 39.65 million ha) (Derpsch and Benites 2004). This shows that farmers are satisfied with the technology, that they feel the numerous benefits of the system, and that profitability is higher than with the conventional tillage systems.

On the other hand, 86 percent of no-tillage is practiced in the Americas (North and South) and 10 percent in Australia, but only 3.6 percent is practiced on the three other continents Europe, Asia, and Africa. There is a huge potential for bringing this soil-conserving, productivity-enhancing production system to those areas where it is still not practiced.

With oil prices forcing tillage cost ever higher, and the proven benefits of no-tillage in reducing costs, erosion, greenhouse gas emissions, etc, it is becoming a worldwide imperative that this technology be practiced by small, medium, and large-scale farmers all over the world. If socioeconomic or agro-ecological reasons make the use of no-tillage difficult, other forms of conservation tillage such as minimum tillage will be the second-best choice.

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Toward a Framework for Conducting Ecoregional Threats Assessments

Jamison Ervin and Jeffrey Parrish

Abstract—*Assessing threats to biodiversity is widely recognized as a critical step in conservation planning. While there have been recent advances in understanding how to assess threats at a site level, there has been relatively little consensus on how threats can be meaningfully assessed at an ecoregional scale. Drawing from numerous threat assessment studies, this paper offers a five-step framework for understanding the scope, purpose and components of a comprehensive, ecoregional-level threat assessment. The proposed framework includes the following components: 1) identifying threats within an ecoregion; 2) assessing the impact of current threats to biodiversity; 3) assessing the impact of future threats; 4) analyzing the root causes of these threats; and 5) integrating threat-related information into conservation planning.*

Introduction

An assessment of threats to biodiversity is widely recognized as a critical component of effective conservation planning (Groves 2003, Margules and Pressey 2000); six of the ten steps in site conservation planning proposed by Poiani and others (1998) are related to some aspect of conservation threats. Despite the widespread recognition of their importance, threat assessments have not been well understood or widely implemented in most parts of the world (Groves 2003). Moreover, until only recently (Salafsky and others 2004), there have been scant studies that compare different methodologies and approaches to conducting threat assessments (Rouget and others 2003). This is particularly true for threat assessments across broad geographic areas, such as an ecoregion.

This paper is an attempt to fill that void. Based on a review of threat assessments (see table 1 for a summary of a selection of these), this paper proposes a five-step framework for conducting comprehensive ecoregional threat assessments: 1) identifying ecoregional threats; 2) assessing the impact of current threats; 3) assessing the impact of future threats; 4) analyzing and interpreting underlying causes; and 5) integrating threats data into conservation planning. Selected from an initial review of over a hundred threat-related studies, the following set is intended to be a representative sample, rather than an exhaustive catalogue. Each study included the following characteristics: they assessed actual threats (versus simply developing a conceptual model); they encompassed a broad geographic scale; and they focused on assessing threats to biodiversity. Table 1 summarizes the main elements of each of these studies.

Table 1 illustrates several points. First, many threat assessments only look at a small number of threats, rather than a full range of potential threats. Second, not all threat assessments are spatially explicit about where threats occur. Third, most indicate the impact of threats on biodiversity, although with widely ranging degrees of detail. Fourth, most include some form of future threat assessment, although the method of determining future threats varies considerably. Fifth, most did not fully assess the underlying causes of threats, although many touched upon them. Finally, in only some cases the results were explicitly used, or were expected to be used, as information to improve conservation planning and practice. The rest of this paper discusses these points more fully.

Identifying Ecoregional Threats

As highlighted in table 1, some threat assessments may consider a wide variety of threats. However, many others consider only a single threat (Rouget and others 2003). Some authors suggest that a more inclusive set of threats be considered as routine practice in conducting threat assessments. Curtin and others (2002), for example, note that the driver of rangeland ecology is far more complex than simply grazing, and therefore rangeland assessments must consider such factors as invasive species, global climate change, and fire, in addition to the intensity and distribution of grazing.

There are numerous approaches to developing a comprehensive set of threats, and every shortlist candidate has

Table 1. Summary of selected broad-scale threat assessments.

Author/s	Geographic area	Threats included	Threat distribution was spatially explicit	Assess impacts on specific biodiversity elements	Assess cumulative impacts of threats	Assess future threat	Assess underlying threat causes	Results clearly linked to conservation planning
Clarke & Harris, 2003	Arctic & Antarctic	Pollution, energy, climate change, fishing	no	yes	yes	yes	no	no
Curtin et al., 2002	Chihuahuan Borderlands. US SW and N. Mexico	Grazing, fragmentation, development, protected status	no	somewhat	yes	somewhat	yes	yes
Dirnböck et al., 2003	Juan Fernandez Archipelago, Chile	Invasive species	yes	yes	no	yes	no	yes
Kramer & Kramer, 2002	Mesoamerican Caribbean Reef	Coastal development, tourism, energy, port management, fishing	yes	yes	somewhat	yes	yes	yes
Laurance & Williamson, 2001	Amazon Basin	Forest fragmentation, El Niño drought, fire	no	no	yes	yes	yes	no
Maddock & Benn, 2000	North Zululand, South Africa	Protected status, agriculture, development	yes	yes	yes	somewhat	no	yes
Neke and du Plessis, 2004	South African grasslands	Mining, agriculture, afforestation, urban development	yes	yes	yes	somewhat	no	yes
Reyers, 2004	Limpollo Province, South Africa	Cultivation, afforestation	no	somewhat	somewhat	yes	no	yes
Rouget et al., 2003	Cape Floristic Region, South Africa	Agriculture, urbanization, invasive species	yes	yes	yes	yes	no	yes
Stoms, 2000	California	Urban development, roads, protected status	yes	yes	somewhat	yes	no	yes
Theobald, 2003	Colorado	Roads, housing	yes	yes	yes	yes	no	yes
Weber & Wolf, 2000	Maryland density, legal protection	Protected status, urban development, transportation	yes	somewhat	yes	yes	no	yes
Stoms, 2000	California	Urban development, roads, protected status	yes	yes	somewhat	yes	no	yes
Theobald, 2003	Colorado	Roads, housing density, legal protection	yes	yes	yes	yes	no	yes
Weber & Wolf, 2000	Maryland	Protected status, urban development, transportation	yes	somewhat	yes	yes	no	yes

its own proponents. Theobald's (2003) primary candidate is inadequate land use planning, while Zalba's (2004) are habitat loss and exotic invasions. Neke and du Plessis (2004) and Clarke and Harris (2003) favor global climate change, which they claim will trump all other threats in certain parts of the globe. In order to develop a logical framework for organizing threats, several authors have proposed a comprehensive taxonomy of threats. For example, Wilcove and others (1998) propose habitat destruction, alien species, over-harvest, pollution and disease as the five most important threats to biodiversity, and Dinerstein and others (2000) propose habitat conversion, habitat degradation and wildlife exploitation as an organizing framework for capturing threats. Salafsky and others (2004) propose one of the more comprehensive threat taxonomies, including habitat conversion, transportation infrastructure, abiotic resource use, consumptive and non-consumptive biological resource use, pollution, invasive species (including pests, pathogens and disease), and large scale modifications of natural processes (for example, global climate change, fire regime alteration). Each of these general threat categories would be translated into a specific threat, appropriate to the regional and biophysical context.

Using a consistent taxonomy would encourage researchers to consider all potential threats, rather than a select few. Bryant and others (1998), for example, assessed global threats to coral reefs, including coastal development, marine-based pollution, over-exploitation, inland pollution and erosion, but not coral bleaching associated with global climate change. In 1998, the same year the study was published, coral bleaching devastated 16 percent of the world's reefs (Wilkinson 2000). A comprehensive taxonomy of threats would also enable a better understanding of the extent, severity and spatial distribution of a wide range of threats by enabling cross-cutting analyses.

Many researchers characterize 'threat' as a future state, defined as a degree of vulnerability, risk or likelihood of change. Margules and Pressey (2000) define a threat as the risk of a conservation area being transformed to another land use, and Rouget and others (2003) as the likelihood of losing a portion of extant biodiversity. Numerous researchers have used this approach to assessing threats by developing suitability indices and then quantifying the likelihood of threat occurring from low to high (Maddock and Benn 2000, Stoms 2000, Rouget and others 2003).

Other researchers define threats as a transformation that has already occurred. Neke and du Plessis (2004), for example, describe threats in South Africa by quantifying the spatial extent of forestry, agriculture, grazing, mining and urban expansion. Similarly, Maddock and Benn (2000) describe threat as the degree of transformation of unprotected and untransformed land in South Africa. They acknowledge that it would be useful to calculate the degree of future transformation, but cite lack of available data as the major constraint in doing so.

Regardless of whether they look at the degree of vulnerability and risk in the future, or the degree of transformation in the past, most authors ultimately define threat as either an event, "extrinsic human and stochastic natural events" (Araújo and others 2002), or an activity, "any human activity or process that has caused, is causing or may cause the destruction, degradation and/or impairment of biodiversity" (Salafsky and others 2004).

Defining a threat at a site level can be fairly straightforward. The Nature Conservancy, for example, assesses "stresses" (processes or events with direct impacts on biodiversity, such as stream sedimentation) and "sources of stress" (the actions of entities causing the stress, such as agriculture). In this model, the relationship between a threat and its impact on a specific species is clear. However, at an ecoregional level, this relationship becomes less so. Most ecoregional threats have multiple and complex relationships with innumerable species and systems. Groves (2003) acknowledges this problem, when he states that in theory, threats should be tied to specific conservation targets, but in practice, most regional planning efforts lack the prerequisite detailed, site-based data and knowledge.

Therefore, a slightly different approach to defining threats may be needed when working at large spatial scales. One approach to large-scale threats is to assess the degree of legal protection as a surrogate for protection against many threats, particularly land use conversion (for example, Theobald 2003). However, there are several flaws with this approach. The phenomenon of 'paper parks' is widely recognized (Ervin 2003), and in some cases, legal protection can even accelerate biodiversity loss (Curtin and others 2002). While protection and management status can be a useful measure of threat, they are only weakly correlated with vulnerability (Stoms 2000), and therefore threats must be inextricably linked with their impacts on biodiversity.

Reyers (2004) notes a recent trend away from linking threats to specific species, toward linking them with higher levels of biodiversity (for example, ecosystems). Conservation International takes the opposite tack; their "Living Landscape" program links threats to a small handful of "landscape species," with the reasoning that a decline in the viability of wide-ranging species mirrors a decline in the integrity of the landscape itself (Sanderson and others 2002). Neke and du Plessis (2004) offer another alternative; their study assessed the degree of land conversion from agriculture, grazing, mining and urbanization in South Africa, and linked these with broad changes in composition, landscape structure and ecological functions.

Clearly each approach has strengths and disadvantages, and no single approach is likely to be adequate to gauge the impacts of threats on biodiversity. Therefore, a broader framework that integrates each of these approaches may be warranted, one that includes the status of coarse-filter biodiversity, a full array of threats, and the legal protection and management effectiveness of an area. In capturing both a full array of threats, as well as their multiple and diffuse impacts on biodiversity, such a framework could provide a more thorough definition of the threats to, and effective conservation of, biodiversity.

Assessing the Impacts of Current Threats

In assessing the impacts of various threats, researchers have used qualitative assessments of scope, severity and sometimes irreversibility, combined to give a score, or ranking for each threat, typically from low to very high (Poiani and others 2003, Clarke and Harris, 2003, Ervin 2003). Such qualitative assessments are simple to use, require minimal data, and are widely accepted, but are often interpreted and applied inconsistently (Todd and Burgman, 1998).

While assigning a qualitative rank to a single threat at a single site is a relatively easy, if limited, process, combining multiple threats across multiple sites within an ecoregion is far more complex. Conservation planners have generally taken two approaches: arithmetic and rule-based procedures (Salafsky and others 2004). Ervin (2003), for example, adds the rank of each threat to create a cumulative threat index, while Kramer and Kramer (2002) and Bryant and others (1998) use "rules" (for example, at least one 'high' threat results in a cumulative 'high' score, four 'low' scores equal a cumulative 'low' overall score, etc.). Both systems portray a general picture of the overall threat load of each site, but they may be misleading. Some threats may appear to have a low score individually, but in combination may have a far more pernicious effect on biodiversity. Indeed, Rouget and others (2003) argue that there is no clear understanding of how to quantitatively combine threats to arrive at a satisfactory value of threat intensity. In order to improve the utility of additive and rule-based approaches, four additional considerations are proposed below: 1) spatially-defined threatsheds; 2) target-specific analyses; 3) an assessment of synergies between threats; and 4) an integration of ecological thresholds.

The spatial configuration of threats are seldom explicit (Todd and Burgman 1998), and only recently have threat assessments begun to identify threat patterns in relation to biodiversity patterns (Rouget and others 2003). Yet spatially explicit threat assessments can be critical in understanding the impact of threats on biodiversity; they enable better predictions of the magnitude and type of biodiversity loss, better priority setting, and better conservation triage (Rouget and others 2003). Furthermore, if they capture temporal patterns (as recommended by Salafsky and others 2004), threat maps can enable better prevention and mitigation of certain threats (for example, restricting recreation during sensitive breeding times). For example, Travis (2003) argues that the distribution of forest fragmentation is at least equally as important as the extent of fragmentation in determining the impact on forest species, and Stoms (200) argues that road density indices seldom explicitly consider the spatial patterns of roads, and typically assume that all road segments have an equal effect on biodiversity.

By creating map layers of the distribution and severity of different threats (see, for example, Kramer and Kramer, 2002, Neke and du Plessis, 2004), conservation planners can identify where threats overlap spatially. When these overlays are then combined with maps of the distribution of biodiversity, the resulting analysis can be a starting point for more precisely combining the effects of multiple threats.

A second approach to combining multiple threats is to gauge the cumulative impacts of threats to a particular species or system. Travis (2003), for example, argues that different species react very differently to the same threats—specialist species with low colonization ability and poor dispersal are far more prone to extinction from global climate change than wide-ranging species, and therefore cumulative threat impacts must be assessed species by species. Similarly, Sanderson and others (2002) advocate evaluating the overall level of impact from all threats on focal landscape species. Theobald (2003) takes a slightly different approach; he evaluates the cumulative impact from roads and development by land cover type and natural communities. Whether by species or by systems, measuring the cumulative impact of different threats on specific biodiversity elements can provide an alternative approach to combining threats.

This approach may entail an additional step—a better understanding of the complex and synergistic interactions between threats. Knowledge of how different threats interact remains elusive; Dinerstein and others (2002) cite this challenge as a major handicap to conducting ecoregional threat assessments. Others, such as Clarke and Harris (2003), acknowledge that synergistic relationships exist, but decline to describe or quantify them; they simply note that the capacity of Arctic and Antarctic marine ecosystems to withstand cumulative impacts of multiple threats acting synergistically is a grave concern.

Nonetheless, some recent studies have made headway in teasing apart the complex relationships between interacting threats. Travis developed at a model that combined the impacts of global climate change and habitat loss on hypothetical species with different characteristics. He concluded that some species could survive either a certain amount of habitat loss *or* a certain rate of global climate change, but they would likely become extinct where these threats occurred in tandem. Laurance and Williamson (2001) analyzed threats from logging and El Niño drought years in the Amazon, and concluded that vulnerability to fire increased dramatically when both threats occurred. Curtin and others (2002) assessed threats to grasslands and concluded that combined grazing, invasive species and an altered fire regime often resulted in a type conversion from grassland to shrub-dominated communities, and that these conversions occurred in a dynamic, non-linear, unpredictable fashion.

Finally, a better understanding of ecological thresholds could improve threat impact assessment methods. For example, Laurance and Williamson (2001) suggests that because of feedback loops between deforestation, fragmentation, regional drying and wildfires, there are thresholds of deforestation beyond which it may become difficult or impossible to halt biodiversity loss. Ecological thresholds could be incorporated into the assignation of single or cumulative threats into a particular category (for example, a "low" score equals well below a threshold, and a "very high" score equals past a threshold, etc.).

Given the uneven distribution of threats and their range of severity across a landscape (Araújo and others 2002), ecoregional assessments should strive to capture this distribution, rather than simply seek an average threat ranking across an entire area. One way to do this is to develop threshold-based categories for each threat. For example, a threshold for fragmentation could include six categories (highly fragmented, moderately fragmented, somewhat fragmented, somewhat intact, mostly intact, fully intact), based on common fragmentation indices. Numerous authors have proposed similar types of threat categorization (Dinerstein and others 2000, Reyers 2004). Such categories, which would ideally be quantifiable, repeatable and clearly linked to biodiversity viability, would enable the consistent interpretation of threat-related data over time, and would enable threats to be compared from one region to the next.

Assessing Future Threats

Assessing the likelihood of multiple threats, and predicting the impact they will have on species and systems will likely pose major challenges. Travis (2003) claims that predicting the impact of global climate change and habitat loss is one of the most vexing challenges facing biologists. Yet an assessment of the degree and impact of future changes is critical to effective conservation planning; not only are current threats poor indicators of future threats (Groves 2003), but they do not provide the full information needed to develop strategies, prioritize conservation areas, and sequence conservation actions. Furthermore, Rouget and others (2003) argue that conservation plans that do not adequately consider future threats cannot fully plan for the persistence of biodiversity with any degree of confidence.

There are three closely related approaches to assessing future threats: 1) assessing the likelihood, probability and risk of a threat occurring and/or of a species becoming extinct; 2) developing predictive models for the likely spatial configuration of threats; and 3) developing multiple threat scenarios.

Researchers have taken a variety of approaches in assessing future threats. Some, (Clarke and Harris 2003), simply rank future threats from most likely to have a high impact on biodiversity to least likely. Some (Kramer and Kramer 2002, Ervin 2003) include a qualitative assessment of the future likelihood as a variable in analyzing each threat. And some (Weber and Wolf 2000, Neke and du Plessis 2004) assess future threat by combining a qualitative ranking of threat with the impact of that threat on biodiversity.

Statistical, predictive modeling is another approach that can complement these qualitative, rule-based threat analyses, as the two approaches have shown a high spatial correlation, and expert judgment may catch nuances that a statistical model may miss, particularly at small scales (Rouget and others 2003). Such models may combine recent and/or historical data, social factors, biophysical features, and species life histories. Dirnböck and others (2003), for example, used invasive species data from the 1830s onward, and combined these data with geographic features, to develop a model of the rate and distribution of future invasions. Such information can be critically important, particularly with a threat such as invasive species, where early detection and prevention are paramount (Zalba 2004). Rouget and others (2003) complicate the equation, however, by calling for models that can incorporate soil disturbance, agriculture, and changing fire and nutrient regimes—all factors that can dramatically increase the spread of invasive species. Researchers have also developed models that incorporate socio-economic factors, patterns of existing land ownership, census data, and environmental conditions, to develop predictive models of the rate and distribution of rural sprawl (Stoms 2000, Theobald 2003).

There are limitations to the accuracy and therefore utility of predictive models. Many do not account for fine-scale data (for example, town zoning ordinances, detailed environmental conditions), or such data may simply not exist (Rouget and others 2003, Zalba, 2004, Clarke and Harris, 2003). Perhaps more importantly, a single model typically shows only one potential outcome, whereas threats interact in a highly dynamic and non-linear fashion, and may have multiple potential outcomes. Theobald (2003), for example, discusses how a simple model of the threat from housing development could have complex interactions with the threat from altered fire regime; at a certain housing density, fire restoration becomes impractical or impossible.

The creation of multiple models and scenarios may be one way to show the various relationships between future threats, and may provide more insight than simple models (Groves 2003). Reyers (2004), for example, looks at future land use scenarios in South Africa, incorporating more than just land suitability, but also a range of potential scenarios based on water availability, laws governing water use, and drought resistant crops. Multiple threat models and scenarios, particularly those that show the potential impacts of land use laws, ordinances and policies, can be a powerful conservation planning tool by enabling policy makers to see the consequences of their actions.

Analyzing and Interpreting Threats

Relatively few studies have attempted to quantify or even identify the drivers of threat (Rouget and others 2003). Furthermore, these drivers, which include the socio-economic forces and circumstances that trigger threats and resulting loss of biodiversity, are generally not well understood, and where they are analyzed, are mostly limited to a few local factors (Stedman-Edwards 2000). Conservation organizations are leading the development of tools to systematically assess these drivers, including The Nature Conservancy, which conducts situation analyses as part of its site conservation planning process (Poiani and others 2003), and the World Wildlife Fund, which conducts root causes analyses as part of its policy development strategy (Stedman-Edwards 2000).

The primary tool that both organizations use for conducting these analyses is a conceptual model that shows the complex relationships, multi-directional linkages and dynamic interactions between social, economic and ecological dimensions. Understanding these complexities is important, since the causal linkages rarely provide precise predictive models (Stedman-Edwards 2000). Kramer and Kramer's (2002) study of threats in the Mesoamerican Caribbean Reef illustrates one example of a root causes analysis. The threats of over-fishing, eutrophication and habitat loss from agricultural and urban expansion are caused by a web of over a dozen root causes, ranging from human population growth and migration to poor law enforcement and inadequate legal jurisdiction over resources. Stedman-Edwards (2000) propose that the majority of root causes fall into one of five categories: 1) demographic change; 2) inequality and poverty; 3) public policies, markets and politics; 4) macroeconomic structures and policies; and 5) social change and development biases.

Incorporating Threats Into Conservation Planning

As discussed earlier, threat assessments are an integral and critical component of both site conservation planning and broad-scale, systematic conservation planning processes. At an ecoregional level, threat assessments can be integrated into conservation planning processes and used for a variety of purposes, including: 1) to develop ecoregion-wide strategies; 2) to set geographic priorities; 3) to sequence and prioritize conservation areas and strategies; and 4) to measure changes in threat status over time. An assessment of existing threats can be used to identify where and how severely multiple threats occur across the landscape, and help in formulating appropriate ecoregion-wide strategies, such as land protection, management strategies, restoration and monitoring (Groves 2003, Poiani and others 2003).

A number of studies have integrated threats into geographic priority-setting processes (Theobald 2003, Reyers 2004). These studies primarily focus on a measure of future threat, usually expressed in terms of vulnerability, as well as a measure of conservation value, expressed in terms of conservation value, focusing on rarity, endemism, species richness, protected status and/or ecological integrity (Stoms 2000, Groves 2003). The resulting information enables planners to prioritize areas most at risk. Maddock and Benn (2000), for example, describes how species, vegetation types, ecological processes, legal protection and threats from land transformation were combined to identify “conservation worthy areas” in Zululand, South Africa.

A third and related use of threat assessments is to determine the timing of conservation actions; an assessment of urgency can help determine the relative sequence of geographic priorities and conservation actions (Araújo and others 2002). Groves (2003) describes this as a process of conservation triage, asserting that threat assessments are vital in identifying which areas will clearly benefit from immediate conservation actions, which ones are likely to persist if nothing is done, and which areas could, with sustained efforts, be feasibly restored over the long term. While such sequencing and prioritization efforts help to ensure efficient use of resources (Theobald 2003), this process also requires an understanding of the potential tradeoffs between restoring land versus preventing threats, high and low cost, effort and feasibility, and between differing conservation values (for example, high endemism versus high species richness).

Threat assessments can also be used to measure threat status over time. A measure of threat status can be taken at any given time by capturing the distribution and severity of current and future threats. Although few studies have done so, tracking the status of threats over time can be useful in several ways. Governments and conservation organizations can use threat status measures to assess the broad effectiveness of their threat abatement actions. Conservation planners can use threat status measures to reassess their programmatic and geographic priorities, as the conservation landscape shifts and new threats emerge. Conservation advocates can use threat status measures to communicate complex information about biodiversity in clear and compelling ways.

Conclusion

Many threat assessments cover some or most of the elements proposed in this paper; few cover all of them. A comprehensive threat assessment framework, such as the one proposed in table 2, could serve several purposes. It could enable conservation planners to be more explicit about which steps are not included in their assessments and why. It could serve to identify information and data

Table 2. Elements of a comprehensive, broad-scale threat assessment.

Identify threats	Assess impact of threats	Assess future threats	Analyze and interpret threats	Incorporate threats into conservation planning
Consider the broad array of potential threats, rather than a small subset of threats	Be spatially explicit about the distribution of each threat, creating multiple threat layers	Assess the likelihood of existing threats to continue and new threats to occur	Develop conceptual models that incorporate both socio-economic drivers and biological factors	Incorporate threats into broad-scale strategy development
The following is proposed as a minimum set of threats to consider:	Be explicit about how each threat affects specific elements of biodiversity	Assess the risk of biodiversity elements to threats, using suitability indices and statistical predictors	Explicitly show multi-directional linkages of relationships between drivers and threats	Use threats to determine geographic priorities
-Habitat conversion -Transportation infrastructure -Energy development -Use and management of biological resources -Tourism and other non-consumptive uses -Invasive species, pests and pathogens -Pollution -Global climate-related events and processe	Assess the synergies and interrelationships between different threats and their impacts on species and systems	Develop predictive spatial models for patterns of threat development in the future	Explicitly link causal factors and drivers of threats to conservation strategies and actions	Use threat information to sequence and prioritize actions and geographies
	Incorporate ecological thresholds into impact assessments	Develop multiple threat predictions that incorporate different scenarios and pathways, including socio-economic factors		Track threat status over time to measure change and enable adaptive management

gaps. Perhaps most importantly, it could encourage a more systematic and thorough approach to threat assessments, one that considers the multiple social, economic and ecological factors and the complex spatial and temporal dimensions of threats to biodiversity.

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Monitoring Bird Populations in Relation to Fuel Loads and Fuel Treatments in Riparian Woodlands with Tamarisk and Russian Olive Understories

Deborah M. Finch, Project Leader; June Galloway, Wildlife Biologist; and David Hawksworth, Biological Technician, USDA Forest Service, Rocky Mountain Research Station, Albuquerque, NM

Abstract—*Over the past decade, wild fire events in riparian bosque (forested) areas along the Middle Rio Grande between Elephant Butte and Albuquerque have increased dramatically owing to flood suppression and accumulation of dead wood and exotic Tamarisk and Russian olive. This problem culminated in a large wild fire in July 1993 that resulted in the evacuation of hundreds of City of Albuquerque residents and captured the national media's attention. Prior to this event, the Rocky Mountain Research Station, in collaboration with the Middle Rio Grande Conservancy District, City of Albuquerque Open Space, and Bosque del Apache National Wildlife Refuge, designed a study in 1999 to compare effectiveness of three methods of fuel removal for reducing fire risk, preventing re-occurrence of exotics, and restoring native habitats, plants and animals. A goal of managers is to preserve cottonwoods while reducing or eliminating Tamarisk and Russian olive stems, so study sites were selected that had cottonwood overstories and Tamarisk and olive understories. As part of this study, the population and nesting responses of breeding bird species have been evaluated prior to and following fuel removal treatments. Our talk reports on 1) the numbers and kinds of bird species inhabiting bosque habitats with cottonwood overstories and varying amounts of Tamarisk and Russian olive, 2) nest substrate use and nesting success of selected bird species prior to treatment, and 3) preliminary results after the first year of mechanical treatments. In addition, we predict short-term and long-term responses of birds and plant communities following treatments.*

Introduction

Along the Middle Rio Grande in New Mexico, between Cochiti Dam and Elephant Butte Reservoir, exotic woody plants have proliferated since their original introductions, altering the structure and composition of riparian plant communities and greatly increasing the frequency and severity of wildfire. Dead and downed wood and exotic salt cedar (*Tamarix ramosissima*) and Russian olive (*Elaeagnus angustifolia*) are fuels that lead to high fire risk in the riparian woodland community of the Middle Rio Grande, referred to locally as the "bosque." Salt cedar plants possess many stems and have high rates of stem mortality, resulting in accumulations of dense, dry dead branches (Hart, 2002). When dense salt cedar stands burn, the fires are often intense and fast moving. Salt cedar's high flammability places native bosque flora and fauna at increased risk of mortality by fire. Native tree species inhabiting the middle Rio Grande, such as the Rio Grande cottonwood (*Populus deltoides* ssp. *wislizeni*) and Goodding's Willow (*Salix gooddingii*) are not fire-adapted, cannot resist fire damage and do not respond with regenerative resilience to fires (Busch, 1995).

Land managers are in need of effective methods for reducing fuel loads and controlling exotic woody plants that minimize negative impacts on native plants, wildlife, and soils. To assist in meeting this challenge, the Albuquerque Laboratory of the USDA Forest Service's Rocky Mountain Research Station agreed to monitor responses of various ecosystem components to fuel removal before and after application of treatments. Our interagency, collaborative project was initiated in 1999, with pre-treatment sampling occurring from 2000-2002. Treatments were initiated in 2003 and will continue through 2004. The study is designed to evaluate the effectiveness of three fuel reduction treatments and their effects on wildlife, soils, and hydrology, with the ultimate goal of providing land managers with information for designing and implementing future treatments. A

Memorandum of Understanding signed in 1999 documents participation and contributions of several partners other than the Rocky Mountain Research Station, including Bosque del Apache National Wildlife Refuge, Middle Rio Grande Conservancy District (MRGCD), City of Albuquerque Open Space (COA), Bureau of Land Management (BLM), New Mexico Department of Environment (NMDE), and NRCS Plant Materials Center (Los Lunas, NM).

Our study team is monitoring and evaluating the responses of groundwater, soils, vegetation, bird, bat, reptile, and amphibian populations to three fuel reduction treatments at 12 research sites. In this paper, we report on the status of treatments and describe some of the pre-treatment and early treatment findings as they pertain to the avifaunal component of the study.

Methods

Study Design

Site locations range from the southern portion of Albuquerque city limits to the Bosque del Apache National Wildlife Refuge (USFWS) 20 miles south of Socorro. We are using a randomized block statistical design with four sites (a control and three treatments) identified in each of three blocks. Randomized block designs are appropriate when a population of experimental units has recognizable structure, in this case riparian cottonwood galleries, and one can utilize that structure in assigning treatments (Williams et al., 2001). The three blocks are labeled North, Middle, and South. Sites are labeled from one to four in each block, for example, South 1 (SO1), South 2 (SO2), South 3 (SO3), and South 4 (SO4). Two exceptions, Middle 7, MO7 and North 7, NO7, are numbered in accordance with a broader study. Sites extend 129 km from southern edge of the city of Albuquerque south to the Bosque del Apache National Wildlife Refuge.

The Rocky Mountain Research Station worked with the several land managers; the MRGCD (Middle Rio Grande Conservancy District), COA (City of Albuquerque), USFWS (U.S. Fish and Wildlife Service), and the NMSP (New Mexico State Parks), to determine which sites along the river would be suitable research areas. The following criteria were used for research site selection: 1) sites had visibly-high fuel loads as identified by landowners and NM Environment Department (Wicklund and Najmi 1998); 2) the site had relatively homogenous vegetation, at least 20 hectares in size; 3) sites had a cottonwood overstory and an understory with exotic woody plants; 4) sites were accessible by road; 5) access and block design treatments were permitted by landowner; and 6) sites were relatively undisturbed by grazing, vehicles, and other uses. Each study site has an average size (n = 12 sites) of 20.4 hectares.

Each management agency is responsible for carrying out treatments on the land that they manage in accordance with the MOU. Treatment types were designed to decrease the risk of catastrophic fire by greatly reducing fuel levels. The primary fuels are comprised of dead and down wood and exotic woody plants. Ideally, fuels would be reduced at the selected sites to a range of 5-30 tons per acre, with an operational goal of 15 tons/acre. The following exotic / fuel removal treatments are being implemented in this study: 1) mechanical removal of dead and downed wood and exotic shrubs/trees followed by the application of herbicide (Garlan 3 and 4) to cut stumps, 2) partial mechanical removal of dead, down, and exotics followed by spot herbicide and light, prescribed fire, 3) mechanical removal of dead, downed, and exotics followed by spot herbicide and revegetation with native plants, and 4) control, no treatment. The research team and all cooperators agreed upon treatment types and goals prior to site selection. Treatment type at each site was selected using a random numbers table. Treatments by site are listed in our annual reports (Finch and others 2003, 2004). More information about prescriptions can be obtained in the Environmental Assessments on file with Bosque del Apache National Wildlife Refuge and Middle Rio Grande Conservancy District.

Vegetative Surveys

Vegetation surveys were analyzed at three levels: landscape-block, site-patch, and local-plot. Ecological classifications followed the scheme described in "Handbook of Wetland Vegetation Communities of New Mexico" (Muldavin et. al. 2000). More details about our vegetation data collection methods are described in Finch and others (2003).

At each site, two vegetation plot centers were established approximately 25 meters in each direction from each bird point count station using the diagonal azimuth (i.e., NW). Individual trees were counted by using the appropriate prism. A tree was counted if the displacement of the prism still touched the tree at approximately breast height. The selected tree was then identified to species, categorized as living or dead, and measured for DBH. In cases where a tree had more than one stem displaced by the prism, only the largest stem was counted. These measurements were entered into equations acquired from the Region 3 Stand Exam Program. This allowed for calculation of basal area, trees per acre and average diameter for each tree species. To measure crown closure, a densiometer reading was taken facing north and south by counting the number of closed points in each direction.

The two readings were then averaged and converted to a percentage to characterize canopy cover at the point. The average for each point was then used to determine canopy cover for the entire plot.

Four-meter radius circular plots were established at each bird count station to characterize understory and ground cover on each study site (James and Shugart 1970). Each plot area was 50.3 square meters or approximately 1/200 of a hectare. All native and exotic trees and shrubs were identified, counted, and measured for DBH. On all plots, woody plants with a DBH > 5 cm were characterized as alive or dead, identified to species, and measured for DBH. Only the largest stem was counted when a plant had more than one stem. All understory plants were identified and counted.

Fuel Inventory

The fuels targeted for treatment are grouped into dead and down, and live exotic trees. Fifty-foot transects were established at the center of each vegetation plot. Two transects were established at each bird point count station. Fuel data collection was based on sampling procedures for planar intercepts. Fuel pieces were counted by size class as they intercepted the transect line, following the procedure established in the attached document. Fuel pieces greater than three inches (diameter) were identified to species and measured to the nearest half-inch. The duff depth was measured twice on each transect. Fuel depth was measured three times along each transect. Resulting data were entered into the "Fuel Management Analyst Suite" (Fuels Management Analyst 2002). The Planar Intercept program was used to produce fuel load per type (tons/acre) and average duff and fuel bed depth (in.). With the exception of nest-vegetation data, pre-treatment vegetation and fuel load data were collected during the 2000-01 field seasons.

Exotic stems were counted at one fixed area plot per bird point station. Each exotic plant was identified to species and measured for DBH. Height and crown ratios for each species were calculated. The Crown Mass Inventory portion of the Fuel Management Analyst Suite was used to determine fuel loading by type (tons/acre).

Breeding Bird Point Counts

At each study site, we established generally eight point count stations along a north to south gradient based on global positioning system (GPS) coordinates. Only two sites do not have the standard number of point count stations: North 3 (7) and South 2 (5). All stations were positioned 150 meters apart and the majority is 75 meters from boundary edges. There is one point count station per 2.5 hectares.

Generally, our point count methods follow Bibby and others (1992). All points were sampled an average of five times per season, with each transect surveyed in a north-south direction, alternating direction each session. A round of counts for all sites was completed before beginning a new session. Point counts were performed every other week during each breeding season (05 May to 15 August, approximately). During each count, the observer at each point recorded all birds seen or heard for 8 minutes. Detection mode (heard, seen), sex, relative age of bird, and distance from point (m) were also recorded. Common and scientific names were based on the A.O.U Check List of North American Birds (American Ornithologists' Union, 1998) and its supplements. Species identification and distance estimations were checked across observers by informal testing throughout the sampling season. Each observer was trained to estimate and record distances to each bird. Each transect was surveyed by 3-5 different individuals over the course of each of the three pretreatment seasons to standardize observer bias (Verner, 1985). On mornings with low wind (<15 km/hr) and no precipitation, surveys were conducted within the first four hours after sunrise with the first count beginning within half an hour of sunrise. Analyses of wildlife abundance and possible responses to fuel removal will be evaluated after treatments.

Nest Monitoring

Each research site was searched for active nests on a regular and consistent basis from May through August each study year. At each nest, observers recorded a nest identification number, species identification, GPS location, directions to the nest (geographical and microscale), and a check of nest contents. Nest checks were repeated until young fledged (recorded as "success") or the nesting attempt failed ("failure") or ended with an undetermined fate ("unknown"). During nest checks, observers recorded monitoring dates, nesting stage, nest contents, and detailed notes about adult behavior, and evidence of cowbird parasitism, predation, and fledging. After the nesting season ended, additional measurements such as nest height, location of nest in plant, nest material, nest tree size and tree condition were collected at each nest site.

Results

Project Status

Data collection for this project began in the summer of 2000. This paper reports on project status through March 2004. Three complete years (200, 2001, and 2002) of pre-treatment bird data were collected. Mechanical removal and herbicide phases of treatments were implemented at 5 sites (NO2, NO4, SO2, SO3, and SO4) during the fall and winter of 2002-2003. Remaining sites other than controls are scheduled to be treated in the fall and winter of 2003-2004. Only one season of "post-treatment" data at five partially-treated sites has been collected up to the time of the writing of this paper. Because treatments have not been fully implemented and post-treatment sampling remains to be completed, only limited analyses of treatment effects can be reported.

Overstory Vegetation

The dominant species at all sites was Rio Grande Cottonwood (*Populus deltoids* ssp. *wislizeni*). Native trees such as Goodding's Willow (*Salix gooddingii*) and Box Elder (*Acer negundo*) were also important components of the overstory in the North and Middle blocks. Sites in the North block had higher canopy closures than those in other blocks. In the North block, the exotic trees, Siberian Elm (*Ulmus pumila*), Honey Locust (*Gleditsia triacanthos*) and White Mulberry (*Morus alba*), are present in the overstory as well as in the understory. Average canopy height for larger trees in the North block was approximately 19 m, and average DBH (diameter-at-breast-height) was 50 cm. Other sites and blocks had more trees per hectare, and trees were younger and/or stunted trees, averaging 12-15 m tall and 20-35 cm in diameter. Mean canopy closure decreased from North to South blocks of sites, ranging from 75.5 percent (+29.9 percent) at South 3 to 96.9 percent (+2.25) at North 2. Variation in canopy closure at South sites was much higher than North sites, as reflected by standard deviations that were about 5-7 times larger at South sites than North sites. A more comprehensive description of vegetation measurement results is given in Finch and others (2003).

Understory Vegetation

The understory layer at all study sites was dominated by exotic trees, the majority of which were Russian Olive and Salt Cedar. Exotic trees at North block sites were generally larger in size than those observed in other research blocks. The number of Russian Olive trees per site increased from North to South blocks, whereas the reverse was generally true for Salt Cedar. Also, the native New Mexico Olive (*Forestiera pubescens*), Seepwillow (*Baccharis salicifolia*) and native Pale Wolfberry (*Lycium pallidum*) were much more prevalent in the South block. The two native willows, Goodding's (*Salix gooddingii*) and Coyote (*Salix exigua*), were more abundant in the Middle block. Rio Grande Seepwillow (*Baccharis salicina*) and Golden Current (*Ribes aureum*) were most prevalent in the North block.

Fuel Loads

Fuel loads across all 12 study sites were comprised of exotic plants and dead and down wood. Total fuel loads prior to treatment varied from a low of 15.3 tons/acre at the South 2 site to a high of 51.0 tons/acre at the North 3 site. The North block of sites had an average fuel load of 42.1 tons/acre, the Middle block of sites had an average of 28.04 tons/acre, and the South sites had 32.1 tons/acre. The high fuel loads in the North sites are associated with high numbers of exotic trees as well as high amounts of dead and down (especially in the small size class). The average site contribution of dead and down in the 0.1-2.9" size class was 8.1 tons/acre/site, compared to 4.37 tons/acre contributed by the 3" size class. Exotic stems contributed an average of 21.6 tons/acre/site, which is about twice as much as the contribution by dead and down wood.

Breeding Bird Counts

Over 100 bird species have been detected across all study sites over the duration of the study. Bird count information is provided by species and year (2000-2003) in our annual reports, available by request. Table 1 gives bird detections/point averaged by site and year for the 20 most common species observed in the pre-treatment phase (2000-2002) and during the first year of the treatment period (2003). At this time, it is premature to evaluate statistically bird population responses to treatments because treatments are still in progress, and variations in bird populations among years and sites must be examined and factored out. We are simply reporting average detection numbers to illustrate the kinds of data we have collected during the pre-treatment phase and will continue to collect during and following treatments to determine treatment effects.

The most abundant species using our study sites during all sampled years was the Black-chinned Hummingbird (*Archilochus alexandri*) with detections in the pre-treatment phase ranging from an average low of 1.80 birds/point at our South 4 site to an average high of 27.99 birds/point at North 3 (NO3). Hummingbird detections in 2003 appeared slightly higher on all sites than site detections averaged across the pre-treatment phase. Annual variation in hummingbird numbers may be an important factor in explaining variation in bird numbers. Site to site variation in hummingbird numbers is also clearly evident in the pre-treatment phase. In particular, hummingbirds were most frequently detected at our northern sites and least frequently detected at our southern sites, suggesting

Table 1. Mean detections/count/site of common breeding bird species at 12 sites in the pre-treatment (a = 2000 – 2002 averaged by year) and treatment (b = 2003) phases of the middle Rio Grande fuel removal study.*

Research Site	NO1		NO2*		NO3		NO4*		MI1		MI2		MI3		MI4/7		SO1		SO2*		SO3*		SO4*	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Cooper's Hawk (*Accipiter cooperii*)	2.66	0.63	1.89	1.56	0.63	0.71	1.25	0.94	2.86	1.56	0.66	1.33	2.55	0.00	1.91	0.52	0.55	0.63	1.31	0.42	0.39	0.31	0.08	0.00
American Kestrel (*Falco sparverius*)	0.31	0.63	0.08	0.00	0.18	0.00	0.31	1.88	0.00	0.00	0.33	0.00	0.49	2.19	0.52	1.04	0.08	0.31	2.02	3.75	0.00	0.94	0.70	0.96
Mourning Dove (*Zenaida macroura*)	3.36	5.31	4.19	3.75	5.71	7.14	8.20	11.88	2.95	1.56	9.62	10.90	9.38	11.25	7.38	13.54	11.56	11.25	12.62	13.33	9.06	12.50	12.42	21.79
Yellow-billed Cuckoo (*Coccyzus americanus*)	0.08	0.00	0.49	0.00	0.18	0.00	0.08	0.00	0.09	0.00	0.00	0.27	0.16	0.00	0.43	0.26	0.31	0.00	0.36	1.67	1.88	2.19	1.09	0.64
Black-chinned Hummingbird (*Archilochus alexandri*)	23.05	32.81	26.97	27.19	27.99	34.29	24.45	33.75	24.55	25.94	26.81	31.65	16.94	16.25	18.32	30.73	10.63	10.31	11.31	11.67	6.41	5.31	1.80	1.28
Downy Woodpecker (*Picoides pubescens*)	3.05	2.81	1.32	1.56	1.09	1.43	3.20	2.19	2.59	0.63	2.63	1.60	1.48	1.56	1.04	0.26	1.25	1.56	0.71	1.67	0.94	0.63	0.78	1.92
Northern Flicker (*Colaptes auratus*)	2.11	2.19	3.04	3.44	5.34	2.14	1.48	2.81	2.50	0.63	3.70	0.00	3.70	3.44	2.69	4.43	1.56	1.56	5.71	3.33	0.78	1.25	4.45	0.96
Western Wood-Pewee (*Contopus sordidulus*)	1.95	0.63	0.99	3.75	7.70	5.36	5.86	13.44	1.07	0.63	2.63	2.66	4.36	4.06	1.39	2.60	8.28	5.00	4.05	4.17	1.48	2.50	2.66	4.17
Ash-throated Flycatcher (*Myiarchus cinerascens*)	5.08	10.94	3.62	7.50	3.89	5.36	4.61	5.94	5.00	7.81	17.60	17.02	6.41	6.56	7.03	15.10	16.33	15.94	11.55	6.25	8.91	15.63	17.81	19.87
Black-capped Chickadee (*Poecile atricapillus*)	6.41	8.75	4.19	3.13	5.43	8.57	2.81	1.25	7.59	9.69	8.14	9.84	2.80	2.19	2.34	7.81	1.09	3.13	0.00	0.00	0.08	0.63	0.00	0.00
White-breasted Nuthatch (*Sitta carolinensis*)	5.63	6.56	4.93	11.56	4.17	5.71	5.78	10.00	3.39	2.50	4.85	5.05	3.13	2.19	1.13	8.59	1.72	2.81	3.33	2.92	0.55	0.31	0.63	2.24
Bewick's Wren (*Thryomanes bewickii*)	8.75	12.19	10.94	7.81	9.33	11.43	13.13	12.81	5.00	11.25	5.35	7.71	4.52	13.44	3.73	13.28	5.23	14.06	11.67	14.58	8.05	8.44	19.45	22.76
Phainopepla (Phainopepla nitens)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.60	15.83	0.23	1.25	0.08	0.96
Yellow-breasted Chat (*Icteria virens*)	7.11	8.44	8.55	11.56	6.07	4.29	3.98	5.94	5.98	3.75	5.35	1.60	9.79	9.06	5.82	1.82	9.14	10.31	21.31	32.08	11.56	8.44	9.61	5.13
Summer Tanager (*Piranga rubra*)	4.14	8.75	4.61	4.38	5.16	9.64	6.33	11.56	5.36	3.13	6.25	5.85	4.19	5.94	6.34	5.47	6.33	8.13	8.81	6.67	6.88	7.50	8.67	10.26
Spotted Towhee (*Pipilo maculatus*)	10.86	12.81	18.09	14.69	16.21	20.71	17.19	12.19	13.39	15.31	17.11	12.50	11.68	11.56	16.06	16.41	14.45	10.63	21.79	18.75	13.67	5.00	13.67	12.82
Black-headed Grosbeak (*Pheucticus melanocephalus*)	10.94	15.63	16.28	18.13	15.13	19.64	20.31	14.69	18.84	7.50	14.64	11.44	12.42	9.06	13.54	18.75	20.47	15.94	10.60	15.83	9.45	8.44	6.25	2.56
Blue Grosbeak (*Passerina caerulea*)	5.70	4.38	4.03	2.81	4.44	4.29	2.81	4.06	4.02	6.25	6.00	3.72	7.73	6.25	9.46	2.08	11.88	12.50	10.48	12.50	7.81	9.38	5.47	3.21
Brown-headed Cowbird (*Molothrus ater*)	4.14	2.81	4.28	11.56	5.07	8.57	6.95	11.88	6.43	4.38	10.36	10.37	7.48	5.94	9.98	2.08	16.72	12.81	12.62	14.17	9.61	7.19	15.23	10.90
Lesser Goldfinch (*Carduelis psaltria*)	1.25	0.00	0.58	1.25	2.63	2.86	1.72	4.38	0.63	1.56	1.64	2.39	3.54	6.56	1.82	3.65	1.02	2.81	0.95	3.75	4.06	4.69	2.03	0.00

*shaded columns indicate sites treated between 2000-2003, and unshaded indicate untreated sites.

that factors that typically vary over space (for example, habitat suitability, air temperature) may explain variation in hummingbird numbers among study sites.

Spotted Towhees (*Pipilo maculatus*), Black-headed Grosbeaks (*Pheucticus melanocephalus*), and Bewick's Wrens (*Thryomanes bewickii*) were the next most commonly recorded species. Like the Black-chinned Hummingbird, most species showed site-to-site variation in numbers of detections during the pre-treatment phase (table 1). In particular, detection rates for Black-capped Chickadees and Black-headed Grosbeaks generally decreased from north to south sites whereas detection rates for Mourning Dove, Ash-throated Flycatcher, Yellow-breasted Chat, Phainopepla, and Brown-headed Cowbird were the reverse. Our annual reports demonstrate that annual variations in detections of many species were also noteworthy.

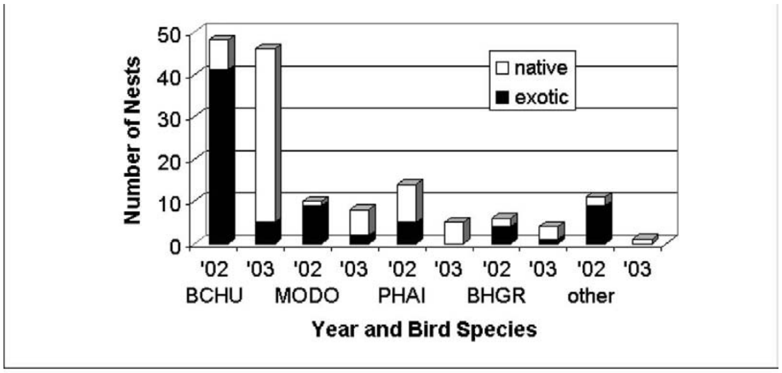
Bird Nests

A total of 580 nests, representing 33 species, were located on our 12 study sites during the pre-treatment phase (2000-2002). Nest fates, categorized as "success" or "failure," were determined for the most common riparian bird species (509 nests). We found more nests of Black-chinned Hummingbirds (253) than of any other species (table 2). This species had an overall nesting success rate of approximately 67.35 percent. Exotic trees (Russian olive, in particular) were used more often as nest substrates than native plants. Assessment of 2000-2001 data indicated that Black-chinned Hummingbird nesting success was not significantly related to use of exotic versus native plant substrates (chi-square, $p > 0.05$). Further monitoring will continue over the next several years.

Raptors, including as Cooper's Hawks (*Accipiter cooperii*) and American Kestrels (*Falco sparverius*), and cavity nesters displayed relatively high nesting success rates compared to the rates for cup-nesting species in the pre-treatment phase (table 2). In contrast, the Blue Grosbeak (*Passerina caerulea*), which nested more frequently in understory exotics than in native plants, appeared to have a fairly high rate of nest failure (70 percent) during the pre-treatment phase. Given that numbers of both Blue Grosbeaks and Brown-headed Cowbirds (*Molothrus ater*) varied together at some of the same sites, the high rate of Blue Grosbeak nest failure might be in part related to brood parasitism by cowbirds. How birds such as these respond to the removal of their preferred nesting plants will be one of the questions we will address by collecting and analyzing post-treatment data.

Table 2. Numbers of successful and failed nests by nest substrate (exotic or native plant) of common bird species during the pre-treatment phase (2000-2002) of the middle Rio Grande fuel model study.

Species	Native Plants					Exotic Plants				
Cup Nesters	Success	Failed	Unknown	Total	% Success	Success	Failed	Unknown	Total	% Success
Black-chinned Hummingbird	29	20	24	73	59.18	99	48	33	180	67.35
Phainopepla	6	6	9	21	50.00	4	2		6	66.67
Summer Tanager	3	4	5	12	42.86				0	
Black-headed Grosbeak	1	1	7	9	50.00	6	3	5	14	66.67
Blue Grosbeak	1			1	100.00	3	7	6	16	30.00
Totals	40	31	45	116	56.34	112	60	44	216	65.12
	Native Plants					Exotic Plants				
Cavity Nesters	Success	Failed	Unknown	Total	% Success	Success	Failed	Unknown	Total	% Success
American Kestrel	2		1	3	100.00				0	
Downy Woodpecker	18		10	28	100.00				0	
Northern Flicker		1	9	10	0.00				0	
Ash-throated Flycatcher	10		18	28	100.00				0	
Bewick's Wren	10	1	10	21	90.91	2			2	100.00
Totals	40	2	48	90	95.24	2	0	0	2	100.00
	Native Plants					Exotic Plants				
Stick Nesters	Success	Failed	Unknown	Total	% Success	Success	Failed	Unknown	Total	% Success
Cooper's Hawk	20		2	22	100.00				0	
Swainson's Hawk	6		1	7	100.00				0	
Mourning Dove	3	13	3	19	18.75	6	20	11	37	23.08
Totals	29	13	6	48	69.05	6	20	11	37	23.08



Legend:

BCHU = Black-chinned Hummingbird
MODO = Mourning Dove
BHGR = Black-headed Grosbeak
PHAI = Phainopepla
other = Northern Mockingbird, Yellow-breasted Chat, Blue Grosbeak, Lesser Goldfinch

native = Rio Grande Cottonwood, New Mexico Olive, Goodding's Willow, Screwbean Mesquite
exotic = Russian Olive, Salt Cedar, Tree of Heaven, Siberian Elm

Figure 1. Numbers of nests of common bird species at treated sites combined found in exotic and native plants in 2002, a pre-treatment year, and 2003, the first year of post-mechanical fuel removal.

Nest searches were conducted in the 2003 field season. This was a year when mechanical treatments were implemented at several sites. A total of 328 nests were found in 2003, the largest number recorded in any year of the Fuels Reduction study. Interestingly, of all sites surveyed, two partially-treated sites, North 4 (50) and South 2 (42), had the highest number of nests. Mechanical removal of exotics had been completed on both sites prior to collection of bird count and nest data. In the previous year, both sites were within the top three for most nests found and monitored per site. Thus, both North 4 and South 2 retained a high proportion of nesting birds in the first sampling season following mechanical removal of exotics and accompanying site disturbance.

Black-chinned Hummingbird nests accounted for almost half of all monitored nests (n = 152) in 2003. As in pre-treatment years, hummingbirds displayed a high nesting success rate (approx. 80 percent for 2003). The second most common nest found in 2003 belonged to Mourning Doves with a 50 percent success rate that paralleled dove nesting success rates from previous years.

As expected, due to the reduction of understory plants and potential nesting substrates, fewer nests (91) were found at the cut sites in 2003 than at uncut sites in 2002 (64 nests) despite 19.5 more hours of nest searching in 2003. In 2002, we found a total 68 nests of eight different species in exotic plants and only 21 nests in native plants on five sites scheduled for fuel removal. After treatment at these same sites, we only found 8 nests in exotic plants (at the periphery of the treated areas or in regenerated plants) but 56 nests in native plants. The two most predominant nesting species at pre-treatment sites in 2002, Black-chinned Hummingbirds and Mourning Doves, appeared to switch readily to native substrates when exotics were removed (fig. 1) at least in this first treatment year. The number of nests for both species only declined slightly. Excluding hummingbirds and doves, we found 31 nests in 2002 and only 10 nests in 2003. No nests of Blue Grosbeaks (*Passerina caerulea*) or Northern Mockingbirds (*Mimus polyglottos*) were found at any fuel reduction sites after cutting, and only 5 Phainopepla nests were found in 2003 compared to 14 nests in 2002.

Discussion

Treatments are scheduled to be completed by fall 2004, and the first year of post-treatment monitoring of vegetation, bird populations, and other variables is planned for the field season of 2005. Our quick evaluation of pre-treatment data revealed that numbers of exotic and native woody plants, canopy closure, and fuel loads varied by site. This variation is likely to affect bird numbers at each site. For example, decreases in observations of Black-chinned Hummingbirds from North to South sites paralleled declines in numbers of Russian Olive and Rio Grande Cottonwood stems and percentage of canopy closure from North to South. During the treatment-analysis phase, we will need to factor in natural variation in vegetation across sites and consequent effects on bird populations. Bird populations also varied by year, another factor to be accounted for when interpreting treatment effects. Annual variation in bird numbers is linked to yearly differences in adult and juvenile mortality and productivity which can vary by species.

More nests were found over all sites in 2003 than in any previous year, even though fewer nests were found at the five mechanically-cut sites than in 2002. Prior to treatment, shrub-nesting birds, especially Black-chinned Hummingbirds and Mourning Doves, frequently nested in exotic plants and experienced comparable nesting success as those nesting in native plants. Cavity-nesters rarely used exotic plants as nest substrates, and hawk nests were never found in exotics. After treatment, the abundant Black-chinned Hummingbird and Mourning Dove adapted to loss of exotic plants at cut sites by switching their nests to native plants. Further analyses and interpretations of bird population and nesting responses to treatments will be conducted after treatments are completed and post-treatment data have been collected.

Fuel loads are comprised of dead and down wood and exotic plants. Some bird species such as Northern flicker and Bewick's Wren forage for insects in dead and down wood. Cavity-nesters build their nests in live and dead snags, some of which will be removed during the treatment phase. Some cup-nesting species appear to have an affinity for exotic woody plants as nest, cover, or foraging substrates. We predict that at least some cavity-nesters, litter-foragers, and shrub nesters will experience population declines at the local site level during the first 1-3 years following treatments. If treatments are successful in restoring native understory shrubs, however, bird species that require shrubs to nest in may experience resurgence in their numbers as native shrubs mature, reproduce, and spread. Although the short-term population responses of canopy-nesters such as Summer Tanager and Yellow-billed Cuckoo are hard to predict, the long-term consequences of restoring native trees (such as Rio Grande Cottonwood and Goodding's Willow) by removing exotic plant competitors are likely to be beneficial for canopy-nesters.

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Soil and Water Indicators of the Sustainable Rangelands Roundtable

M.G. "Sherm" Karl, Inventory & Monitoring Specialist, National Science & Technology Center, Bureau of Land Management, U.S. Department of the Interior, Denver Federal Center, Lakewood, CO

D.A. Pyke, Research Rangeland Ecologist, Forest & Rangeland Ecosystem Science Center, U.S. Geological Survey, Corvallis, OR

P.T. Tueller, Professor Emeritus of Range Ecology, Department of Natural Resources and Environmental Science, University of Nevada, Reno, NV

G.E. Schuman, Soil Scientist, Rangeland Resource Research Unit, High Plains Grasslands Research Station, Agricultural Research Service, U.S. Department of Agriculture, Cheyenne, WY

R.W. Shafer, Operations Research Analyst, Office of Environmental Information, Quality Staff, Environmental Protection Agency, Washington, DC

S.J. Borchard, Deputy Group Manager, Rangeland Soil Water and Air Group, Bureau of Land Management, U.S. Department of the Interior, Washington, DC

D.T. Booth, Rangeland Scientist, Rangeland Resource Research Unit, High Plains Grasslands Research Station, Agricultural Research Service, U.S. Department of Agriculture, Cheyenne, WY

W.G. Ypsilantis, Soil Condition and Health Specialist, National Science & Technology Center, Bureau of Land Management, U.S. Department of the Interior, Denver Federal Center, Lakewood, CO

R.H. Barrett, Jr., Rangeland Management Specialist, Oregon State Office, Bureau of Land Management, U.S. Department of the Interior, Portland, OR

Abstract—*The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion, a category of conditions or processes that can be assessed nationally to determine if the current level of rangeland management will ensure sustainability. Within the soil/water criterion, 10 indicators, 5 soil-based and 5 water-based, were developed through the expert opinions of rangeland scientists, rangeland management agency personnel, non-governmental organization representatives, practitioners, and other interested stakeholders. Out of these 10, 5 were judged by the soil/water criterion group members as being most expedient for a future national level U.S.A. report on rangeland sustainability. The soil and water indicators are not inclusive, but provide a suite of variables, that when complemented with indicators from the 4 other criteria of SRR, produce a viable system to monitor at the national level the biophysical, social, and economic characteristics indicating trends of sustainability on rangelands.*

Introduction

Soil and water are essential for ecosystem processes. Primary production of ecosystems requires soils in terrestrial systems and water bodies in aquatic systems to support energy capture through photosynthesis and energy flow through consumption, growth, and respiration. Terrestrial nutrient cycling generally requires soil before nutrient uptake can occur in plants whereas aquatic nutrient cycling requires physical or temperature-induced mixing of nutrients within the water. In terrestrial systems, soil influences hydrologic processes by the capture, storage, and release of water (Whisenant 1999), but water and wind can erode soil. Soil erosion is regarded as a major contributor to declines in human civilizations over the past 7,000 years (Lowdermilk 1953). Rangelands and their associated communities rely on conservation and maintenance of soil and water resources to maintain them over time.

The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion, a category of conditions or processes that can be assessed to determine if the current level of rangeland management will ensure sustainability. As a criterion, conservation and maintenance of soil and water resources is too general to monitor directly, but it can be characterized by a set of indicators monitored over time to detect change.

Indicators are quantitative or qualitative variables that are assessed in relation to a criterion. An indicator describes attributes of the criterion in an objective, verifiable, and unambiguous manner, and is capable of being estimated periodically to detect change.

The indicators for the conservation of soil and water resources are divided between soil-related and water-related components of this criterion (table 1). The indicators are the outcome of an evaluation of the conservation and maintenance of soil and water resources indicators identified in the Roundtable on Sustainable Forests (RSF), soil and water resources indicators from Heinz (2002), plus our identification of new indicators that relate specifically to rangeland sustainability. Neary and others (2000), in an effort not associated with the Sustainable Rangelands Roundtable, evaluated the applicability to rangeland sustainability of the eight RSF soil and water indicators. We evaluated Neary and others (2000) and based on this evaluation we retained four of the RSF soil and water indicators (table 1).

We applied a standard set of questions to each indicator. The questions focus on: (1) what is the indicator, (2) what the indicator measures and why it is important to rangeland sustainability, (3) geographic variation of the indicator, (4) the meaning of the indicator at various spatial and temporal scales, (5) the availability, and quality of data sets, and (6) the degree of understanding that stakeholders have for the indicator. Here we provide answers to these questions for five of the 10 indicators. These five indicators are ones the soil/water group members judged to be most expedient for future national-level reports on rangeland sustainability.

Table 1. Indicators for soil and water conservation on rangelands, in no particular order of importance.

Indicators	What the Indicator Describes
Soil-based	
Area and Percent of Rangeland with Significantly Diminished Soil Organic Matter and/or High Carbon:Nitrogen (C:N) Ratio[a]	Soil productivity, infiltration, nutrient content, nutrient availability, nutrient cycling, carbon sequestration, resistance to erosion
Area and Extent of Rangelands with Changes in Soil Aggregate Stability[b]	Resistance to erosion by water and wind, soil water availability, root growth
Assessment of Microbial Activity in Rangeland Soils[b]	Soil productivity, decomposition, nutrient content, nutrient availability
Area and Percent of Rangeland with a Significant Change in Extent of Bare Ground[b]	Erosion potential, aboveground vascular plant productivity
Area and Percent of Rangeland with Accelerated Soil Erosion by Water and Wind[a]	Soil loss by water or wind, soil productivity
Water-based	
Percent of Water Bodies in Rangeland Areas with Significant Changes in Natural Biotic Assemblage Composition[a]	Water quality and aquatic habitat conditions
Percent of Surface Water on Rangeland Areas with Unacceptable Levels of Chemical, Physical, and Biological Properties[a]	Water quality
Changes in Groundwater Systems[b]	Water quantity, watershed functioning, change in geographic extent of riparian and wetland ecosystems
Changes in the Frequency and Duration of Surface No-Flow Periods in Rangeland Streams[c]	Aquatic and terrestrial biodiversity, watershed functioning
Percent Stream Miles in Rangeland Catchments in which Stream Channel Geometry Significantly Deviates from the Natural Channel Geometry[b]	Watershed functioning, including sediment transport, sediment filtering and retention, substrate composition, flood amelioration, fish and wildlife habitat, aquifer recharge, water temperature, and season and duration of surface flow

[a] Originated with Roundtable on Sustainable Forests and was retained in SRR.
[b] A new indicator identified by SRR.
[c] Originated with Heinz (2002) and was retained in SRR

Area and Percent of Rangeland With Significantly Diminished Soil Organic Matter and/or High Carbon:Nitrogen (C:N) Ratio

Importance of the Indicator

This indicator measures the soil organic carbon (soil organic matter) content of the soil, and the carbon:nitrogen (C:N) ratio of the soil organic matter. The C:N ratio is a relative measure of soil organic matter's potential for biological decomposition. Soil organic matter provides many benefits to the soil and is associated with the productive potential of soils and soil sustainability. The C:N ratio of soil organic matter provides an indication of the potential availability of the organic matter to microbial decomposition, and therefore, nutrient release for plant growth. Soils with a high C:N ratio would indicate that the organic matter is more resistant to biological decomposition whereas soils with a C:N ratio of < 10:1 would indicate a good healthy soil and one that would have good biological decomposition of organic matter occurring.

Geographic Variation and Scale in Time and Space

Soil organic matter levels vary by soil type, plant community, and climate. Fine-textured soils with greater clay content generally exhibit greater soil organic matter levels, because the productivity potential is greater, attributable to the greater water holding capacity and reduced decomposition and oxidation rates in fine-textured soils (Reeder and others 1998). Changes in vegetation and litter inputs, for example as a result of a significant shift from C3 grass-dominated plant communities to C4 grass-dominated plant communities, result in greater root:shoot ratios and greater C:N ratios (Schuman and others 1999). Climate and its effects on soil moisture and temperature affects rangeland productivity, which directly influences soil organic matter levels. For example, tallgrass prairie will have greater soil organic matter levels compared with shortgrass prairie because of the greater contributions of litter and root biomass attributable to the greater productivity. Climate also affects decomposition rates, which influences soil organic matter levels.

Soil organic matter and its C:N ratio also can reflect temporal changes attributable to changes in management. Although temporal changes in soil organic matter and C:N ratios lag somewhat to temporal changes in vegetation and litter, the changes can be detected in enough time to initiate management changes to prevent serious degradation of soil. Spatially, soil organic matter varies considerably, reflecting the heterogeneity of soils across short distances. The degree of heterogeneity across short distances infers difficulty in sampling rangelands adequately for a national-level assessment of soil organic matter; however, baseline-sampling sites can be established to compare and detect change over time and space.

Data Collection and Availability

Methods of assessing soil organic matter and C:N ratios are available and are adaptable to the regional and national level. Soil organic matter is generally reported as soil organic carbon, rather than vice-versa. It is recommended that soil organic carbon be assessed to detect spatial and temporal changes in soil organic matter. The laboratory methodologies available for measuring soil organic carbon are economical, repeatable, and accurate but to date, no in situ field methodology exists for assessing soil organic carbon. Whereas a great deal of soil organic carbon data exist that can be used to make initial assessments, C:N ratio data are not as prevalent because simultaneous nitrogen data were not always collected in earlier studies. Recently, researchers have begun to collect soil organic carbon and nitrogen, because of the heightened recognition of the interrelationships of carbon and nitrogen from a microbial and nutrient cycling standpoint. Also many laboratories are now using combustion methods for determination of soil organic carbon which routinely includes nitrogen analyses. In general, soil organic carbon and nitrogen data are limited for rangelands compared with croplands.

Clarity to Stakeholders

Stakeholders generally understand the importance of organic matter as it relates to soil. However, soil organic carbon and the C:N ratio are less well understood, particularly how they relate to litter decomposition and nutrient cycling.

Area and Percent of Rangeland With a Significant Change in Extent of Bare Ground

Importance of the Indicator

Bare ground is exposed mineral or organic soil that is susceptible to raindrop splash erosion (Morgan 1986). Increases in bare ground and greater homogeneity of existing bare ground relate—directly—to a site's susceptibility to accelerated wind or water erosion (Benkobi and others 1993, Blackburn and Pierson 1994, Cerda 1999, Gutierrez and Hernandez 1996, Morgan 1986, Pierson and others 1994, Smith and Wischmeier 1962). The importance of bare ground as an indicator is a function of: 1) its direct relationship to erosion risk; 2) its known value as an indicator of changes in land management and watershed function (Branson and others 1972); and 3) the ease and economy with which this indicator can be monitored over extensive areas, particularly when using remote sensing methods (Abel and Stocking 1987, Booth and Tueller 2003, Tueller and Booth 1975). It also lends itself, more than most other natural resource indicators, to automated measurement by computer image-analysis techniques (Bennett and others 2000, Booth and others 2003).

Geographic Variation

The amount and distribution of bare ground varies. On many rangelands, little bare ground exists because litter, rock, gravel, and sometimes functional biological soil crusts, cover the non-vegetated areas. Bare ground also varies among: 1) soils of differing parent materials, texture, and age; 2) plant communities; 3) lands with differing precipitation patterns; and 4) grazing intensities—to name some of the more prominent variables.

Bare ground is a meaningful indicator in all different regions when compared by site over time so that the natural range of variation is established. Soil series or ecological site descriptions (http://esis.sc.egov.usda.gov/, accessed 09/02/2004) might become useful for predicting bare ground; however, that use must be preceded by years of trend-analysis data collection and correlation of bare ground with the relevant variables such as climate, aspect, vegetation (existing and historical), geology, and slope.

Scale in Time and Space

Until the stability and range of variation of a given ecosystem or management unit is established, it seems advisable to measure bare ground frequently (1 to 5 year intervals). Where the natural range of variation is established and data indicate bare ground is relatively stable over time, a 5 to 10-year sampling interval seems appropriate unless there is a significant disturbance or change in management. Methods of measuring bare ground include point, plot (area), and linear (line intercept) methods. Point methods include the point frame (Levey 1927), and the point-step (Evans and Love 1957). Plot methods include the now archaic charting (usually of a 1-m^2 plot) by means of a pantograph (Stoddart and Smith 1955) and 2-cm diameter Parker loop (Parker 1951).

Bare ground measurement by image analysis has developed considerably since Cooper (1924) described his methods for obtaining vertical photographs of vegetation from 1.8 m above ground level. Daubenmire (1968) observed that cover could be measured from an image (chart, map, or photograph) by using a planimeter, by cutting out and weighing parts of the image, or by using a dot grid. Computers greatly facilitate cover measurements from images. Where image pixel resolution is similar to the 2 mm per pixel used by Bennett and others (2000), image analysis can be considered a direct, point-sampling of ground-cover that gives greater precision than is obtained by on-the-ground methods like the point frame (Bennett and others 2000, Walker 1970, Wells 1971). Images with less resolution give an area measurement. Point sampling (dot grid or pixel count) used with lower-resolution images measures image cover (as opposed to ground cover) and image cover converts to a ground-area measurement. The greater the ground area per pixel, the greater the inaccuracies attributable to pixels containing mixtures of bare ground and other attributes (for example, vegetation, rock, gravel, litter, and biological soil crusts). These are inaccuracies of absolute bare ground per unit area. The inaccuracies are less problematic if we consider only temporal changes by delineating the exact area and using the same method to measure change over time. Regardless of methods, season and annual variation in vegetation cover may impact the measure of bare ground and must be considered when interpreting changes (Anderson 1974, Gutierrez and Hernandez 1996).

As with all indicators, data collected at a local level are not easily extrapolated to, and reported over, larger geographic areas without a sampling design consistent with the inherent variability of the larger geographic area being monitored. It is usually impractical for extensive land areas such as public grazing allotments or watersheds to be monitored using sample numbers and a distribution adequate to something like a 95% confidence interval if sampling is limited to ground-based methods. Aerial sampling as used by Abel and Stocking (1987), Booth (1974), and Booth and others (2003) greatly enhances the practicality for adequate sampling over extensive areas.

Data Collection and Availability

Some data set(s) exist at the regional to national level, but methods and procedures are not standardized at the regional to national level. For most available data, bare ground was not measured using the strict definition we used above (for example, the National Resource Inventory began using our strict definition in 2003 for rangeland surveys, Pyke and others (2002), Spaeth and others (2003)). The data sets exist as 2 types, ground data collected with various methods, and remotely sensed data.

Ground data: Bare ground is included in vegetation analyses for many agencies and non-governmental organizations, including most military reservations in the United States (for example, the military's Land Condition and Trend Analysis). The data within and among these agencies and organizations have been collected using various methods and for numerous sites yet lack adequate sampling designs for regional to national aggregation. However, where sequential, comparable data exist, they may provide a useful measure of the natural range of variation for the site. Another potential source for obtaining the natural range of variation for bare ground is the USDA-NRCS, individual soil pedon data for recent surveys. The aggregated data for soil map units and taxonomic units are stored in NASIS (National Soil Information System) and available through the SSURGO (Soil Survey Geographic) database for digitized surveys. A limitation here is that ground cover is probably ancillary data in most soil surveys, without stringent standards for providing estimates (C. Talbot 2003, pers. comm.).

Remote sensing data: Data sets (U.S.A. or otherwise) with an image resolution that potentially allows an accurate measure of bare ground (Morgan 1986) are rare and largely limited to research efforts (Bennett and others 2000, table 1 in Booth and Tueller 2003, Booth and others 2003, Wells 1971). No remote sensing study has measured bare ground classification accuracy using the strict definition adopted from Morgan (1986). Theoretically, bare ground can be measured using existing remote sensing data bases but measurement inaccuracies are likely, attributable to pixels containing mixtures of factors and to variable amounts of soil moisture and organic matter that confound image analysis. Research is addressing these limitations.

The brightness, or intensity, of radiation reflected from bare ground is high because there is nothing to absorb it. Conversely, a dense vegetation cover absorbs most of the incoming red radiation, so its brightness is low. The light that vegetation does not absorb well is the infrared wavelengths; therefore, heavily vegetated areas reflect a high proportion of infrared light. The combination of low red and high infrared reflectance is often referred to as "greenness." Most remote sensing studies categorize areas as bare ground in an indirect manner, by assuming that areas not reflecting infrared must be non-vegetated. This is somewhat simplistic however because of the confounding classification factors mentioned previously, and the fact that many arid land plants exhibit little spectral greenness. However, the results of such studies do describe increases in bare ground associated with land degradation.

A number of remote sensing studies have shown a high accuracy for a bare ground category when classifying images at various scales (Tueller and Oleson 1989, Tueller and others 1988), however, these studies do not adhere to our strict definition for bare ground, nor do they partition out the confounding factors mentioned previously. For arid rangelands, areas of bare ground can be identified with high accuracy using representative fraction scales varying from 0.2 m pixel Kodak Color infrared digital air photo data, to 0.6 m Quick Bird (commercial satellite system) data, to 1 m IKONOS (commercial satellite system provided by Space Imaging, Inc., Thornton, Colo.) data, to 5 m pixel IRS satellite data. Changes can be quantified easily where areas are classified and the bare ground category is reasonably accurate based on image processing techniques. Resolution of these confounding classification factors at various scales will enhance the usefulness of remote sensing for quantifying bare ground and monitoring bare ground changes on rangelands.

Recently, remote sensing experts have been experimenting with hyperspectral data. Hyperspectral systems provide complete spectroradiometric curves of various sized polygons, representing individual plants or plant communities (vegetation types) depending on the scale. Spectroradiometric curves show discrete absorption features that can represent bare ground, individual soils, or the mineral characteristics of specific kinds of soils. The shape of spectroradiometric curves can be indicative of the amount of bare ground in a pixel. Research in this field is promising and should be encouraged. In addition, new IFSAR (Interferometric Synthetic Aperture Radar) systems may provide new data that will be useful to evaluate bare ground.

Ground vs. remote sensing: West (1999) stated, "I see no hope that traditional methods of monitoring, via point sampling on the ground (italics added), will be able to accomplish those (monitoring) needs…especially when landscape and regional perspectives are required. There are simply not enough adequately trained people and that approach would not be affordable, even if the necessary professionals existed." This was demonstrated by the National Resource Inventory, Colorado Test (a prototype procedure) where random sampling and ground data (objective and subjective) collection was used (Pellant and others 1999). Pellant and others (1999) reported an average 2.5 hours travel time for 3-person teams to reach sample sites. This included the use of helicopters for sites not accessible to wheeled vehicles. Field data collection cost (with no data analysis included) was $893 per sampled site. The field crews sampled 448 locations at a total cost of $400,000 (Pellant and others 1999).

The dilemma has been in choosing where to error. The smaller the scale (larger sized pixels) used in remote sensing the greater the extensive information about large-sized geographic areas, but the lower the accuracy of our inference about specific details (that is, the area of land susceptible to raindrop splash). Conversely, accurate measurement of bare ground at specific sites limits the geographic area of inference and has high cost and increasingly difficult access for ground work. Hopefully, the newly evolving technologies will solve the dilemma.

Clarity to Stakeholders

The public generally understands that bare ground is less desirable than soils covered by vegetation. Changes in the extent of bare ground over time, rather than how much bare ground there is at any moment in time, are more compelling in regard to rangeland sustainability. The concept of some bare ground being normal for many rangelands, rather than all bare ground being viewed as negative, is a concept that stakeholders still need to understand.

Area and Percent of Rangeland With Accelerated Soil Erosion by Water and Wind

Importance of the Indicator

Soil erosion by wind or water begins with the loss of all or part of the surface horizon. Surface horizons of soils are important to maintain because they contain the majority of the organic material and are the exchange medium for transferring nutrients from the soil to plants. Losses of soil through erosion may lead to reductions in the productivity of the site (Davenport and others 1998, Dormaar and Willms 1998). Upper soil horizons typically contain the highest organic matter and nutrient content therefore this component of the soil generally controls the rate of water infiltration, plant establishment, and growth (Wood and others 1982). Excessive erosion can contribute soil sediments to waterways thereby reducing water quality.

Since 1945, UNEP (1990) estimates that 11% of Earth's vegetated soils (1.2 billion ha) have become degraded to the point that their original biotic functions were damaged and that reclamation would be impossible or too costly. Wind and water erosion caused most of this degradation. Accelerated erosion is arguably the number 1 contributor to declines in human civilizations over the last 7,000 years (Lowdermilk 1953), which points to the importance of monitoring soil erosion rates as an indicator of rangeland sustainability and the sustainability of human civilizations associated with rangelands.

This indicator will identify areas where erosion is greater than expected for the soils on a specified site. It is not to identify areas with high natural erosion rates (for example, the South Dakota Badlands in U.S.A.). This indicator measures soil loss by the action of water or wind.

Geographic Variation

Soil erosion on rangelands was recognized as a serious problem at both local and national levels in the U.S.A. in the 1920's (Weltz and others 1998). Soil erosion varies by soil and by plant community but is important in any region. Local, regional, and national data on soil erosion can only be accumulated if similar soils and vegetation are affected and the data summarized for the total of the affected areas.

Scale in Time and Space

This indicator is applicable at various spatial and temporal scales. Its applicability depends on the kind of soil involved and the ability to measure rills and gullies, provide evidence of interrill erosion, and measure soil movement through the air. Rill erosion is caused by concentrated runoff water flowing over the soil, whereas interrill (sheet) erosion results from raindrop impact and splash. Soil aggregate size and stability, biological soil crusts, physical crusting, random and oriented roughness, and extent of vegetative cover are related to wind and water erosion. The distribution of these erosion characteristics and their changes across spatial scales from an individual plot to large geographic areas will influence changes in erosion. The temporal scale would be in terms of years but often related to individual storm events in relationship to overgrazing and other sources of rangeland degradation.

Data Collection and Availability

Accelerated erosion by water can be observed using several parameters including movement of litter downslope, evidence of sheet erosion, or an increase in the number and size of rills and gullies (Pellant and others 2000). Soil erosion rate can be viewed as a function of site erosion potential (SEP) determined by climate, slope conditions, soil erodibility, and ground cover. In pinyon-juniper dominated areas with high SEP, the erosion rate is highly sensitive to ground cover and can cross a threshold so that erosion increases dramatically in response to a small decrease in cover (Davenport and others 1998). After disturbance, both runoff and erosion amounts tend to increase and remain at elevated levels for a decade or more although the rate is not increased with time (Wilcox and others 2003). As rangeland vegetation mosaics change resulting from disturbance, ecologically important changes in runoff and erosion can result (Reid and others 1999).

Wind erosion and transport of surface materials depends on the strength of the wind, the soil surface texture, and the surface protection materials including rocks, biological soil crusts, and vegetation. Surface soil texture is an important key to wind erosion hazard potential. Loamy sand and sand are the most vulnerable soil textures to wind erosion. Clayey soil, because of the ultrafine particle size with highly reactive surfaces, has better structure, and hence is more resistant to wind erosion. Coarse sand and gravelly or rocky soils also are more resistant to wind erosion, because the particles are too heavy to be removed. Wind erosion can lessen soil productivity because wind erosion physically removes soil particles and organic matter near and at the soil surface, and because soil fertility (for example, nitrogen and phosphorus) decreases with decreases in organic matter content (Foth 1984). Soil particles can enter suspension and become part of the atmospheric dust load. Dust obscures visibility, pollutes air, and fills road ditches and the result can be decreased water quality, automobile accidents, fouling of machinery, and imperilment of animal and human health (Skidmore and Layton 1988). Accelerated erosion constitutes a very strong indicator of rangeland degradation.

Standardized methods and procedures for data collection and reporting have been studied for use at the regional to national level, but useable data set(s) do not exist at the regional to national level. However, on natural rangelands the Universal Soil Loss Equation (USLE), Revised USLE (RUSLE), RUSLE2 and Water Erosion Prediction Project (WEPP) have been or are being evaluated for rangeland use. Early models (USLE and RUSLE) were developed for cropland and failed as useful predictors of erosion on rangelands. NRCS soil survey data potentially can provide a national level soil erodibility and soil erosion data set on rangelands, but erosion was a visual estimate of an observer at an NRI point while erodibility was calculated using the inaccurate USLE or RUSLE models.

Remote-sensing techniques provide a promising technology to obtain information on soil erosion, but limited testing has been done. We encourage additional research to refine and test various methods for obtaining accurate data over larger areas.

Clarity to Stakeholders

Stakeholders understand erosion. When interested individuals see active or past erosion the reaction is often a concern for the health of the land. More subtle signs of erosion and the concept of wind-caused dust and the relationship of these to good land stewardship is obscure, requiring further stakeholder tutoring over time.

Percent of Surface Water on Rangeland Areas With Unacceptable Levels of Chemical, Physical, and Biological Properties

Importance of the Indicator

This indicator measures the percent of surface water with impaired water quality. Surface water includes the length of small, medium, and large streams and rivers, and the area of lakes and reservoirs. Under the Clean Water Act, states and authorized tribes develop water quality standards for their individual stream and river segments, often including their lakes and reservoirs (U.S. EPA 1994). A water body segment is a bounded part of a stream, river, lake, or reservoir that is regulated by a set of water quality standards. To establish these standards, states and tribes identify designated beneficial uses (for example, drinking water, recreational, agricultural) for each of their water segments, and then set water quality criteria to ensure protection of its chemical, physical, and biological integrity (U.S. EPA 1994). A water quality criterion is an ambient concentration of an important parameter (for example, dissolved oxygen, or pH, or temperature, or heavy metals; usually a LD50 or other metric) that ensures that the designated use or uses for a given water segment are not impaired. Impaired water quality means that 1 or more of the criteria adopted to protect the designated use or uses of an individual water body segment are not being met. Leading causes of water quality impairment of our nation's waters are excess nutrients (nitrogen and phosphorus), sediment/siltation, pathogens, and metals (USDI-USGS 1999). EPA's National Water Quality Inventory 2000 Report states that approximately 40% of the nation's assessed streams are impaired (http://www.epa.gov/305b/, accessed 09/02/2004). Water resources must be of adequate quality to support a variety of uses such as human and livestock consumption, wildlife habitat, agricultural and industrial supply, and recreation (Heinz 2002). Water quality is important to rangeland sustainability because wildlife, recreation, livestock, downstream water users, and others depend on clean water, particularly in arid and semi-arid rangelands.

Geographic Variation

Water quality standards will vary geographically. For a particular water body, the water quality parameters which are deemed important, and the appropriate criteria or thresholds, will depend on the designated uses. In addition, states and tribes consider natural ranges of variation when designating uses and developing water quality standards. Water quality impairment assessments are local decisions because our nation's waters do not naturally exhibit the same characteristics, for example the ability to support a cold-water fishery. However, states and tribes regularly monitor and assess water quality, and identify their water bodies that do not meet their standards. These impaired water bodies are reported on a Clean Water Act Section 303(d) list that is updated biennially (US EPA 2003).

Scale in Time and Space

States and tribes have flexibility on how they determine designated uses, what water quality parameters to monitor, what monitoring methods to use, and what methods are used to assess water quality. Also, to meet management and compliance objectives, most water quality monitoring is conducted at "fixed" stations, and the resultant data are not necessarily representative of the whole water body or watershed. National reports on water quality do not yet provide an assessment of all the watersheds in the United States. For these reasons, scaling water quality parameter data up to a regional or national reporting level would be very difficult, as would be assessing comprehensive regional or national trends of important water quality parameters. However, the Section 303(d) impairment lists, updated by the states and tribes using the local water quality data, provide information nationally of deteriorated water quality and its causes (US EPA 2003). Reporting of Section 303(d) lists began in 1998, and the states are required to update their lists every 2 years. As part of their Section 305(b) requirements, States have for the last 30 years been monitoring and reporting water quality information into EPA's national data system, STORET (not a true acronym, stands for Water Quality Storage and Retrieval System).

Data Collection and Availability

Under Section 305(b) of the Clean Water Act, EPA, other federal agencies, states and tribes are to monitor their waters for water quality, and report that information in STORET. Additionally, a National Water Quality Inventory is required biennially, which is a report that summarizes water quality reports submitted by states, territories, interstate commissions, and tribes. For reasons stated previously, this report cannot be used as a regional or national assessment, or for national trends in water quality. Also required is a biennial Section 303(d) list of impaired waters (US EPA 2003). These impaired waters are required to develop a TMDL (total maximum daily load). TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. This is probably the best information we have on impaired water quality, and initially should be the data sources for this water quality indicator.

Another potentially useful data source is the USGS (United States Geological Survey) National Water Quality Assessment (NAWQA) program. To help support local decision makers in developing TMDLs and to provide long-term, nationwide information on water quality, NAWQA is starting its second decade of intensive water quality assessments. These assessments will cover 42 large hydrologic systems representing about 60% of the nation's waters used for drinking and irrigation, and include a broad list of physical, chemical, and biological measures including stream flow and stream habitat, water, sediment, and tissue chemistry, and characterization of algae, invertebrate, and fish communities. However, NAWQA data coverage on rangelands is limited, because at least half of the 40% non-coverage area is rangeland.

Clarity to Stakeholders

The concept of a water body meeting or not meeting a water quality standard is an easily understood concept to stakeholders.

Changes in the Frequency and Duration of Surface No-Flow Periods in Rangeland Streams

Importance of the Indicator

This indicator is patterned on an indicator developed by The Heinz Center (Heinz 2002). This indicator annually measures: 1) the percentage of rangeland streams with at least 1 day of no flow (also referred to as zero flow) in a year; and 2) for stream gauging stations showing at least 1 day of zero flow, the duration of zero flow events compared with a long-term average. Together, these 2 variables describe the frequency and duration of surface no-flow periods. There are numerous reasons for why streamflow is important in sustaining environmental, biological, social, and economic systems, not the least of which are: 1) the maintenance and recharge of ground water and the retention and productivity of streambank-stabilizing vegetation; 2) the continuity and quality of fish habitats; and 3) the availability of water for agricultural and municipal use and recreation.

Surface no-flow periods can occur naturally. Surface no-flow periods also can occur because of increased water use for domestic, irrigation, or other purposes, or because of changes in land use (for example, transition from rangeland to urban), or because of changes in vegetation which modify the flow of surface water and the recharge of groundwater (for example, expansion of deep-rooted vegetation such as pinyon or juniper, which can draw down surface aquifers). Changes in surface no-flow periods also can be attributable to changes in weather and/or climate.

Geographic Variation

This indicator has been reported at the division level of Bailey's ecoregions (for example, 250—prairie division; 260—Mediterranean division [Bailey 1995, in Heinz 2002]), and in the temporal range from 1949-1999 based on USGS stream gauge data, http://nwis.waterdata.usgs.gov/usa/nwis/discharge, accessed 09/02/2004, in Heinz (2002). Differences are discernible over time at the division level of Bailey's ecoregions, and spatially between divisions.

Scale in Time and Space

The indicator does not identify cause of increases or reductions in the frequency or duration of zero flow events, but is meaningful at the division level of Bailey's ecoregions and at decadal scales (Heinz 2002).

Data Collection and Availability

Methods and procedures for data collecting and reporting, and data sets of useable quality exist at the regional to national level, and are maintained by USGS and are available at http://nwis.waterdata.usgs.gov/usa/nwis/discharge.

Clarity to Stakeholders

Stakeholders can understand that changing streams from perennial to ephemeral or intermittent will impact the aquatic organisms that cannot tolerate periods without flowing water, but we anticipate they do not understand the relationships between periods of no-flow and groundwater levels.

A Look Ahead

Several of the indicators pose challenges regarding their applicability over broad geographic areas. Sampling schemes have not yet been designed for some of the indicators to achieve an objective of regional to national-level reporting of change over time. Some indicators are esoteric and would need effort to increase their understanding among stakeholders before they would be widely accepted as being credible.

We are discovering that regional and national level data sets are not available for most of the indicators; data sets often are more available for smaller geographic areas, with various methods used for measurement. Elaborating on the quality of data sets has been challenging because quality-control information is scant in the literature.

The 5 indicators presented here represent the "keystone" indicators from the Soil/Water Criterion Group that will likely be of focus in a proposed interagency (Bureau of Land Management, Forest Service, and Natural Resources Conservation Service) sustainable rangelands report scheduled for completion by 2010. Soil and water are the basic resources of rangeland sustainability. The identification and eventual quantification of rangeland indicators related to soil and water might provide an approximation of rangeland sustainability for our nation and provide a blueprint for evaluating rangeland sustainability worldwide.

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An Overview of University of Alaska Anchorage, ENRI Research on the Spruce Bark Beetle Infestation, Kenai Peninsula, Alaska, 1997–2002

Vernon J. LaBau, University of Alaska Anchorage, Environment and Natural Resource Institute, Anchorage, AK

Abstract—*In the mid 1990s, one of the largest bark beetle infestations seen anywhere in the world occurred on the Kenai Peninsula of Alaska. In one year, the infestation affected over one million acres of spruce in Alaska. This paper presents a coalescence of several aspects of study on the problem, including tree inventory and mortality, regeneration, understory response, a phytomass study, an assessment of mortality inventory methodology, and an assessment of forest health after the bark beetle infestation declined. The basis for the data collection in these studies was a two-phase sampling design (aerial photos and ground plots), established by the author in 1997 and subsequently re-measured in 1998.*

Introduction

The Deep, Dark, Forest by A.S. Harris

Crunch, crunch, crunch,
listen to 'em munch,
it's always time for lunch,
in the deep, dark, forest.

It's awful to behold
the creeping, crawling, mold,
entwining in its fold,
the deep, dark, forest.

The lepidopter-ees,
are eating up the trees,
until the winter freeze,
in the deep, dark, forest.

The parisite-ees hover,
and lunch upon each other,
including their own mother,
in the deep, dark, forest.

Oh Lord, deliver me,
from these awful mysteries,
as I crawl from tree to tree,
in the deep, dark, forest.

I will begin my presentation on this subject with figure 1. It is a graphic display showing estimates of the area impacted in Alaska (primarily in southcentral) by the spruce bark beetle (*Dendroctonus rufipennis* [Kirby]) between 1970 and 2003. These data are based on annual aerial insect surveys made jointly by the Alaska Department of Natural Resources (ADNR), Forestry (ADNR 1996), and the U.S. Forest Service, Office of State and Private Forestry (S&PF).

From this graphic, it is possible to see the progression of the bark beetle population from an endemic state, impacting only about 120,000 acres in 1970, and the increase to epidemic proportions in 1996, when it impacted an estimated 1.1 million acres. It is apparent that the bark beetle has eaten itself out of house and home until it only impacted about 54,000 acres in 2002.

The primary spruce species under attack were white spruce (*Picea glauca* [Moench] Voss) and Lutz spruce (*Picea Xlutzii* Little), although, in this study, some bark beetle presence was found in stands of black spruce (*Picea mariana* Mill. B.S.P.), and Sitka spruce (*Picea sitchensis* [Bong.] Carr.).

By 1995, there was a great reservoir of unique natural resource information to be gained from an inventory of the spruce bark beetle infestation on the Kenai Peninsula, and there certainly was a need to evaluate the changing forest health condition related to that epidemic. In 1997 and 1998, the University of Alaska Anchorage (UAA), Environment and Natural Resources Institute (ENRI) conducted two seasons of field measurements, resulting in six technical publications and two poster papers. It is the purpose of this paper to summarize those presentations.

In 1996, the University of Alaska awarded a $27,000 grant from its Natural Resources Fund to ENRI to conduct a field study to evaluate the inventory and mortality of the Kenai Peninsula forest stands during the summer of

YEAR	ACRES
1970	119,800
1975	102,366
1980	354,537
1985	290,394
1990	232,406
1991	375,000
1992	600,000
1993	700,000
1994	610,200
1995	893,900
1996	1,133,000
1997	563,700
1998	316,800
1999	253,300
2000	120,900
2001	104,200
2002	53,600
2003	92,800

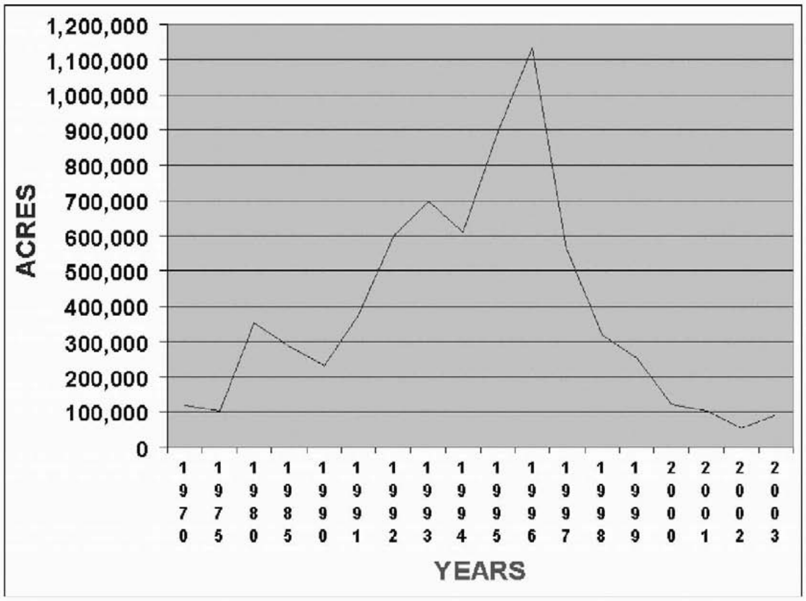

Figure 1. Alaska Acres Impacted by Spruce Bark Beetle 1970 to 2003.

1997. The objective of this study was to conduct a study of five-year spruce mortality and spruce regeneration and the effects of inhibiting vegetation (grasses, shrubs, etc.) on spruce regeneration on a pilot area within the region of the Kenai Peninsula that was road accessible.

Specifically, the objective was to answer the following questions:

1. What was the estimated area of High, Moderate, and Low intensity bark beetle impact areas?
2. To what extent was the bark beetle impacting growing stock, especially for white and Lutz spruce? What size trees were being attacked? What percent of the trees were being impacted? What was the ratio of live tree growth to mortality?
3. What was the level of regeneration in the above impact areas, especially for white and Lutz spruce? Was there any indication that grass was inhibiting regeneration of spruce where the spruce overstory was killed by beetle attack.

The results of the 1997 study were published in a UAA ENRI report (LaBau 1998). In the fall of 1997, another Natural Resource Fund award in the amount of $25,000 was made to ENRI to revisit the 1997 plots and evaluate a one-year impact of the bark beetles and to try to collect fuel- loading information associated with the bark beetle kill. It was also decided to evaluate the efficacy of sampling plot designs in capturing mortality information. The number of ground plots sampled was increased in the 1998 study.

The objectives of the 1998 study were twofold:

1. Expand the 1997 study, primarily to collect data to develop a forest fire fuels model (Rothermel1983) as well as collect additional data on total vegetation phytomass and down wood biomass.
2. Expand the study sample size and ground plot configuration to evaluate the efficacy of sampling plot designs in capturing mortality information.

The results of the 1998 study were published in a UAA ENRI report (LaBau 2002). Additional results were presented at the Carbon Sequestering Conference in Anchorage, AK, in May 2000 (LaBau and Mead 2001), giving an overview of what the phytomass distribution and fuel loads were relative to the 1998 re-inventory study.

The results of the study to evaluate efficacy of the sample plot designs can be found in a paper presented at an IUFRO and SAF Inventory Working Group Conference in Boise, ID in August 1998 (LaBau and Hazard 2000).

Finally, an evaluation was made of forest health of the residual live spruce and birch (*Betula paperifera* Marsh) on the Kenai Peninsula. The results of that evaluation were published in the 2002 National Society of American Foresters Convention in Winston Salem, NC, in October 2002 (LaBau and Boughton 2003).

As previously mentioned, the purpose of this presentation is to provide an overview of the results of those various studies.

Methodology

The first step of the study was to establish the sample unit. A sample unit boundary was laid out to encompass the major areas of bark beetle attack, which had been mapped up through 1995 on the S&PF maps for the Kenai Peninsula (see Map A). This boundary was established following section, township, and range lines so that land areas could be assigned to the sampled area at a later time. Subsequent evaluations of the sample area using U.S. Bureau of Land Management (BLM) land records resulted in an estimated 2,802,569 acres for the entire sample unit.

It had been predetermined that there was not sufficient funding to sample areas beyond 6 miles from the road system (designated as "inaccessible" areas). The final "accessible" sampling unit was 1,232,587 acres in size. Given the limitations of funding, it was decided that a statistical design should be utilized that would provide a maximum return for the money. It was felt that the study should take advantage of ancillary information from aerial photography, as well as from the ADNR/S&PF aerial insect survey maps, and attempt a stratification of the populations of interest to the greatest degree possible.

The sampling design chosen was a two-phase (double) sampling (Bickford 1952) approach, stratifying the populations of interest on high altitude color infrared (IR) aerial photos at the first phase. For both the "Accessible and Inaccessible" Zones the photos were interpreted (15 points systematically gridded around each photo center) and each point was assigned strata codes based on photo interpretation techniques. A minimum area of about .4 hectares (one acre) was evaluated at each photo point. To provide a strata of bark beetle attack intensity, four years (1992-1995) of ADNR insect aerial survey maps (ADNR 1996) were overlain on 1:250,000 USGS maps of the Kenai Peninsula, and bark beetle impact intensity strata were assigned as follows:

- *High Impact*: Photo point falling inside an S&PF mapped insect attack polygon.
- *Moderate Impact*: Photo point falling within one mile of an attack polygon.
- *Low Impact*: Photo point beyond one mile of a polygon, but within one mile of a "dot" on the S&PF maps, indicating an area of isolated attacks.
- *No Impact*: Photo point beyond one mile of a polygon or "dot."

The data collected at the phase 1 level at each photo point included:

- USGS Map Quad (1:250,000)
- Photo Flight Year
- Photo Flight Roll
- Photo Flight Number
- Photo Grid Point Number
- Forest Type
- Accessibility Type
- Distance to Road
- S&PF Insect Impact Intensity

A recording form and a manual of photo interpretation procedures and coding instructions were prepared. Over 2600 photo plots were evaluated within the area selected, of which about 1100 were in the "accessible" zone. These data were entered directly into EXCEL spreadsheets in order to facilitate summarization later.

In phase 2, a random sub-sample was selected in proportion to photo interpreted bark beetle impact classes from the strata of phase 1. This sub-sample was then visited on the ground to collect more detailed data on the populations of interest. In this study, ground data were desired to obtain more detailed information about how many trees are attacked or killed, the size of the trees killed, regeneration following the bark beetle killing the overstory, and the response of vegetation that might inhibit tree regeneration. Forest health data were also collected following National Forest Health Monitoring (FHM) procedures (Conklin 1996).

In establishing the phase 2 sampling frame, because funds were not available to use aircraft to travel into inaccessible areas, only the "accessible" zone photo points were sampled. All nonforest, water, and hardwood photo calls were assumed to have been made without error, and having no spruce forest present, these photo plots did not need to be ground visited. Therefore, the sampling frame for the ground plots consisted of the photo points from just the four impact strata within the "accessible" zone, giving a sampling frame of 456 photo points. Ten phase 2 plots were selected at random from each of the four impact strata in the "accessible" zone giving a total of 40 ground plots to visit.

After receiving permission from the landowners to access the plots on the ground, the ground plots were visited and data measurements taken and observations made during the summer of 1997 by a two-person crew trained in measuring forest inventory and forest health monitoring plots.

Recording forms, a manual of ground plot measurement procedures, and coding instructions were prepared as part of the study plan. In 1997, the ground plots were visited in order of their draw until all funds were expended. This resulted in the visitation and data collection for seven ground plots in each of the four strata (28 ground plots). Each ground plot consisted of four subplots on which the live tree and vegetation information was measured or observed and a full acre plot taken to record all trees that had died within the previous five years. Accepted U.S. Forest Service guides were used to estimate 5-year mortality. For the 1998 re-measurement, twelve more ground plots were added (three in each strata). A 6-year mortality criteria was applied and a larger mortality plot (1.5 acres) was laid out. All measurements were recorded in metric units. A diagram of the ground plot layout is shown in figure 2.

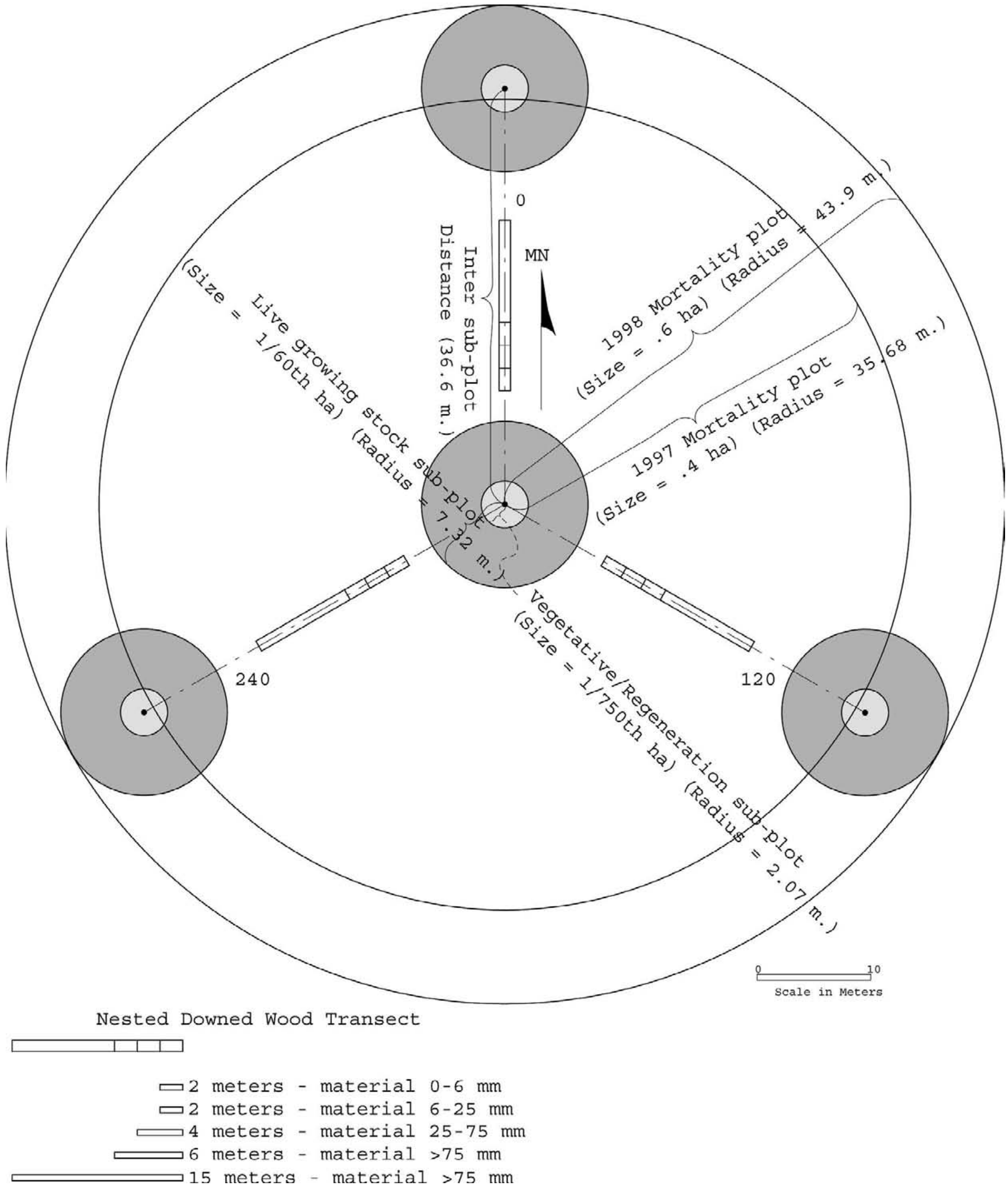

Figure 2. Spruce Bark Beetle Study Plot Schematic, 1998.

The following data were collected in the various categories of interest:

- Live tree tally for all trees over one inch in diameter at breast height recording:
- Species, diameter at breast height, dominance, total height, and beetle attack if any. Forest health observations were also made relative to crown ratio, density, dieback, and transparency. Assessments of damage to the tree were also made according to type of damage, severity, and location on the tree. Finally, all trees were monumented by recording the distance and azimuth from the plot center to the tree.
- Regeneration of seedlings over 0.3 meters tall recording:
- Count by species, height and age.
- Mortality trees (trees dying within the last five in 1997 or six years in 1998) were tallied on one acre in 1997 and on the 1.5 acres in 1998, recording:

- Species, diameter at breast height, dominance, total height, cause of death, estimated year of death, and beetle attack if any. All mortality trees were monumented by recording the distance and azimuth from the plot center to the tree. The mortality plot size was enlarged to 1.5 acres in size in 1998 to accommodate a planned mortality sampling accuracy test using a Chi Square analysis (Freese 1960).
- Plot ground vegetation composition—percent cover of:

Mosses, shrubs, grasses, herbs, seedlings under 1 foot tall.

- Plot summaries of forest condition on each of four subplots, recording:

Forest type, stand size class, stand age, slope, aspect, and past disturbance.

In the 1998 study, two more data sets were collected, recording:

- Downed wood on three 45 foot transects to help assess fuel loads (Brown 1974).
- Understory phytomass in tree seedlings, shrubs, grasses, forbs, mosses, and lichens (Yarie and Mead 1988). Understory profiles would be constructed to assess phytomass of the lower vegetation.

Aboveground phytomass, as oven dry weight per unit area, would be derived from:

- Sapling trees (>1.0 inch but < 5.0 inches diameter at breast high (dbh)),
- Live trees (> 5.0 inches dbh),
- Mortality trees (> 1.0 inches in dbh)

At the end of the day, all data were coded into EXCEL spreadsheets in a laptop computer to facilitate easy analysis at a later date. At the end of the field season, a complete check was made comparing the original field data sheets with the EXCEL summaries. All discrepancies of this type were resolved prior to any data analysis being made.

During the analysis phase, cubic foot volumes were computed using formulae provided by the USFS's Anchorage Forestry Sciences Laboratory. These were the same formulae used in their most recent inventory of the Kenai Peninsula forest resource (van Hees and Larson 1991).

Also, during the analysis phase, a decision was made to evaluate tree health. It was therefore necessary to establish a method for determining poor health trees ("at risk" trees). With the consultation of various colleagues familiar with tree health criteria, a matrix of tree condition factors was developed that could be used to establish the "at risk" tree class (LaBau and Boughton 2003). The criteria in that matrix included crown condition, such as ratio, density, dieback, etc. and presence of significant tree damage, such as conks, wounds, broken or dead branches, and dead tops.

Results (1997 and 1998 Assessments)

Area Estimates

Area estimates were derived for strata classes along with respective standard errors for the 1,232,587 acres in the "accessible" zone. Of the 1.2 million acres evaluated with photo and ground plots, the study inferred that about 515,000 acres was in forest, and of that forested area, about 33.3 percent was in High impact areas, 25.0 percent in Moderate impact areas, 19.8 percent in Low impact areas, and 18.9 percent in the No impact areas. The remaining 3.1 percent was in unaffected pure hardwood stands.

About 78 percent of all forest land (conifer, mixed, and hardwood) was impacted by the bark beetle. Over 58 percent was within the combined High and Moderate impact areas. One encouraging finding was that when variances and percent sampling errors were evaluated for the four combined strata of interest (High, Moderate, Low, and No), the percent sampling error for the combined strata was a very respectable 5.38 percent.

Growing Stock Tree Inventory Findings

Standard report tables of cubic foot volumes were prepared, but they will not be the focus of this report. For detailed information in that regard, see LaBau (1998).

Six-year Spruce Mortality Findings

For the plots measured in 1997, it is estimated that 32.2 percent of the basal area of white and Lutz spruce that was alive in 1992 had been killed by the bark beetle. However, the 1998 study showed a dramatic one-year increase in mortality, resulting in 41 percent of the 1992 white and Lutz spruce being killed, primarily by bark beetles. The occurrence of spruce mortality followed the expected trends set forth when stratifying areas into the insect impact strata.

About 57 percent of all spruce mortality occurred in the High insect impact class, with more than 80 percent of all spruce mortality occurring in the High and Moderate impact classes. The 1998 study showed a one-year increase in mortality of about 83 percent for all forested areas, with about 106 percent increase in the High insect impact class. This increase in one-year mortality occurred, despite a decrease in rate of bark beetle spread, as observed in the 1997 and 1998 S&PF aerial surveys (fig. 1). This implies that although the rate of spread was decreasing, the bark beetles were making heavy impact on the stands that had already been infected by them in prior years.

The bulk of the insect mortality occurred in trees 10 inches in diameter or larger. However, as the insect population began to kill most of the larger trees, they moved into smaller trees, some as small as three inches. Further, as the live white spruce and Lutz spruce disappeared, the beetles also killed even black spruce as small as 3 inches dbh.

Regeneration Findings and Effect of Grass Invasion

Regeneration rates for white and Lutz spruce appear to be about at par with what forest management minimums are for stocking. The High impact stands had the most regeneration of seedlings (under 1 inch diameter). Regeneration plots in these areas showed about 450 white spruce seedlings per acre and an additional 1500 seedlings per acre from birch, aspen, and black spruce. The other three strata (Moderate, Low, and No impact) had a regeneration rate of from 150 to 407 spruce seedlings per acre and 557 to 1500 other species. The Chugach National Forest tries to manage for about 300 seedlings per acre in their white spruce forests. Birch regeneration is quite high, but survival to tree size for any given birch seedling is greatly limited by moose browsing. About 67 percent of the birch seedlings showed signs of moderate to severe browsing.

Because these studies were limited to two years, it was not possible to establish definitive measurements of grass invasion. However, it was apparent that the stands where most of the overstory had been killed by bark beetle attack showed higher levels of grass in the understory, and this would inhibit establishment of spruce seedlings, and where seedlings did get established, there was evidence of the spruce seedlings being damaged by "lodging" due to the dead tall grass going down and pushing the seedlings down with it in the fall and winter months.

Phytomass Findings–Fuel Loading Implications

- Phytomass was summarized by five vegetation components (live trees, six-year mortality trees, saplings, understory plants, and downed wood). The most important findings for the tree components were:
- The live tree component of the aboveground vegetation contained more phytomass than the remaining components combined. Live trees accounted for 77 percent of the aboveground phytomass in the No impact class.
- The highest proportions of phytomass in the six-year mortality component occurred in the Moderate (32 percent) and High (29 percent) insect impact classes. Only 2 percent of the phytomass was in mortality trees in the No insect impact class.
- Phytomass in sapling trees varied between 2.5 percent and 6.0 percent across the four insect impact classes. Most saplings were present before the bark beetle seriously impacted the Kenai forests.
- Understory vegetation made up about 2 percent of the total phytomass in each insect impact class. Increases in understory phytomass resulted from overstory mortality and increased sunlight reaching the understory.
- Shrub phytomass accounted for over 40 percent of the understory phytomass in three of the four insect impact classes. Shifts in shrub phytomass in response to reduced conifer overstory were not apparent.
- There was an inverse relationship between conifer-seedling phytomass (29 percent) and the mass of grass and forbs (16 percent). Grass phytomass was three to four times greater in the High and Moderate insect impact classes than in the Low and No impact classes. This tends to support the suspected trend of increasing densities of grass and forbs where overstory is decreases, and supports the theory that in beetle-killed forests increasing grass cover may impede conifer regeneration.
- Hardwood seedling phytomass was four to ten times larger in the High and Moderate insect impact classes than in the Low and No impact classes suggesting a hardwood invasion in response to increased light under the beetle-killed conifer stands.
- Moss phytomass was inversely related to severity of the beetle infestation. Moss was 6.3 percent, 9.2 percent, 8.3 percent, and 10.5 percent of the understory phytomass in the High, Moderate, Low, and No insect impact classes, respectively. Opening of the conifer overstory increased light intensity and drying of the understory vegetation, thus reducing moss presence.
- Lichens were less than 1 percent of the understory phytomass in all impact classes.

Down-Wood Findings–Fuel Loading Implications

- The downed wood component is important in modeling fuel loading and wildfire potential. The following are some of the implications of this study:
- As beetle-killed spruce fall, the potential for serious ground fires increases. As of 1998, few of the standing beetle-killed spruce had fallen. The downed wood in

the highly impacted areas, where bark beetle attacks were generally less than 10 years old, averaged 21.4 metric tons per hectare. This compares reasonably with accumulations found in stands impacted for 5 and 9 years which showed, respectively, about 16 and 22 metric tons per hectare of downed wood (Schulz 1995).

- Plots in the No insect impact class had most of the large Sitka spruce and hemlock trees. When these trees mature and fall, the ratio of down to standing wood inflates due to the large size of the dead material.
- The combined dead material in standing mortality and downed wood comprises 54.5 percent, 50.0 percent, and 33.0 percent of all phytomass in the High, Moderate, and Low beetle impact classes, respectively. As more of the surviving white and Lutz spruce are killed, these percentages will increase in all impacted areas.

Findings Relative to Forest Health of Residual Stands

- Only about 5 percent of the residual white and Lutz spruce trees were rated as having "at risk" tree health in 1998, comprising 9.5 percent of the spruce basal area.
- About 26 percent of the residual paper birch trees were rated as having "at risk" tree health in 1998, comprising over 35 percent of the birch basal area.
- The paper birch, when evaluated on a basal area basis, was found to have almost four times as much basal area in the "at risk" tree health class as the spruce.
- When assigning tree health, it is important to not just evaluate crown conditions, but to also include tree health risks, such as conks, wounds, and insect attacks.
- About 24 percent of the white and Lutz spruce trees still alive in 1998 were under attack by bark beetles.

Findings Relative to Mortality Sample Plot Evaluation Using Chi Square

For over a decade, a debate has been going on as to how well the four-point cluster of 1/24th acre plots (1/6th acre sample in total) (Conklin 1996) would capture the Poisson distributed population of mortality trees. The efficacy of that four-point cluster design is very important when considered in the context of measuring mortality to assess forest health. For the past decade, the four-point cluster has been comparatively evaluated against a larger 1-acre plot throughout the forests of California, Oregon, and Washington.

To test the efficacy of the cluster design in the epidemic beetle attack situation of the Kenai, a plot 1.5 acres was laid out (completely encompassing the 4-point cluster), and all trees 5 inches and larger dying between 1992 and 1997 were measured and stem-mapped, noting if they also occurred on the four point cluster.

Four Chi Square tests of accuracy (Freese 1960) were run, one for each of the strata in the study, with 10 pairs of data being tested in each strata, providing 10 degrees of freedom for each strata tested. For the ten degrees of freedom in these tests, the Chi Square threshold for rejecting the null hypotheses at the .05 level is 18.31. The larger 1.5 acre plot was assumed to capture the "true population" for the purposes of this test. However, it is recognized that the larger plot population is still from a sample, and is not, in fact, a "true population" statistic.

For all four of the strata evaluated, the null hypotheses were rejected at the .05 level, implying that the tally of mortality trees on the four-point cluster is significantly different from the tally on the 1.5 acre plot, and that the four-point cluster plot did not give estimates of mortality as accurately as the larger 1.5 acre plot. More details of this analysis can be found in LaBau and Hazard (2000).

Summary

In summarizing the findings of the two UAA/ENRI bark beetle studies there are several points that should be highlighted. The author encourages those interested in more detail to read the original papers. The most important findings of the various papers are listed below:

- Of the white and Lutz spruce alive in 1992, by 1998, 41 percent had been killed by the bark beetle. By the turn of the century, the bark beetles killed most of the oldest and most vulnerable spruce in the study area.
- As expected, the largest numbers of mortality trees were found in the High and Moderate impact classes.
- The stratification system used in this study worked well, yielding a sampling error of only 5.4 percent for the 1.2 million acres of Kenai area forest under study.
- Regeneration of spruce seedlings in the study area was marginal to poor and there was strong evidence that spruce seedling establishment was being inhibited by grass competition and lodging. Birch seedlings were regenerating at a very acceptable rate, but because of heavy moose browse, few would reach growing stock size (5 inches dbh) without severe browsing by moose. As expected, the highest bank of phytomass

was found in the live and dead trees over 5 inches in dbh, with the distribution of phytomass being about equal between the live and dead growing stock trees. This is consistent with the fact that 41 percent of the spruce had been killed in the previous 6 years.

- Understory phytomass was only about 2 percent of that found in the overstory with almost half of the understory phytomass occurring in shrub vegetation.
- There was evidence of an increase in grass phytomass and a decrease in moss phytomass as the crown cover disappeared due to the bark beetles killing the spruce overstory, with grass phytomass in High and Moderate impact strata was found to be up to four times greater than in the Low and No impact strata.
- In evaluating the down wood, the bark beetle killed trees were just beginning to fall down at the time of the study. This was more in evidence in the High impact strata. The down wood component should see significant increase in phytomass in the near future as more spruce trees fall down.
- From a forest health perspective, only about 5 percent of the residual white and Lutz spruce trees were rated as having "at risk" tree health in 1998. However, about 26 percent of the residual paper birch trees were rated as having "at risk" tree health. The paper birch was found to have almost four times as much basal area in the "at risk" tree health class as the spruce.
- In a Chi-square test of accuracy, the standard four-point cluster used by FIA and FHM underperformed the larger 1.5 acre plot. The test was significant at the 95 percent probability level.

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Ground-Based Photomonitoring of Ecoregional Ecological Changes in Northwestern Yunnan, China

James P. Lassoie, Professor, International Conservation and Kiran E. Goldman, Project Assistant, Department of Natural Resources, College of Agriculture and Life Sciences, Cornell University, Ithaca NY
Robert K. Moseley, Director of Conservation Science, The Nature Conservancy, Kunming, Yunnan, 650051, China

Abstract*—Barring abrupt natural or anthropogenic disasters, ecological changes in terrestrial landscapes proceed at a pace not readily detected by humans. The use of historical repeat photography can provide valuable information about such changes, but, these studies are opportunistic in that they must rely on old photographs. Hence, their ecological interpretative power is compromised by the intention of the original photographer, the quality of the original photographs, an incomplete and potentially misrepresentative sampling design, and a limited analytical framework for interpreting ecological changes. The Nature Conservancy (TNC) has been using historical repeat photography to document ecological changes in northwestern Yunnan Province as part of its conservation planning efforts in China. This experience supported the development of a forward-sampling, ground-based, photomonitoring methodology designed around a high quality digital camera and a comprehensive database management system, which was tested during the summer and fall of 2003 across two adjacent ecoregions in northwestern Yunnan: the Hengduan Mountains and the Nujiang-Lancang Gorge. Based on results from a collaborative ecoregional conservation assessment for the region, visual indicators obtainable from the resulting photographs were identified and used to assess the threat status (for example, logging, grazing, mining) for five key ecosystem conservation targets (cold evergreen oak, evergreen broadleaf forest, mixed forest, subalpine forests, alpine mosaic). A sampling design strategy then was developed based on the inherent geographical variation in the distribution of targets, ethnic minorities (a surrogate for land-use), and climatic zones (based on precipitation and temperature) across the region. This distribution information is being used to design photomonitoring transects for establishing the baseline for the long-term monitoring of ecological changes. The photographic temporal assessment that eventually will result will help assess conservation and development activities across geographically extensive and diverse ecoregions, and serve as a means for monitoring the outcomes of conservation programs at specific locations.*

Introduction

Northwestern Yunnan Province in southwestern China is considered a conservation 'hot spot' worldwide owing to its spectacular landscapes and abundant biological diversity (Myers and others 2000). This region is also home to three million people, whose lives depend on the sustainable utilization of its natural resources. Faced with rapidly changing socio-economic conditions and development expectations, however, some of their livelihood strategies (specifically, enhanced agricultural and livestock production, and the increased collection of wood and various non-timber forest products) are now threatening the area's rich biodiversity (Li 2002, Xu and Wilkes 2004). As a consequence, northwestern Yunnan (NWY) is receiving much attention from the international conservation community, as well as all levels of the Chinese government.

The Nature Conservancy (TNC) was invited by the provincial government in 1998 to address the threats to biodiversity in the NWY using its collaborative and systematic 'Conservation by Design' process (TNC 2001). Called the Yunnan Great Rivers Project (YGRP), the collaboration produced an ecoregional assessment in 2002, which identified 19 conservation areas of biodiversity significance across the five ecoregions that intersect NWY (YGRPPT 2002).

Following the assessment phase, TNC and local partners then concentrated their efforts at five action sites within the YGRP to produce conservation plans and strategies for effectively protecting and enhancing biodiversity and the livelihoods of local people (Moseley and others 2004). However, TNC and the Yunnan government also are concerned about conservation and rural development across the portfolio of 19 conservation areas of biodiversity significance identified during the ecoregional assessment. While some species-level inventories exist and detailed vegetation maps are being assembled for the region, there has been little research on important landscape-level questions, such as rates of ecosystem succession, scale and frequency of disturbance regimes, and patterns and intensity of past and ongoing threats to conservation targets (Moseley 2004).

TNC has been using repeat historical photography (for example, see Rogers 1984, Hall 2001, Turner and others 2003) to understand rates and patterns of ecosystem change under varying land-uses, to set realistic goals for conservation programs, and to establish reliable methods for measuring conservation successes (Moseley 2004). Such investigations also provide a base for developing a comprehensive photomonitoring system for the entire YGRP. Such forward-sampling, ecological studies of landscape changes are very important to designing and implementing sustainable conservation and management strategies (Lunt 2002, Pickard 2002) and, hence, are critical to the future of biodiversity and local people in NWY, and elsewhere.

Here we report the development of a relatively simple, yet rigorous, methodology that employs ground-based, repeat photography as an extensive, efficient, and cost-effective means for monitoring ecological changes at the landscape level across expansive ecoregions. Specifically, this study: (1) designs, tests, and refines an image capturing and processing workflow methodology that includes image and metadata management; (2) develops and tests an indicator-based analytical framework for assessing ecological changes identifiable and quantifiable from oblique, ground-based photographs; and (3) designs a sampling methodology for selecting photomonitoring transects representative of spatial and temporal variations in landscapes across NWY.

Study Area

This study was conducted across the Yunnan Great Rivers Project (YGRP), an area of over 66,000 km2, comprising 15 counties and four prefectures (fig. 1). The region's biophysical uniqueness arises from its location between the Qinghai-Tibet and the Yunnan-Guizhou Plateaus and from the four major rivers (Jinsha, Lancang, Nu, and Dulong) that cut deep, parallel gorges in the landscape all within 90 km of one another. This results in very steep elevation gradients that can rise from river valleys below 1500 m to glaciated peaks at over 6500 m within a distance of 20 km or less. Although at a subtropical latitude, the region's climate is characteristically temperate, modified by a summer monsoon season leading to warm, wet summers and cool, dry winters. The topographic extremes that characterize the region cause major microclimatic differences associated with changes in elevation, slope, and aspect.

The region's wide ranging environmental conditions support a biological diversity that rivals that found in the tropics (CBD 2001). Five World Wildlife Fund (WWF) ecoregions (Olson and Dinerstein 1998) are found within the YGRP, the largest being the Nujiang-Lancang Gorge and the Hengduan Mountains (fig. 1). Ten different vegetation types occur across the region with the most important being the alpine mosaic and a variety of natural forest ecosystems, the latter covering over 60 percent of region (Xu and Wilkes 2004).

All landscapes in NWY have been influenced by human activities for thousands of years. Population density is relatively low, especially compared to eastern China, and except for a few modest urban centers, most people live in rural areas. Although income-generating endeavors are becoming more important, local people historically have focused on subsistence agriculture, including livestock production and the collection of plants and animals from natural areas. All but two counties in the YGRP are considered poverty counties under the Chinese classification system. Fourteen ethnic minority groups are living within the region, which is significant because of their differing cultures and practices relative to land-use (Xu and Wilkes 2004).

Methods

Workflow Development

An extensive review of repeat photography literature and modern photographic techniques and equipment was conducted. Equipment had to be durable and dependable under wet or dusty field conditions, extremely portable, able to take and process potentially thousands of images, and capable of daily operation for multiple weeks without access to AC power. We examined data management programs for their comprehensive capabilities to catalogue a large number of images in formats useful for future analysis. Back up and archival needs were examined in relation to current technology. A comprehensive workflow was designed in Ithaca, New York during the first half of 2003, and tested during the summer and fall in NWY, all leading to a refined system for image capture, management, and storage.

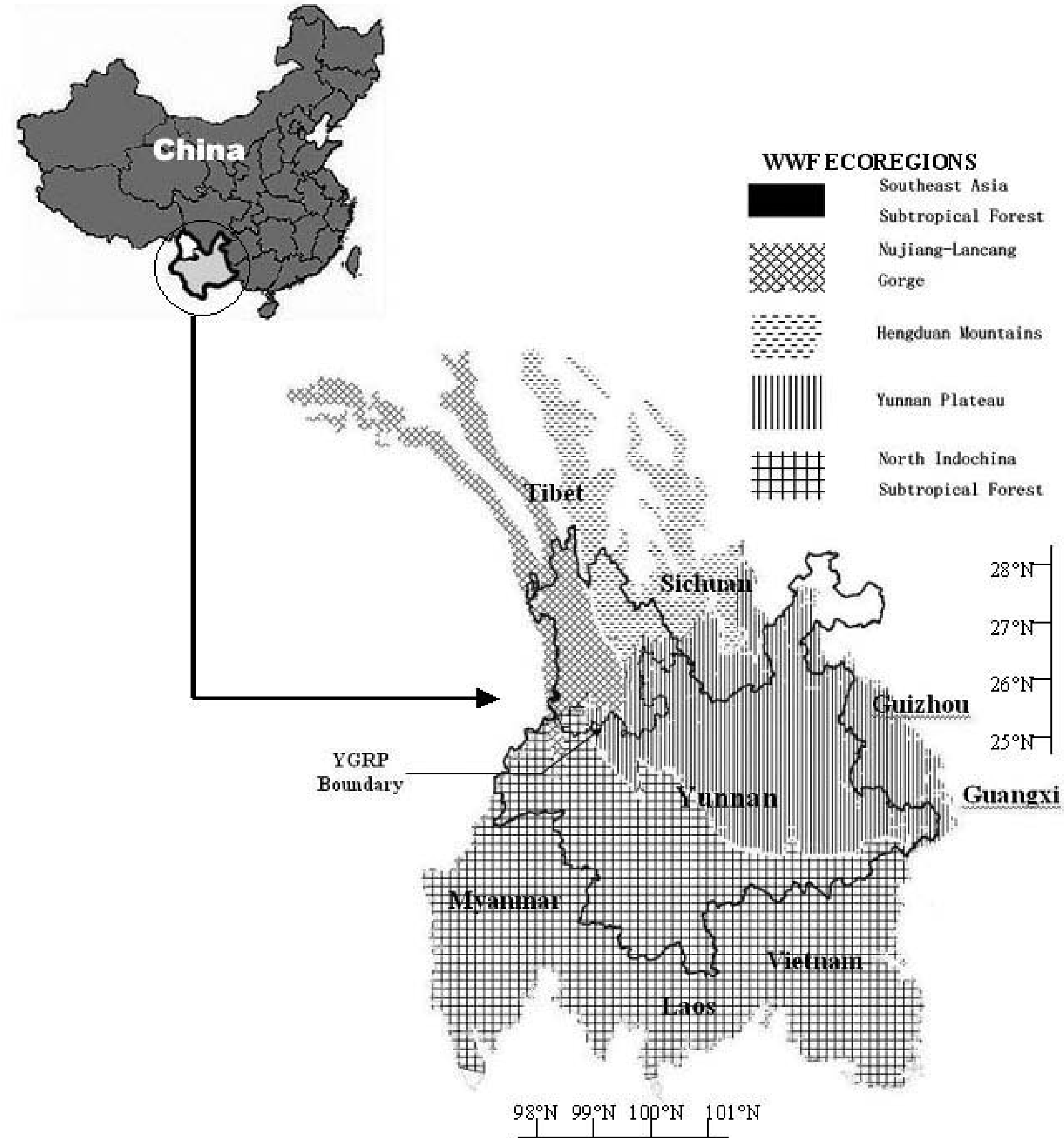

Figure 1. Map Showing Location of the Yunnan and Yunnan Great Rivers Project (YGRP) in Relation to Five World Wildlife Fund (WWF) Ecoregions.

Analytical Framework

Critical to the successful use of repeated photographs for measuring the impacts of conversation programs is the analytical framework for interpreting indicators of change to biodiversity and threats. TNC's four-part conservation framework called 'Conservation by Design' provides this important analytical context (TNC 2001). The framework was developed to systematically focus conservation action on priority biodiversity and critical threats in a dynamic, adaptive process involving setting geographic and threat priorities through ecoregional assessments, developing strategies, taking actions, and measuring conservation impacts (Groves and others 2002, Groves 2003).

The conservation planning framework for ecoregional assessments includes four steps relevant to the current study: (1) selecting focal conservation targets from the universe of possible species and ecosystems, (2) setting representation and quality goals for conservation targets, (3) evaluating the ability of conservation targets to persist (in other words, assessing viability and ecological integrity) and (4) selecting and designing a network of conservation areas of biodiversity significance (Groves 2003). Because Conservation by Design is an adaptive process, it requires monitoring the conservation status of ecoregions. Critical attributes of ecoregional measures include:

- Tracking progress toward quantitative goals set for each conservation target during ecoregional assessments.
- Informing whether current management is sufficient to protect the viability and persistence of conservation targets in the long run.
- Providing a gauge of conservation priorities and whether they should shift as environmental conditions change over time.
- Measuring threat status within an ecoregion to provide an 'early warning system' to detect changes more quickly than relying solely on biodiversity health measures.

After completing the YGRP ecoregional assessment, we developed a monitoring framework of 28 prioritized indicators—nine being health indicators (for example, size, erosion, fragmentation) for conservation targets and 19 being threat indicators (for example, unsustainable collection of fuelwood and non-timber forest products, over-grazing, mining). This ecoregional photomonitoring methodology is designed to assess several of these threat and target health indicators that are observable from examining photographs of landscapes. These were tested for usefulness based on earlier work using historical photographs by Moseley (2004). Additional land cover, land-use, development infrastructures, geopolitical and conservation classifications were developed based on experience in the study area. Combined, all were used as 'keywords' for classifying images taken during the 2003 field season.

Sampling Design

A unique feature of the work presented is the development of a sampling methodology that accurately represents the diversity inherent across extensive ecoregions. Even stratified randomization is inoperable here owing to the extent of the areas involved, challenges of accessibility in rugged landscapes, and the need to gain a landscape perspective that is often distant from the indicator(s) under consideration. Our approach was to stratify the study area by features central to the analytical framework and then to use TNC's GIS database to determine the area represented by each. This work was carried out during the summer of 2004 in preparation for the fall field season. The features examined were: (1) WWF ecoregions, (2) conservation areas of biodiversity significance identified during the ecoregional assessment, (3) distribution of key conservation targets from the ecoregional assessment, (4) principle ethnic minority present (a surrogate for culturally based land-use practices), and (5) modeled climatic zones (B. Baker, Climate Change Scientist, TNC; personal communication) (table 1). Next, we designed transects for obtaining 'baseline' photographs. The scheme devised sampled each feature proportional to its distribution within each stratum. For example, if the mixed forest target covers 34 percent of the Baima Conservation Area, then about 34 percent of the photographs in this area should be taken of this target. Each feature was examined in relation to one another to gain a qualitative assessment of the sampling needs. Since the location of roads and/or trails is critical logistically, accessibility also was addressed when designing transect locations.

Results and Discussion

Workflow Development

The workflow process was designed to yield images and their supporting metadata that could be used in the analysis of indicators of landscape change over time (discussed later). It consisted of four interrelated steps: (1) initial image capture, metadata collection, and

Table 1. Features used to stratify Yunnan Great Rivers Project area to determine photomonitoring sampling design.

Feature	Elements
Ecoregions (n = 5)	e.g., Hengduan Mountains, Nujiang-Lancang Gorge, Yunnan Plateau
Conservation Areas (n = 19)	e.g., Baima, Nushan, Zhongdian Highlands
Conservation Targets	CEO: cold evergreen oak; EBF: evergreen broadleaf forest; MF: mixed forest SAF: subalpine forests; AM: alpine mosaic (shrub, meadow, scree)
Ethnic Minorities (n = 14)	e.g., Lisu, Naxi, Tibetan
Climatic Zones (Clusters)	1: hot summers, cool winters, very wet; 2: cool summers, cold winters, moderate precipitation; 3: warm summers, cool winters, moderate precipitation; 4: warm summers, warm winters, moderate precipitation; 5: warm summers, cool winters, dry

temporary storage; (2) imaging processing; (3) image and metadata management; and (4) storage of working and archival data files. It is presented in generic fashion, but specifications for all equipment and software are available from the senior author. Although the entire process could be conducted under field conditions, it was found that inclement weather conditions and the lack of AC power over long periods of time made computer processing difficult, thus making all but the image capture step better suited for the office.

Image capture

The system was built around a professional quality, high resolution, digital single lens reflex camera capable of accepting exchangeable lenses. Such cameras offer many options for capturing, modifying, and storing images. For this study, settings were selected to maximize the quality of resulting images, which simplifies to holding the camera steady and striving for the highest quality captures possible. A sturdy tripod matched with a ball head was used to precisely position the camera enabling level, overlapping images typically representing views of 180-360o and, as necessary, to hold it steady during long exposures. A low effective ISO rating (125 – 200) was used to reduce digital noise (similar to grain in film cameras). Images were taken in the RAW 12-bit data file format yielding uncompressed files approximately 8 MB in size. When storage capacity in the field was limited, RAW files were compressed by 50 to 60 percent using a proprietary process reported to cause only a minor loss in image quality (Cardinal and Peterson 2002). The RAW format yields unadjusted data from the camera's CCD sensor, thus providing the greatest amount of image information possible while also allowing the greatest amount of post-exposure manipulation (Cardinal and Peterson 2001).

Lens quality is an important variable in photography and various high quality professional zoom lenses representing digital camera focal lengths from 30 to 600 mm were tested during the 2003 field season. Based on this work, two new lenses designed for the digital camera were purchased for the 2004 field season. These yield an effective focal length range of 18 to 180 mm, which is well suited to expansive landscapes typical of NWY.

In-camera image capture and temporary storage capacities must be relatively fast and large owing to the large files involved. Although we found that carrying two 512 MB cards provided enough storage capacity for two or three days of intensive photo-sampling, there was a need to have a portable image storage unit during longer trips into remote areas. A number of rechargeable storage devices are available, the most useful and expensive being those capable of image display. However, because of a concern over battery longevity, we used a relatively inexpensive (about US$200), 220-volt rechargeable, 20 GB Chinese unit that lacked image display capabilities. The major considerations when deciding to rely on such devices are their battery life, durability under adverse conditions, and their cost relative to purchasing multiple, in-camera storage cards. For this project, having three or four 1 GB cards would be sufficient storage for a field trip lasting two weeks, thus forgoing the uncertainty of an additional piece of battery-powered equipment. The use of multiple cards is recommended because of the possibility of malfunctioning of a single, large-capacity card.

The rechargeable proprietary battery used in our camera proved to be long lasting under the conditions of this study (approximately 100 images/day, no flash, and limited use of the camera's LCD screen), and two were sufficient for trips lasting up to two weeks. However, digital cameras, and most of their modern film counterparts, are totally inoperable without battery power. Hence, adequate back up is a must – this project used a 30-watt, 220-volt rechargeable unit during long periods in the field. The auxiliary battery also allowed greater use of the camera's LCD screen to examine tonal histograms in the field leading to improved exposures (Cardinal and Peterson 2001).

Metadata associated with each image arose from two sources. First, the camera tags an EXIF (Exchangeable Image File Format; see: http://www.exif.org/) text file to all images that provides a record of shooting information (for example, date, time file format, lens, focal length, shutter speed, etc.). In addition, when properly connected to a GPS unit (Cardinal and Peterson 2002), longitude, latitude, and elevation are added to this file. Comments also can be added at the time of downloading images to the computer. The second source of metadata was a written record of location; transect, stop, and view numbers; weather conditions; and camera compass and tilt orientations. This information was added to each image's IPTC (International Press Telecommunications Council; see: http://www.iptc.org/metadata/) file during the image processing stage.

Imaging processing

Once in the office, RAW images from the camera's storage cards (or the storage unit) were transferred to a high capacity laptop computer using proprietary transfer software. These were opened using 12-bit RAW software and adjusted as needed (for example, tonal range, color balance, sharpening, white balance, etc.) to provide the high quality images possible. Camera data from the EXIF files were automatically added to the IPTC files while written information had to be added manually. These images can be opened in any professional image processing software and further manipulated as needed. All images were numbered consecutively from 00000 and stored in folders by transect.

Image and metadata management

A high capacity, versatile professional software package was used for image and data management. This program uses low-resolution 'thumbnail' images linked to original files, which are rapidly searchable using a system of predetermined keywords and custom fields (for example, date/time, numbers, text, etc.). Each thumbnail also carries general information that is not searchable (for example, title, IPTC data, information about the image file and when it was catalogued, etc.).

The linchpin for any searchable database is the development of standardized framework for cataloging individual pieces of stored information. For this study, such characterizations had to describe visible or otherwise discernable indicators of impacts or threats on key conservation targets. Custom fields were designed for this study primarily to identify photomonitoring locations in relation to geographical, ethnic, conservation, and political boundaries (table 2), while keywords focused on identification of ecoregional conservation targets, land cover, land-use, infrastructure, and disturbance (table 3).

Data storage

Great care was taken in developing and utilizing a multiple storage/archival system owing to the large investment of time and money that was required to obtain the original images. Original RAW images and resulting processed images were backed up on the laptop computer's secondary hard disk and a portable hard disk, as well as archived on a desktop workstation's hard disk and on high quality DVDs. The final image database catalogue was backed up on the portable hard disk and archived on a high quality CD-R.

Analytical framework

The YGRP ecoregional monitoring framework identified indicators for discerning trends in key conservation

Table 2. Custom fields used for cataloging images in database management system.

Custom Field Name	Definition
Camera Orientation	Direction (degrees) camera is pointed for image
County	County where image is located (n =16)
Ecoregions	Ecoregion where image is located (multiple entries possible) (N = 5)
Ethnic Groups	Ethnic groups found in area image is located (multiple entry possible) (N = 14)
Focal Length	Lens focal length (mm) used for image
GPS	Latitude (UTM), Longitude (UTM), and Altitude (m)
Image Repeat # (0=original)	Identifies whether image is original, 1st retake, 2nd retake, etc.
Location/Directions	Description of the location and directions to photo-stop
Miscellaneous	Other information including whether telephoto lens is used, whether camera is tilted up or down, whether there was a mistake in the shot, or whether the image is linked to other projects (e.g., Alpine Ecosystem Project, Historical Repeat Photography Project, etc.)
Conservation Areas	TNC identified Conservation Areas where image is taken in (multiple entries possible) (n = 19)
Prediction/Significance	Comments on whether we predict any changes or see any significant impacts worth mention
Prefecture	Prefecture that image is taken
Protected Area	If applicable, government protected area where image is taken
Stop Code	The photo-stop number along the given transect
TNC Conservation Action Area	If applicable, TNC Conservation Action area where image is taken (N =5)
Transect Code	Transect number (e.g., 1-15 for 2003 field season)
View Code	View number for a given photo-stop number
Weather, Air/Light Quality	Description of weather and air/light quality when image is taken

Table 3. Selected list of keywords used in image database.

Ecoregional Targets	Land Cover	Land Use	Infra-structure	Disturbance
alpine mosaic	warm conifer forest	commercial logging	bridges	disturbed forest
evergreen broad-leaf forest	warm scrub	crop fields	roads	human caused fire
mixed forest	upper/lower timberline	grazing	trails	logging roads
dark needle conifer forest	humid shrub	horticulture	public utilities	natural forest disturbance
deciduous broad-leaf forest	arid grassland	fuelwood harvesting	seasonal houses	skid trails
cold evergreen oak forest	lacustrine aquatic	mines & mining	towns & villages	soil erosion

Table 4. Example of indicator matrix for Evergreen Oak Forest Target in the Hengduan Mountains Ecoregion.

Target	Threat	Target Health Category	Visual Indicators
Evergreen Oak Forest	Fuelwood	Size	Clearing
		Condition	Structural changes Extraction methods
	Livestock Bedding	Condition	Structural changes
	Tourism & Infrastructure	Size (loss of native habitat)	Roads, Buildings/structures for tourism, trails, cableways, billboards
		Condition (erosion, pollution)	Roads, Buildings/structures for tourism, trails, cableways, billboards
		Landscape context (fragmentation)	Roads, Buildings/structures for tourism, trails, cableways, billboard
	Mining	Size (loss of native habitat)	Mines, roads, waste material, buildings, impacts to hydrology, evidence of soil erosion
		Condition (erosion, pollution)	Mines, roads, waste material, buildings, impacts to hydrology, evidence of soil erosion
		Landscape context (fragmentation)	Mines, roads, waste material, buildings, impacts to hydrology, evidence of soil erosion

targets and related threats. As illustrated in table 4 for the Evergreen Oak Forest Target in the Hengduan Mountains Ecoregion, this information was used to generate related indicators of changes in target health that could be visually detected from landscape images. These were in turn either tied to specific keywords used to catalogue landscape images in the database (table 3) or were detectable from examining changes in the target over time (for example, structural changes in canopy, extent of burning or clearing, etc.). Figure 2 illustrates how a few of these indicators appear in an image from about 3900 m in one conservation area in the Hengduan Mountains Ecoregion.

When accessing the image database, custom fields are used to restrict the search to certain ecoregions, specific conservation areas, and/or other geopolitical units (table 2), and then keywords (table 3) are used to further sort for conservation concerns. For example, all photographs of dark needle forests (with their respective ICPT information), in Baima Conservation Area and also Deqin County, that show commercial logging, logging roads, and soil erosion can be quickly located from a catalogue of thousands of images from across the entire YGRP area. The power of the system as a search engine is obvious, but its real value to this project arises from its use as an analytical framework for assessing changes in conservation targets and threats over time.

This project has developed a new methodology that will be used for an initial survey to document 'baseline' conditions of the YGRP. Hence, comparison photographs will not be available until some time in the future. However, Moseley's (2004) historical repeat photography work makes it possible to test the potential interpretative value of having an extensive set of paired and well-documented photographs for all conservation targets across all ecoregions and conservation areas in the YGRP area. For example, Moseley (2004) presented two photographs separated by almost 80 years looking into a Tibetan alpine valley in the Nushan Conservation Area. This comparison illustrated marked increases in the ecological impacts of yak grazing on the Alpine Mosaic Conservation Target: increased number of trails through meadows and rhododendron shrublands, increased number of herder camps, and reduced cover of juniper shrublands due to burning. The conclusion was, at least for this area, that there has been an increase in grazing pressure by yaks during the past 80 years. Moseley (2004) went on to analyze 115 paired photographs basically assessing whether they showed an increase, decrease, or no change in area or density of various land cover (for example, settlements, glaciers, lower and alpine treelines) and vegetation (for example, crop fields, subalpine forests, alpine meadows) types, drawing ecological and conservation conclusions based on the changes observed. This 'qualitative' assessment of temporal ecological change has been a common and useful approach to interpreting repeated historical photographs (for example, Meagher and Houston 1998).

However, the high quality images resulting from this methodology offer more options for interpretation. Figure 3 illustrates the same valley just discussed, but taken in the fall of 2003. The ability to digitally 'stitch' multiple images together into panoramas greatly enhances the landscape perspective over single images, and the use of high-resolution color strikingly improves the ability to discern vegetation, landscape, and land-use features

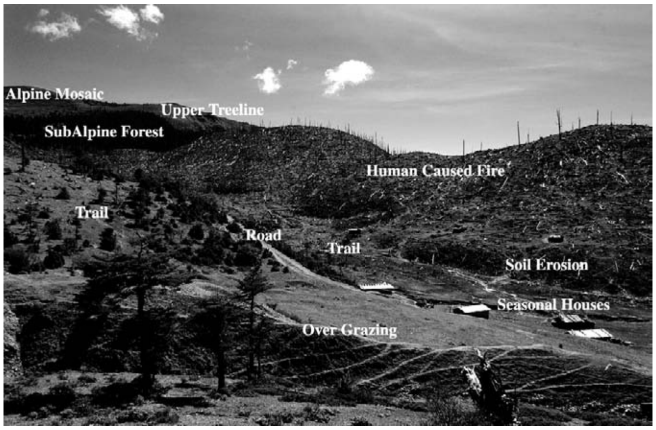

Figure 2. Visual Indicators in an Image from Shangri-La Gorge Conservation Area, Hengduan Mountain Ecoregion, Yunnan Great Rivers Project.

Figure 3. 2003 Three-Image Photomontage of Alpine Pasture from Dokela Pass in Nushan Conservation Area, Yunnan Great Rivers Project. (see fig. 3 and text for explanation).

over using black and white images, which is necessary when comparing them to historical photographs. In addition, the high image quality means that post-capture digital enlargements or telephoto images in the field of portions of a landscape can provide excellent details for fine-scale interpretations.

Sampling Design

A significant limitation of repeat historical photography as an ecological tool is the inherent lack of a sampling methodology that assures representative coverage of natural variation within and between ecologically diverse areas (Pickard 2002, Moseley 2004). This study attempted to overcome this problem by first examining the general variation represented across the YGRP, and then by designing a series of photomonitoring transects that proportionally sampled this variation. A comprehensive GIS database, developed by TNC, was used to examine the variation in key features across the region (table 1). The proportional coverage of particular targets for each conservation area was found to best serve the purposes of this study (table 5). Distribution maps of dominant ethnic minority groups and climatic zones were used in refining the sampling conclusions arising from an examination of the proportion of targets sampled (discussed later).

2003 data set

During the summer and fall of 2003, 15 transects along roads and trails were conducted in NWY, yielding 157 geo-referenced photo-points and 1501 images (fig. 4). Overlapping, multiple images at different camera orientations were taken at each photo-point to allow photomontages (fig. 4) and to avoid the 'subject bias' criticism commonly directed at historical repeat photography studies (Pickard 2002). This data set primarily served to test and refine the methodological workflow

Table 5. Comparison of photomonitoring coverage of five conservation targets relative to their geographical extent for three conservation areas.

Conservation Areas	Total for all Area[a]		Conservation Targets[b] EBF		CEO		SAF		MF		AM	
	Images %	Area %	Images %	Area %	Images %	Area %	Images %	Area %	Images %	Area %	Images %	Area %
Baima	14	18	2	1	5	6	41	47	25	4	42	28
Nushan	20	18	<1	4	0	1	17	35	37	12	35	23
Zhongdian Highlands	48	24	0	<1	10	2	50	46	10	6	34	35

[a] Images N = 1501; Area N = 3.033 x 10^6 ha for 19 areas
[b] See Table 1 for codes
[c] Percentages of images from conservation area (N: Baima = 202, Nushan = 303, Zhongdian Highlands = 726; 270 of 1501 were from outside the conservation areas)
[d] Percentage of conservation area

discussed earlier. As such, the focus was on developing appropriate camera techniques and image and meta-data management, and not on acquiring a representative sample. Hence, some images and transects were flawed making their analysis difficult. However, those that were adequate for the purpose of analysis, particularly transects from the latter part of the 2003 field season (fall), will become part of the baseline sample (discussed in the next section).

Fieldtrips were opportunistic in that they took advantage of trips arranged for other TNC program purposes. As a result photographs came from only two (Hengduan Mountains and the Nujiang-Lancang Gorge) of the area's five ecoregions, and only three (Baima, Nushan, and Zhongdian Highlands) of its 19 conservation areas. Only three minority groups (Lisu, Nu, and Tibetan) were represented out of 14 inhabiting the region. All five conservation targets were sampled, but since much of the fieldwork was conducted in association with TNC's Alpine Ecosystem Ecology Project, there was a disproportionate sampling of the Subalpine Forest and Alpine Mosaic targets relative to their areas. For similar reasons, almost 90 percent of the images represented landscapes influenced by Tibetan communities, as they predominately graze livestock at higher elevations throughout the YGRP area (Xu and Wilkes 2004).

Baseline sample

The three conservation areas surveyed in 2003 were examined to determine voids in the database and to design transects needed to complete the coverage of the variation represented by the conservation targets, principle ethnic minorities present, and the climatic zones. For example, for Baima additional images of the Subalpine Forests Target are needed in the northern portion of the area (table 5), and a complete sampling scheme is needed for the southern portion in order adequately represent the area's distribution of two additional ethnic groups and two additional climatic zones (fig. 5).When working in this southern portion, transects and photo-points will be established to sample the distribution of targets proportional to their representation (table 5),

Next, the locations of the transects required to cover the sampling requirements need to be determined. Owing to the rugged topography, existing roads and trails must serve as transect paths. Fortunately, the long history of human use in NWY means that trails are common, even across the most isolated regions. GIS-generated maps show the general location of roads and trails in relation to conservation targets (fig. 5), but determining the exact location of transects requires input from professionals and local people knowledgeable of the region.

Future sampling

The baseline photomonitoring survey will be completed over the next two or three years, yielding thousands of images across the YGRP area. The health indicators identified in this project change relatively slowly, but there is little doubt that repeated photographs 50-100 years hence will illustrate marked differences (Moseley 2004). However, if repeat photomonitoring is to be useful to conservation planning by TNC and others, it must yield insights much quicker, within a decade or less.

It is expected that photo-sample points will be relocated and landscapes re-photographed in 3-8 years. This time period will illustrate relatively little ecological change in undisturbed landscapes. However, socio-economic conditions are changing quickly in NWY leading to rapid changes in land-use and infrastructure, which are represented by changes in threat indicators. For example, a current government program aimed at rehabilitating many over-grazed lands is fencing thousands of hectares

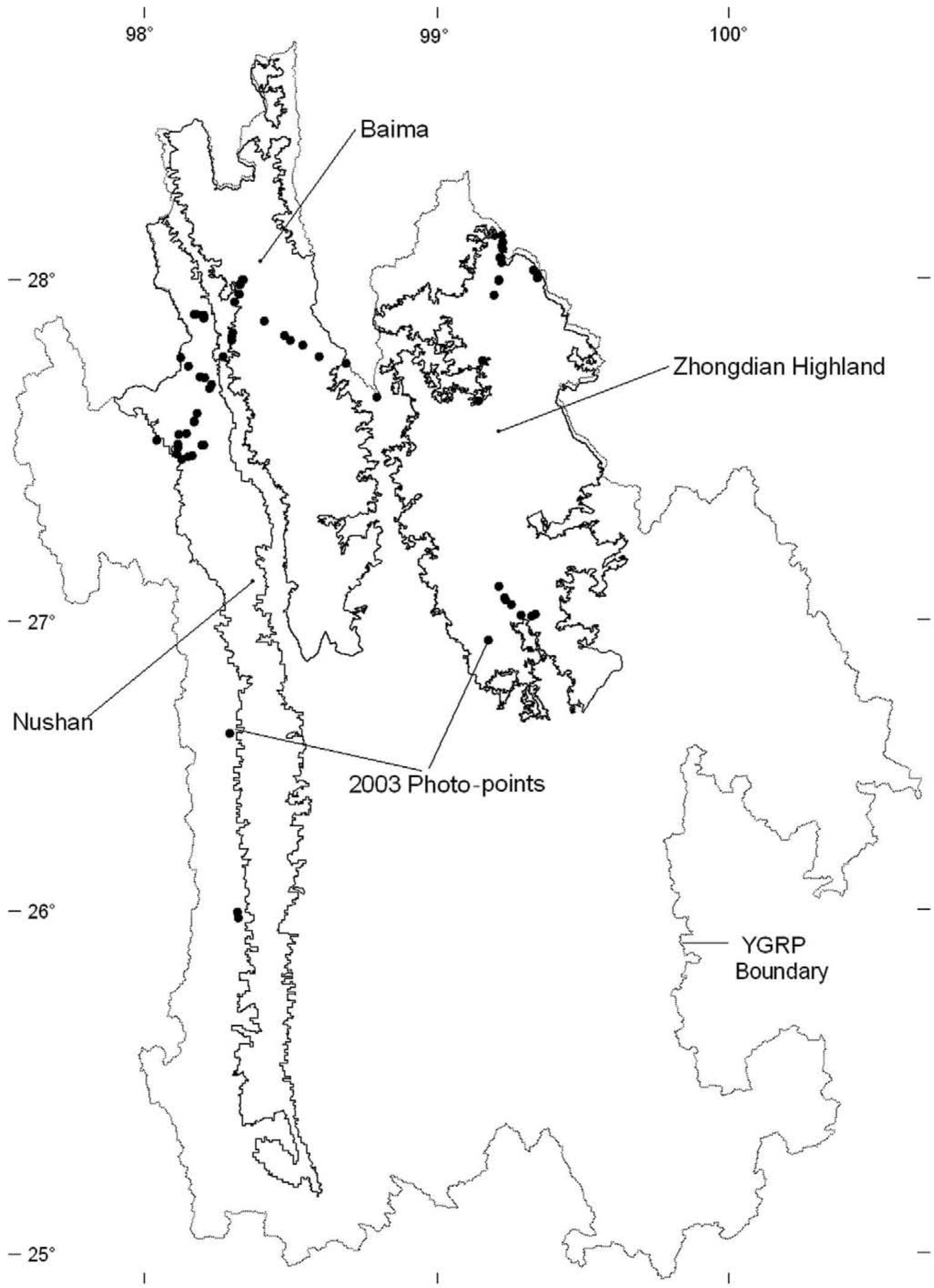

Figure 4. Location of 2003 Photo-points Across three Conservation Areas in the Yunnan Great Rivers Project (YGRP) Area.

across the region ('Grazing to Grassland'), roads are being built to improve access to remote areas as well as to open new routes for mining and tourism development, and the 1998 logging ban remains in effect. In addition, intensive conservation efforts underway by TNC and other organizations and government agencies are influencing indicators of target health and threats. Hence, it is highly probable, depending on the location, the degree of human disturbance, and the type and extent of conservation interventions, that marked changes in certain landscapes might be detected within a few years. How TNC and its partners address these changes in relation to their conservation activities across the YGRP area is a challenge they are currently addressing. In any case, the systematic and complete ecoregional photomonitoring of NWY will provide one tool, an analyzed visual database, to help with such determinations.

Conclusions

This project developed a forward-sampling, ground-based photomonitoring system for examining ecological changes in landscapes within five major ecoregions in northwestern Yunnan, China. It is unique in its design, as other studies rely on historical photographs to support conclusions concerning the present ecological conditions of the landscapes in question. The approach reported will yield a comprehensive inventory of such conditions over time and a means for analyzing visual indicators of ecological change across extensive ecoregion.

Three features of this study are critical to its future success as a tool for measuring the impact of conservation programs. First, is the use of high quality photography techniques and the efficient management of the resulting images and metadata. Second, is the design of an analytical framework for identifying and measuring visual indicators of change that are tied to a comprehensive conservation planning scheme, here TNC's Conservation by Design process. Lastly, is the design of a sampling methodology that accounts for the variation inherent in the ecoregions under consideration.

This project was designed within a conservation context specific to protecting biodiversity and local livelihoods in northwestern Yunnan. Hence, it will prove useful in monitoring not only TNC-specific activities in the region, but also the efforts of other organizations and government agencies concerned with the conservation and sustainable development of this particular biodiversity hotspot. However, this methodology also should be adaptable to other locations and different conservation contexts – especially situations where detailed ecological data are sparse, access to aerial photographs and satellite data is limited, and relatively rapid and inexpensive landscape-level or ecoregional inventories are needed.

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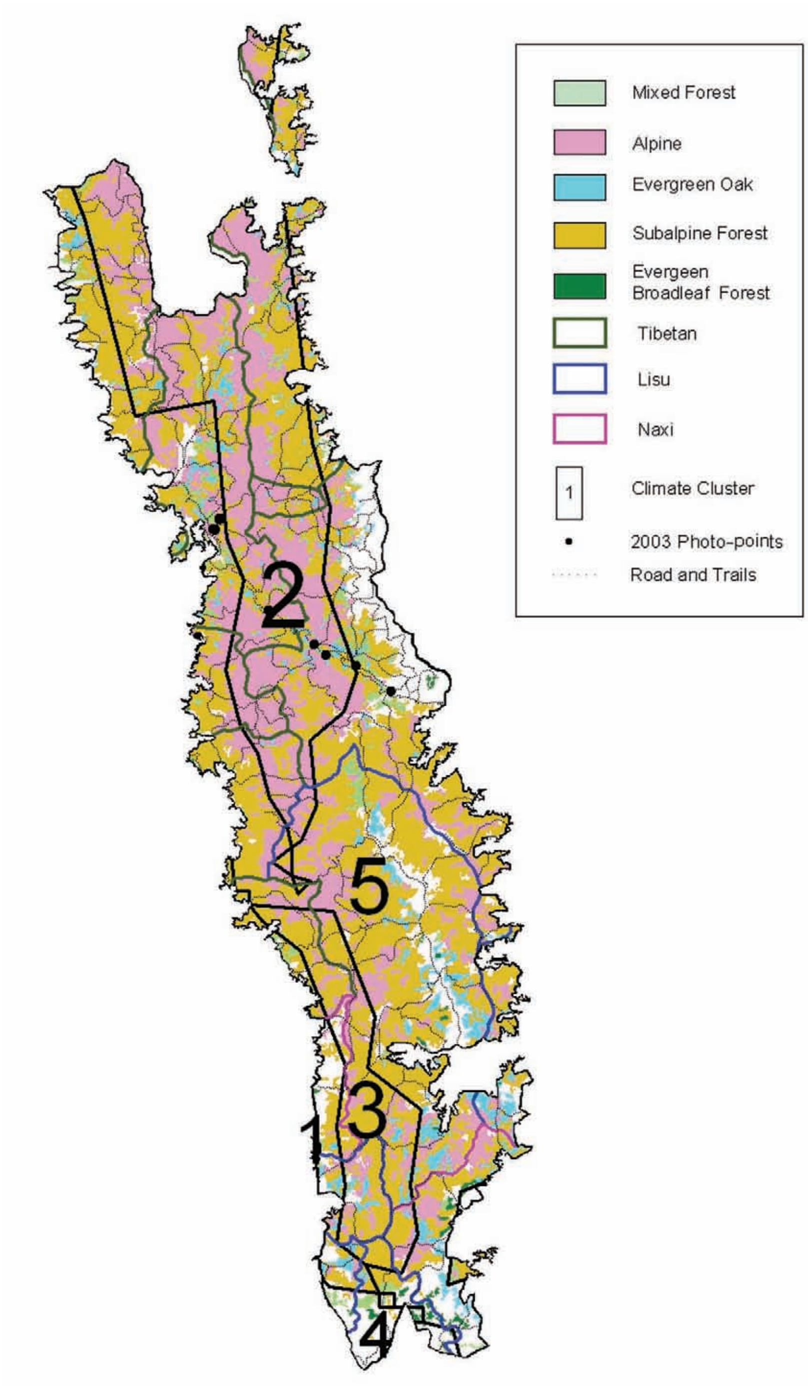

Figure 5. Distribution of 2003 Photo-points in Relation to Conservation Targets, Ethnic Minorities, Climatic Clusters (Zones) (see table 1 for key), and Trails and Roads in Baima Conservation Area, Nujiang-Lancang Gorge Ecoregion, Yunnan Great Rivers Project (YGRP).

Carbon Pools—Checking the Deep End, Before Diving In (The ME Experience)

K. M. Laustsen, Biometrician, Maine Forest Service, Department of Conservation, Augusta, ME

Abstract—*Maine's initial Greenhouse Gas (GHG) estimates of the Land Use Change and Forestry (LUCF) sub-accounts predicted that this account supplied 15 percent of the net emissions in 2000. The magnitude and direction of this estimate ran counter to internal assumptions and the recently published analysis on multiple and positive forest inventory changes for the period of 1995 to 2002. The major cause was the simple assignment and linkage of a forest soil's organic carbon level to a single specific forest type group. Carbon emissions were predicted as a result of changes in the forest type distribution over successive periodic and annual inventories (1980 to 2002). In general, plots transitioned from previous softwood to a new hardwood forest type group, creating an assumed and immediate diminution in the underlying soil's organic carbon level. Improved carbon flux estimations were obtained by: the use of a single forest-typing algorithm to ameliorate changes in the soil sub-account; incorporating regional and local biomass equations; utilizing FIA P3 DWM data; state level accounting of processed wood products and residues; and a structured analysis of land use coding for conversion and reversion rates.*

Introduction

In 2003, Maine's legislature charged the Department of Environmental Protection, Bureau of Air Quality, with a statutory requirement to produce an annual statewide Greenhouse Gas (GHG) emission inventory. The federal Environmental Protection Agency (EPA), through its contractor, and with input from the USDA Forest Service, developed a spreadsheet program to assist individual states in compiling their GHG inventories. The spreadsheet program has built-in default inventory data, with an option for users to input their own data in order to improve the prediction accuracy of various sub-accounts. The default inputs utilize Maine's 1995 USDA Forest Service Forest Inventory and Analysis (FIA) Periodic Inventory, without updating, to estimate forested conditions for the base year of 2000. The spreadsheet estimated that the "Land Use Change and Forestry" (LUCF) account provided 15 percent of the CO2 emissions (fig. 1). Both the magnitude and direction of this estimate were counter to recent annual inventory reports, released by the Maine Forest Service (MFS), estimating increased forestland coverage and biomass stocking over the period of 1995 to 2002 (Laustsen 2003).

Additional investigation and discussion determined that the soils carbon component represented nearly 60 percent of predicted emissions in the total forest carbon flux. For the initial base estimate, the 1990 Forest Carbon Flux uses updated estimates of Maine's 1982 FIA Periodic Inventory as reported in the 1987 Resource Planning Act Assessment (RPA). The ending base estimates a 2000 Forest Carbon Flux using Maine's 1995 Periodic Inventory as reported in the 1997 RPA. The inconsistent treatment and updating of the base estimates

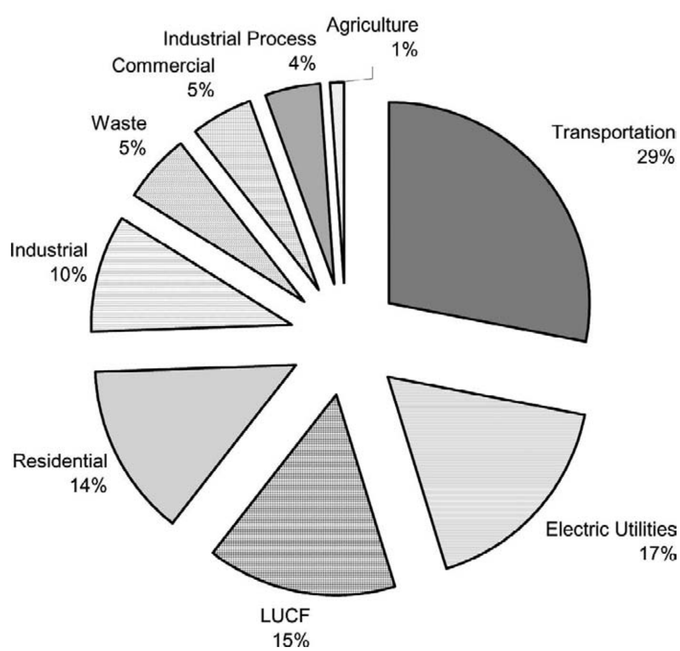

Figure 1. CO2 Emission Estimates, Maine, 200.

was further compounded with additional changes in classification techniques, sampling design, and FORCARB models.

In cooperation with the Durham, NH USDA Forest Service office, MFS was tasked with developing improved inventory and change estimates for the LUCF account (Smith and others, this proceedings).

Methods

An initial assessment provided a successful multi-staged approach to improved estimation techniques:

1. Since a single national equation treats a given species the same everywhere, but truly does not represent that species well anywhere, MFS offered to review additional sources. Published sources of biomass equations were offered in an effort to identify more species-specific regional and local volume equations to replace the imbedded National equations utilized in FORCARB2 for bole, sapling, seedling, and understory vegetation estimates (Chase and others 1978, Heath and others 2001, Honer and others 1983, Wharton and others 1998, Young and others 1980, Young and others 1967).
2. FIA Phase 3 data on down woody material (DWM) was incorporated to improve estimates of the forest floor and the down woody material (DWM) sub-account.
3. A repartitioning of harvested wood products, residue volumes, and import/export accounting was effected, based on historic MFS Wood Processor Reports. Further analysis was required in order to obtain improvement in the two remaining pieces of the forest carbon flux dynamics.
4. The forest soils sub-account proved to be the most difficult to enhance and refine. This sub-account is set up as a simple look-up matrix, in that a single soils carbon value is linked to a single forest type group (MFTYP), regardless of stand age, stocking, or average tree size. The typing algorithm, however, uses relative assessments of each plot's stocking, tree size, crown position, and species composition of primarily merchantable sized trees (5.0"+ d.b.h.) to assign MFTYP. The crux is that the forest typing algorithm and classification process underwent numerous alterations between the inventories of 1982, 1995, and 2003. These imbedded changes confound any trend analysis in trying to determine whether the plot truly underwent natural or management dynamics and had a real type change or rather the algorithm just remixed the classification metrics and assigned a new MFTYP (table 1). The example cited most often is that between the 1982 and the 1995 Periodic Inventories, Maine's Spruce-Fir MFTYP acreage decreased by approximately 2 million acres, with the bulk of the change showing up with increases in the Sugar Maple/Yellow Birch/Beech MFTYP. The associated soil carbon loss in this transition is over 50 tons per hectare and this change was simply averaged as a steady state 10-year emission.
   The parties realized that changes in soil carbon are not that spontaneous, yet were very reluctant to imbed a no net soil carbon change. Some consideration was given

Table 1. Area of forestland by forest type group as originally published or current estimate, Maine.

Forest Type Group	Original & Published 1982 Forest Type Group (Forestland Acres)	Original & Published 1995 Forest Type Group (Forestland Acres)	Estimated 2003 Forest Type Group (Forestland Acres)
Aspen/W. Birch	1,504,900	2,249,600	2,341,937
Elm/Ash/Cottonwood	238,200	434,700	407,184
Other Forestland - Untyped	547,200	751,410	
Loblolly/Shortleaf	8,300	6,700	-
Maple/Beech/Y. Birch	5,000,900	6,408,800	7,055,581
Nonforested	2,229,400	2,064,200	2,033,849
Oak/Gum/Cypress	-	-	11,720
Oak/Hickory	306,500	453,200	320,044
Oak/Pine	36,200	127,600	334,384
Softwood Plantation	-	-	19,062
Spruce/Fir	7,770,500	6,011,200	5,819,039
White/Red/Jack Pine	2,194,700	1,245,900	1,359,302
Timberland - Nonstocked	-	-	49,293
Grand Total	19,836,800	19,753,310	19,751,394
Total Forestland	17,607,400	17,689,110	17,717,545
Total - Nonforested	2,229,400	2,064,200	2,033,849

to modeling a logarithmic type growth/decay function, that would systematically approach the real change over some period of time, but there was no research available to help that progressive transition.

By May 2004, the Northeastern Research Station FIA Unit had already completed the validation and classification of Maine's 1999 to 2003 Annual Inventory Panels using the new National Forest Typing Algorithm. That FIA unit had also completely rerun the plot sample from Maine's 1995 Periodic Inventory using the same algorithm for a determination of real trends and changes in stocking, stand size, and forest types over this 8-year period. MFS requested and received the continued extension of this reclassification, using the same identical algorithm, to the plot sample in Maine's 1982 Periodic Inventory. For the initial 1982 Periodic Inventory, this resulted in only 683 plots being retained and remeasured in the current 1999 to 2003 annualized inventory. The proposal was to use just the 683 remeasured plots as representative of the statewide transitions in carbon accounting.

Furthermore, ongoing MFS analysis raised suspicions about the validity of the 1995 tree level assessments of bole height and cull deduction. This lead to the decision to generate base estimates for 1982 and ending estimates for 2003 and derive average 20-year change components for all of the forest flux sub-accounts.

Another complication was that each of these three inventories used different county-level census acreage for their derived plot expansion factors. The MFS resolution was to utilize the current plot expansion factor (Census 2000) and 2003 Phase 1 stratum weights for both the base and final estimates, assuring additivity across time.

5. A better system of accounting for the conversion of forestland to non-forest and offsetting reversion of non-forest land uses to forestland was needed.

   FIA uses the term "condition class" to identify and map areas of discrete landscape and forest attributes that identify and define different strata on the plot. A condition class is a unique combination of condition status, land use, owner group, forest type, stand origin, stand size, reserve status, stand density, and a disturbance/treatment history. The identification, delineation, and assignment of condition class evolved between the 1982 and the 2003 inventories. Protocols for Maine's 1982 inventory were two-fold: newly established plots were forced to rotate until they represented a single condition class; while remeasured plots were assigned a single condition class based on the observed and encompassing attributes located at plot center.

   For Maine's 1999 to 2003 annualized inventory, condition classes are mapped, allowing multiple delineations on a single sub-plot (1/24th acre). The assignment of condition class #1 was still based on the qualifying attributes at the sub-plot #1's plot center. This sub-plot center is identical to the 1982 plot center for the 683 remeasured plots.

   MFS decided to analyze land use changes between 1982 and 2003 solely on the changes in the land use coding between the 1982 and 2003 inventories for condition class #1.

Results

The first step was to develop an initial forest type group transition table, based on the 683 remeasured plots. This table provided estimates of acres retained, lost, and gained over the 20-year period by specific MFTYP (table 2). For example, the Aspen/White Birch forest type group had a total estimated acreage of 2,245,685 acres in 1982 and 2,594,240 acres in 2003, indicating an overall acreage gain. Over the 20-year period; 863,532 acres remained unchanged; 1,730,708 acres were retyped into this group; and 1,382,153 acres converted to another forest type group, so that the derived annual change is an increase of 17,428 acres per year.

Of the eleven forest type groups, five had net gains (ranging from 1,220 to 53,411 acres per year) and six had net losses (ranging from –2,973 to –45,267 acres per year) (table 3). The average annual net change in table 3 is derived using just the 683 remeasured plots, while table 4 uses all available inventory plots at each measurement occasion. The estimated 1982 to 2003 rates of change are all in the same direction and are roughly of the same magnitude, except for the Oak/Hickory group, which flip-flopped from a 5,000 acre per year decline in table 3 to an estimated 1,500 acre per year increase in table 4.

The next apportionment was to adjust the 1982 individual MFTYP acres, such that they collectively summed to the current 2003 total forestland estimate of 19,751,394 acres (table 4). Table 4 also allows the comparison of this final 1982 reapportionment to three other 1982 estimates of MFTYP acreage.

The most meaningful check compares the "Restated 1982 MFTYP" column to the "Reapportionment of 1982 acres" column. Sugar Maple/Beech/Birch and Spruce/Fir represent 65 percent of the acres and each of their estimates are within 1 percent of the final 1982 reapportionment, Nonforested is within 5 percent, and Aspen/White Birch is within 8 percent. All in all, a pretty good indication that the original 683 plots are representative of the corrected 1982 forest type acreage

Table 2. Cross-tabulation of forest type group and all major land use changes (source 683 FIA plots measured in 1982 and remeasured in 1999-2003). Shaded Cells represent the intersection of acreage (2000 Census and 2003 Phase 1 weighting process) that did not change over the period. The other row values represent acres transitioning out to a new 2003 MFTYP, I.e. Aspen/W. Birch lost 641,975 acres to Maple/Beech/Birch by 2003. The other column values represent acres transitioning into a new MFTYP, I.e. Aspen/W. Birch gained 142,046 acres from Elm/Ash/Cottonwood by 2003.

1982 MFTYP	2003 MFTYP Aspen/W. Birch	Elm/Ash/Cottonwood	Maple/Beech/Y. Birch	Nonforested	Oak/Gum/Cypress	Oak/Hickory
Aspen/W. Birch	863,532		641,975	32,889		27,889
Elm/Ash/Cottonwood	142,046	171,762	157,470			
Maple/Beech/Y. Birch	376,806	73,152	3,893,692	116,942		66,388
Nonforested	231,008	13,139	296,135	1,226,891		
Oak/Gum/Cypress			10,411			
Oak/Hickory	53,924	27,845	28,480	14,296		94,920
Oak/Pine			117,793			
Softwood Plantation						
Spruce/Fir	735,255	108,301	1,263,258	284,873	34,809	
White/Red/Jack Pine	191,670	37,763	291,390	91,375		
Timberland - Nonstocked		34,809		51,256		
2003 MFTYP Totals	**2,594,240**	**466,770**	**6,700,603**	**1,818,522**	**34,809**	**189,196**

1982 MFTYP	2003 MFTYP Oak/Pine	Softwood Plantation	Spruce/Fir	White/Red/Jack Pine	Timberland - Nonstocked	1982 MFTYP Totals
Aspen/W. Birch	34,541		630,564	14,296		2,245,685
Elm/Ash/Cottonwood	11,805		43,140			526,223
Maple/Beech/Y. Birch	92,423	54,084	675,093	283,805		5,632,383
Nonforested	54,735		309,543	44,757		2,176,207
Oak/Gum/Cypress						10,411
Oak/Hickory	48,237		19,456			287,158
Oak/Pine	36,224			61,716		215,733
Softwood Plantation						
Spruce/Fir	68,736		4,353,149	131,285	17,134	6,996,800
White/Red/Jack Pine	87,834		60,517	680,085		1,440,633
Timberland - Nonstocked						86,064
2003 MFTYP Totals	**434,535**	**54,084**	**6,091,461**	**1,215,944**	**17,134**	**19,617,297**

Table 3. A summarized version of table 2, checking to ensure additivity across the assumed average 20-year period (1982 - 2001). Column labeled "Overall Net Change Direction" is a simple gain/loss indicator. Derived Annual Net Change is the calculated annual change (+/-) by MFTYP or land use.

MFTYP	Estimated 1982 Acres	Acres Gained 1982 - 2003	Overall Net Change Direction	Derived Annual Change (Acres/Year) for 20 Years	Acres Lost 1982 - 2003	Estimated 2003 Acres Net Change Summary
Aspen/W. Birch	2,245,685	1,730,708	+	17,428	1,382,153	2,594,240
Elm/Ash/Cottonwood	526,223	295,008	-	(2,973)	354,461	466,770
Maple/Beech/Y. Birch	5,632,383	2,806,912	+	53,411	1,738,691	6,700,603
Nonforested	2,176,207	591,630	-	(17,884)	949,316	1,818,522
Oak/Gum/Cypress	10,411	34,809	+	1,220	10,411	34,809
Oak/Hickory	287,158	94,277	-	(4,898)	192,238	189,196
Oak/Pine	215,733	398,311	+	10,940	179,508	434,535
Softwood Plantation	-	54,084	+	2,704	-	54,084
Spruce/Fir	6,996,800	1,738,311	-	(45,267)	2,643,651	6,091,461
White/Red/Jack Pine	1,440,633	535,859	-	(11,234)	760,548	1,215,944
Timberland - Nonstocked	86,064	17,134	-	(3,447)	86,064	17,134
Totals	**19,617,297**			**0**		**19,617,297**
Total Forestland	**17,441,089**			**17,884**		**17,798,775**
Total - Nonforested	**2,176,207**			**(17,884)**		**1,818,522**

distribution. To get an idea of the fluidity of the typing compare the Restated 1982 MFTYP column (current algorithm) to the Recalculated 1982 MFTYP column (old algorithm) (table 4).

The last step is a combined rubber sheeting and apportionment step, making the apparent type changes in and out of a given MFTYP to be totally additive to the current total of 19,751,394 acres. In doing this final adjustment, MFTYP acres that remained static over the 20-year period were not re-proportioned (table 5).

Table 6 provides the estimated annual change acreage of gains and losses within each MFTYP. Because of the step-wise reapportionment process, changes in the forest soil's organic carbon can now be linked to specific MFTYP changes. This enhanced capability results in soil carbon having a revised and minimal emission value, roughly just 10 percent of the previous estimate.

The same accounting and rebalancing process was conducted to look at specific trends in land use changes. The available land use codes for the 1982 data were limited to four broad land use classes (Forestland-Reserved, Forestland-Unproductive, Nonforested, and Timberland-Rural). These were matched to a full transition matrix identifying the current land use, a listing of 15 possible classes. Because of the limited identification in 1982, and the further restriction to just the land use coded for condition class #1 at sub-plot #1, some invalid transitions were estimated (table 7). An annual net loss of over 5,000 acres per year was estimated to occur from Reserved Forestland to a Timberland-Rural land use code. By FIA definitions, this transition is not allowed.

To minimize the impact of this specific incorrect estimate, Forestland-Reserved and Forestland-Other were recombined into a single 1982 land use class of Forestland. This still estimated a transition of 369 acres per year to a timberland land use, which could now, at least be feasibly attributed to unproductive land becoming productive over the 20-year period. The most frequent use of this table, for carbon flux estimation, is documenting conversions to nonforested uses and the offsetting reversions to forestland. The land use analysis should be re-processed to take into account the two noted problems. To do this, MFS would need to obtain the original 1982 field data. There was a full suite of land use codes, which would improve the transition on sub-plot #1 by allowing acreage to flow to all land uses currently identified on this sub-plot. With these enhancements, a more specific and accurate transition matrix can be produced.

Table 4. Reapportioned 1982 MFTYP, revised annual net change estimates, and 2003 MFTYP Acreage.

MFTYP	Informational Purposes ONLY: Original 1982 MFTYP (Acres) [Published]	Informational Purposes ONLY: Recalculated 1982 MFTYP (Acres) [82 Eastwide] (2,483 plots)	Restated 1982 MFTYP (Acres) (Current Typing Algorithm) (2,483 plots)	Reapportionment of 1982 MFTYP (Acres) (Current Typing Algorithm) (Sums to 2003 total)[2]	New Annual Net Change (Acres/Year) for 20 Years[3]	Current 2003 MFTYP (Acres)[1]
Aspen/W. Birch	1,504,900	1,603,555	2,449,254	2,261,035	4,045	2,341,937
Elm/Ash/Cottonwood	238,200	296,304	618,145	529,820	(6,132)	407,184
Noncommercial Forestland	547,200					
Loblolly/Shortleaf	8,300	4,277	4,277	-	-	-
Maple/Beech/Y. Birch	5,000,900	4,911,681	5,636,349	5,670,884	69,235	7,055,581
Nonforested	2,229,400	2,084,412	2,084,412	2,191,083	(7,862)	2,033,849
Oak/Gum/Cypress	-	12,238	56,522	10,482	62	11,720
Oak/Hickory	306,500	314,953	305,410	289,121	1,546	320,044
Oak/Pine	36,200	313,157	240,676	217,207	5,859	334,384
Softwood Plantation	-	-	-	-	953	19,062
Spruce/Fir	7,770,500	8,438,274	7,130,445	7,044,628	(61,279)	5,819,039
White/Red/Jack Pine	2,194,700	1,952,720	1,304,663	1,450,481	(4,559)	1,359,302
Timberland - Nonstocked	-	17,461	118,879	86,652	(1,868)	49,293
Grand Total	**19,836,800**	**19,949,032**	**19,949,032**	**19,751,394**	**0**	**19,751,394**
Total Forestland	**17,607,400**	**17,864,620**	**17,864,620**	**17,560,311**	**7,862**	**17,717,545**
Total - Nonforested	**2,229,400**	**2,084,412**	**2,084,412**	**2,191,083**	**(7,862)**	**2,033,849**

1 Actual 2003 Acres Column is the current 5-panel estimate by MFTYP, using the current typing algorithm
2 Adjusted 1982 Acres is a proportional construct to obtain additivity across the 20-year period, I.e. {(Table 3. 1982 Estimated 1982 acres/Table 3. 1982 Total acres) X (19,751,394)
3 New Annual Net Change by MFTYP or land use uses just values in Table 4.

Table 5. Rubber Sheeting and Proportionation of the Adjusted 1982 acres and aggregate change into respective Forest Type Groups. Assumed that Forest Type Group acres that remained static did not need any reapportionment. Adjusted remaining column cell values using their table 2 share of Forest type Group Acreage to the current 2003 Forest Type Acreage in table 4. For example, table 1 had Aspen/W. Birch gaining 142,046 acres from Elm/Ash/Cottonwood over the 20-year period. This has been re-proportioned to be only a 121,338 acre gain.

MFTYP	Aspen/W. Birch	Elm/Ash/Cottonwood	Maple/Beech/Y. Birch	Nonforested	Oak/Gum/Cypress	Oak/Hickory
Aspen/W. Birch	863,532	-	723,162	44,859	-	66,595
Elm/Ash/Cottonwood	121,338	171,762	177,385	-	-	-
Maple/Beech/Y. Birch	321,875	58,377	3,893,692	159,503	-	158,529
Nonforested	197,331	10,485	333,586	1,226,891	-	-
Oak/Gum/Cypress	-	-	11,728	-	-	-
Oak/Hickory	46,063	22,221	32,082	19,500	-	94,920
Oak/Pine	-	-	132,690	-	-	-
Softwood Plantation						
Spruce/Fir	628,069	86,426	1,423,017	388,554	11,720	-
White/Red/Jack Pine	163,728	30,135	328,241	124,631	-	-
Timberland - Nonstocked	-	27,778	-	69,910	-	-
2003 Total	**2,341,937**	**407,184**	**7,055,581**	**2,033,849**	**11,720**	**320,044**

MFTYP	Oak/Pine	Softwood Plantation	Spruce/Fir	White/Red/Jack Pine	Timberland - Nonstocked	New Proportioned 1982 Total
Aspen/W. Birch	25,856		531,744	18,121	-	2,273,869
Elm/Ash/Cottonwood	8,837		36,379	-	-	515,701
Maple/Beech/Y. Birch	69,184	19,062	569,294	359,731	-	5,609,246
Nonforested	40,972		261,032	56,731	-	2,127,029
Oak/Gum/Cypress	-		-	-	-	11,728
Oak/Hickory	36,108		16,407	-	-	267,300
Oak/Pine	36,224		-	78,226	-	247,140
Softwood Plantation						
Spruce/Fir	51,453		4,353,149	166,408	49,293	7,158,090
White/Red/Jack Pine	65,749		51,033	680,085	-	1,443,602
Timberland - Nonstocked	-		-	-	-	97,688
2003 Total	**334,384**	**19,062**	**5,819,039**	**1,359,302**	**49,293**	**19,751,394**
					Total Forestland	**17,624,365**
					Total - Nonforested	**2,127,029**

Table 6. MFTYP Annual Net Change. Suggested Use is calculating the Forest Soil's Organic Carbon flux by Forest Type Group. Need to read JUST down the column, looking at JUST the unshaded values, to avoid duplication. For example, on an annual basis, Aspen/W. Birch has gained 6,067 acre per year from Elm/Ash/Cottonwood and concurrently lost (20,064) acres to Maple/Beech/Birch.

	Annual Net Change (Acres/Year) estimated for the period of 1982 - 2003					
MFTYP	**Aspen/W. Birch**	**Elm/Ash/Cottonwood**	**Maple/Beech/Y. Birch**	**Nonforested**	**Oak/Gum/Cypress**	**Oak/Hickory**
Aspen/W. Birch		(6,067)	20,064	(7,624)	-	1,027
Elm/Ash/Cottonwood	6,067		5,950	(524)	-	(1,111)
Maple/Beech/Y. Birch	(20,064)	(5,950)		(8,704)	(586)	6,322
Nonforested	7,624	524	8,704		-	(975)
Oak/Gum/Cypress	-	-	586	-		-
Oak/Hickory	(1,027)	1,111	(6,322)	975	-	
Oak/Pine	(1,293)	(442)	3,175	(2,049)	-	(1,805)
Softwood Plantation	-	-	(953)	-	-	-
Spruce/Fir	4,816	2,502	42,686	6,376	586	(820)
White/Red/Jack Pine	7,280	1,507	(1,575)	3,395	-	-
Timberland - Nonstocked	-	1,389	-	3,496	-	-
Grand Total	**3,403**	**(5,426)**	**72,317**	**(4,659)**	**(0)**	**2,637**

MFTYP	**Oak/Pine**	**Softwood Plantation**	**Spruce/Fir**	**White/Red/Jack Pine**	**Timberland - Nonstocked**	**Aggregate MFTYP Net Change**
Aspen/W. Birch	1,293	-	(4,816)	(7,280)	-	3,403
Elm/Ash/Cottonwood	442	-	(2,502)	(1,507)	(1,389)	(5,426)
Maple/Beech/Y. Birch	(3,175)	953	(42,686)	1,575	-	72,317
Nonforested	2,049	-	(6,376)	(3,395)	(3,496)	(4,659)
Oak/Gum/Cypress	-	-	(586)	-	-	(0)
Oak/Hickory	1,805	-	820	-	-	2,637
Oak/Pine		-	(2,573)	624	-	4,362
Softwood Plantation	-		-	-	-	953
Spruce/Fir	2,573	-		5,769	2,465	(66,953)
White/Red/Jack Pine	(624)	-	(5,769)		-	(4,215)
Timberland - Nonstocked	-	-	(2,465)	-		(2,420)
Grand Total	**4,362**	**953**	**(66,953)**	**(4,215)**	**(2,420)**	**-**

Table 7. Final transition matrix annual land use changes (acres per year). For the period of 1982 – 2003.

1982 Land Use Class	Apportioned 1982 Acres (Sums to 2003 Total)	Overall Net Change Direction	Derived Annual Net Change (Acres/Year) for 20 Years	Current 5 Panel Estimate 2003 acres
Forestland - Reserved, Unproductive, Other	522,374	-	(369)	515,001
Nonforested	2,191,083	-	(7,862)	2,033,849
Timberland - Rural, Other, Urban	17,037,937	+	8,230	17,202,544
Grand Total	**19,751,394**			**19,751,394**
Total Forestland	**17,560,311**		**7,862**	**17,717,545**
Nonforested - Total	**2,191,083**		**(7,862)**	**2,033,84**

Discussion

The fine tuning and improved accounting of Maine's LUCF GHG flux was achieved by identifying the problem areas, finding references to improved estimations, trying approximations, and then having the wherewithal to reprocess and analyze the results. An asset to this process was Maine's continued high percentage of forestland, which minimizes some of the potential permutations that other regions are experiencing, particularly in land use changes. While the above described carbon estimation process will continue to be enhanced, the focus can now comfortably shift to finding and recommending forest management practices that realistically improve the current state of carbon fluxes and effect a reduction in GHG amounts both for the immediate short-term, (next 10 years) and for the long-term (20 plus years).

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Analyzing the Economics of Tamarisk in the Pecos, Rio Grande, and Colorado River Watersheds

Lewis, Joseph W., Economist Forest Health Protection, Arlington, VA
Basala, Allen; Zavaleta; Erika; Parker; Douglas L.; Taylor, John; Horner, Mark; Dionigi, Christopher; Carlson, Timothy, Spiller, Samuel; and Nibling, Frederick

Abstract—*The potential economic effects of tamarisk (saltcedar), and the costs and benefits associated with controlling tamarisk infestations are being evaluated on the Pecos, Rio Grande, and Colorado River watersheds. Resource impacts analyzed include water, wildlife habitat, and fire risk. The extent of existing infestations will be quantified and projected over the next 30 years under the following four scenarios:*
1. No action (status quo)
2. Containment
3. Maximum control in 20 years
4. Maximum control in 30 years
The economic costs and benefits associated with each alternative scenario will be estimated, and a sensitivity analysis will be conducted to determine which variables have the most impact on the results of the economic analysis.

Introduction

An economic analysis of Tamarisk (saltcedar) is being conducted to evaluate this invasive shrub in some areas of the Pecos, Rio Grande, and Colorado Rivers in the southwestern United States. Russian olive and Siberian elm infestations will be incorporated into the analysis to the extent feasible. The analysis consists of two case studies that address the extent of the existing infestations in the analysis areas; risk of spread to susceptible areas that are currently not infested; potential damage to various resources; and the costs and benefits associated with controlling tamarisk and restoring native vegetation. The case studies will provide a sample decision making format that can be used to evaluate future project proposals, set priorities for allocating Federal funds, and provide policy makers with accurate and credible information to help determine the most effective and efficient courses of action for dealing with tamarisk infestations.

The economic costs and benefits associated with each alternative scenario will be estimated, and a sensitivity analysis will be conducted to determine which variables have the most impact on the results of the economic analysis.

Methodology

Determining Current Conditions and Rate of Spread

The extent of the current infestations in the study areas is being determined and depicted on a map. Historical information is used to determine the average annual rate of spread during the past few decades. Projections of future acres affected over a 30 year period will be made based on historical growth rates.

Over the past decade, a number of independent mapping efforts have attempted to capture the distribution and abundance of tamarisk infestations in several areas of the western United States. However, many of these projects are spatially and temporally discrete, making it difficult to determine a broad, comprehensive picture of tamarisk spread over time. Some of the underlying difficulties stem from issues regarding mapping methodology, scaling, considerations of mixed stands, overstory/understory relationships, accessibility problems, and inclusion/exclusion of different functional mapping parameters (for example, upper watersheds). Merging these various mapping efforts should increase our ability to assess and track tamarisk infestations. Further, a subsequent comparative effort should then foster a reasonable estimation of the rate of spread over time and space. However, issues regarding data quality and resolution, and therefore accuracy and precision, remain unclear.

Categorizing Levels of Infestation

Areas within the watersheds are placed into four broad categories: 1) not currently infested (in other words, no tamarisk, no Russian olive, and no Siberian elm), 2) lightly infested, 3) moderately infested, and 4) heavily infested. There are uncertainties regarding how much of an invasive species is in a given area in the base year, let alone future years. The four categories are perhaps better viewed as ranges. For example, 0 percent to 10 percent could be called uninfested (not currently infested in the case of the base year), 10 percent to 40 percent could be lightly infested; 40 percent to 80 percent moderately infested; and 80 percent to 100 percent heavily infested. Guidance on the appropriate percentages will be sought from ecologists and weed science experts.

Developing Alternatives

Four alternatives will be evaluated for the Pecos, Rio Grande, and Colorado River watersheds. These are not the only possible alternatives, but they represent a plausible range of actions, including variations in intensity and timing of control efforts:

Alternative 1

Maintain Status Quo—This serves as the "no action" alternative. Under this alternative, existing and planned private, local, tribal, state, and federal programs continue into the future, but no additional effort is made to control the spread of tamarisk or rehabilitate currently infested areas. The period examined is 30 years (2004 to 2034).

Alternative 2

Containment—The containment alternative is analogous to a strategy used to fight wildfires or control a disease epidemic. For example, by controlling the outer edges, the fire, the disease, or the invasive species infestation is contained, and prevented from spreading. Using 2004 as a base year, the containment alternative applies additional measures to ensure that areas that are not infested in 2004 remain that way throughout the 2004-2034 analysis period. The additional measures include a variety of tactics, including chemical, mechanical, and possibly biological control techniques, as well as maintenance, assessment, revegetation, and monitoring efforts.

A strict definition of containment would have areas with no invasive species remain that way throughout the 2004-2034 period. However, under Alternative 2, some ramp-up period or lag structure in applying the measures and getting the results is assumed.

Alternative 3

Maximum Control in 30 Years—As in Alternative 2, Alternative 3 requires that the areas within the watersheds with no invasive species in 2004 remain that way throughout the 2004-2034 period. In addition, under Alternative 3, further actions will be taken to provide a continuous rate of progress toward reducing the intensity of infestations and restoring native vegetation to the maximum feasible extent by 2034. This continuous rate of progress is measured in part by determining the number of acres shifting from the high infestation category to moderate, to low, and to the uninfested category.

Alternative 4

Maximum Control in 20 Years—Alternative 4 represents the most aggressive approach to controlling tamarisk. This alternative is similar to alternative three, except that the maximum feasible level of control is achieved by 2024 and maintained through 2034.

Categorizing Vegetation Types

The impacts of tamarisk infestations differ by location. In riparian zones, tamarisk replaces native cottonwood and willow trees. In the semi-arid upland terrace area adjacent to the riparian zone, tamarisk replaces native grasses, sedges, and woody shrubs.

The amount of water consumed by tamarisk compared to the amount consumed by native vegetation will differ greatly in the two areas. Thus, currently-infested, as well as projected acres will be divided into these two categories for this analysis.

A third category representing areas of sensitive or special status will also be identified to represent areas of special concern for a number of reasons. These areas are tracts along rivers having unique or important attributes that would require or compel local managers or private landowners to protect, maintain, or improve their condition. Examples include: (1) habitat for threatened, endangered, and sensitive species; (2) dense stands of tamarisk and riparian sites with heavy fuel accumulations that increase the risk of wildfire; (3) historical cottonwood gallery forests; (4) areas of religious and cultural significance; and (5) areas where perennial water could be restored. Due to their importance, such sites often receive priority for management with limited funds. A very small percentage of the total acres analyzed will fall into this category.

These categories will be further divided into three "difficulty of access" classifications that will help determine type and cost of potential control techniques.

The selection of the most efficient tamarisk control technique is highly influenced by the difficulty of access to each site. For areas that are relatively level with adjacent roads, heavy equipment can be used; whereas, in canyons, access is limited to foot, horseback, or river travel. The control costs per acre are significantly different for these two situations. Thus, a good understanding of the accessibility throughout the Colorado, Pecos, and Rio Grande watersheds is essential to accurately estimate tamarisk control costs. The three "difficulty of access" classifications are:

- *Highly difficult to access*—This classification is associated with those areas that can only be accessed by foot, horse, or boat. Examples include steep embankments, canyons, and roadless areas.
- *Moderately difficult to access*—This classification covers those areas that have a mix of level terrain where heavy equipment could be used, and steep embankments that would require hand labor to control tamarisk. Typical of this classification are river channels where the side slopes adjacent to the river are too steep for equipment use, but have broad flood plains that have good access potential.
- *Low difficulty of access*—An area that is easily accessible is defined as one that is relatively level, near an existing road, and where heavy equipment can be used throughout.

Identifying Resource Impacts

The following three resource impacts will be assessed for each alternative:

1. Water
2. Fire
3. Wildlife Habitat (including endangered species)

These resource impacts will be quantified in physical and monetary terms to the extent possible, given the availability of data and the ability of scientists to provide expert judgments.

Identifying Costs

All costs associated with control and restoration of infested areas will be compiled for each alternative. Cost components include direct control costs, as well as costs related to research, maintenance, assessment, revegetation, and monitoring. Also, costs associated with biomass utilization will be estimated to the extent feasible.

Identifying Benefits

Benefits of containing or controlling tamarisk infestations are based on changes in resource impacts related to water, fire, and wildlife habitat (including endangered species). For example, the benefits of Alternative 2 (Containment) would be the increased water yield, reduced fire risk, and reduced impact on wildlife habitat that result from moving from conditions under Alternative 1 to conditions under Alternative 2. Likewise, the benefits of Alternative 3 result from moving from conditions under Alternative 2 to Alternative 3. Also, benefits associated with biomass utilization will be estimated when appropriate.

Results

We expect to have preliminary results of the analysis completed by April, 2005.

Monitoring Insects to Maintain Biodiversity in Ogawa Forest Reserve

S. Makino, T. Inoue, K. Hamaguchi, K. Okabe, M., and I. Okochi, entomologists, and H. Tanaka, botanist, Forestry and Forest Products Research Institute, Matsunosato 1, Tsukuba, 305-8687, Japan

H. Goto, entomologist, Kyushu Research Center, Forestry and Forest Products Research Institute, Kumamoto, 860-0862, Japan

M. Hasegawa, soil zoologist, Kiso experimental station, Forestry and Forest Products Research Institute, Nagano 397-0001, Japan

M. Sueyoshi, entomologist, Department of Systematic Biology, Entomology Section, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA

Abstract—*The results of a biodiversity monitoring program conducted in the Ogawa Forest Reserve and its vicinity, situated in a temperate region of Japan, identified three different patterns for species richness. Forests of the region are characterized by a mosaic of secondary deciduous stands of various ages scattered among plantations of conifers. The three different types of change in species richness observed in response to the stand age are as follows:*

1. Type I (butterflies, tube-renting bees and wasps, hoverflies, fruit flies, and longicorn beetles), the species diversity was highest in open areas, just after clear cutting, decreasing with the stand age;

2. Type II (mites associated with mushrooms), older stands showed greater diversity than younger stands; and,

3. Type III (moths, oribatid mites, collembolas, carabid beetles, and ants), the number of species did not change greatly with the stand age, though ordination analysis revealed that there was variation in species compositions. These results indicate that combinations of stands of different ages, or heterogeneously arranged stands, can contribute to the maintenance of insect biodiversity at the landscape level.

Introduction

In Japan, many natural broad-leaved forests were converted into conifer plantations of Japanese cedar (*Cryptomeryia japonica*) or hinoki cypress (*Chamaecypris obtusa*) throughout the country in order to fulfill urgent needs for timber as construction materials after World War II. Many of the remaining broad-leaved forests have been managed as small scale woodlots to obtain logs for mushroom culture, for example. These practices have contributed to the formation of a landscape, typical of many Japanese villages, which is characterized by a mosaic of small, secondary broad-leaved stands of different ages scattered among conifer plantations.

In order to better understand the present status of biodiversity in this man-made landscape, we have been conducting a biodiversity monitoring program in broad-leaved and conifer stands in cool temperate Japan. In both, the monitoring was carried out in a chronosequential series of stands, in order to see how biodiversity changes over time in secondary broad-leaved forests and in conifer plantations. Results of the monitoring program will contribute to the development of a management policy for the village landscape that considers the maintenance of biodiversity as an objective. In this report, we describe the monitoring design and outline the tentative results for insects and soil arthropods in the broad-leaved forests.

Monitoring Methods

Study Sites

The monitoring sites were located in the Ogawa Forest Reserve (OFR) (36º56' N, 140º35' E) and its vicinity, situated near the northern border of Ibaraki Prefecture, Japan. Although OFR is an old growth natural forest, the surrounding area is predominantly occupied by plantations of Japanese cedar and hinoki cypress with scattered secondary deciduous forests of various ages. From the total study area (about 3200 ha about 600 to 800 m a.s.l.) including OFR, we selected nine monitoring plots (4 to 98 ha), ranging from grasslands just after clear-cutting to old growth forests over 170 years old. Konara oak (*Quercus serrata*), Mongolian Oak (*Q. Crispula*), Japanese Beech (*Fagus japonica*), Sweet chestnut tree (*Castanea crenata*), are some of the predominant tree species (Inoue 2003). In addition to the plots, a few grasslands near OFR were also monitored for butterflies. Monitoring was primarily carried out in 2002 with the exception of the butterfly transects which were done in 1997 to 2001 (Inoue 2003).

Plants in the OFR have been studied intensively by a host of ecologists (Nakashizuka and Matsumoto 2002) and inventory studies have been conducted in OFR and its vicinity for some insect taxa (Maetô and Makihara 1999, Totok and others 2002, Sueyoshi and others 2003, Inoue 2003).

Biodiversity Monitoring

Plants

Because all animals depend on plants directly or indirectly, information on the vegetation is indispensable as a background to any analysis of insect diversity. Trees and vines taller than 2m and larger than 5 cm d.b.h. were tagged in forty 5m x 5m quadrats. Forest floor vegetation (vegetation height smaller than 2 m) was inventoried following the Braun-Branquet method for 40 subquadrats (1 x 1 m) along a 100 m line in each plot. Standing dead stems larger than 5cm d.b.h. were also tagged and measured.

Insects and other arthropods

Target organisms were selected from a variety of taxa representing different ecological roles. The particular insect traps mentioned below were placed well inside the study plots to avoid possible edge effects.

Butterflies

Butterflies are typical herbivores: during the larval stage they almost exclusively feed on plants, while adults generally depend on nectar or other carbohydrates. Line transects were conducted to monitor butterflies. One-hour transect counts were made twice a month from April to October between 9:00 and 15:00 (Inoue 2003). Species and the number of butterflies sighted (or collected in a small number of cases where species were not identified at sight) were recorded at each census.

Nocturnal moths

Larvae of moths are also herbivores, though they use woody trees more frequently than butterflies. We used portable light traps (Okochi 2002) to collect nocturnal moths. Once or twice in June or July, a single trap was left overnight at each of the monitoring sites, and moths trapped inside were collected the following morning.

Carabid beetles on the forest floor

Carabids are usually predators of small animals. They have been widely studied as promising indicators of forest conditions using pitfall traps (Niemelä 2001). The pitfall trap we used was a transparent plastic bottle (77 mm diameter, 158 mm height) with three small holes (about 5 mm in diameter) in the middle for drainage of rainwater. A 20 x 20 cm white plastic plate was fixed above the opening with stainless wire in order to prevent various materials falling into the trap. In each plot, ten pitfall traps were aligned in three parallel lines (three, four, and three traps per line, respectively) with a distance of 10 m between each trap and between adjacent lines. Trapped insects were collected every two weeks from April to November.

Tube-renting bees and wasps

Solitary bees and wasps respectively play roles as pollinators and predators of various insects or spiders. Some groups preferentially or obligatory nest in pre-existing holes. It is thus possible to monitor their abundance and diversity using nesting traps with various tube sizes (Fye 1965, Tscharntke and others 1998). The nesting trap we used was made of 16 bamboo stalks (approximately 8 to 16 mm in diameter) and four reeds (6 mm), which were tied together side by side with strings. Nine traps were tied to tree trunks or wooden posts (where no substrate trees are available) at 1.5 m above the ground in April, and removed in November. Any immature wasps or bees were reared until eclosion for identification.

Longicorn beetles

Longicorn beetles (Cerambycidae) are usually xylophagous at the larval stage. Many feed on recently felled or killed trees, contributing to the decomposition of dead woody materials. Adult longicorn beetles, particularly of the subfamily Leputurinae, frequently visit flowers to feed on pollen and nectar. Longicorn beetles were collected with standard Malaise traps (Golden Owl Publishers, 180 cm long, 120 cm wide, 200 cm high); five traps were set in April at each plot at intervals of 10 m. Collection of trapped insects was made every two weeks as in pitfall traps.

Hoverflies and fruit flies

Adult hoverflies (Syrphidae) visit flowers to feed on nectar, and probably on pollen. Feeding habits of larval hoverflies are divided into aphidophagous, phytophagous, xylophagous, and fungivorous. Fruit flies (Tephritidae) are phytophagous, feeding on various parts of plant tissues at the larval stage. These flies were also collected with Malaise traps (Sueyoshi and others 2003).

Ants on forest floor

Ants were collected between July and August with litter sampling and pitfall traps along a 100 m (or 200 m in a few sites) transect line in each plot. Litter was sampled at intervals of 20 m, and ants were hand-sorted. Pitfall traps (disposable plastic cups) were set along the same line at 10 m intervals for a maximum duration of three days.

Oribatid mites and Collembola in forest floor litter

Both of these arthropods play important roles as decomposers. A cylindrical core (25 cm^2 x 5 cm high) of soil was removed from eight divisions (4 x 2 m) of a quadrat (8 x 8 m) in April, August, and November. Soil arthropods were later extracted with Tullgren funnels (Hasegawa and others 2004).

Mites associated with mushrooms

Mushroom fruiting bodies were collected in each plot once a month from April to November. Mites were hand-sorted and identified under a microscope.

Results and Discussion

Species richness of the various indicator organisms groups, in response to stand age after clear cutting, is schematically depicted in figure 1. Trofymow and others (2003) did a similar analysis for arthropod species richness in Douglas-fir forests in Canada as a test of the conceptual ideas presented by Spies and Franklin (1988).

Forest floor vegetation in young stands, was composed of a large number of species. While there was a slight decrease in middle-aged stands, the number of species increased thereafter. Plants in the tree layer with d.b.h. larger than 5 cm showed increased diversity after clear-cutting, saturating at 50 to 60-years. Responses of arthropods to stand age were classified into the following three types.

Type I: Species richness (the number of species) is high in grasslands or in early stages of succession, while much lower in older forests. This pattern of change was observed with butterflies, hoverflies, fruit flies, tube-renting bees and wasps, and cerambycid beetles.

Type II: Species richness is low in early stages of succession, but becomes greater as forests mature. This pattern of change was observed with mites associated with mushrooms.

Type III: Species richness does not significantly change with forest age. This pattern was observed with moths, oribatid mites, collembolas, and carabid beetles, and ants. Although the species richness of oribatid mites and collembolas was a little lower in a plot one year after clear-cutting, it soon recovered thereafter (Hasegawa and others 2004). Moths also showed a relatively small change across the chronosequence of stands. Their change pattern was moderately bell-shaped, attaining the peak at 50 to 60 years following clear-cutting.

Taxa showing the Type I change pattern response are herbivores during the larval stage, and/or largely depend on flowers for carbohydrates as adults. Many butterfly species live in grasslands and utilize herbaceous plants as hosts. Even species whose host are tree species visit herbaceous plants for nectar (Inoue 2003). Tube renting bees and wasps probably collect nectar and pollen, or

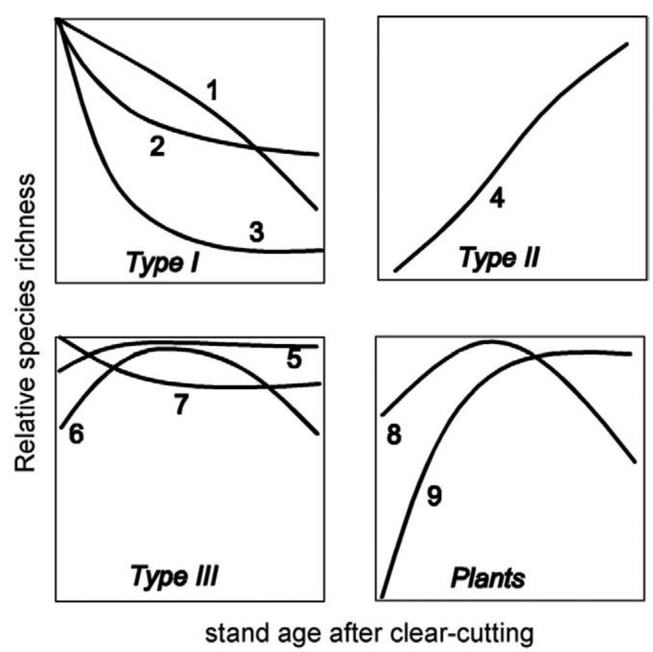

Figure 1. Schematic representations of species richness response to the age of deciduous broad-leaved stands after clear-cutting. Numbers near the response curves represent the following arthropod taxa: 1, butterflies; 2, tube-renting bees and wasps, and longicorn beetles; 3, hoverflies and fruit flies; 4, mites associated with mushrooms; 5, oribatid mites and collembola; 6, moths; 7, carabid beetles and ants; 8, forest floor plants; 9, tree layer plants (d.b.h. >5cm).

hunt prey (for example, lepidopterous larvae, spiders, and grasshoppers) respectively, in grasslands or in very young and open stands. Although most longicorn beetles feed on dead trees during the larval period, adult insects frequently visit flowers. These ecological observations indicate that, for Type I species, abundance of flowers is one of the important factors contributing to the high species richness in plots of early stages of succession. This hypothesis can be tested by monitoring density and abundance of flowering plants in the study sites throughout the seasons.

For mites associated with mushrooms, the species richness response clearly reflects the number of mushroom species, which in turn increased with the forest age. This response seems to be partly due to the frequency of fallen trees, important substrates for mushrooms, which was much greater in older stands.

The arthropod taxa showing the Type III change pattern (moths, oribatid mites, collembola, carabid beetles, and ants) did not show change in species richness in response to forest age. It is noteworthy that moths and butterflies, both lepidopterans feeding mainly on plant leaves, showed different responses to forest age, in spite of the systematic and ecological affinity of the two groups. This may be partly due that a greater percentage of butterfly hosts are herbaceous plants as compared with moth hosts, according to host records from Miyata (1983) for moths, and Matsuka (1994) for butterflies. In additional, adult moths do not depend on flowers for food as butterflies do. Although the underlying mechanisms are unknown, these feeding behaviors may partly explain the observed differences between moths and butterflies.

The Type III pattern with little observed change in species diversity with forest age, does not mean that different aged stands were inhabited by the same assemblage of arthropods. For example, with the exception of the first year following clear-cutting plot, the number of species of oribatid mites did not differ greatly between plots in different age stands. A multivariate ordination analysis, however, showed that a four-year-old plot had an oribatid community distinct from those in other, older plots (Hasegawa and others 2004).

The different responses in terms of species richness shown by different taxa indicate that combinations of stands of different ages, or heterogeneously arranged stands, contribute to the maintenance of insect diversity at the landscape level. Future studies, will monitor other animals, in addition to other insect taxa, to test hypotheses formulated using the results of this study. More detailed analyses of communities or species assemblage of both plants and animals will be undertaken in order to understand how diversity changes over time following clear-cutting.

In this short paper, we have only reported on species richness as a measure of biodiversity. Future studies will also analyze information additional ecological variables beyond species inventories including abundance of coarse woody debris (snags, fallen trees or twigs) as a biotic factor, and light intensity or soil properties as abiotic factors.

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Social and Economic Indicators of the Sustainable Rangelands Roundtable

John E. Mitchell, Rangeland Scientist, Rocky Mountain Research Station, Fort Collins, CO
Daniel W. McCallum, Research Economist, Rocky Mountain Research Station, Fort Collins, CO
Lewis E. Swanson, Head, Dept. of Sociology, Colorado State Univ., Fort Collins, CO
John Tanaka, Professor, Oregon State University, Union, OR
Mark Brunson, Assoc. Professor, Dept. of Environment and Society, Utah State University, Logan, UT
Aaron Harp, Director, Caldwell Research and Extension Center, University of Idaho, Caldwell, ID
L. Allen Torell, Professor, Dept. Agricultural Economics, New Mexico State University, Las Cruces, NM
H. Theodore Heintz. Asst. Dir. for Economic Analysis, U.S. Dept. of Interior, Washington, DC

Abstract—*Social and economic systems provide a context and rationale for rangeland management. Sustaining rangeland ecosystems requires attention to the social and economic conditions that accompany the functioning of those systems. We present and discuss economic and social indicators for rangeland sustainability that have possible relevance in the United States. A brief conceptual basis for each indicator is offered describing its potential relationship to rangelands. The importance of these indicators to other countries having different social and economic conditions is less assured.*

Introduction

Sustainability and use of rangelands are inherently linked to the sustainability and health of complementing and supporting social and economic infrastructures. Social and economic infrastructures provide the context in which rangeland use occurs and continues. In Sustainable Rangeland Roundtable (SRR) discussions, emphasis has been generally given to ways in which the natural resource base benefits the economy and society. SRR gives equal consideration to the reciprocal relationship between the potential positive and negative impacts of the economy and society on the sustainability of rangelands.

The fundamental realization that rangeland sustainability must be examined within the social and economic framework exposes a dilemma. It is difficult to define measures that unambiguously relate rangeland conditions to social and economic structure or activity. One part of that dilemma is that social and economic structures are more encompassing than rangeland ecosystems. In the United States, rangelands and their use play a major role in the social and economic framework of some regions, while they have virtually no role in other areas. Because of the different levels of involvement of rangeland (or any particular resource use) in the social and economic framework of a given place, the SRR Socio-Economic Criterion Group decided to consider indicators of the health and sustainability of communities, of which rangelands and rangeland use are one of multiple components.

Directly measuring economic and social indicators at the national and regional levels of analyses presents some conceptual and methodological challenges when the objective is to provide unambiguous empirical associations with other indicators of rangeland biophysical trends. These challenges include: (1) establishing and documenting the relationship of economic and social factors to rangeland sustainability; (2) dealing with issues associated with the unit of analysis (scale); (3) determining causal relationships among socioeconomic and ecological indicators; and (4) overcoming the unavailability of indicator data.

Each of the indicators indirectly reflect different conceptual ways to examine socioeconomic data. These indicators include economic and social structures that are generally associated with individual and community well-being. For example, measures of demographic structure, including age, gender, ethnicity, and social stratification, provide indirect indicators of population stability, as well as rates of change that can be assumed to indirectly measure individual and community well-being. The challenge is to establish the degree of association among these indicators that can be reasonably attributed to the relationship between ecosystem status and function and human activity. Even in regions of the United States that are predominantly characterized by rangeland ecosystems, the economic and social activities occurring on these landscapes may have limited direct impact on rangeland commodities, amenities, and ecosystem services. A rural community, for example, may be gaining in population because of attractive features that promote immigration by retirees while the number of people involved in production activities on rangeland is in decline. Or, where rural communities diversify their economic base, they often provide off-ranch employment opportunities that make it easier for economically marginal ranching operations to stay in business. Portraying the health and sustainability of economies and communities, and then associating those communities with rangeland regions, provides a more complete picture from which to evaluate rangeland sustainability.

We concluded that the pragmatic way to address the lack of direct measures was to provide a minimum number of indicators that could describe key conceptual issues associated with economic and social activity. While this approach provides basic information, it will not be statistically adequate for detecting interaction effects among these variables.

The issue of scale constitutes a persistent challenge. Given the local nature of social and economic structures, and the potential for diversity of economic and social conditions within any county, state, or region, the methodological problem of discerning measures of activities directly related to rangeland conditions at broader scales is problematic. Aggregating the scale of analysis to a national level can also mask relationships that would only show up at more local levels.

In the United States, social and economic variables are frequently reported at the county level. The sampling units for these statistics are at a finer level, such as the individual, family, or household. Thus, in some cases opportunities may exist for spatial and temporal analysis below the county level. This is true of census data, where Topologically Integrated Geographic Encoding and Referencing (TIGER) system files make some analyses possible at the census tract (sub-zip code) level.

We have adopted three groupings of indicators comprising a comprehensive perspective of sustainability within the larger social and economic context in which rangelands exist and use occurs. National Economic Benefits describes the types of products coming from rangelands and valued by society. Community Well-Being and Capacity seeks to define the value of community social and human capital in rangeland-dominated areas. Community-Level Explanatory Indicators That Might Be Relevant to Sustainability seek to understand how communities affect rangelands. Indicators within these grouping are considered in terms of their importance, geographic variation, scale, data sufficiency, and clarity to stakeholders.

National Economic Benefits

National Economic Benefits indicators monitor products and benefits derived from rangelands and rangeland use. The interpretation of these indicators can be meaningful at the national, regional, and local levels.

The Value of Forage Harvested From Rangeland by Livestock

Livestock grazing is the historical economic use of rangelands and it continues to be an important use on both public and private lands. Measuring the value of this use remains important to understanding a major economic and social benefit derived from rangelands.

Collecting meaningful data on the value of forage harvested by livestock will not be trivial. Regional differences in the value of forage for livestock production exist. Private land lease rates are different by region. Total grazing costs (fee and non-fee costs) are highly variable with as much difference within regions as between regions. Grazing cost data are not collected and reported regularly.

This indicator appears to be meaningful at multiple spatial and temporal scales. Differences in data and data trends are observed through time and with data collected at the state level. Values are expected to vary among and within states. However, given current national data collections, the scale most appropriate would be at the state level, although state-level estimates of private land lease rates are not valid at the state level except to measure general trends. Overall, methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level.

While the procedures for forage valuation are accepted, their use is not always consistently applied. There are generally four methods that have been used to estimate forage value: private land lease rates adjusted for lessor services, competitive bid, replacement feed value, and marginal value analysis. Of these, the private land lease rate (unadjusted for lessor services) is the only one consistently collected on a national scale.

Lease rates are reported on a dollar/head, dollar/animal-unit-month (AUM), and dollar/cow-calf pair basis. The data are repeatable and reasonably accurate. The survey data have been criticized for being based on hearsay and the small sample size collected by state. The average lease rate measures both the forage value and the value of leasehold services provided by the lessor. No attempt is made in this data set to arrive at only the forage value for either private or public lands.

Once we are able to establish a forage value, total forage value can be estimated when total AUMs from rangeland are determined. The finest level of detail given current reporting of average lease rates would be at the state level, but there is some question whether data are reliable when disaggregated to that level.

The value of forage used by livestock is understandable and interpretable through time and space. In its current form, however, few stakeholders understand that it measures more than just the value of forage. This must be relatively constant over time if trends are to be monitored.

Value of Non-Livestock Products

This indicator monitors the economic value of products produced from rangeland that are not related to livestock production, including recreation, scenic views, nature experiences, open spaces, and so on. Rangelands produce more than just livestock and wildlife. The value of these non-livestock outputs is important for recognizing the diversity of outputs produced from rangelands. The combination of non-livestock products of interest to stakeholders and those that can be monitored through time needs to be identified. Once that combination is known, values can be derived through a variety of market and nonmarket valuation techniques.

Data availability will depend upon the specific products and services chosen to be monitored. Some data may exist for non-livestock outputs on federal lands and state trust lands, but we know of no data sources for private lands, some of which may be proprietary. A few wildlife species in specific situations have been evaluated for their values using both travel cost and contingent valuation methodologies with varying availability and scope. However, for the most part, no data exist.

This indicator will only be understood by the public if the set of non-livestock rangeland outputs to be valued is defined. Stakeholders understand dollar values. Some care must be taken to ensure that the dollar values derived through various nonmarket valuation techniques are comparable to those determined in the marketplace.

Number of Visitor Days by Activity and Recreational Land Class

This indicator is a measure of the amount of recreation use on rangelands. It has relevance to sustainability as a measure of benefits from recreation. Recreational land classification into primitive areas, roadless areas, open public land, private lands, and other types provides one possible basis to compare the types of recreation and how those change through time.

With the exception of national parks and monuments that draw visitors from around the world, rangeland recreation use is generally highest at sites that are relatively close to population centers. There are also regional variations in the popularity of various outdoor recreation activities, such as hunting and hiking. USDA Forest Service monitors recreation use by type of location (day use developed sites, overnight use developed sites, wilderness, other National Forest System land use, and viewing from corridors).

Some data set(s) exist at the regional-national level, but methods and procedures are not standardized. There are two problems associated with recreation use monitoring. First, different land management agencies use different measures and obtain data in different ways, although the lack of consistency will decrease somewhat when the Forest Service and Bureau of Land Management (BLM) switch to a "visitors" measure instead of the current "recreation visitor-days" measure (an RVD is 12 person-hours, a measure that is more valid because it better accounts for duration of use, but has proven too difficult for the multiple-use agencies to measure over extensive landscapes.) Second, these measures are not tied to land types but to ownerships. There is not a good way to aggregate use data from multiple agencies, although the Forest Service attempts to estimate use across ownerships in its periodic RPA assessments.

Reported Threats to Quality of Recreation Experiences

This indicator is envisioned as a way to address a problem inherent in recreation use; i.e., rangeland health is influenced by the physical and social impacts of recreation use, and these impacts are not necessarily correlated with user density.

Biophysical impacts of recreation typically follow a curvilinear pattern where marginal changes, such as soil compaction, become smaller as use levels increase. Therefore, changes in visitor numbers may or may not indicate loss of value at the site level, depending on whether use is already low, moderate, or high. Social impacts of recreation, like crowding and conflict between user groups, are more dependent upon characteristics of the use and users than on simple numbers of users, although the potential for conflicts between users increases with the number of users.

Accordingly a useful indicator of recreation value should account for quality of use as well as quantity. One way to do this would be to create a composite index. Such an index could address trends in crowding complaints by recreationists, levels of conflicts among recreation user groups, and depreciative behaviors (vandalism, rule violations, etc.).

There is also the need to develop quantitative data related to physical features (for example, road density, trails, home densities) to complement the subjective information provided by managers and put it in context.

Standardized methods and procedures for data collecting and reporting exist at the regional-national level, but useable data set(s) do not exist at the regional-national level. In particular, no index of quality of recreation use has been devised. The method is technically feasible, easily aggregated, interpreted, and repeated using standard survey protocols. Measures are subjective so there will be random error associated with differences in the perceptions of persons completing the questionnaires; however, there is no reason to suspect systematic data biases.

Value of Investment in Rangeland, Rangeland Improvements, and Recreation/Tourism Infrastructure

This indicator monitors expenditures on new and existing structures and similar inputs for a variety of uses. It is the amount agencies and individuals actually spend on infrastructure for any given use of rangelands. It would be useful if data could be found to differentiate between public investment, private investment, and cost sharing. The indicator should depict how much the current generation is willing to invest in maintaining current usefulness of the resource base for a variety of uses. Investment explicitly implies that funds are being expended to obtain future returns from productive rangeland uses. Productive rangeland uses include more than just livestock production.

A value of investment indicator is conceptually feasible, but no regional-national methods, procedures, or data sets currently exist. U.S. federal agencies reports on units and dollars spent annually for range improvements. Some data for private lands may be available through Natural Resources Conservation Service and some of the USDA subsidy/cost-share programs. It may also be possible to develop a data collection protocol where none exists by using a standard survey.

Rate of Return on Investment for Range Livestock Enterprises

This indicates whether ranch families are making a competitive rate of return on their investment from producing livestock on rangelands. If the rate of return on rangeland-based livestock operations is not competitive, it means that other forms of returns are important, other sources of income are important, or that the ranch is likely to be converted to other uses.

Data to monitor returns on rangeland investments are conceptually feasible or initially promising, but no regional-national methods, procedures or data sets currently exist. In the United States, western universities periodically prepare cost and return estimates for range livestock operations at the county, region, or state level. Although standardization is improving, methodological differences exist across institutions and researchers. All geographic areas are generally not updated annually, and many cost and return studies are only done every five to 10 years. Some states have no information. The USDA Economic Research Service (ERS) makes cost and return estimates at the national scale using surveys conducted every five to eight years for each commodity. USDA Livestock budgets are defined across wide geographic areas.

Livestock cost and return estimates consistently show that livestock producers are not currently and have not in the past made a competitive rate of return on investment. Ranches are overpriced relative to the value of the livestock produced. Livestock is the only product considered in the cost and return series.

For data to be useful, new data sources will have to be initiated. These data would need to use similar accounting procedures and valuation of opportunity costs. It would have to be done in a timely manner. Because land appreciation is a major long-term return from ranch ownership, this variable must in a site specific way).

Number and Value of Conservation Easements Purchased

This indicator would measure the number of conservation easements and/or the number of acres protected under conservation easement. This is an indicator of the presence and trend of open-space, and acts as a measure of amenity availability. It speaks to the desirability, adaptability, and resilience of communities, and the community perception of the importance/value of that land use.

Methods and procedures exist for data collecting and reporting; and data sets of useable quality exist at the regional-national level. Data are compiled by various land trusts and conservation groups and reported centrally to the Land Trust Alliance (LTA) at http://www.lta.org.

The LTA compiles information about conservation easements by state. Data on the number and size are collected from surveys with known groups doing land trusts and conservation easements. USDA ERS also reports upon the extent of land trusts in the United States.

Expenditures (Monetary and In-Kind) on Restoration Activities

This indicator measures the amount of funds that organizations and individuals contribute to rangeland restoration activities. It indicates the strength of importance people place on restoring rangelands. These expenditures are made to maintain, enhance, or restore the rangeland ecosystem without explicit monetary future returns expected from the investment.

No regional or national methods, procedures, or data sets currently exist for monitoring restoration expenditures. Some data are available at local levels by agency or organization; however, costs for rangeland improvements on private lands are nearly always proprietary.

The Threat or Pressure on the Integrity of Cultural and Spiritual Resource Values

This indicator measures the intensity of concern and pressures for management. Cultural and spiritual resources are assets valued by all sets of people. The indicator is important because it assesses the status of a characteristic of rangelands valued by people and protected by federal law. We assume that, when spiritual or cultural values are threatened by activities on rangelands, citizens will suffer loss of value from those rangelands, and may act to protect those values in ways that decrease the value of other resources; for example, by restricting livestock grazing or recreation access.

This indicator is conceptually feasible and promising, but no regional-national methods, procedures, or data sets currently exist. Any measures will be subjective so care must be taken to ensure against bias of any kind in the estimates. Aggregated data should be reliable if sufficient responses are obtained on a regular basis. Despite the legal protection afforded to cultural/spiritual resources, there currently is no regular, large-scale effort to monitor their status.

Community Well-Being and Capacity

Indicators in this Section are intended to portray social structure. When measurements are made at anything larger than a community level, they begin to lose meaning when the appropriate theoretical concept is a community or other local unit of social organization. In the United States, county-level data provide insights of social structure, thus giving a reasonable approximation of local socio-economic trends.

Poverty Rate—General

USDA, in cooperation with other federal agencies, sets the poverty rate at the level where one-third of the household budget or more is going to food. It is assumed that any household that spends one-third of its budget on food is unlikely to be maintained at a minimal quality of life. This general poverty rate is a gross measure of social stratification that indicates the level of poverty within a county, and is indicator is needed to interpret interaction effects with other indicators.

Methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level. Data are collected and reported as part of the U.S. Census of Population.

Poverty Rate—Children

This is a ratio of persons less than 17 years of age who live in households determined to be at or below the poverty threshold. It measures the proportion of children in poverty. Higher rates are associated with lower integration into the community and the higher likelihood of undesirable outcomes like reduced health, human capital, and social capital. This indicator is needed to interpret interaction effects with other indicators.

Methods and procedures exist for data collecting and reporting; and data sets of useable quality exist at the regional-national level. Data are collected and reported as part of the U.S. Census of Population.

Income Equality

This indicator measures the extent to which income is equally distributed among households in the economy. It addresses economic distribution and equity. It indicates the general welfare of the community by looking at the distribution of people across the range of incomes. It is a direct measure of economic and social stratification. Equality levels are positively correlated with other measures of community cohesion or integration.

Methods and procedures exist for data collecting and reporting and data sets of usable quality exist at the regional-national level. Data are collected at the county level and this is the most useful scale. The use of Gini coefficients to measure income equality is one standard method. Such coefficients are available at web sites such as http://www.unc.edu/~nielsen/data/data.htm.

Index of Social Structure Quality

Social science literature often addresses the multidimensionality of concepts that are being measured using indices – the adding together of multiple indicators to create a single broad based measure. These indices are subject to the same rules of validity and reliability as the data upon which they are based. The quality of social structure could include access to and quality of medical care (for example, per capita hospital beds, physicians, nurses), presence of cultural community services, public recreational facilities (expenditures per capita), and crime rates. This is an indicator of the capacity of communities to address the quality-of-life and may indicate their willingness to address environmental issues.

Standardized methods and procedures for data collecting and reporting exist at the regional-national level, but useable data do not exist at the regional-national level. The base data are available, but no specific index has been developed.

It is imperative to recognize here, as well as other places where indices are proposed, that indices can hide countervailing influences. Thus, increases in one component can cancel out decreases in another. Also, while indices can simplify the presentation of or results to non-specialists, they can bury political and other biases, thus allowing more benign but deceptive labels. In general, it is very difficult to keep indicators politically and ethically neutral, such that they don't favor some groups over others.

Community Satisfaction

This indicator measures the degree to which the local community feels about sustaining local resources and attitudes that contribute to a social foundation for acting to achieve stability over the long-term. This indicator is hypothetical at this point, but could provide useful information on how communities feel about natural resources.

Methods and procedures exist for data collecting and reporting; and data sets of useable quality exist at the regional-national level. In the United States, the National Opinion Research Center collects data that may be useful. However, data improvements are greatly needed for this indicator to be viable.

Federal Transfers by Categories (Individual, Infrastructure, Agriculture)

Federal transfer payments (for example, food stamps, social security, Medicare/Medicaid, Forest Service payments-in-lieu-of-taxes, crop loans, crop subsidy payments, emergency livestock feed payments) are relatively stable sources of income to individuals and local governments during most economic conditions. The indicator measures another aspect of economic resiliency and capacity to endure changes in economic condition.

Methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level. The U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Information Service, reports upon these data for counties, states, and the Nation as a whole.

Presence and Tenure of Natural Resource Non-Governmental Organizations at the Local Level

The presence of private sector non-government organizations (NGOs) is considered to be an indicator of professional administrative capacity for managing community projects relating to rangeland sustainability that otherwise would be unsupported by government agencies. It is also an indicator of how strongly such groups feel about the importance of natural resources in an area.

The indicator is conceptually feasible or initially promising, but no regional-national methods, procedures, or data sets currently exist. A comprehensive data set would require collaboration among various NGOs, including land trusts, involved in rangeland management and stewardship.

Sources of Income and Level of Dependence on Livestock Production for Household Income

This indicator measures the dependence of ranch families on livestock production for household income. Recent surveys have shown that few U.S. ranchers rely totally on the ranch for family income. Measuring the livestock component of disposable income and the percentage of ranchers highly dependent on livestock for income are both potentially useful measures. Higher dependence on ranch income may be correlated with grazing intensity during droughts, and the associated ability to follow sustainable grazing practices.

Useable data sets do not exist at the regional-national level. Data sources are available for components of the questions about dependency on livestock production for household income. Some data may provide an indication of level of dependency. However, the data collection interval is problematic. Census of Agriculture data are collected every five years and do not distinguish between farms and ranches. The Agricultural Resource Management Survey data base may be another potential source but these data are collected at different intervals.

The Census of Agriculture reports on operator characteristics. Three reported characteristics could be useful for this indicator: (1) On farm operated versus not on farm operated; (2) Operators by principal occupation, Farming versus other; and (3) Operators by days worked off farm, broken down by day categories. Data are not available specifically on the level of income dependency on livestock production from any known source on a consistent basis.

Employment Diversity

An Economic Diversity Index would respond too the number and size of industries/sectors present in an economy. It is typically measured in terms of employment. We think that economic diversity is related to economic resiliency and the ability of an economy to respond to and adapt to changes in conditions.

Methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level. The U.S. Census Bureau collects this information as part of the Economic Census Data. Changes from Standard Industrial Classification (SIC) to the North American Industrial Classification System (NAICS) makes comparisons over longer time periods difficult. Only national and state level SIC and NAICS data can be compared.

In the United States, economic diversity indices, using the Shannon-Weaver entropy function, have been computed for all U.S. counties, labor market areas, BEA functional economic areas, BEA component economic areas, and states using IMPLAN employment data.

Agriculture (Ranch/Farm) Structure

This is a multi-faceted measure of direct production in agriculture. In the United States, a farm or ranch is defined as having $1,000 or more in gross annual agricultural sales. Other facets of this indicator include type of commodity raised, acres in production, categories of farm sales (measure of scale), and the business organization (for example, individual, partnership, corporate).

Farm structure is an indirect indicator of production capacity for food and fiber. It has become a data point for different perspectives to assess whether or not production can be sustained. There is not broad agreement on how the data might be interpreted, but there is agreement that these data are the basis for assessment.

Methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level. Potential sources of data are provided by USDA National Agricultural Statistics Service and USDA ERS.

Years of Education

This indicator measures the years of formal education of a population. It is an important measure of the human, and to a lesser extent the social, capital available for sustaining social groups and communities.

Data are collected by both census enumeration and through the Current Population Survey.

Community-Level Explanatory Indicators that may be Relevant to Sustainability

Indicators in this Section are the likely to be directly tied to rangeland sustainability. They describe the population and conditions in local areas in ways that are conceptually linked to good rangeland use and stewardship. They also attempt to capture some of the underlying beliefs and attitudes in local areas relevant to the way people relate to, and interact with, natural resources in general and rangeland in particular. They are linked to sustainability with uncertainty because the linkages are neither documented nor unambiguous. Establishing some of the specific linkages between the indicators and rangeland sustainability is a subject for continued research.

Value Produced by Agriculture and Recreation Industries as Percent of Total Economy

Agriculture and recreation based industries appear to be the two important sectors of the economy related to rangeland sustainability. While neither occurs exclusively on rangelands, their trends in rangeland-dominated counties should respond to pressures being placed on rangelands, particularly as population densities increase and economies change.

Methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level. While both data and methods are available, the linkage between the data and sustainability measures needs to be strengthened. In the United States, data are available from the U.S. Census Bureau.

Employment, Unemployment, Underemployed, and Discouraged Workers by Industrial Sector

This indicator provides information on the vitality of the local economy. High relative percentages in the unemployed, underemployed, and discouraged categories indicate an economy in trouble. Underemployment occurs when one is employed, but at less than the desired level; that is, employed part time when full time employment is desired. Discouraged workers are those who are unemployed and no longer actively looking for employment. High proportions of such workers in rangeland-related industries (for example, livestock production, recreation, tourism) may signify decreased health and vigor of rangeland related activities. Such changes would indicate how society was demanding uses from the rangelands and how such demand was being supplied.

Methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level.

Land Tenure, Land Use, and Ownership Patterns by Size Classes

This indicator measures changes in ownership, such as public vs. private and production agriculture vs. exurban development, ownership stability, and land use. It is important to sustainability because land use changes have been shown to have multiple effects on rangelands (for example, loss of open space, habitat fragmentation, and noxious weeds). Land use changes also can limit future options for the land.

The indicator seems conceptually feasible or initially promising, but no regional-national methods, procedures or data sets currently exist. Most relevant data come from the quinquennial Census of Agriculture and the Agriculture Economics and Land Ownership Survey. However, data are not reported in a form meaningful to this indicator. Sales classes rather than tract sizes report ownership and tenure data. One of the problems appears to be that neither the Census nor USDA currently sorts the data by tract size.

Population Pyramid and Population Change

Population pyramids are the most common descriptor of population structure. It requires actuarial data on gender and age. Data are organized into five-year age cohorts. Each population pyramid provides a snapshot of the distribution of age groups and gender. For example, the baby boom cohorts between 1945 and 1960 have bulged out as they moved up through the population structure.

This measure directly provides evidence of community sustainability. A population pyramid that varies little from the youngest to the oldest cohorts is considered to be stable. The proportion of population in different age classes can be informative; for example, very young or very old age structures indicate differing needs with respect to social and economic goods and services, some of which are derived from or associated with rangeland activities.

This indicator would measure changes in components of the population between base years, probably U.S. Census years. Births, deaths, and net migration patterns are also important components to understand population change in a community. Some changes in population structure are associated with different pressures on land, water, and fiscal resources.

Methods and procedures exist for data collecting and reporting; and data sets of useable quality exist at the regional-national level.

Income Differentials from Migration

This indicator measures the differentials between existing household income in an area and household income of in-migrants. It addresses whether the people moving in are wealthier than those already there. Retirees or the wealthy do not usually rely on local natural resources for livelihoods in the same fashion as long-time residents.

Methods and procedures exist for data collecting and reporting, and data sets of useable quality exist at the regional-national level. Data are available from U.S. Census population reports, the CIESIN population dataset for migrations, and the LANDSCAN dataset. County-to-county migration files that directly measure household income from current residents, out-migrants, and in-migrants by county are available from Internal Revenue Service data sets.

Length of Residence (Native, Immigrant More Than 5 Years, Less Than 5 Years)

This indicator measures the years of residence in a particular community and relates strongly to social cohesion/integration and willingness to interact with others for a common good. This indicator is also a measure of economic stability.

Methods and procedures exist for data collecting and reporting and data sets of useable quality exist at the regional-national level. The Census of Population and the Current Population Survey collect data on tenure of residence for households. The primary question is whether or not a person has lived in a place for less than five years.

Income by Work Location versus Residence

This indicator relates to whether income is generated where one lives or from outside the area of residence. It should relate to the importance of the residence communities, both economically and socially, to the income earner. It measures whether rangelands are providing the desirable rural setting where people want to live, but without the employment opportunities they require.

Methods and procedures exist for data collecting and reporting, and data sets of useable quality exist at the regional-national level; for example, location adjustments in the Regional Economic Information System produced by the Bureau of Economic Analysis and the journey-to-work data from Bureau of the Census.

Public Beliefs, Attitudes, and Behavioral Intentions toward Natural Resources

Public beliefs, attitudes, and behaviors influence cultural, legal, and public policy decisions toward the management, consumption, and preservation of natural resources. In order for rangeland management decisions to be socially sustainable (especially on public lands), they must achieve and retain some minimum threshold of social acceptability. This indicator would provide for regular measurement of preferences, attitudes, and intentions with respect to rangelands. Social science research indicates that a person's behavior in political and planning arenas is influenced by his/her beliefs, attitudes, and behavioral intentions.

Comprehensive data sources for this indicator are generally not available. Some data sets exist at the regional-national level, but methods and procedures are not standardized. In the United States, the National Opinion Research Center maintains data sets, but they do not presently assess rangeland-related issues. Some national-level studies have evaluated public beliefs and attitudes regarding federal rangeland management and analyses included regional comparisons, but they have not been repeated through time. Methods and survey instruments from such studies may be modified for periodic re-sampling, although additional information would need to be gathered on issues not considered in the original studies.

Conclusion

Our development of indicators for the social and economic benefits criterion has focused upon three levels. The first emphasis was on the products derived from rangeland ecosystems that are used by communities. Second, we focused on the communities themselves and how they react to what is happening in the larger ecosystem. Finally, we tried to examine whether what is happening in communities is having an impact on surrounding rangeland ecosystems. In order for this approach to be useful, we reiterate that data reporting must be made at the rangeland county level.

In order to be helpful in policy discussions, we need simple, yet comprehensive, composite indices of socioeconomic conditions that can be portrayed in understandable ways. Perhaps, a remaining task is to develop a composite index for each of the three primary groupings. While all the background data associated with the complete set of indicators is developed and considered, it is the next step to offer information to the policy discussion with an answer to the "so what?" question. While we have not taken this step at this point, failing to do this task only delays the inevitable and leaves one with a false sense of security associated with the sustainability discussion.

In closing, we believe that much of the data needed to assess this criterion are currently available. Indicators in the first grouping, National Economic Benefits, have the weakest link to adequate data; only two have good, existing data while two others have partial data. Taken as a whole, the set of indicators should provide information that can be used to assess the social and economic benefits derived from the Nation's rangelands. How this information is integrated with the ecological and legal information into a coherent statement of sustainability remains to be seen. The issue still remains whether data can be disaggregated to the level that is relevant to rangeland dependent community sustainability.

Monitoring Riparian Restoration: A Management Perspective

Yasmeen Najmi, Planner, and Sterling Grogan, Biologist and Planner, Middle Rio Grande Conservancy District, Albuquerque, NM

Abstract*—As the largest landholder of cottonwood-dominated riparian forest or "bosque" in the 150 miles of the middle Rio Grande from the Cochiti Dam to the Bosque del Apache National Wildlife Refuge, the Middle Rio Grande Conservancy District (MRGCD; a political subdivision of the State of New Mexico) and its cooperators are implementing "fuels reduction" projects throughout the bosque. Fuels reduction is defined as the removal of exotic phreatophytes such as Tamarisk (*Tamarix ramosissima*) and Russian olive (*Elaeagnus angustifolia*), treatment of the exotic stumps or stems with herbicide, and removing most dead and down wood to reduce fire hazard. Primary objectives for fuels reduction projects include: Fire management; habitat diversity; water salvage, and recreation access. While projects were initially small-scale, recently increased funding, and the availability of mechanical equipment such as mulcher-grinders and tree extractors, has enabled managers to implement projects more rapidly and on a larger scale. Concern for the effects of fuels reduction activities on wildlife, particularly the southwestern willow flycatcher (a Federally endangered species), and the growing influence of fire as the primary disturbance force in the bosque, has led to the establishment of two research projects by the MRGCD and the USDA Forest Service Rocky Mountain Research Station. These studies are examining the effects of different fuels reduction treatments and wildfire on vegetation, water resources, wildlife, and fuel loads in the middle Rio Grande bosque. They and other studies are part of an overall focus on bosque restoration that involves monitoring and research emphasizing ecosystem-level processes. The University of New Mexico's Bosque Ecosystem Monitoring Program (BEMP), utilizing K-12 students between San Juan Pueblo and Lemitar, New Mexico, monitors monthly changes in litterfall biomass, precipitation and groundwater depth at 19 similarly organized sites. BEMP is now supported to begin monitoring large-scale restoration work in the Albuquerque reach of the Rio Grande. In addition, universities and government agencies are monitoring evapotranspiration from bosque vegetation as well as groundwater levels and movement in order to learn how restoration activities affect water supply. Scientifically sound monitoring and research programs have the potential to strongly influence how we look at the bosque and approach restoration, now and in the future. The question for bosque managers like the MRGCD is how monitoring fits into a management scheme—that is, whether, when and how information from different monitoring programs can be integrated efficiently into restoration plans and implementation strategies, including best management practices.*

Monitoring Riparian Restoration: A Management Perspective

Scientifically sound monitoring and research programs have the potential to strongly influence how we look at the middle Rio Grande's riparian forest or "bosque" and approach restoration, now and in the future. The question for bosque landowners and managers like the Middle Rio Grande Conservancy District (MRGCD) is how monitoring fits into a management scheme—that is, whether, when and how information from different monitoring programs can be integrated efficiently into restoration plans and implementation strategies, including best management practices.

There are numerous monitoring and research projects in the middle Rio Grande concerned with the river and riparian ecosystem. Many of these efforts are taking place on land owned by the MRGCD. At least three efforts have used public funding to identify and map restoration, research, and monitoring projects in the middle Rio Grande bosque ecosystem. Collecting and assimilating this information from a variety of sources is a difficult task, however, and most of these efforts are focused on particular programs and don't claim to be comprehensive. Efforts to identify monitoring efforts thus far have not included evaluations of their scopes and methods. This information is needed to determine whether data from different programs is comparable and/or usable by managers but raises the question of whether those doing the monitoring should be the ones to evaluate methods and interpret monitoring data (Crawford 2004).

Other important questions for managers are how to do monitoring in the context of ecosystem-based management and who will do the monitoring? Coordination of groups conducting or funding monitoring and research is essential but can be thwarted by differences in management objectives and lack of planning and communication among agencies. This can result in different policies to address similar management issues (Crawford 2004). In the absence of good monitoring design, with replication of restoration methods, project design and implementation can be based on managers' personal observations and experience and/or the perspectives of other managers, without the benefit of comparative evaluation.

There are examples in the middle Rio Grande of managers developing monitoring programs and using results to develop or adapt management activities. The Bosque del Apache National Wildlife Refuge developed salt cedar removal (McDaniel and Taylor 2003) and controlled flooding studies (Sprenger and others 2002), the results of which have been published and used to design restoration projects on the Refuge. Adaptive management plans and monitoring programs are being developed for habitat restoration plans for the active floodplain on the Refuge (Dello Russo 2004) and from San Acacia to San Marcial, New Mexico as part of the Save our Bosque Task Force's Conceptual Restoration Plan (Tetra Tech, Inc. 2004). These plans will help coordinate and focus monitoring and management for a large reach of the middle Rio Grande.

The Middle Rio Grande Bosque Fuels Reduction and Wildfire Effects Studies are examples of cooperative research projects, involving multiple agencies interested in answering questions about the best way to accomplish hazardous fuels reduction and post-fire rehabilitation in the bosque ecosystem. The Fuels Reduction Study's research design contains replications of three fuels reduction treatments with control sites to determine effects on wildlife, groundwater tables and vegetation. This data can be used to guide objectives for restoration and rehabilitation projects and to develop specific prescriptions. However, time is needed to evaluate treatment effects and restoration activities are moving forward without the benefit of this information. Managers must weigh the possible negative impacts of implementing large-scale fuels reduction projects with the risks and effects of catastrophic wildfire.

The Middle Rio Grande Endangered Species Act (Collaborative Program), while focusing monitoring activities on habitat restoration and protection for targeted endangered species, nevertheless provides one mechanism for stakeholders to collaboratively develop, implement and evaluate monitoring programs and target funding toward coordinated efforts. The Collaborative Program is also in the process of developing a database that would be a logical focal point for storing monitoring plans, data and other information that could be used by anyone developing restoration projects in the Program area. It is critical for Program signatories and others to provide input on the content and form of the database, the frequency of database updates and how monitoring programs will be evaluated relative to Program goals.

The MRGCD and others have proposed efforts to collaboratively develop and evaluate restoration goals, methods and outcomes by developing a strategy for bosque "landscape alteration," and by revising and expanding the Draft Prescription Guide for the Rio Grande Bosque (Najmi and Wicklund 2000), which contains objectives and prescriptions for fuels reduction and fire rehabilitation projects.

In 2004, Dr. Cliff Crawford, Professor Emeritus of Biology at the University of New Mexico and Sterling Grogan, Biologist/Planner for the MRGCD, developed a proposal for reducing catastrophic bosque fires and water use by riparian vegetation through landscape alteration (Crawford and Grogan 2004). The suggested approaches for reorganizing the bosque's landscape were the subject of a workshop hosted at the University of New Mexico's Utton Transboundary Resources Center on May 25, 2004. Participants commented on the basic principles outlined in the proposal, raised additional questions and began to discuss implementation strategies and considerations in break-out groups. A workshop report was produced and distributed that articulated the following objectives for bosque landscape alteration:

1. Reorganize the bosque landscape to retain, within current constraints, its historical processes and wildlife communities
2. Recreate, by doing this, its former patchy mosaic of native trees and open spaces along the present day river's narrow floodplain, while containing the distribution of invasive species
3. Reduce, by having created this mosaic, the intensity of bosque wildfires both at the wildland-urban interface and within the rest of the bosque, and the landscape water depletion by bosque evapotranspiration (ET) (Utton TRC, 2004).

Assuming these goals and associated implementation strategies are adopted by bosque managers and integrated into planning efforts and projects, a monitoring program must be developed to determine whether these goals are met. If monitoring criteria are components of the goals, the following could serve as initial guidance:

- Monitor changes in habitat diversity and corresponding biological diversity, changes in water availability and ET, fuels loads and fire behavior.

We then must examine the question of the minimum level of monitoring required to indicate whether we are meeting goals. The following is a preliminary list for consideration:

- Vegetation structure, composition and cover
- Bird and mammal populations
- Endangered or sensitive species habitat
- Invertebrates
- Fuel load estimates (dead and live)
- Surface and groundwater hydrology, and ET (in select areas)
- Fire extent, behavior and intensity
- Soils and geomorphology
- Other conditions such as weather, soil and fuel moistures

Out of the suite of current restoration and/or monitoring programs in the middle Rio Grande bosque, four are collecting, or have the potential to collect, a range of data for multiple sites throughout the middle Rio Grande bosque with reference sites for comparison. These programs are The University of New Mexico's Bosque Ecosystem Monitoring Program (BEMP), the Middle Rio Grande Bosque Fuels Reduction and Wildfire Effects Studies, and the Middle Rio Grande Endangered Species Collaborative Program. Table 1 provides a broad overview of the scope and locations of these programs to begin to assess whether their methods are adequate to monitor the outcomes of bosque landscape alteration and whether the results from different programs might be comparable or complementary. Monitoring components for BEMP (Eichhorst and others 2002) and the Middle Rio Grande Bosque Fuels Reduction (Finch and others 2003a) and Wildfire Effects Studies (Finch and others 2003b) were taken from annual reports submitted to the MRGCD, and updates for BEMP were obtained from program volunteers. Monitoring components for the Endangered Species Collaborative Program are taken from the Program's Draft Monitoring Plan (MRGESACP 2004). The Draft Monitoring Plan has not been approved by the Collaborative Program but is useful for comparison purposes.

Table 1. Comparison of four monitoring programs in the middle Rio Grande bosque.

	Program name and location by New Mexico County			
Monitoring Components	**BEMP[a]**	**BFRS[b]**	**BWES[c]**	**MRGESACP[d]**
Vegetation structure		X	X	X
Vegetation composition	X	X	X	X
Vegetation cover	X	X	X	X
Post-fire veg. growth and survival			X	
Fuels inventories	X	X	X	
Fire intensity & behavior				
Leaf fall	X			
Hydrology (groundwater)	X	X	X	X
Hydrology (surface water)	X			X
Water quality				X
Riparian evapotranspiration				X
Geomorphology				X
Bird surveys (breeding)		X	X	X
Nest monitoring		X	X	X
Bird surveys (fall & winter)		X	X	X
Arthropods	X		X	
Herpetofauna		X		
Bats/Small mammals		X		
Ichthyofauna				X
Endangered species		X		X
Soils		X	X	X
Precipitation	X			

[a] Bosque Ecosystem Monitoring Program (Rio Arriba, Sandoval, Bernalillo, Valencia, Socorro counties)
[b] Middle Rio Grande Bosque Fuels Reduction Study (Bernalillo, Valencia, Socorro counties)
[c] Middle Rio Grande Bosque Wildfire Effects Study (Valencia and Socorro counties)
[d] Middle Rio Grande Endangered Species Collaborative Program (Taos, Rio Arriba, Santa Fe, Sandoval, Bernalillo, Valencia, Socorro counties

Monitoring is an essential component of any restoration program but often gets inadequate attention and planning in the rush to implement projects, and can be the first budget reduced or eliminated when funding shortfalls occur. Monitoring programs developed as part of ecosystem-based or large-scale restoration plans may result in better designs that answer the critical questions, with coordination and support among stakeholders. Monitoring programs developed as part of larger restoration efforts are also more likely to be peer-reviewed. Some of the current large-scale restoration efforts in the middle Rio Grande provide the best opportunities to develop coordinated monitoring and adaptive management plans and secure the funding to implement them.

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Urban Forest Health Monitoring in the United States

David J. Nowak, Project Leader, Robert Hoehn, Biological Science Technician, Jeffrey T. Walton, Research Forester, Daniel E. Crane, Information Technology Specialist, and Jack C. Stevens, Forester, USDA Forest Service, Northeastern Research Station, Syracuse, NY
Daniel Twardus, Forest Health Specialist, and Anne Cumming, Urban Forester, USDA Forest Service, Northeastern Area State and Private Forestry Morgantown, WV
Manfred Mielke, Forest Health Monitoring Specialist, USDA Forest Service, Northeastern Area State and Private Forestry, St. Paul, MN
Bill Smith, Research Quantitative Ecologist, USDA Forest Service, Southern Research Station, Forest Sciences Laboratory, Research Triangle Park, NC

Abstract—*Trees in cities can contribute significantly to human health and environmental quality. Unfortunately, little is known about the urban forest resource and what it contributes to the local, regional, and national societal and economic interests. To help better understand the urban forest resource and its numerous values, the USDA Forest Service has initiated a pilot program to sample urban forests and street tree populations across various states. Pilot tests of monitoring the total tree population in urban areas have been or are being conducted in Indiana, Wisconsin, and New Jersey. Pilot tests of monitoring state-wide street tree populations have been conducted in Maryland, Wisconsin, and Massachusetts. Results from the pilot studies include information on urban forest population size and composition, health, potential risk from insects and disease, and various forest functions (for example, carbon storage, air pollution removal, building energy conservation) and values. Results from the pilot study in Indiana reveal that there are approximately 92.7 million urban trees ($55.7 billion structural value) and that these trees removed about 6,600 metric tons of air pollution in 2000 ($53.4 million value) and store about 8.4 million metric tons of carbon ($170.2 million value).These base values provide insight into urban forest structure, functions, and tree health to aid in urban forest planning and management. Through long-term monitoring of these plots, critical information can be obtained to assess how this resource is changing.*

Introduction

People are having an ever increasing impact on local, regional, and global environments. This impact is particularly significant in and around urban areas (for example, cities, towns, villages). Urban forests (trees in urban areas) can mitigate certain detrimental human impacts and improve environmental quality and human health. Urban forests can provide clean air and water, recreation, energy conservation, carbon storage, protection from ultraviolet radiation, cooler air temperatures, habitat for wildlife, forest-based products, and aesthetic values, and enhance the social and psychological well-being of millions of Americans. As a valuable national resource that will continue to increase in extent and importance in the years ahead, urban forests face many pressures (for example, insects, diseases, storms, and pollution) that can affect forest health and numerous related benefits.

In 1997, a National Research Council report titled "Forest Lands in Perspective" recognized that urban and community nonfederal forests are the fastest growing forests in the United States and recommended strengthening federal forest health monitoring of these forests. In 1998, USDA Forest Service Chief Michael Dombeck developed a Natural Resource Agenda that emphasized sustainable development of communities, and Deputy Chief Phil Janik released an action strategy for State and Private Forestry that would increase forest health monitoring in urban areas. In 1999, former USDA Secretary Dan Glickman noted "We still have plenty of work to do to make Americans take notice of the dwindling natural resource base in their cities" (Glickman 1999)

In a survey of forestry professionals regarding urban forest health needs, less than 25 percent of the respondents ranked the overall health of the urban forests in their state as good to excellent, 99 percent indicated that preserving the health of community forests should be an integral part of urban and community forest programs, and more than 90 percent identified long-term tree care and maintenance programs as critical to preserving the health and sustainability of urban forests in the Northeast (Pokorny 1998).

Although urban forests are a significant resource affecting the vast majority of the population, little is known about the nation's urban forests, how this resource is changing, or the factors that might lead to changes in urban forest structure and health. By knowing how the urban forest is changing, better policies can be developed to protect, sustain, and/or enhance urban forest health and benefits for future generations. In an attempt to learn more about this resource and to aid in its management and planning, various pilot studies were developed to test the application of a National Urban Forest Health Monitoring (UFHM) Program. This program is being designed to acquire information about the urban forest while concurrently establishing a nationwide system of urban forest pest detection and forest health monitoring (Nowak and others 2001). The program is a cooperative effort involving the United States Department of Agriculture's (USDA) Forest Service's Forest Health Monitoring Program, Urban and Community Forestry, Forest Inventory and Analysis, Northeastern Research Station, and state agencies.

As part of this program, two separate field sampling protocols were developed. One protocol is designed to assess the entire urban forest resource (known as Urban Forest Inventory); the second focuses specifically on the street tree resource (known as Statewide Urban Street Tree Monitoring). The purpose of this paper is to review the status of the UFHM program and provide results from the first Urban Forest Inventory pilot study in Indiana and the Statewide Urban Street Tree Monitoring pilots in Maryland and Massachusetts.

Urban Forest Inventory

Urban Forest Inventory seeks to extend the Forest Inventory and Analysis (FIA) sampling grid that is used to collect information about forests nationwide. FIA personnel are responsible for providing periodic assessments of the nation's forest resources and conducting statewide inventories. Currently data are only collected on "forested" plots, which are defined as areas that are at least 1 acre in size, at least 120 feet in width, at least 10 percent stocked, and the intended use is forest (in other words, not agriculture, urban, etc.). Thus, field data are not collected on "nonforest" plots (for example, urban areas), though many trees may be present on the plot. As most urban areas are classified as "nonforest," data on urban vegetation are not collected as part of this national forest inventory program. The urban forest inventory phase of the UFHM Program is designed to collect information on the FIA plots in urban areas and fill this critical "data gap."

Plots in urban areas are sampled using the FIA sampling grid (one plot every 6,000 acres). Boundaries of urban areas are based upon data from the U.S. Census Bureau and overlaid with the FIA grid. Plots falling within the urban boundaries that are classified as "nonforest" are included in the UFHM inventory. The plots are sampled during the growing season to collect an extended suite of ecological data including a full vegetation inventory and evaluation of tree damage and crown conditions, plus additional variables that were needed for conducting analyses using the Urban Forest Effects (UFORE) model (for example, percent crown missing, distance from building) (Nowak and Crane 2000). For the existing FIA forest plots in urban areas, data collected by FIA crews were used for analysis and combined with the new urban FHM plots. Recent research has shown that the cost of measuring non-forest plots is about 1/3 the cost of a forested FIA plot (Riemann 2003).

Pilot implementation of the inventory took place in Indiana in 2001 and 2002. The pilot, conducted by the Indiana Department of Natural Resources, was designed to extend the on-going FIA statewide inventory into urban areas. This extension resulted in 32 sample locations within urban boundaries (six of these sample locations met the FIA definition of "forested" and were not included in the urban pilot as data were already collected at these locations as part of the national FIA program). As the Indiana inventory was designed to be collected over a five-year period, only 1/5 of the total number of urban sample locations were collected the first year.

A second pilot took place in Wisconsin in 2002 and was conducted through the Wisconsin Department of Natural Resources. Using Census-defined urban areas, 119 urban plots were sampled (plus an additional 28 plots from FIA "forest" plots). All urban plots in Wisconsin were established and measured the first year. After the first year of complete data collection, the inventory was designed to monitor 1/5 of the plots every year so that all plots are updated every five years. A third inventory pilot was initiated in New Jersey in 2003.

Urban forest inventory plots conform to all standards of Forest Inventory and Analysis and the National Forest Health Monitoring programs. They consist of four 24-foot fixed-radius sub-plots spaced 120 feet apart. This particular plot layout, though useful in forested situations, has proven difficult within the urban setting. The distance between sub-plots often results in numerous property owner contacts to establish a plot. In Wisconsin, there was an average of five property owner contacts per plot, with a record 12 property owner contacts for one plot. Training of field crews included extensive manual review and field demonstrations of plot layout and tree measurements.

The FIA National Core Field Guide was modified to include urban data: urban land-use codes, plantable space, sub-plot tree cover, and ground cover and shrub information. An extended tree species code list has been incorporated. All trees one inch in diameter and larger are measured. This Urban Forest Field Guide is located at http://www.fs.fed.us/ne/syracuse/Tools/tools.htm.

Indiana Urban Forest Inventory

Within urban areas of Indiana there are an estimated 92.7 million trees (standard error (SE) =32.8 million). Of these trees, approximately 49.1 million (SE=26.8 million) are found in forests in urban areas and the remaining 43.6 million (SE=19.1 million) in other urban land uses (for example, residential, vacant, commercial – industrial). The most common tree species overall were sassafras (15.1 percent), silver maple (14.6 percent), and eastern cottonwood (10.9 percent). In forest areas, sassafras (28.6 percent), northern red oak (15.8 percent), and white oak (11.0 percent) dominated; on other urban lands, silver maple (24.5 percent), eastern cottonwood (18.2 percent), and Siberian elm (9.5 percent) were the most common. Overall tree cover in the urban forest is estimated at 20 percent. Most of the trees in the total urban forest are small with diameters less than 3 inches (fig. 1).

The species that dominates in terms of basal area (which is related to tree size and functional value) is silver maple. Trees that are relatively small (that is, percent basal area much less than percent of total population) in this population are sassafras, eastern cottonwood, American basswood, and boxelder (fig. 2). Species that are not native to the state comprise about 7 to 14 percent of the urban forest stands, and about 18 to 20 percent of the remaining urban lands.

While trees cover approximately 20 percent of Indiana's urban area, shrubs cover about 8 percent. Other cover types include herbaceous cover (for example, grass, gardens) (46 percent), impervious surfaces, including buildings (28 percent), duff, mulch and bare soil (24 percent), and water (2 percent). Ground cover in forested stands is dominated by duff/mulch, while the other urban lands are dominated by herbaceous ground cover.

Urban forests have a structural value based on the tree resource itself (for example, the cost having to replace the tree with a similar tree), and annually produce functional values (either positive or negative) based on the functions the tree performs. The structural or compensatory value (Nowak and others 2002) of Indiana's urban forest is approximately $56 billion dollars.

Urban trees in Indiana removed an estimated 6,600 metric tons of pollution per year, with an associated value of about $35.4 million dollars (based on estimated national median external costs associated with air pollution). Pollution removal was greatest for ozone (O3), followed by particulate matter less than 10 microns (PM10), sulfur dioxide (SO2), nitrogen dioxide (NO2) and carbon monoxide (CO) (fig. 3).

Urban trees in Indiana are estimated to store 8.4 million metric tons of carbon ($170.2 million value). Of all the species sampled, silver maples store the most carbon (approximately 32 percent of carbon stored). Urban trees are also estimated to sequester about 280,000 metric tons of carbon annually ($5.7 million/year).

Urban trees in Indiana are estimated to save homeowners $14.7 million annually by reducing MWh of energy consumed, but increase costs by $20.8 million annually due to increased MBtu usage to heat buildings in winter due to tree shade from branches. The net effect of the current structure is an annual cost of $6.1 million dollars. Even though costs go up, Indiana's urban forest helps to reduce about 23,600 metric tons of carbon emissions from power plants due to energy conservation from trees. This disparity is due to the difference between cost and carbon production involving the

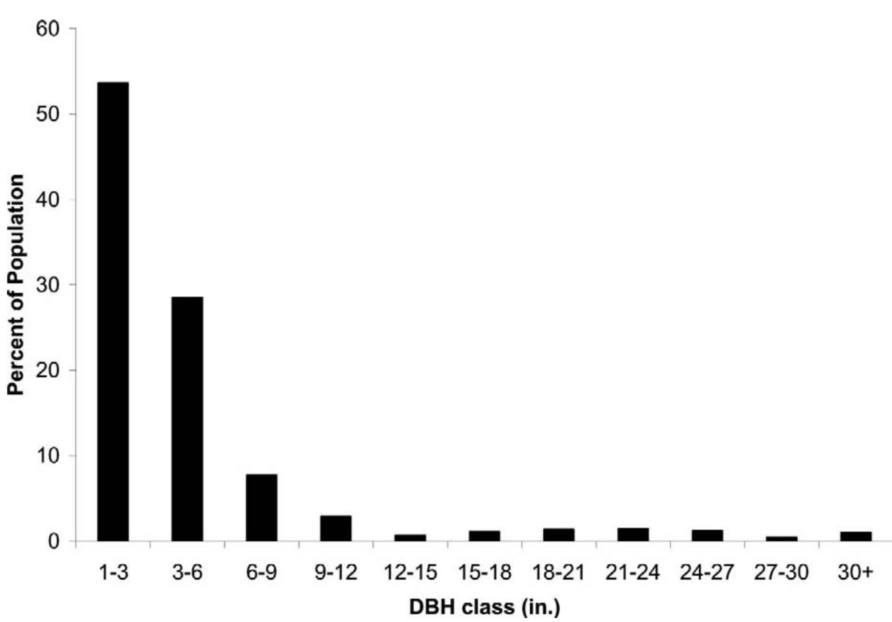

Fig. 1. Tree diameter distribution of Indiana's urban forest.

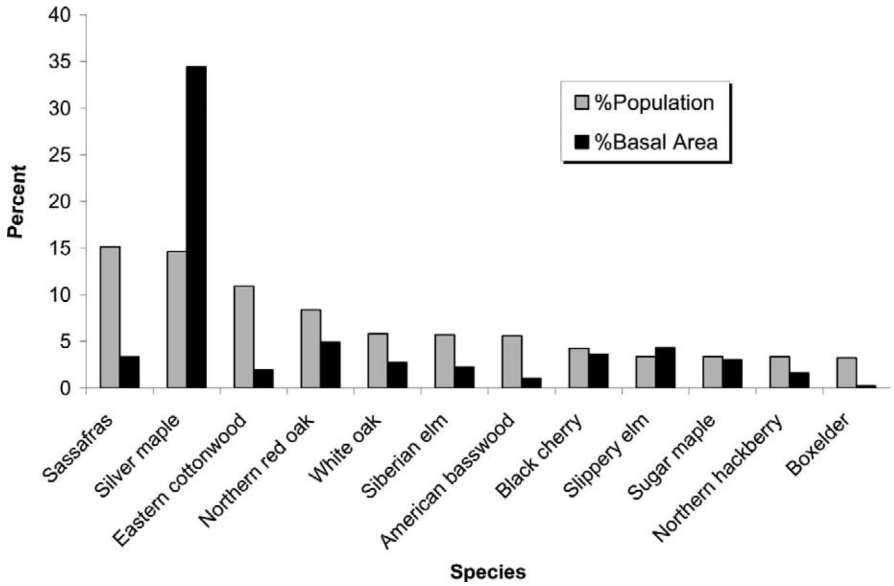

Fig. 2. Percent of population and percent basal area of 12 most common tree species in Indiana's urban forest.

winter and summer season energy use. As tree location around buildings and tree size are key determinants of energy effects, the small sample size compounded with relatively few trees in energy effect positions, means the results of this analysis are highly uncertain.

Exotic pests can also have a significant influence on Indiana's urban forest. The Asian long-horned beetle (ALB) is an insect that bores into and kills a wide range of hardwood species (USDA Forest Service 2004a). The risk of ALB to Indiana's urban forest is a loss of $30.3 billion dollars in structural value (57.8 percent of the population). The gypsy moth is a defoliator that feeds on a wide variety of tree species and can cause widespread defoliation and tree death if outbreak conditions last several years (USDA Forest Service 2004b). The risk of this pest is a loss of $9.0 billion dollars in structural value (22.7 percent of the population) in Indiana. The risk of the emerald ash borer, an insect that has killed thousands of ash trees in Michigan and Ohio (USDA Forest Service 2004c), is a structural value loss of $4.5 billion dollars (2.3 percent of the population) in Indiana.

The overall pilot test was based on 32 plots, which is a relatively small sample size. Increased sample size with future sampling will lead to increased confidence in the analyses.

Statewide Urban Street Tree Monitoring

Statewide Urban Street Tree Monitoring seeks to implement a statewide street tree assessment using plots established within the public right-of-way in urban areas. Though street trees represent only a small portion of the urban forest (approximately 5 to 10 percent), they are the trees that municipal foresters are responsible for and are often the most visible component of the urban forest. A street tree monitoring system provides information about the nature and condition of the street tree population and can be used for detection of new or exotic insect or pathogen problems. Like urban forest inventory plots, the street tree plots are to be continually updated to provide information on change in street tree populations.

Statewide street tree monitoring is based upon urban areas as defined U.S. Census Bureau boundaries. Sample locations are randomly located in urban areas in the right-of-way along public roads. The statewide sample consists of 300 plots. In year one, all 300 plots are installed, and this becomes the baseline sample. In subsequent years, a sub-sample of plots is revisited to allow for assessments of change.

A state may choose to intensify the baseline sample. Baseline intensification was done in Wisconsin in 2002, with 900 plots installed through the efforts of the Wisconsin Department of Natural Resources. The Massachusetts Division of Forests and Parks (2002) and Maryland Department of Agriculture (2001), each installed 300 baseline plots. In 2002, Maryland initiated the first revisit. Plots were revisited using a rotating panel design to get an estimate of year-to-year change in condition. A panel consists of one-fifth of the 300 baseline plots (60) along with a re-measurement of one-third of the previous year's plots (20 overlap plots) for a total of 80 plots per year.

Each plot consists of four sub-plots, two on each side of the roadway. Plots were installed within the public right-of-way so property owner contacts were not an issue. Each sub-plot is 181.5 feet in length and 10 feet in width (area equals the area of an urban forest inventory sub-plot). Instructions were provided for cul-de-sacs, dead-end roadways, and roadways with median strips. While not permanently set with monument markers, plot locations are identified by distance and azimuth to landmarks. Divided highways, private communities, interstate access ramps, and military installations were excluded from the sample location selection. Plot locations were provided to the State along with replacement plot locations in case the original plots could not be accessed (for example, plots with dangerous access or located in private or gated communities).

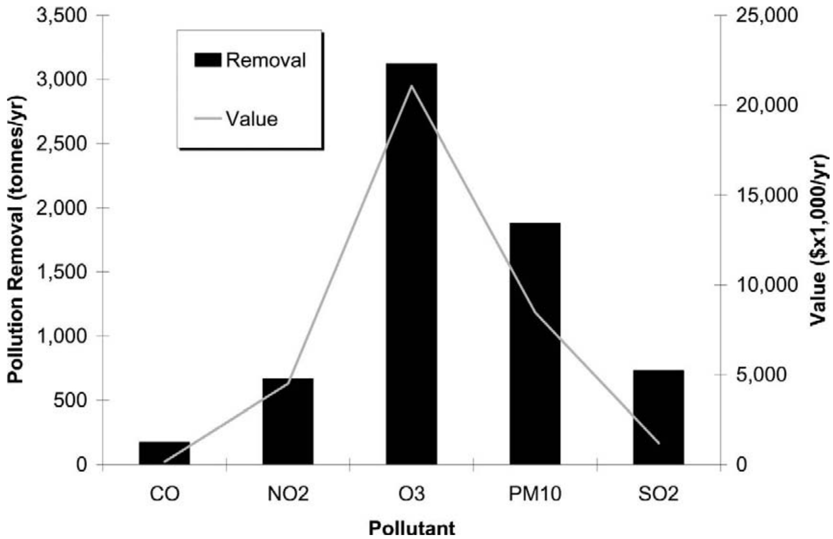

Fig. 3. Estimated pollution removal (2000) by Indiana's urban forest. Removal value estimated using median externality values in United States for each pollutant: nitrogen dioxide (NO2) = $6,750 t-1, particulate matter < 10 microns (PM10) = $4,500 t-1, sulfur dioxide (SO2) = $1,650 t-1, carbon dioxide (CO) = $950 t-1 (Murray et al.1994). Externality values for O3 were set equal to those for NO2.

A street tree data collection manual has been developed and includes information on plot location guidelines, plot establishment procedures, and data collection. All trees 1 inch in diameter and larger are tallied. Data includes tree diameter and height, crown condition, and damage. Ground cover types on the plot are also estimated. Sidewalk conflicts and utilities information are recorded. Training was conducted for all field crews. Training included a review of the field manual and in-field plot establishment procedures.

Street Tree Monitoring in Maryland and Massachusetts

There are an estimated 643,958 trees along Maryland's 14,139 miles of urban roadway (approximately 46 trees/mile). In Massachusetts, the 20,384 miles of urban roads are lined with an estimated 1,184,776 trees (58 trees/mile).

In Maryland, the street tree population contained 67 different species, none comprising more than 13 percent of the total population (table 1). Species diversity at the genus level showed 32 different genera, with over 70 percent of the trees falling into only five genera (Acer, Pyrus, Quercus, Prunus, and Platanus).

In Massachusetts, Norway maple clearly dominates the population, with more than 34 percent of all 66 species encountered (table 2). Massachusetts street trees are represented by 29 different genera, with over 50 percent of all trees falling into only two: Acer and Quercus.

Overall, the street population in both states is dominated by maples with nearly 50 percent of the trees in Massachusetts and 40 percent of the trees in Maryland being Norway, Sugar, Red, Silver, or other maple species. This distribution has implications for insect or disease infestations that could cause significant losses in street tree populations. An example is the recently introduced Asian long-horned beetle, which is known to attack and kill at least six species of maple. Other potentially significant pests are the gypsy moth, which could have a significant impact on oaks; Emerald ash borer, which could kill many ash trees, and Dutch elm disease, which has been killing elm trees.

Available planting space was determined by factoring an accepted planting space between trees (50 feet), knowing what proportion of the roadways do not currently have street trees, and taking into consideration trees adjacent

Table 1. Ten most frequent species found on Maryland's urban roadways

Species	Percent of total	Mean DBH (inches)
Callery pear	13	9
Red maple	11	13
Maple spp.	10	10
Norway maple	6	11
Silver maple	5	13
Cherry Plum	3	6
Oak spp.	3	16
Crabapple	3	10
Honey locust	3	12
Sweetgum	2	8

Table 2. Ten most frequent species found on Massachusetts' urban roadways

Species	Percent of total	Mean DBH (inches)
Norway maple	34	15
Red maple	9	12
Northern red oak	8	16
Callery pear	4	6
Pitch pine	4	8
White ash	3	19
Black oak	3	9
White oak	3	15
Sugar maple	3	18
Silver maple	3	25

to the public right of way whose crowns overlap the right of way and essentially function as street trees. In Maryland, there are an estimated 23 plantable spaces/mile of urban roadway, and 20 spaces/mile in Massachusetts. In Maryland, the planting potential spaces would almost double the number of street trees, while in Massachusetts, planting available spaces would increase the street tree total by roughly 30 percent. However, this potential planting space estimate is liberal as it includes the amount of hardscape including driveways, sidewalks, and other impervious surfaces that may limit tree planting.

Tree size distribution as reflected by diameter class distribution indicates that street tree populations in Maryland are relatively well distributed with the largest proportion of trees falling within the five to 15 inch diameter classes. In Massachusetts, larger trees (15 inches and greater in diameter) constitute about 50 percent of the total, indicating a somewhat older or maturing street tree population. While large street trees are aesthetically pleasing in terms of how they shade the roadway and sidewalk, they often can present additional management needs such as pruning or sidewalks and overhead wire interference. The relatively mature street tree population in Massachusetts had a higher incidence of sidewalk conflicts (28 vs. 18 percent) and overhead wire conflicts (25 vs. 18 percent) than the Maryland street tree population.

In Maryland, 64 percent of the trees did not have damage that met the minimum threshold for recording, compared to 71 percent in Massachusetts. In Maryland, the most common damage recorded was open wounds (16 percent of damage recorded); in Massachusetts it was conks and signs of advanced decay (17 percent).

Street tree monitoring results, particularly long-term monitoring results that will reveal rates of change, can provide useful information to the state to sustain the street population and benefits, and minimize liability.

Conclusion

The National Urban Forest Health Monitoring Program is developing protocols for national urban forest data collection. Pilot studies in various states are revealing new information about urban forests at the state level, as well as allow for improvements in the National Urban Forest Health Monitoring and Urban and Community Forestry programs. It is hoped that an Urban Forest Health Monitoring Program will be established nationwide in the upcoming years after the pilot program develops and tests the most appropriate procedures and methods of reporting results.

National urban forest monitoring can provide critical information for improving urban forest health, management, and benefits across the country. Though the type of information provided by UFHM plots can be used immediately to aid in management and planning, increased value will be derived after the plots have been re-measured. A long-term tree and forest monitoring effort in urban areas provides essential information on rates of change, as well as a means to detect and monitor the spread and range of numerous tree health-related factors (for example, spread and damage associated with the introduction of exotic pests). By knowing how the urban forest is changing, better policies can be developed to protect, sustain, and/or enhance urban forest health and benefits for future generations.

Acknowledgments

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Monitoring Patagonian Rangelands: The MARAS System

Oliva, Gabriel, INTA EEA Santa Cruz. Chacra 45 A 9400 Rio Gallegos Santa Cruz Argentina Juan Escobar, INTA EEA Chubut, Guillermo Siffredi, INTA EEA Bariloche, Jorge Salomone, INTA EEA Chubut, and Gustavo Buono, INTA EEA Chubut

Abstract—*Rangelands in Patagonia have been managed with a lack of regulation since the introduction of sheep in the late 1880's. Most rangelands are under private freehold in 'estancias' and the rest are public and managed by small subsistence-type farmers. Natural resources of rangelands are property of the provincial states according to the Constitution, but they have no mandate or resources to monitor their condition and public support funds have not been tied to proper management. Government agencies designed in the 1990's two range evaluation systems hat have been applied extensively but they focus on short time - scale processes to allocate forage resources at the "estancia" scale. The need of a regional monitoring system to evaluate rangeland condition and trend is slowly being recognized by governments and farmers, and scientists of Patagonia have been discussing a possible unified methodology. The system has been named MARAS and is based on Australia's WARMS (Holm 1998) and other similar methods. Lines of point interception and frequency samplers are used to evaluate herbaceous vegetation, Camfield lines to evaluate shrubs and patches, surface sampling, and estimates of soil condition. Ground observation points would be set one per cadastral unit (about 20.000 ha) and evaluated at five-year intervals. State funding has been obtained in 2004 to put in place the first monitors, and to design a web data base that would give selective access to the information to federal, provincial, or non-governmental institutions. The main challenge of the system is to assure funding through decades in order to assess long time-scale processes. We expect that ecocertification market requirements will induce farmers to support it, and that the new trend of public funding included in a new sheep promotion law will allow the system to continue.*

Introduction

Cold semi-deserts in Patagonia are mostly rangelands stocked with about nine M sheep, 0.8 M cattle and 0.8 M goats. Most of the 75 M hectares of land are in private hands in medium sized estancias that range from 10 to 20 thousand hectares, under freehold type tenure, although smaller production units on public land are also frequent in the N of the region. These areas for sheep tending were colonized at the end of the XIX century, but even today the total population of 1.75 M is scarce (.23 inhabitants/km^2) and concentrated in cities, as only about 0.2 M people live in the rural area. A more detailed description of the land is presented elsewhere in this Symposium Proceedings (Cibils and Oliva 2004).

Rangeland degradation is a concern for farmers and governments due to sheep stock decrease from the historical 20 M to less than half (Mendez Casariego 2000). The reasons of the crisis include low profitability of the sheep products, and mainly the decline in production indexes that slowly reduce number of stock in individual estancias and make the systems sensitive to periodic natural disasters, such as snowfalls. Dwindling productivity and unfavorable macroeconomic policies placed most of the producers of medium sized estancias in trouble (Borrelli and others 1997). About 10 M ha of the Central Plateaus have been abandoned by the year 2000 in Santa Cruz province. Farmers of smaller enterprises remained in the land and survived with little commercial exchange and serious social problems. Big enterprises followed on with reduced employment rates and smaller profits.

The objective of this paper was to shortly summarize the state of rangeland science in Patagonia. We discuss the progress in range forage assessment at "estancia" scale with stocking adjustment and adaptive management. From this we will address the need of a monitoring system that would measure variables at an appropriate temporal and spatial scale. We will present the MARAS initiative of a group of range scientists of Patagonia, and discuss briefly the main challenges of such a system.

Range Science

Rangeland science in Argentina is recent, and still has to develop fully and build into the government policies and rural financial instruments. Although 90 percent of Patagonia is occupied by rangelands, their management depends entirely on the decisions of the farmers. Some early researchers have pointed out the need of a scientific approach of the management of rangelands taking into account early degradation indicators (Auer 1951, Soriano 1956a, b). However, range science development started in the late 70's, mainly in federal Agricultural Research Agencies such as INTA (Anderson 1980) and University of Buenos Aires in basic ecological research. By the end of the 1980´s two different range evaluation methods were developed, one based on Pastoral Value indexes drawn from step-point quadrat estimations of forage species cover (Elissalde and others 2002), and a second one know as Santa Cruz method, that evaluates forage biomass by direct cuts of shortgrasses and herbs, and utilization degree using residue height of key species of short grasses (Borrelli and Oliva 2001). Range condition inventories have been used to aid management, and interpreted into State and Transition models (Paruelo and others 1993). Between 1990 and 1994, with international support of GTZ (Germany), INTA and other institutions performed a general assessment of the desertification status and reached to the conclusion that about 34 percent of the rangelands of Patagonia was in severe or very severe degradation status (Goergen 1995, Oliva and others 1995, Del Valle 1998, DHV-SWEDFOREST 1998). As a side effect of this project, image processing units and GIS training and equipment were installed in the area. Public funds for range evaluation were allocated to different desertification projects between 1989 and 2003, and allowed for training and support for rangeland evaluation that has reached to approximately 4.5 M ha by 2004.

Range Evaluation Methods

Range evaluation strategies have focused on providing objective assessment of the forage status at a typical estancia scale with reasonable costs. They are the basic input for management plans that are paid by the producers and performed by private or semi- private range professionals that are included in a provincial registry after being trained in special courses. Evaluation usually implies about 10 and 15 paddocks with a mean area of 2.5 thousand ha, and the production of detailed maps using satellite imagery. The pastoral value method is usually applied fully in an initial assessment, that includes cover of all species, but the stocking rates are adjusted furthermore in relation to rainfall (Rimoldi and Buono 2001). The SC method involves annual evaluations of shortgrass biomass and height to adjust stock allocation, but less palatable plants are not included (Borrelli and Oliva 1999). The main assumption is that undesirable transitions will be avoided if sheep leave approximately half of the standing biomass of the main forage species.

The Need for a Monitoring System

After 14 years of the first range evaluations, it is clear that a monitoring system is needed for three reasons (1) The variables recorded in repeated rangeland assessments are few and not sensitive enough to avoid transitions, (2) the time scale (years) and the spatial scale (estancias) are not appropriate to monitor regional processes and (3) the private funding of range evaluations implies restrictions on data and limits the area of application.

Indicators are Needed

Research sites have demonstrated that cover of the dominant species in these rangelands dominated by long lived perennials is not a good indicator of the proximity of transitions to degraded states. Oliva and others (1998) monitored yearly vegetation cover in a stocking rate experiment in Moy Aike Chico, Santa Cruz for over a decade, and concluded that the rangelands had reached stable states under grazing, under high stocking rates (0.60 sheep/ha) the cover of the most important species and even the main forage items did not change at all or actually increased. Vegetation change had nevertheless took place under high stocking rates as the most palatable and rare species disappeared, the diversity index declined, soil texture changed where fine lime particles were lost by erosion (Oliva and others 2000), and N and organic matter diminished with long lasting effects (unpublished data). These rangelands also show distinctive patterns of mounds associated to tussocks (Oliva 1996) or shrubs (Rostagno and others 1991) that act as sinks of nutrients and facilitate grass establishment (Soriano and Sala 1986, Aguiar and Sala 1999), and their disruption may change the function of the grassland. An appropriate set of soil, vegetation, and structural indicators of the rangeland seems to be necessary to in order to prevent unfavorable transitions.

Time and Spatial Scale

Range evaluations concentrate in annual variations of forage quantity that are a clearly perceived by farmers and allow adaptive management practices. Long term declines in production that could be the result of range degradation are regarded as signs of declining rainfall (Oliva and others 2004b), a tendency that is not evident in climatic data (Cibils unpublished). Demographic models have shown nevertheless that processes such as subdivision of tussocks under high stocking rates could determine the extinction of the tussock population after 4 or 5 decades (Oliva 1996). A monitoring system should keep track of slow changes that are best evaluated at long intervals to allow for cumulative processes to be revealed, but these changes will not be easily interpreted and recognized by managers.

Funding

The best efforts of range consultants and extensionists have reached about 6 percent of the total area of Patagonia. New financial tools tied to range evaluations may imply an expansion, but there is a small probability that they will reach the vast spaces of land withdrawn from sheep production, run by small subsistence type producers that may not pay for new practices or farmers that are simply not interested in new practices and stick to the traditional ways. The monitoring system should therefore be based on public funds and the ground points selected as a sample of all the rangelands.

The MARAS System

Since 2002, a group of range scientists (Oliva and others 2004a) of Patagonia backed by a National Action Against Desertification (PAN INTA-GTZ Germany) program has been developing a monitoring system whose acronym MARAS (Monitoreo Ambiental Regional de zonas Aridas y Semiaridas) relates to regional monitoring of arid and semi-arid rangelands. The initial methodology has been established in two previous meetings and the first monitor was set up in the Rio Mayo INTA experimental field in April 2004. Our system aims to monitor ecologic units that range from 0.4 to 11.4 M ha. They would be covered by ground monitors at a density of one per 20.000 ha, that approximately matches the size of cadastral units. The location of the monitors would be set in a cadastral GIS layer divided into ecological units, and then reassigned in the field in order to avoid edges of vegetation communities or the proximity of waterpoints or fences. A web data base will validate the entries using a single species and indicators list for the entire region and connect the points in the GIS layer. Information will be selectively accessible to different federal and provincial governmental agencies and NGO's. The data base will be developed in order to connect with GIS software of different vendors that are used in the region, and will hopefully be adopted as a unified system by the different provincial departments of agriculture.

The field layout (Fig. 1) matches the one used by West Australia's WARMS method (Holm 1998). It consists in a photographic pole that bears the identification of the site. A trapezoid shaped polygon marked with permanent poles and delineated with ropes covers the area of a digital camera with a 50 mm lens. Three 50-m transects at the end of the trapezoid allow for the

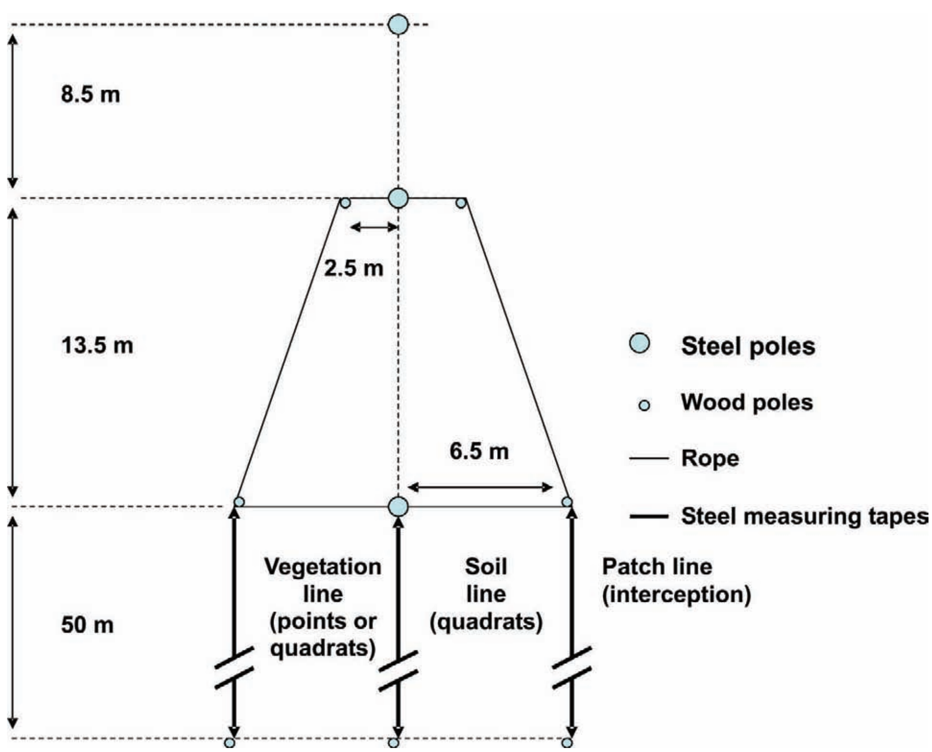

Figure 1. Schematic layout of a MARAS monitor.

Table 1.

Indicator	Method
Vegetation	
Cover of vascular species (except shrubs)	Point quadrat or Daubenmire
Bare ground %	Point quadrat or Daubenmire
Desert pavement %	Point quadrat or Daubenmire
Litter %	Point quadrat or Daubenmire
Standing dead %	Point quadrat or Daubenmire
Cover of Lichens and mosses	Point quadrat or Daubenmire
Forage cover %	Synthetic variable from cover estimations
Shortgrass cover %	Synthetic variable from cover estimations
Bunchgrass cover %	Synthetic variable from cover estimations
Dwarf shrub cover %	Synthetic variable from cover estimations
Srub cover %	Interception lines
Non-native species relative cover %	Synthetic variable from cover estimations
Invasive species relative cover %	Synthetic variable from cover estimations
Shannon Weiner diversity index	Synthetic variable from cover estimations
Species richness	Synthetic variable from cover estimations
Patch structure	
Number of patches	Interception lines
Size of patches	Interception lines
Soil	
Rills (water erosion signs)	Visual inspection in soil quadrats
Nebkas (wind accumulation signs)	Visual inspection in soil quadrats
Surface crust stability	Slake test
Pedestals or plants with uncovered roots	Visual inspection in soil quadrats
Total N (%)	Kjendhal
Organic C (%)	
P (mg/kg)	Olsen
pH	
Resistance (ohm.cm)	
Clay %	
Lime %	
Sand	

evaluation of vegetation and soil (Table 1). Herbaceous and dwarf shrub cover are estimated along one transect using either the Dagget Poissonet's point quadrat method with 500 points or a modified Daubenmire with one hundred 0.20 m^2 quadrats and visual estimation of the cover of each species. The second transect serves as a Canfield line to estimate the number, size and type of patches of vegetation and bare soil, allowing also for the estimation of shrub cover, if present. The third transect is used to evaluate signs of wind and water erosion on soils, and soil surface aggregate stability using the slake test (Tongway 1994). A superficial (0-10 cm) soil sample will be extracted and analyzed in the laboratory. Evaluations will be performed by trained and registered private consultants or by government personnel. The monitors will be revisited every five years, and the initial number will be carefully assessed in order to assure fewer repeated measures instead of a high number of single observations based on WARMS experience.

Who will pay for the MARAS and why? Most of the land in Patagonia is under private freehold, and although the provincial governments in principle own the natural resources of the rangelands, they have no legal mandate or resources to monitor them. Public funds for crisis relief or support of sheep farms have historically been distributed without taking into account the state of the land and management, but the trend of allocation of funds is slowly changing as the society becomes aware of the degradation of rangelands and producers involve in certification processes such as organic productions that require monitoring. It is foreseeable that some sort of ecocertification of sustainable practices will be eventually required to export products of rangelands, so that monitoring could be strategic from a commercial point of view. In a recently promulgated Sheep law, sustainable range management plans based on forage evaluations are mandatory to obtain benefits (Poder.Legislativo. Nacional 2004). Resources allocated to this law are managed yearly by a joint commission of government and producers and have been assigned in 2004 to construct the data base, train the evaluators and put in place the first ground monitors of the MARAS initiative in Santa Cruz province. A GEFF funded initiative to aid in monitoring, environmental education, and conservation in Patagonia is also expected to start shortly and may facilitate the scaling of this initiative to the whole region. Soft money may allow the system to start, but the real challenge is to assure that hard money of governmental budgets will be available in a long time scale, and to coordinate INTA as a federal agency and five provincial agencies to work together and interoperate. Progress depends on political decisions, but also on the evolution of public knowledge of goods and services that are provided by rangelands and the concern of producers in relation to ecocertification.

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Nonnative Invasive Plants in South Carolina: Combining Phase-2 with Phase-3 Vegetation Structure and Diversity Pilot Data to Enhance our Understanding of Forest Health Issues

Sonja N. Oswalt, Forest Resource Analyst, USDA Forest Service, Southern Research Station, Knoxville, TN

Abstract*—Studies suggest that the Southeast is an area of primary concern with regards to the spread of alien plant species (Miller 2003, Stapanian and others 1998). Data collected by Stapanian and others in 1998 showed that Japanese honeysuckle (*Lonicera japonica*) occurred over 2 million acres in the Southeast, invading forests and displacing native species. Among the most important mechanisms for the early detection and prevention of the spread of nonnative species is monitoring on large spatial scales for the presence of alien species, and for the presence of vulnerable sites (in other words, sites affected by certain disturbance types) (Jose and others 2002). In the Southeast, a primary research priority is the need for better assessments of on-going biological invasion, for public and scientific use (Mack and others 2000). As one method for addressing this need, the Forest Service's Forest Inventory and Analysis program incorporates assessments of the presence of nonnative species into its Phase-2 forest inventory. Additionally, pilot studies are currently underway for a new forest health variable that would describe native and alien vascular plant diversity and extent. This paper describes results gleaned from 2002 to 2004 Phase-2 data combined with 2002 Phase-3 vegetation structure and diversity pilot study data in South Carolina, USA. While small sample sizes limit the reliability of statistical tests for the pilot study, the results from the 2002 pilot illustrate potential uses for the new Phase-3 variable in monitoring and detecting the spread and impact of nonnative species in Southern forests.*

Introduction

Southern forest health can be noticeably affected by anthropomorphic stress, including the introduction of nonnative plant species. Humans continue to increase the rate of spread of alien species as populations soar and global travel becomes more commonplace (Pimental and others 2001, Mack and others 2000, Stapanian and others 1998). Research indicates that nearly 4,000 alien plants occur outside of cultivation in the United States (Stein and others 1996). While the current lack of available data limits the ability of scientists and economists to determine the impacts of introduced plant species on the environment and economics (Pimental and others 2001), these and other alien species cost the United States an approximated $97 billion in direct economic losses over an 85-year period (Stein and others 1996). In addition to the economic costs associated with the control of nonnative plant species, environmental costs are high. Invasive species have the ability to transform entire ecosystems through modifications of soil, water, and light resources (Gordon 1998, Stapanian and others 1998, Stein and others 1996). In addition, some plant species prevent forest regeneration through the formation of thick rhizomatous mats in the forest soil (Jose and others 2002). In some cases, regeneration is further prohibited through an increase in the aboveground biomass available as fuel. For example, forest fires occurring in pine forests of the Southeast containing the alien invasive cogongrass (*Imperata cylindrica*) burned at higher temperatures than forests containing only native species, damaging seedlings and preventing regeneration (Jose and others 2002).

Studies suggest that the Southeast is an area of primary concern with regards to the spread of alien plant species (Miller 2003, Stapanian and others 1998). In 1998, data collected by Stapanian and others showed that Japanese honeysuckle (*Lonicera japonica*) occurred over 2 million acres in the Southeast, invading forests and displacing native species. Similarly, Craver (1982) noted that nonnative honeysuckles, including Japanese honeysuckle, were found on commercial forestland in every county in South Carolina. In addition, current studies regarding the problematic regeneration of northern red oak on high-quality sites suggest that the invasive Nepalese browntop (*Microstegium vimineum*) may behave like cogongrass in preventing the establishment and development of seedlings (Oswalt and others 2004). Forest fragmentation due to agriculture, urban development, road construction, and other similar disturbances may increase the ability of alien species to invade forest ecosystems by increasing light availability and exposing bare mineral soil (Parendes and Jones 2000, Brothers and Spingarn 1992). Additionally, while alien species generally exhibit low levels of growth and distribution in the forest understory, removal of the forest canopy due to timber harvesting activities, development, or natural mortality often results in "explosions" of growth (Oswalt and others 2004, Barden 1987).

The United States Department of Agriculture (USDA) Forest Service (FS) has identified invasive species as one of the top four threats to forests in the United States in the twenty-first century. Among the most important mechanisms for the early detection and prevention of the spread of nonnative species is monitoring on large spatial scales for the presence of alien species, and for the presence of vulnerable sites (in other words, sites affected by certain disturbance types) (Jose and others 2002). In the Southeast, a primary research priority is the need for better assessments of ongoing biological invasion, for public and scientific use (Mack and others 2000).

As one method for addressing this need, the USDA FS Forest Inventory and Analysis (FIA) program incorporates rapid assessments of the presence of nonnative species into its Phase-2 (P2) forest inventory. In conjunction with presence/absence of alien species, field crews also estimate the distance of each plot center to agriculture, urban development, and roads. Additional studies are currently underway for a new Phase-3 variable that describes native and alien vascular plant diversity and extent.

The goals of this study were to: 1) quantify the occurrence of nonnative invasive species across the state of South Carolina using FIA data; 2) determine differences in nonnative species occurrence between physiographic and ecological regions; 3) examine impacts of plot distance from agriculture, urban development, and roadways on presence/absence and number of nonnative species present on plots; and 4) compare results gained from FIA P2 plots with results collected from a pilot study conducted during the same time period to evaluate the effectiveness of both methods in documenting nonnative invasive species.

Methods

The USDA Forest Service FIA program collects data using a three-phase process. During Phase-1 (P1), aerial photographs are interpreted; broad classifications of forest versus nonforest areas are determined; and plot locations are identified. P2 consists of field data collection concerning tree variables on all plots, at the rate of 20 percent of plots in a given State per year (USDA Forest Service 2003). In this manner, data collection for an entire State is completed in a five-year cycle, though some data analysis may begin after a minimum of one year of collection (Stapanian and others 1998). The plots are arranged on an unbiased, systematic sampling grid across the United States. The grid is composed of hexagons covering approximately 2,428 ha (6,000 acres) each, with one sample plot located within each hexagon (USDA Forest Service 2003). Individual plots consist of four subplots with a radius of 7.3 m (24 feet). Field crews estimate the distance of each plot from agriculture, urban development, and improved roads based on aerial photos of each plot location (USDA Forest Service 2003). During the final phase (P3) of the inventory process, forest health monitoring data related to soil, down woody materials, crown health, and other variables of interest are collected on a subset (one-sixteenth) of the P2 plots. Detailed descriptions of both P2 and P3 data collection programs, copies of field guides detailing data collection methodology, and detailed definitions of FIA terminology may be found by accessing the USDA Forest Service FIA Internet site at http://fia.fs.fed.us/ and following links to FIA program information.

Nonnative invasive species information was collected on P2 plots beginning in February 2002 and extending through July 2004. Data collection consisted of noting the four most prevalent nonnative species present on a subplot, and estimating their abundances in approximated cover classes (USDA Forest Service 2003). Species were selected from a predetermined list of nonnative plants considered to be problematic in the Southeast (table 1) (Miller 2003). This data collection method provides some information regarding the most abundant nonnative species present on a given sample plot, but does not allow the data collector to record in excess of the four most abundant species. A total of 1,589 P2 plots were sampled at the time analysis began. Plots were included for analysis only if all subplots were fully forested (in other words, no nonforest conditions were included in the analysis), for a total of 752 analyzed plots (Miles and others 2001).

Because of the limited extent of nonnative species data collected on P2 plots, additional information is included from a pilot study conducted from May 2002 to September 2002. The P3 vegetation structure and diversity pilot study required the scientist to record the presence of all vascular plants occurring on a subplot, regardless of life form or U.S. nativity. Vegetative structure and diversity data collected for all vascular plants occurring within the four sampled subplots were combined to produce plot-level summaries. All vascular plants occurring on the subplots were identified to the most specific level possible. Unidentified plants were collected "off plot" and were submitted to local herbaria for identification (USDA Forest Service 2003). The PLANTS database nomenclature was used for all plants recorded (USDA-NRCS 2004). The PLANTS database designation of "invasive and noxious" species was also used to determine whether a plant was native or nonnative for analysis purposes (USDA-NRCS 2004).

The pilot study provided a total of 31 forested plots for P3 analysis. Because of logistical problems during data collection, data were not always complete at the plot level. The resulting heterogeneity of variance violates statistical assumptions, making the plot level data invalid for many statistical tests. In those instances, analysis was conducted at the subplot level, and results are labeled as such. Because of small sample sizes, and the lack of complete datasets for each plot, the reliability of statistical tests is limited and results should be viewed with caution. This report consists of separate analyses for the P2 and P3 datasets (in other words, data are not combined).

Statistical analyses of edited P2 data were conducted at the plot level statewide and by three FIA designated physiographic regions: the Piedmont, Southern Coastal Plain, and Northern Coastal Plain (fig. 1). Data were also analyzed by three ecological regions as defined by Keys and others (1995): the Southern Appalachian Piedmont, Coastal Plains and Flatwoods, and Atlantic Coastal Flatwoods. ArcMap 8.1 (ESRI 2001) was used to assign each county and its complement of plots to an ecological region (fig. 1). Data were consolidated using Microsoft database tools, and analyzed using a combination of SAS version 8.02 (SAS Institute 2001), NCSS (Hintze 2001), and Microsoft Excel statistical software. Chi-square tests for independence were used to determine whether the proportion of plots containing nonnative species differed across physiographic regions or ecological regions. Fisher's Exact Test was used to further explain any detected differences between regions. Logistic regression with backward variable selection was then used to select and evaluate impacts of plot distance from agriculture, urban development, and roadways on presence/absence and number of nonnative species present on plots.

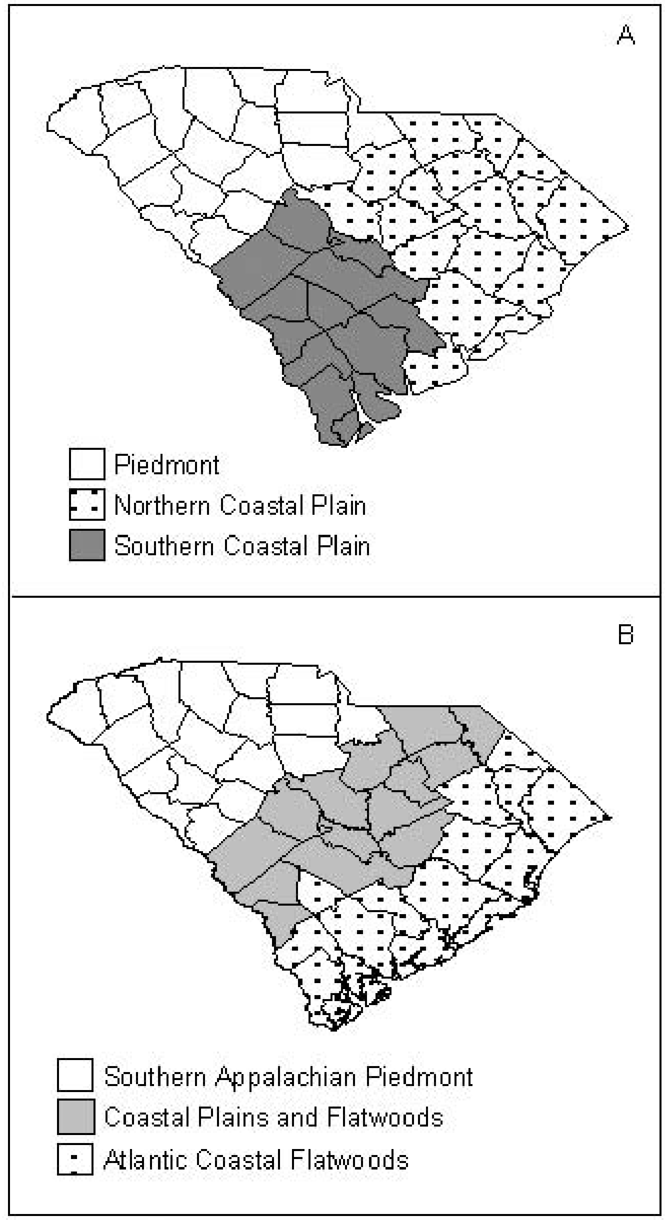

Figure 1. USDA Forest Service FIA physiographic regions (A) and ecological regions (B) as defined by Keys and others (1995).

Analyses of P3 data were conducted on data edited and compiled using a combination of SAS, NCSS, PC-ORD (McCune and Mefford 1999), and Microsoft Excel statistical software. Descriptive statistics are presented for P3 data, as well as results from a one-way analysis of variance using generalized least-square means.

Results

P2 Results

A total of 752 P2 forested plots were measured in 46 South Carolina counties in 2002 to 2004 for the presence of nonnative invasive plant species. Of those plots, 40 percent (n=300) contained at least one alien species; 15 percent (n=111) contained at least two; 4 percent (n=27) contained at least three; and less than 1 percent (n=4) contained four or more. A total of 21 nonnative species were detected using the FIA P2 sampling protocol (table 1). The most abundant nonnative invasive species identified was Japanese honeysuckle, occurring in 81 percent of all plots containing invasive plant species, and 32 percent (n=244) of the total number of forested plots sampled (table 1). These results are similar to Stapanian and others (1998) who found that Japanese honeysuckle is a leading problem in the Southeastern United States, followed closely by Chinese privet (*Ligustrum sinense*).

Physiographic units of South Carolina differed in the proportion of plots containing exotic species (χ^2=175.80, p=≤0.001). The Piedmont region had a significantly larger proportion of plots containing at least one nonnative species compared to both the Northern and Southern Coastal Plains (p=≤0.001). In contrast, the proportion of plots containing at least one nonnative species was similar for the Northern and Southern Coastal Plains units (χ^2=1.06, p=0.30) (table 2).

Similarly, the ecological regions defined by Keys and others (1995) differed in the proportion of plots containing exotic species (χ^2=185.52, p=≤0.001). The Southern Appalachian Piedmont contains a higher proportion of plots with at least one nonnative species than either the Coastal Plains and Flatwoods region (χ^2=82.59, p=≤0.001) or the Atlantic Coastal Flatwoods region

Table 1. Scientific names, common names and frequencies (percent of all forested plots occupied by a given species) of species evaluated using the USDA Forest Service, Forest Inventory and Analysis Phase-2 guidelines. Data are for South Carolina, 2002 through 2004. Species are in alphabetical order by scientific nomenclature.

Species	Common name	Frequency percent
Ailanthus altissima (P.Mill.) Swingle*	tree of heaven	0.27
Albizia julibrissin Durazz.*	mimosa	0.53
Alliaria petiolata (Bieb.) Cavara & Grande	garlic mustard	0.00
Arundo donax L.	giant reed	0.00
Celastrus orbiculatus Thunb.	Oriental bittersweet	0.00
Dioscorea spp.	climbing yams	0.00
Elaeagnus angustifolia L.	Russian olive	0.00
Elaeagnus pungens Thunb.*	silverthorn	0.13
Elaeagnus umbellata Thunb.*	autumn olive	0.66
Euonymous alata (Thunb.) Sieb.*	winged burning bush	0.13
Euonymous fortunei (Tursz.) Hand.-Maz.	winter creeper	0.00
Hedera helix (L.)	English ivy	0.00
Imperata cylindrica (L.) Beauv.	congongrass	0.00
Lespedeza bicolor Turcz.*	shrubby lespedeza	2.39
Lespedeza cuneata (Dum.-Cours.) G.Don*	Chinese lespedeza	3.59
Ligustrum japonicum Thunb.*	Japanese privet	2.79
Ligustrum sinense Lour.*	Chinese privet	8.51
Lolium arundinaceum (Schreb.)*	tall fescue	1.20
Lonicera japonica Thunb.*	Japanese honeysuckle	32.44
*Lonicera spp.**	bush honeysuckle	0.13
Lygodium japonicum (Thunb. ex Murr.) Sw.	Japanese climbing fern	0.00
Melia azedarach L.*	chinaberry	0.80
Microstegium vimineum (Trin.) A.Camus*	Nepalese browntop	1.06
Miscanthus sinensis Anderss.	Chinese silvergrass	0.00
Nandina domestica Thunb.	nandina	0.00
Paulownia tomentosa (Thunb.)*	royal paulownia	0.13
Phyllostachys aurea (Carr. Ex A.& C.) Riviere*	bamboo	0.13
Pueraria montana var. lobata (Lour.) Merr.*	kudzu	0.66
Rosa multiflora Thunb. ex Murr.*	multiflora rose	0.80
Solanum viarum Dunal*	tropical soda-apple	0.13
Triadica sebifera (L.) Small*	tallowtree	1.06
Vinca spp.	periwinkle	0.00
Wisteria sinensis (Sims) DC.*	nonnative wisteria	1.33

* Species detected on 752 forested plots in South Carolina during 2002-2004 sample seasons using Phase-2 methodology.

Table 2. Proportion of P2 plots containing at least one nonnative species. Data are presented by physiographic region and ecologic region. Physiographic region and ecologic region were evaluated separately.

Ecological division	Sample size number	Proportion containing nonnatives percent
Physiographic region		
Piedmont	268	71.6 A[1]
Northern Coastal Plain	272	20.6 B
Southern Coastal Plain	212	24.5 B
Ecologic region		
Southern Appalachian Piedmont	268	71.6 A
Coastal Plains and Flatwoods	218	30.3 B
Atlantic Coastal Flatwoods	266	15.8 C

[1] Results of Fisher's Exact Test. Means followed by the same letter are not significantly different at the alpha 0.05 level.

(χ^2=169.16, p<0.001) (table 2). The Coastal Plains and Flatwoods region also differed from the Atlantic Coastal Plain in the proportion of plots containing at least one exotic species (χ^2=14.50, p=0.001). The proportion of plots containing an exotic species was slightly higher for the Coastal Plains and Flatwoods region than for the Atlantic Coastal Plain (table 2).

Logistic regression with backward variable selection identified the distance of a plot from improved roads, urban development, and agricultural land as significant in explaining the presence of nonnative species on a plot (p<0.001). However, predictability was very low (r^2=0.05) and plots were classified correctly only 71 percent of the time. Adding physiographic unit (p<0.001) to the model increased the r-square value to 0.22 with the percent of plots classified correctly 76 percent of the time. The low r-square values (and thus low predictability) could be due to sample size, estimation errors, or the absence of another variable that may be of more use for predictability measures.

P3 Results

In 2002, a total of 31 plots were measured, but few (n=4) plots provided data from measurements taken at all four subplots. A total of 44 percent (n=71) of the available subplots were measured. There were 102 plant families represented in the dataset, excluding unknowns (specimens not identified due to immaturity, lack of flowering parts, or other reasons). A total of 537 unique records representing 2,391 individuals were collected. Of these, muscadine grape (*Vitis rotundifolia*) was the most abundant, occurring in 78 percent of subplots measured, and 77 percent (n=24) of plots. Red maple (*Acer rubrum*) followed closely in abundance, occurring in 67 percent (n=48) of subplots and 71 percent (n=22) of plots (table 3).

There were no differences in the mean number of all (native and nonnative) species per plot between the three physiographic regions of South Carolina (p=0.24). There were also no differences at the subplot level (table 4). However, the mean number of vascular plant species per subplot did differ between ecological sections (p=0.09) as defined by Keys and others (1995), with the largest number of species occurring in the Southern Appalachian Piedmont region (μ=36.94 +/- 2.34), followed by the Coastal Plains and Flatwoods region (μ=33.0 +/- 2.55), and the Atlantic Coastal Flatwoods region (μ=27.7 +/- 3.48).

Nonnative species accounted for 6 percent (n=27) of all identified species, and 50 percent (n=14) of the alien species are also invasive. Although only 6 percent of all species recorded were nonnative, alien plant species occurred in 80 percent (n=25) of measured plots. In contrast, 73 percent (n=394) of native species occurred in less than 10 percent (n=3) of all plots measured, and 48 percent (n=258) occurred in only one measured plot. As in the P2 data, Japanese honeysuckle was the most abundant nonnative invasive, occurring in 28 percent (n=20) of the 71 subplots and 45 percent (14) of the 31 plots. Chinese privet followed in abundance, occurring in 17 percent (n=12) of subplots and 32 percent (n=10) of plots (table 5). P3 methods detected 27 nonnative species as compared to the 24 species detected by P2 methods. Nine of the species detected by P2 were also detected by P3, while 18 species were unique to P3. Small sample sizes prevent further analysis of the dataset.

Discussion and Conclusion

The results of this analysis suggest that nonnative invasive species present a substantial threat to forest resources in South Carolina. This is supported by the more detailed P3 data, which indicate that although nonnative species comprise only a small percentage of all vascular plants found throughout the State, those few plants are alarmingly widespread. Currently, Japanese honeysuckle

Table 3. Scientific names, common names, and frequencies (percent of all forested subplots occupied by a given species) of the twenty most abundant species evaluated using the USDA Forest Service, Forest Inventory and Analysis Phase-3 guidelines. Data are for South Carolina, 2002. Species are listed in order of abundance.

Scientific name	Common name	Frequency *percent*
Vitis rotundifolia Michx.	muscadine	73.24
Acer rubrum L.	red maple	67.61
Smilax glauca Walt.	cat greenbriar	57.75
Pinus taeda L.	loblolly pine	56.34
Prunus serotina Ehrh.	pond pine	54.93
Liquidambar styraciflua L.	sweetgum	53.52
Diospyros virginiana L.	common persimmon	49.30
Gelsemium sempervirens (L.) St. Hil.	evening trumpetflower	47.89
Parthenocissus quinquefolia (L.) Planch.	virginia creeper	47.89
Quercus alba L.	white oak	42.25
Nyssa sylvatica Marsh.	black gum	40.85
Quercus laurifolia Michx.	laurel oak	40.85
Rubus argutus Link	sawtooth blackberry	40.85
Smilax rotundifolia L.	roundleaf greenbriar	40.85
Ilex opaca Ait.	American holly	36.62
Quercus nigra L.	water oak	36.62
Cornus florida L.	flowering dogwood	35.21
Quercus falcata Michx.	southern red oak	33.80
Toxicodendron radicans (L.) Kuntze	poison ivy	33.80
Vaccinium arboreum Marsh.	farkleberry	32.39

Table 4. Comparison of mean species per subplot by nativity and physiographic region using 2002 Phase-3 pilot study results. Results from analysis of variance (ANOVA) testing for differences in mean number of species by physiographic unit are given for each nativity category.

Nativity (p-value)	Physiographic region	Mean number of species per subplot (+/- 1 s.e.)
Native (0.23)	Piedmont	34.00 (2.12)
	Northern Coastal Plain	30.42 (2.32)
	Southern Coastal Plain	27.79 (3.16)
Nonnative (0.26)	Piedmont	1.29 (0.24)
	Northern Coastal Plain	1.08 (0.26)
	Southern Coastal Plain	0.57 (0.36)
All species (0.17)	Piedmont	36.94 (2.36)
	Northern Coastal Plain	31.88 (2.58)
	Southern Coastal Plain	29.79 (3.51)

and Chinese privet appear to present the largest immediate threat to forest health. Japanese honeysuckle was often planted by wildlife managers and farmers as forage during late fall and winter (Stransky 1984, Craver 1982), and both plants are still offered as ornamental species in lawn and garden stores in the Southeast (S.N. Oswalt personal observation). These uses have resulted in their widespread propagation throughout the southern United States. Studies of the physiology of Japanese honeysuckle have revealed that the ability of the plant to remain semi-evergreen and photosynthetically active in the warm climate of the Southern states may result in a competitive advantage over native deciduous components of the vegetation community (Schierenbeck and others 1994). Similarly, the semi-evergreen to evergreen growth of Chinese privet may afford it an advantage over native deciduous shrubs and forbs. The ability of these species to dominate the understory of disturbed stands, potentially impacting the regeneration of economically important species makes this a cause for immediate concern (Mooney and Cleland 2001). Additionally, the potential decline in plant species richness that accompanies the invasion of exotic species could be detrimental to wildlife populations in South Carolina forests.

Interestingly, one species that has received great attention in the southern United States because of its widespread visibility along forest edges and gullies, Kudzu (*Pueraria montana*), was detected in less than one percent of the forested plots sampled. Kudzu has been described as "the vine that ate the South" in popular literature, owing to its ability to grow up to one foot per day during the growing season (Bergman and Swearingen

Table 5. Scientific names, common names, and frequencies (percent of all forested plots and subplots occupied by a given species) of nonnative species using the USDA Forest Service, Forest Inventory and Analysis Phase-3 guidelines. Data are for South Carolina, 2002.

Scientific name	Common name	Frequency by subplot *percent*	Frequency by plot *percent*
Ailanthus altissima (P. Mill.) Swingle*	tree of heaven	1.41	3.23
Alternanthera philoxeroides (Mart.) Griseb.*	alligatorweed	2.82	6.45
Blumea viscosa (P.Mill.) Badillo	clammy false oxtongue	1.41	3.23
Centella asiatica (L.) Urban	spadeleaf	2.82	6.45
Duchesnea indica (Andr.) Focke	indian strawberry	1.41	3.23
Eremochloa ophiuroides (Munro) Hack.	centipede grass	5.63	6.45
Hypochaeris radicata L.	hairy catsear	1.41	3.23
Kummerowia striata (Thunb.) Schindl.*	Japanese clover	1.41	3.23
Lespedeza cuneata (Dum.-Cours.) G. Don*	Chinese lespedeza	4.23	6.45
Ligustrum sinense Lour.*	Chinese privet	16.90	32.26
Lonicera japonica Thunb.*	Japanese honeysuckle	28.17	45.16
Melia azedarach L.*	chinaberrytree	2.82	3.23
Microstegium vimineum (Trin.) A. Camus*	Nepalese browntop	4.23	9.68
Murdannia keisak (Hassk.) Hand.-Maz.*	wartremoving herb	7.04	12.90
Paspalum dilatatum Poir.	dallisgrass	1.41	3.23
Paspalum notatum Flueggé	bahiagrass	2.82	6.45
Picris echioides L.	bristly oxtongue	1.41	3.23
Poa annua L.	annual bluegrass	2.82	6.45
Rosa multiflora Thunb. ex Murr.*	multiflora rose	1.41	3.23
Rumex acetosella L.	common sheep sorrel	1.41	3.23
Sambucus nigra L. ssp. *canadensis* (L.) R. Bolli	common elderberry	2.82	6.45
Sonchus oleraceus L.	common sowthistle	1.41	3.23
Stellaria media (L.) Vill.	common chickweed	1.41	3.23
Triadica sebifera (L.) Small*	tallowtree	1.41	3.23
Verbascum thapsus L*.	common mullein	1.41	3.23
Wisteria floribunda (Willd.) DC.*	Japanese wisteria	1.41	3.23
Wisteria sinensis (Sims) DC.*	Chinese wisteria	1.41	3.23

*Indicates species considered to be invasive by the USDA-NRCS PLANTS database (2004).

1999). However, while Kudzu threatens native diversity along forest edges and roadways where high levels of light are available, its shade-intolerance prevents it from penetrating the forest edge and invading the forest understory. Similar observations of low populations of Kudzu as compared to Japanese honeysuckle in east Texas have led some researchers to suggest that when considering forest health the emphasis previously placed on Kudzu should be shifted to the shade tolerant Japanese honeysuckle (Vic Rudis, Forester, USDA Forest Service, personal communication).

Edge effects associated with agriculture, urban development, and road construction are often considered as dispersal pathways when considering the potential of an alien species to invade forest ecosystems (Parendes and Jones 2000, Brothers and Spingarn 1992). The data from this study indicates that the distance of a forested plot from agriculture, urban development, or improved roads is significant in explaining the presence/absence of nonnative species from the site. However, those variables are not useful in predicting whether a plot would contain a nonnative species, making them of little value for identifying potential "hotspots" of invasion. Brothers and Spingarn (1992) suggested that the development of a thick wall of vegetation at the forest edge may discourage invasive plants from penetrating into the understory, suggesting that other factors may be more useful for understanding the spread of shade tolerant nonnative species in forested systems. More studies examining the multivariate effects of soil type, onsite disturbance, previous land use, and other environmental variables are necessary to fully understand and predict the potential of a nonnative species to invade a given forest. As the more detailed P3 vegetation structure and diversity data continue to be collected, further examination of these variables may provide some insight into how to recognize the potential for the invasion of nonnative species into forests in the Southeast. With additional P3 sampling, more statistically reliable information may be gained with regards to the impacts of certain types of disturbance patterns on the establishment and reproduction of vascular plant species, including nonnative species, once datasets reach a more statistically reliable sample size.

Differences in the proportion of plots containing nonnative species exist between the physiographic units, and between the ecological regions of South Carolina. Both analyses indicated that the Southern Appalachian Piedmont is particularly susceptible to colonization by nonnative species. These differences may be due to land use, differences in overall species richness, site productivity, length of growing season, forest type characteristics or other environmental differences (for example, soil, moisture, temperature, precipitation, elevation, aspect). For example, the predominately deciduous forest of the Southern Appalachian Piedmont may be more susceptible to invasion by semi-evergreen and evergreen alien species than the evergreen pine forests of the Coastal Plain. Additionally, Craver (1982) suggested that, in the case of nonnative honeysuckles, invasion was correlated with soil moisture and light availability. Incorporating future P3 soil data, forest type characteristics, vegetation community analysis, cover estimates, and utilizing larger sample sizes will aid in extracting important predictive variables from the data and in identifying potential trends.

Overall, the use of USDA Forest Service FIA P2 nonnative species data provides an indication of the current extent of invasive plants in Southern forest ecosystems. However, incorporating the new P3 variables add a wealth of previously unavailable information regarding the spatial arrangement and distribution of these species, the proportion of nonnative to native species, and the relative influence of the species over the plot (using cover and frequency estimates). Moreover, P3 methods do not limit the collection of nonnative species present on a subplot to four, as is the case for P2 plots. While the P3 methods resulted in the detection of only nine of the 21 species listed as invasive in the P2 methodology, the increase in the detection of other nonnative species suggests that, given a full sample, P3 methodology may increase our ability to detect nonnative invasive species. In the future, this may enable forest managers to identify species that may become invasive, or to identify areas that may be of particular concern.

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Socioeconomic Root Causes of Biodiversity Loss in Madagascar

Anitry N. Ratsifandrihamanana, Conservation Director, WWF Madagascar and West Indian Ocean Program Office, Antananarivo, Madagascar
Dawn Montanye, Senior Program Officer, Macroeconomics Program Office, Poverty and Environment Program, WWF-US, Washington, DC
Sarah Christiansen, Senior Program Officer, Endangered Spaces Program, WWF-US; and Sheila O'Connor, Director, Conservation Measures and Audits, WWF International, Avenue du Mont-Blanc, 1196 Gland, Switzerland

Abstract—*In 2000 and 2001 a root cause analysis was conducted for the Spiny Forest Ecoregion in Madagascar, identifying the local level root causes of biodiversity loss in the ecoregion as well as the policy and institutional issues at the national and international levels that contribute to them. Most of the research was conducted in and around Tulear and Fort Dauphin. Findings will be used to develop a strategic action plan for the ecoregion.*

The direct threats to biodiversity loss in the ecoregion are forest clearing, land conversion, and habitat alteration. Root causes include demand for wood as a primary source of fuel for rural and urban populations, limited technical support to farmers, and the tying of land ownership to forest clearing. The current situation of deforestation, heavy land use, poverty and urban expansion is exacerbated by population growth and in-migration. In the regional government, lack of both management skills and training to execute programs and enforce laws is compounded by uncomplimentary and uncoordinated national policies. The deregulation of the agriculture sector—including the reduction of export taxes on all agricultural commodities, the elimination of cheap urban food policies in the late 1990s, and currency devaluation—contributed to increased agricultural production and exports, further driving deforestation.

Recommendations include the establishment of formal land tenure rights; enhancement of agricultural extension services; improved market access and economic development for agricultural crops and alternative forest products, including medicinal plants; and increased access to micro-credit by the poor. Avenues for promotion of linkages between the ministries that oversee the environment and economic and social development are identified.

Introduction

The Spiny Forest Ecoregion in southwestern Madagascar, one of the World Wide Fund for Nature (WWF) priority ecoregions, includes some of the biologically richest drylands on Earth. Native plants (didieraceae and euphorbia) have uniquely adapted to the extremely arid climate and poor soil conditions. Ring-tailed and sifaka lemurs (*Lemur catta* and *Propithecus* v. *verreauxi*), terrestrial tortoises (*Geochelone radiata* and *Pyxis arachnoides*), and several birds, reptiles, and amphibians are endemic to this ecoregion.

Over the last decade these natural areas have been exposed to various pressures, most stemming from human activity. With a human population of over 1.7 million (INSTAT 1993) concentrated in the urban areas of Toliara, Fort Dauphin, and the emerging towns of Beloha, Ampanihy, and Tsihombe (fig. 1), the ecoregion is one of the poorest areas on the island of Madagascar. It is estimated that 88 percent of the population in the ecoregion lives below the national minimum per capita annual income (equivalent to US$38 in 2003) as defined by the World Bank (1999), and that 79 percent live in extreme poverty. The population is heavily reliant on natural resources for its livelihood, practicing agricultural and pastoral activities, as well as harvesting natural resources for subsistence and commercial purposes. Less than 3.2 percent of the remaining natural habitat in the

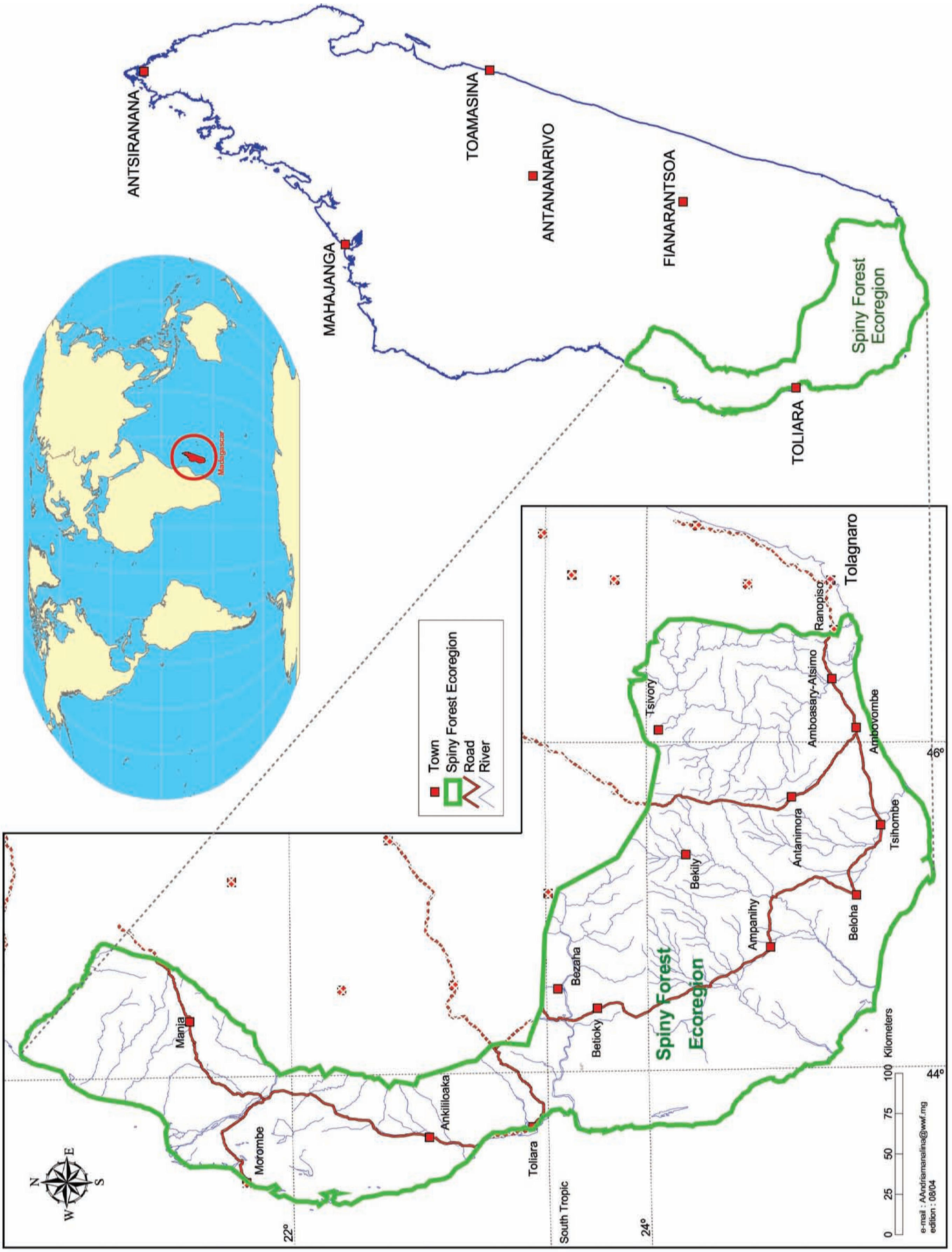

Figure 1. Spiny Forest Ecoregion.

ecoregion is currently included in the country's network of protected areas.

WWF Ecoregion Conservation Approach

WWF defines an ecoregion as a relatively large parcel of land or water that harbors a characteristic set of species, communities, dynamics, and environmental conditions. Ecoregions therefore stretch over administrative and political boundaries. The WWF ecoregion approach aims at 1) ensuring the representation of biodiversity; 2) ensuring the viability of key species populations; 3) maintaining the key ecological factors that sustain life; and 4) maintaining blocks of natural habitats that are large enough to ensure resilience to large-scale disturbances. Ecoregion-based conservation is characterized by a larger spatial scale than protected areas, and by a longer time frame—with a conservation vision of 25 to 50 years.

In 1998 WWF initiated an ecoregion-based conservation program for the Spiny Forests Ecoregion of Madagascar. A series of rapid biological assessments was undertaken across all major blocks of natural habitat in the ecoregion to assess conservation needs, potential threats, and opportunities for conservation. In 2000, a more thorough analysis of the biodiversity of the ecoregion identified a network of nine priority areas for conservation that became the cornerstone of WWFs work in the region.

To be effective and sustainable, the conservation program's partnerships, strategies, and interventions need to address the deeper political and institutional settings that affect biodiversity conservation in Madagascar. A detailed and comprehensive threat analysis was conducted to identify the root causes of biodiversity loss around the target areas.

The Root Causes Methodology

The methodology adopted for this study was modelled after the WWF Macroeconomics Program Office's Root Causes of Biodiversity Loss Framework (Stedman-Edwards 1998), which includes the following steps: 1) identification of direct pressures on natural resources and their socioeconomic root causes at the local (micro level), meso (communal, regional, provincial) and macro (national and international) levels, thereby highlighting key causal chains from one level to another; 2) identification of future social, economic, and political trends that may affect biodiversity conservation, based on development plans and projections at various levels; 3) development of a conceptual model to represent the linkages between biodiversity targets and the root causes at different levels, and the linkages between levels; and 4) development of recommendations to address the identified root causes of biodiversity loss at various levels. The root causes methodology is designed to give a holistic picture of biodiversity and the intricate socioeconomic factors that affect its conservation.

Results

Local Level Root Causes

The spiny forest has experienced some of the highest deforestation in Madagascar over the past decade. Forest loss translates into reduced availability of habitat for wildlife, and reduced availability of essential natural resources such as wood and medicinal plants for the local population. The loss of forest cover has led to decreased rainfall and loss of humidity, increasing the frequency of drought, and putting further pressure on farmers to produce enough food for consumption and income generation.

One of the primary causes of forest loss throughout the Spiny Forest Ecoregion is the demand for wood as a primary source of fuel for rural and urban populations. Rural inhabitants cut the forests to provide charcoal, fuelwood, and construction wood for their own consumption, and for sale in urban centers and large towns. Firewood is a major source of fuel for most households and the cutting of wood for cooking is a significant cause of environment degradation (EIU 2000). Over 90 percent of Madagascar's urban population uses charcoal and firewood for energy in its homes. The sale of wood and charcoal provides a key source of income to the poor rural population; wood products are brought directly to town centers by wagon, or more often are sold roadside for a small percentage of the selling price in the urban centers.

Rural populations also exploit forests for the harvest of non-timber products such as honey. The collection of both wood and non-wood products is often unsustainable; a whole tree may be felled during honey collection, the honey removed and the tree wood left unused. Along the coast, canoe builders often utilize only the center portion of felled trees, leaving the remaining portions in the forest unused.

Although wood and other forest product collection puts tremendous pressure on the forests, maize cropping is the main threat to forest loss. Higher prices for maize, demand for maize exports, and low input requirements have provided the impetus for increased production and land clearing. The practice of slash and burn agriculture, coupled with poor quality soils, results in fields being abandoned and standing forests being cut for new crop land every two to three years. Rural populations are consequently moving further into previously forested land and away from existing communities, services, and roads, exacerbating rural poverty. Ultimately poor roads, lack of transportation, and weak links to market leave the rural populations insecure in their ability to participate in the local economy. Increasingly there are signs that this insecurity is leading many farmers to switch most of their effort from cash crops to the production of food for their own communities.

Keeping livestock is an important component of rural livelihoods, and forests and abandoned cropland are used for grazing. Increasing the size of the herd is a symbol of prestige, and income generated from the sale of agricultural crops is often used to buy more cattle. Production costs for this activity are low since household members take care of tending the herds. Overgrazing has degraded the forest understory, and repeated burning of pastureland has left only those species unsuitable for feed.

At the moment there is very little investment in the land and only limited support for improving farming techniques; only 1.5 percent of small farmers have access to credit. While there is a lack of formal land tenure, a license sold illegally from the local forest authority to remove the forest and convert it to agricultural land is considered by the rural population to equal land title rights. The incentive of land ownership and the tying of ownership to forest clearing have furthered deforestation.

Lack of local economic development and the difficulty of getting goods to town centers, coupled with low inputs for production of maize and lack of policing, means there is little incentive for favoring forest protection and conservation. Deforestation is often seen as the only means to survival, as it is directly linked to income generation through agricultural production and land ownership.

The current situation of deforestation, heavy land use, poverty and urban expansion is exacerbated by pressure from population growth and in-migration. A 22 percent increase in the human population in the ecoregion in the last six years has been driven largely by migration.

Regional Level Root Causes

At the regional government level, a lack of management skills and training in program execution and law enforcement is compounded by national level policies that are neither coordinated nor complementary. In some areas policies are in place that simultaneously attempt to promote both development and environmental protection. From 1997 to 2002, the Environmental Program tried to manage and organize these policies in five regions through Regional Development Committees, but bringing together the different representatives was difficult. There are also great inequities between urban and rural programs. The lack of health, education, and other public services at the local level serves to further exacerbate poverty.

Although a decentralization of government services and decision making is underway, it has yet to be seen how increased revenue to the regions will be utilized. Before decentralization, local authority control over spending equaled just 0.5 percent of GDP, and a large percentage of the income generated from export products from the regions went to the centralized government in the capital.

National/International Level Root Causes

National and international level forces, often out of the control of local resource users, have heavily influenced patterns of resource use in the Spiny Forest. Over the last decade, the government has instituted a number of reform programs in response to the requirements attached to loan agreements with the International Monetary Fund (IMF), World Bank (WB), and European Union (EU). The deregulation of the agriculture sector (including the reduction of export taxes on all agricultural commodities), the elimination of cheap urban food policies in the late 1990s, and currency devaluation have meant higher prices for agricultural products and increased agricultural production and exports. Maize exports from Toliara increased from 12 million Malagasy Francs in 1991 to 10 billion Malagasy Francs in 1997. Devaluation and liberalization, coupled with the low inputs required for maize production, have been drivers behind increased deforestation.

The greatest amount of deforestation has taken place in areas managed under the jurisdiction of the Forest Administration (DEF), which receives very little funding. This situation contrasts with that of ANGAP; this government body manages protected areas (national parks and reserves), and has a much larger budget. DEF budget cuts have led to weakened enforcement of the forestry regulation system, unchecked illegal harvesting, and internal corruption. In 1995, regular monitoring of logging and charcoal permits was restricted to large-scale exploitation, ignoring smaller scale logging and leaving little incentive for small-scale rural farmers to adhere to forest protection and conservation regulations.

Structural adjustment programs for stabilization resulted in public expenditure compression, which further reduced the funds available for government outlays. Reduced government spending has jeopardized enforcement and monitoring of existing environmental legislation. This can be seen at the local level in terms of lack of service delivery and compliance; a mere 5 percent of all investors comply with environmental impact assessment requirements.

International trade liberalization has stimulated activity by both artisanal fishermen and industrial operators. However, European, Russian and Japanese boats take much of the potential offshore catch. Commercial offshore prawn fishing and traditional river fishing are now both in decline from over-fishing, but modern seawater prawn farms, traditional fish farming in rice paddies and artisanal sea fishing are doing well. Prawns accounted for 80 percent of seafood export revenue in 1997.

Lack of coherence between the Ministries has led to inconsistent government policies. In 2000, 10 zones for tourism and industrial production were identified for lease and infrastructure development. These plans have, however, come into conflict with conservation priority sites designated by the Ministry of Environment and its implementing agency, the National Office for the Environment, which has conservation objectives and development projects of its own. This lack of policy coherence has led to inefficient management at the regional and local levels and has ultimately delayed the delivery of services and project implementation on the ground.

The World Bank's 1997 Country Assistance Strategy (CAS) for Madagascar attempted to tackle widespread poverty by encouraging broad-based economic growth, led by significantly higher levels of foreign investment. The core strategies were aimed at creating a business-friendly climate by unleashing market forces, improving public finances, and emphasizing the delivery of public goods and services to the poor. In many ways national efforts at market stimulation have never reached the rural communities in the Spiny Forest Ecoregion. In spite of efforts over the past 15 years to boost the agricultural sector, performance has remained low.

Trends, Threats, and Opportunities in Key Sectors

By borrowing from international financial institutions such as the World Bank, IMF and EU, Madagascar is required to adhere to certain policy reform measures, including: maintaining economic growth through government expenditure reduction and privatization; encouraging privatization; increasing agricultural production; increasing labor intensive industry and services; investing in support for the poor; making government more efficient and closer through the devolved provincial authorities; and establishing efficient revenue collection. Madagascar has also qualified for debt relief under the Highly Indebted Poor Country (HIPC) initiative and is now scheduled to receive final loan disbursement under the IMFs poverty reduction and growth facility. In connection with qualification for debt relief under HIPC, the government is required to develop a national poverty reduction strategy (PRSP) that focuses on improvements in the areas of health, education, social services delivery, water and sanitation, rural development and protection of the environment, and improved governance to address poverty alleviation.

The IMF is also concerned with strengthening tax revenue and continued liberalization of trade. Much of the economy remains informal and beyond the reach of the tax authorities and the formal sector carries the burden of providing most tax revenue. In structural terms the focus is on regulation and transparency with the aim of curbing corruption and promoting competition in the provision of services. Involvement in regional trade liberalization is also encouraged.

The EU, World Bank, and IMF have identified tourism, mining, manufacturing, and agriculture as the sectors having potential for achieving high economic growth for the medium and long term; tourism is estimated to grow at an average rate of 15 percent per year, agriculture at an annual rate of 5 percent, and mining from 3 to 5 percent (EIU 2000).

The government plans to create an atmosphere favorable to private sector investment and will do this by liberalizing the movement of capital, reducing administrative constraints, improving access to land, establishing more secure land tenure rights, and improving road networks.

Tourism

The tourism industry is identified as underexploited and has the potential to more than double during the next 10 years. An investor friendly environment includes measures to provide access to land for development of infrastructure to accommodate a 10 to 15 percent increase in tourists per year. Applicants are expected to be internationally established hotel chains.

The spiny forest region is currently the first destination for nature-based tourism in Madagascar, with two-thirds of visitors coming to Madagascar for ecotourism, and another one-fourth coming for beach holidays. Marketing has been minimal, but the recent establishment of direct air links from Asia has opened new opportunities. Authorities have taken a number of steps to encourage tourism and bring down travel costs. A national tourism development committee and a tourism agency were established in 1991, and in 1995 the laws governing the sector were overhauled. Liberalization of the internal and regional air routes in 1994 opened up the local travel market to four new carriers. The long-haul air routes were also liberalized; the privatization of Air Madagascar could introduce further competition to the airline market, bringing prices down. There has been investment in both tourism infrastructure and staff training for improved services (EIU 2000).

Ten zones for tourism and industrial production have been identified and land will be leased and infrastructure developed, but there is the risk that informal land ownership will be disrupted by the assignment of commercial zones. The World Bank would like the government to give its own guarantees against interference by any third party and competing property claims, even in those originating in local governments (World Bank 1999).

Investment in ecotourism may be dubious in that its ability to reach the poor population and benefit development may be limited. In reality not all of the forested lands are priority sites for protection and conservation, thereby limiting the ability of ecotourism to provide incentive for controlling logging and forest clearing and delivering real benefits to the poor.

Mining

The exploitation of titanium sand, nickel, and cobalt could eventually double the size of the mining sector, and there is also the potential for exploitation of precious and semi-precious gems, gold, chrome ores, and quartz, as well as graphite, mica and marble at a smaller scale. The government strategy consists of the application of mining codes that promote large mines through changes in investment laws; developing small-scale mining with respect for the environment; and eradicating illicit trade and exploitation (World Bank 1999). A new mining code was approved in 1999, the objective of which was to reduce the existing mining application backlog by 80 percent. This is expected to create conditions for transparent allocation of mining licenses, providing the public sector with a more predictable business environment in mining activities (EIU 2000).

The new mining code is consistent with existing environmental regulations, but these should be reviewed along with enforcement mechanisms. Large-scale mines should be examined for their direct and indirect impacts on environmental and human health.

Manufacturing

Madagascar's eligibility in the Africa Bill initiative should assist in the growth of this sector, which includes activities from garment making to information processing. There has been increased success with the growth of textiles and other industries due to the new U.S. Africa Growth and Opportunities Act. The growth in this sector also offers opportunities for agriculture as it uses raw materials produced in the Malagasy farm sector (EIU 2000).

Fishing and Agriculture

Increased agricultural production is key to economic growth and poverty reduction in Madagascar, and fish exports are an increasingly important source of foreign currency and an underexploited resource. Improvement of the performance of the shrimp aquaculture industry will be addressed through shrimp fishing licenses which will also provide tax revenue for the state. Guidance for enhancing the sector will be taken from the Rural Development Action Plan (PADR) and the involvement of the Rural Development Working Groups in each region. The proposed allocation of fishing licenses is designed to counteract the current incentive framework, and should provide a better incentive for sustainable exploitation by clarifying property rights (EIU 2000). The government must define an allocation system particular to Madagascar's conditions, taking into account traditional fishermen, local participation, and fair competition for those firms that may receive foreign subsidies. Madagascar is being considered as a pilot country on which the Forum for Sustainable Fisheries (a coalition of multilateral agencies, bilateral donors, and NGOs) may focus to develop a dynamic and sustainable fisheries sector. Since 2002, WWF has been involved in supporting the establishment of sustainable shrimp farming and shrimp fisheries systems.

In terms of agriculture, the government is now focusing on land security in rural areas and supporting labor organization. The government plans to increase funding and development of income-generating agricultural practices, specifically short-cycle breeding and aquaculture. Increased agricultural research and rural credit is important as only 1.5 percent of small farmers have access to credit and a mere 5 percent of total lending goes to agriculture (World Bank 1999).

In addition to supporting small farmers, the World Bank is pushing for investor incentives to ensure easier exportation, which is expected to encourage the settlement of large scale farms. This would encourage dense populations to concentrate in high-potential areas, making infrastructure costs less prohibitive.

There may be danger in increasing large scale land holdings, as it may lead to increased landless laborers and exploitation by large scale owners where management may be far removed from the site. In addition, attention should be paid to export-oriented crops that rely heavily on imported inputs, such as petroleum-based products that respond dramatically to fluctuating global market prices. Training and information dissemination in the use of inputs that can pose health risks—such as those associated with pesticides and herbicide use—is essential.

Agriculture "underperformance" is seen as a major cause of widespread rural poverty. Methods of agricultural intensification and extension must take into account environmental considerations as well as the impacts on the rural societies currently involved in small scale agricultural production (EIU 2000).

Infrastructure

Economic growth and poverty alleviation are impeded by basic economic infrastructure (EIU 2000). Possible improvements include adoption of a transportation policy in rural areas, rehabilitation of roads, the rehabilitation and construction of ports, and long-term maintenance to establish security and stability of market links. A port proposed by Rio Tinto Mine and the World Bank could benefit the developing industries of tourism, sisal, seafood and meat, and could reduce the costs of imported construction goods and other products in Taolanaro. The impact of the proposed port on the traditional fishing communities and the estuary will need to be investigated, and access by industries other than the Rio Tinto Mine must be guaranteed.

Upgrading and expanding infrastructure has been prioritized for meeting the infrastructure and support service needs of the 10 new industrial and tourism zones. This development strategy should be monitored for its potential to allow access to previously unexploited areas and the impacts on resource degradation, migration and social disruption.

Recommendations

Establishing Formal Land Tenure Rights

Land tenure reform is a primary objective of the World Bank and EU. Any efforts at reform must be coupled with education on formal versus informal and legitimate versus illegitimate land rights. Sensitivity must be paid to the fact that many rural inhabitants perceive that they already have land ownership from the purchase of permits, many of which were distributed illegally. In addition, land tenure reform must be coupled with agriculture extension.

Land tenure rights need to be extended to forested as well as non-forested land, and services provided for sustainable cultivation and sale of non-forest products. Monitoring and compliance for land ownership should take place and be accountable to users with sanctions put in place. There must be a system to ensure the financial sustainability of the programs that monitor and enforce existing forest and forest resource laws.

Agricultural Extension

Agricultural extension services need to be enhanced to provide information to rural farmers on better crop production and soil conservation. Work can be coordinated with agriculture donors and operators to develop more ecologically and economically sustainable uses for land production. SOPAGRI (Société de Production Agricole) should be encouraged to integrate crops other than maize into their collection and export scheme. Quality control, marketing and processing for country-wide food consumption needs to be improved to reduce reliance on food imports. Improvements of irrigation and water networks are needed, as only 16 percent of arable land is irrigated. The agriculture sector has the potential to provide raw materials for industrial products. The industrial sector has been successful and has the potential to take advantage of the limited import liberalization clauses of the new U.S. Africa Growth and Opportunities Act. This can in turn increase demand for the agricultural sector to produce primary inputs.

Improved Market Access and Economic Development

Better market access for agricultural crops and alternative forest products should be coupled with major investment in infrastructure, market outlets, and means of transport for the rural communities. National government strategies should also be coupled with regional and local capacity development. Efforts should be made to influence current development policies to this effect, including the Poverty Reduction Strategy Paper (PRSP) and the World Bank's Country Assistance Strategy (CAS). The Regional Development Committee (CRD) can be another avenue through which information and education on the market for goods could be provided. The Rural Development Working Group (GTDR) can provide information, education and communication regarding efforts to attract the private sector. GTDR can also be mobilized to identify income-generating activities and the CRD used to link environment considerations with investment strategies for the region.

Micro-credit

Many Malagasy are outside of micro-credit networks which are vital for grassroots development and poverty reduction. The introduction of credit schemes to rural populations is important for investment, and should be pursued by the national government in conjunction with land tenure policies and agriculture extension practices. In addition, local networks organizing micro-financing and providing loans should be supported.

These strategies need to be coupled with enforcement of existing environmental laws and forest protection, and incentives for increased agricultural production need to be assessed for perverse incentives inducing forest clearing and further land degradation. Money must be allocated to the DEF to ensure capacity development and adequate pay for forest officers, as well as the ability to address corruption. The government should be encouraged to view the DEF as being responsible for environmental conservation along with ANGAP. In addition, sanctions must be levied on violators of forest and park laws.

Increased Government Capacity

The national government should be encouraged to transfer funds and trained personnel from the central government in order to empower local councils. This should improve with the recent decentralization. Delivery of grassroots services could prove popular with donors, and may also help tax collection if people see their payments resulting in direct services. Programs like the existing provision to municipalities of budgets for reforestation should be encouraged.

National Policies and Their Coordination

There must be greater outreach and education explaining the relationship between economic policies and environmental degradation. Coordination of the various ministries must be facilitated to dispel the perception that environmental problems are only the problems of the Environment Ministry.

The Poverty Reduction Strategy can be used to promote linkages between the ministries overseeing the environment and economy, to encourage support of rural development and sustainability. Work at the national level should also focus on programs linking poverty alleviation with environmental protection, including the Sectorial Transport Programme, the National Programme for Support to the Private Sector, the National Population Policy for Economic and Social Development, the National Policy for the Promotion of Women, and the Environment Programme.

The national energy policy must move away from reliance on firewood, and opportunities to finance plants fuelled by solar power or bagasse should be pursued. A program to deliver alternative cooking fuels should be encouraged; a subsidy on kerosene could lower demands on fuelwood. Plans to reduce fuelwood consumption would need to be coupled with alternative income generation in those rural communities whose primary source of income is wood and charcoal sales.

Use of Study Results

Figure 2 illustrates the various socioeconomic causes of biodiversity loss and the linkages between them. These results were also summarized and shared with the donor community and with decision-makers in the key sectors of agriculture, tourism and the environment.

WWF used the study recommendations to design interventions at various levels and to mobilize partnerships to implement these interventions.

Local level interventions include:

- supporting local stewardship of forests and natural resources by facilitating forest management transfer contracts between the State and communities neighboring priority conservation areas;
- helping integrate environmental issues in local and communal development plans and helping introduce spatial zoning for development and conservation in such plans.
- Communal and regional level interventions include:
- partnering with PADR executing agencies and programs to provide sustainable alternatives to natural resource exploitation in target communities. This includes agricultural extension and the introduction of revenue generating activities such as small scale businesses;
- mobilizing support to reinforce communal and regional structures and the ability to design and implement development plans;
- developing an energy strategy for the Spiny Forest Ecoregion.
- National and international level interventions include:
- more in-depth study of the linkages between trade liberalization, rural poverty and the environment with a special emphasis on the case of maize exportation, and the creation of a National Advisory Committee to help influence trade policies in favor of the environment and rural development;
- creation of and participation in a joint Environment Programme-PADR committee to ensure coherence and synergy between the rural development and environmental sectors;
- creation of and participation in a joint forests/mining committee to facilitate dialogue between the two sectors, and to develop mechanisms for conflict resolution in areas of both high biodiversity and high mining

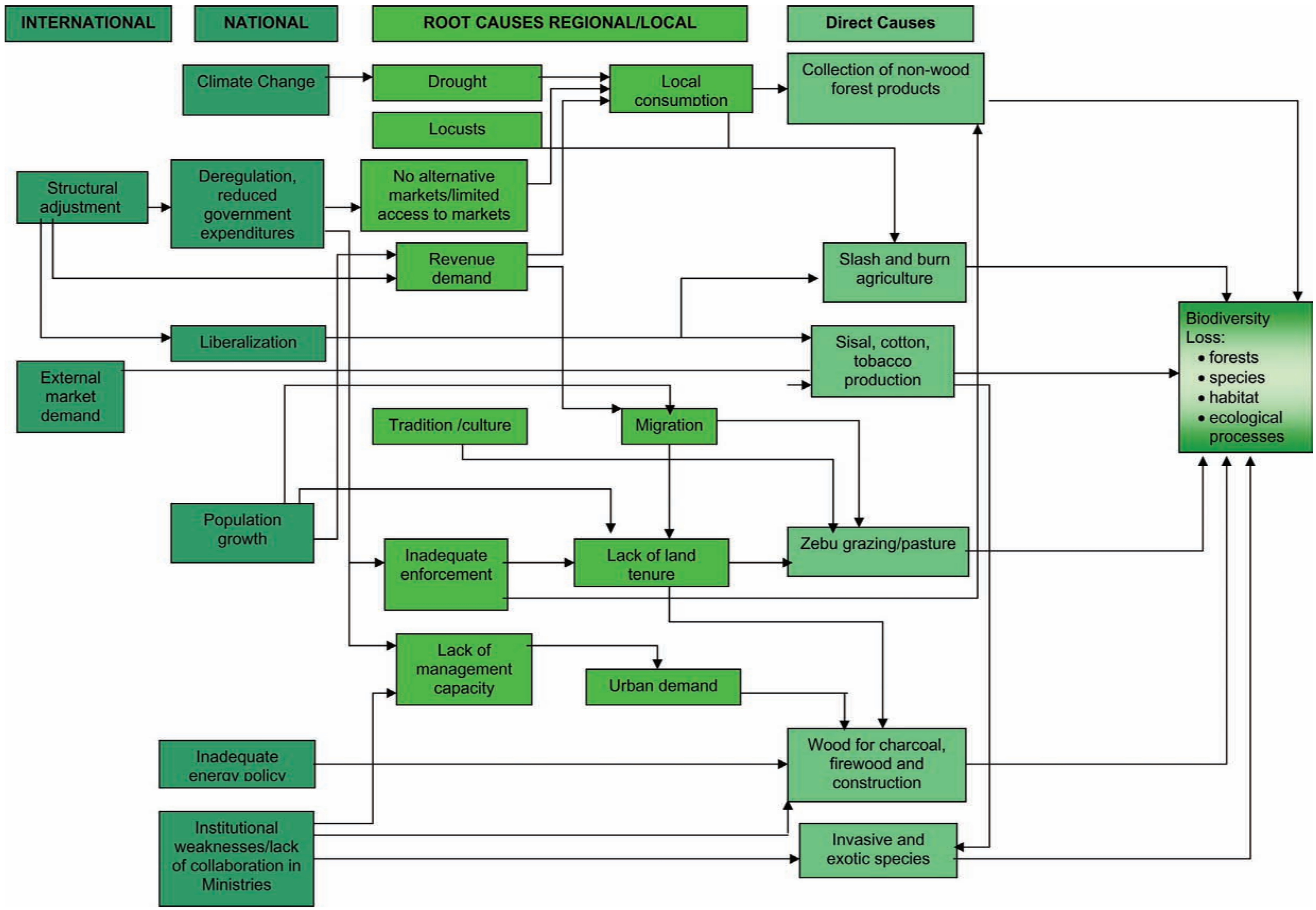

Figure 2. Socioeconomic causes of biodiversity loss and the linkage between them.

potential. These joint committees are playing a key role in the implementation of Madagascar's recent commitment to triple its protected area coverage over the next five years.

Conclusions

The analysis of the root causes of biodiversity loss in the Spiny Forest has provided the basis of a 15-year Ecoregion Action Plan that identifies the strategies, actions, partners, and means necessary to ensure effective and sustainable conservation of the ecoregion's biodiversity. The results of the study have been very useful in fostering dialogue with other sectors and raising their awareness of the potential environmental and social costs of their actions, and will eventually inform them on how these actions can be more sustainable.

The study has helped us gain a better understanding of the complex dynamics among which our work is taking place, and has helped us make more informed decisions on how to act. It must be stressed that the value of such a study heavily relies on the level of specificity that can be achieved; a root cause analysis should ideally start from the analysis of specific biodiversity targets (key species or habitats) in specific sites so that the higher level causes and subsequent interventions can be better adapted and targeted and hence be more responsive.

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Tamarisk Mapping and Monitoring Using High Resolution Satellite Imagery

Jason W. San Souci, Director of Remote Sensing Applications, Native Communities Development Corporation, Colorado Springs, CO
John T. Doyle, Sales Manager, DigitalGlobe, Inc., Monument, CO

Abstract—*QuickBird high resolution multispectral satellite imagery (60 cm GSD, 4 spectral bands) and calibrated products from DigitalGlobe's AgroWatch program were used as inputs to Visual Learning System's Feature Analyst automated feature extraction software to map localized occurrences of pervasive and aggressive Tamarisk (*Tamarix ramosissima*), an invasive species found along riparian corridors throughout the Western United States. Mapping was carried out along two major river systems known for widespread tamarisk invasions (Colorado River near Grand Junction, CO & Rio Grande River near Albuquerque, NM) using imagery acquired in late Fall, 2003. Mapped tamarisk occurrences were conservative, because only tamarisk vegetation with spatial areas greater than 10 square meters were classified and senesced tamarisk were not taken into account. Classification accuracies were greater than 80 percent based on ground verified data. Overall, these results confirm that high spatial but low spectral resolution remote sensing data coupled with machine learning classifiers can be used effectively for local precision mapping of tamarisk in dominant environments found in riparian landscapes.*

Introduction

Tamarisk is a deciduous shrub/small tree that was introduced to the western U.S. in the early nineteenth century from Central Asia and the Mediterranean for use as an ornamental, in windbreaks, and for erosion control. Tamarisk, also known as salt cedar, is well suited to the western U.S., and has displaced much of the native vegetation along low-elevation river and stream banks from Mexico to Canada. Tamarisk is now estimated by some researchers to cover between 1 and 1.5 million acres of land in the western U.S.

Tamarisk is a tenacious plant that has a deep root system (up to 100 feet) and leaves a salt residue in the soil. These characteristics enable it to quickly displace native cottonwoods and willows as well as adjacent upland plant communities; such as bunch grasses, sage and rabbit brush. The resulting tamarisk thickets crowd out streams and rivers; provide poor habitat for livestock, animals, and birds; increase fire hazards; and limit human use of the waterways.

While each of these points is important to one or more constituencies, the single most critical problem is that tamarisk steals water by using more water than native vegetation that it displaces. This non-beneficial user of the West's limited water resources dries up springs, wetlands, and riparian areas by lowering water tables. Based on average water use values for tamarisk and the native plant species it has replaced, a rough estimate of the non-beneficial consumption of water by tamarisk throughout the West ranges from 2.0 to 4.5 million acre-feet of water per year. These values are above and beyond what the native riparian vegetation would have consumed and represent enough water to supply upwards of 20 million people or the irrigation of over 1,000,000 acres of land. And every year, the problem only continues to get worse.

A key requirement for the effective management of invasive plants is the ability to identify, map, and monitor invasions as well as the invaded plant communities. Hand-mapping in the field or from aerial photos are techniques commonly used in support of eradication efforts, but these methods are labor intensive and limited. Hand-mapping from field observation requires access to the site from the ground, a prospect that is not always practical, safe, or timely, especially on an active military base. Interpretation of aerial photos is extremely time-intensive and often necessitates interpretation of large numbers of photographs. In addition, it can be difficult to distinguish the weed species in the photos even with magnification, making the interpretation process highly subjective and likely to differ from one analyst to another. Because of these constraints, weed mapping is usually done on an as-needed basis, and comprehensive maps that would support time-series evaluation are not generally made. There is the need, therefore, to develop repeatable and reliable automated techniques for monitoring the spread of weeds and the effects of eradication efforts as well as changes in the habitats being managed. DigitalGlobe has developed a unique set of algorithms that have advanced the capabilities of remote sensing technologies for vegetation assessment. Specifically, they have discovered a method to calibrate the imagery to reflectance at the earth's surface. DigitalGlobe has also developed the capability to remove variation in vegetative indexes caused by differences in soil brightness. This processing step potentially allows for mapping of the invader and surrounding plant communities that cannot be accomplished using more conventional multispectral imagery. Feature Analyst, the flagship automated feature extraction tool of Visual Learning Systems, Inc., is used in this study to exploit the strengths of the high-resolution digital imagery while reducing the extreme variability effects inherent to high-resolution imagery classification.

This study tested the suitability of AgroWatch data and Feature Analyst algorithms for improved mapping of a riparian plant community invaded by Tamarisk. This work will be useful in future decisions about methods for mapping Tamarisk and associated riparian vegetation in other regions.

Technical Objectives

1. Develop methodology to accurately, repetitively, and consistently map tamarisk invasions using:
   - Pan-Sharpened QuickBird Imagery
   - Calibrated AgroWatch Products
   - Advanced COTS Software
2. Test methodology in two study areas along separate riparian corridors within the Southwest
   - Leaf-on and multiple dates
   - Target size ranging from single tree to dense monoculture
3. Assess the accuracy of the classification
   - Collect reference data within each study area

Project Areas

The first study area was a 3.5-mile stretch of the Rio Grande River in Sandoval County, NM. This area recently underwent a tamarisk eradication and riparian restoration project completed by the Santa Ana Pueblo. The riparian vegetation in the area was characterized by individual tamarisk plants and monotypic cottonwood stands. The second study area focused on a 5-mile section of the Colorado River in Mesa County, CO. This area is characterized by dense monotypic stands of tamarisk intermixed with native vegetation such as willow and cottonwoods, as well as non-native russian olive. Table 1 compares the QuickBird image parameters for the two project areas.

Table 1. Project Area Imagery Comparison.

River System	Colorado River	Rio Grande River
Acquisition Date	October 25, 2003	September 27, 2003
Off Nadir Viewing Angle	12.7°	14.3°
Image Quality	Excellent	Excellent
Cloud Cover	0.0%	0.0%

Classification Methods

Regions of interest (ROIs) were created for use as training sets using a combination of field data, field notes and hand-mapped polygons. ROI polygons were created on an un-georeferenced true-color display of the image data using the field notes as reference by visually matching features in the un-georeferenced and georeferenced images.

The high spatial resolution of these data sets seemed to fit perfectly with the Feature Analyst workflow and analytical capabilities. Feature Analyst allows for a simplified, intuitive classification workflow: Train Learner, Remove Clutter, and Add Missed. The ROIs generated in the field were used to train the Feature Analyst learner on the spectral and spatial characteristics of tamarisk. Using Feature Analyst's Learning Explorer feature and AgroWatch's calibrated vegetation products allowed the learner derived during the first project area to be used directly on the second project area, with only slight modifications regarding the average tamarisk stand size in the latter project area. After a single iteration, results were very promising for tamarisk delineation in both project areas. The results of the accuracy assessment are illustrated in tables 2 and 3.

Conclusions

This study shows that the invasive plant Tamarisk and associated riparian vegetation types can successfully be mapped using QuickBird and AgroWatch data and with advanced machine learning techniques available in the commercial off-the-shelf software, Feature

Table 2. NM Accuracy Assessment Results.

Classification	Reference # Plots	Tamarisk	Other	Totals	User's Accuracy
	Tamarisk	17	2	19	89%
	Other	3	18	21	86%
Totals		**20**	**20**	**40**	
Producer's Accuracy		85%	90%		88%

Table 3. CO Accuracy Assessment Results.

Classification	Reference # Plots	Tamarisk	Other	Totals	User's Accuracy
	Tamarisk	25	6	31	81%
	Other	7	22	29	76%
Totals		**32**	**28**	**60**	
Producer's Accuracy		78%	79%	78%	

Analyst. These techniques show promise as useful tools for evaluating the status of important habitats and the advance (or eradication) of an invasive weed. This is especially applicable in the management of riparian systems because constituent habitat types can change significantly in their spatial extents and distribution in just a few years. More work is needed to discover if learners can be used in images from different years for the same region for development of a sequence of maps that would allow change analysis, since variations from year to year in the timing of plant phenological stages will certainly be a factor.

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Monitoring Ecosystems and Biodiversity at a Continental Scale—A Proposal for South America

Dr. Xavier Silva, Director, IDB-TNC Ecoregional Project, South America. Teacher and Lecturer, San Francisco de Quito University. Board Member, OÏKOS Foundation

Abstract—*A monitoring system plan is being developed in South America to assess critically endangered ecoregions. The system will be based on a previous ecosystem and biodiversity inventory developed through a large gap analysis program in five South American ecoregions. The monitoring system will include three main elements: (1) Landscape Ecology: vegetation cover, fragmentation and deforestation, infrastructure (road, dams, pipelines); (2) Biological guidelines: species richness, endemism, endangered species and species of a particular interest; and (3) Conservation Policy and Socio-Economic guidelines: national protected areas systems, conservation policies, human population on important areas, main economic activities and other. Such a system is an important need for governments and private organizations in South America, especially to detect critical sites and socio-political issues before the environmental problems become too large.*

Introduction and Background

Environmental surveillance at a continental scale is an important conservation requirement in vast territories, such as in South America, where large and diverse ecoregions are being altered by a number of unsustainable development practices (Busch and Trexler 2003, World Conservation Union, IUCN 1992). Although deforestation, soil erosion and biodiversity loss have become the primary sources of poverty and social distress in the region, very few continental baseline studies are available for initiating a large scale monitoring program in South America.

A recent gap analysis project developed by UNEP (United Nations Environmental Program) and The Nature Conservancy (funded by the Global Environmental Facility, GEF), provides large amounts of data, maps and other types of information that should be used as a starting point for a monitoring system in five of the biotically richest ecoregions in the world (UNEP, The Nature Conservancy, NatureServe 2003).

The project was executed by local conservation/science organizations in Colombia, Ecuador, Peru, Bolivia and Paraguay, for five global priority ecoregions as described by Dinerstein E. and collaborators (1995) in a World Bank and WWF study. From north to south, the ecoregions are: the Choco Humid Forests (Colombian Pacific and Norwest Ecuador), three ecoregions on the eastern slopes of the Andes in Ecuador, Peru, and Bolivia, and the Dry Chaco in northern Paraguay and southern Bolivia.

Among the results, 6,473 species of flora and fauna have been analyzed (each one with a map indicating it's potential geographic distribution), and over 6,500 thematic maps have been produced, indicating vegetation types, centers of high diversity and endemism, current and potential threats, forest fragmentation, infrastructure, location of protected areas, and basic socio-economical information.

During the project the best contacts with governmental agencies in each country where developed (Environmental Ministries and other agencies), as well those with international organizations and foundations and with local NGOs and local communities. More than a 100 organizations were contacted in the region, many of them collaborating directly with the project. As a result the Inter American Development Bank is currently funding the social and economic studies for the selected sites (Inter American Development Bank 2004).

With this basic inventory information, monitoring system plans are being developed. The goal of implementing such a system is based on the fact that governments, NGOs and local groups need to be able to rapidly develop conservation activities over precise areas of importance that may be detected by the system. In that way, the monitoring system will contribute to better conservation results using fewer monetary resources.

A number of elements will be considered first, such as the monitoring system structure from a technical, organizational, and political points of view. The three main planned elements for the system will be: Landscape Ecology, Biological guidelines, and Conservation Policy

/ Socio-Economic issues. These guidelines will include a variety of topics, such as vegetation cover, forest fragmentation, deforestation (rates & specific location), species richness, endemism, species of a particular interest (including economic interests), national protected areas systems, local conservation policies, human population over critical areas, main economic activities, and other issues (Pearce 1993, Dillon and others 1996).

The monitoring network structure is being planned to include different executing partners in different countries, all following the same basic monitoring philosophy and methodology. Executing partners and other partners related to the monitoring system will periodically make available critical information to environmental government offices, NGOs, local organizations, specific communities and other stakeholders in order to catalyze immediate action.

Remote sensing, GIS, and field monitoring activity will be integrated in the monitoring system. Basic field observations can be developed for implementation by local peoples, park guards, university students, and scientists. A set of indicators will be identified for different scales and levels of the monitoring system. Also, basic social and economical indicators are being integrated into the system. Coordination with other systems and databases in the region is also a priority, such as with Conservation International and the University of Maryland which are monitoring certain areas of the Amazon Basin.

Planned to be implemented in 2005, this will be the first continental-scale environmental monitoring system in South America.

Monitoring System Outline

Goals

The main goal of the Monitoring System in South America is to provide early detection and warning of emerging environmental problems in the region, especially at an ecoregional scale. This should catalyze conservation and environmental management processes and negotiations at national levels before the problem becomes more difficult to control.

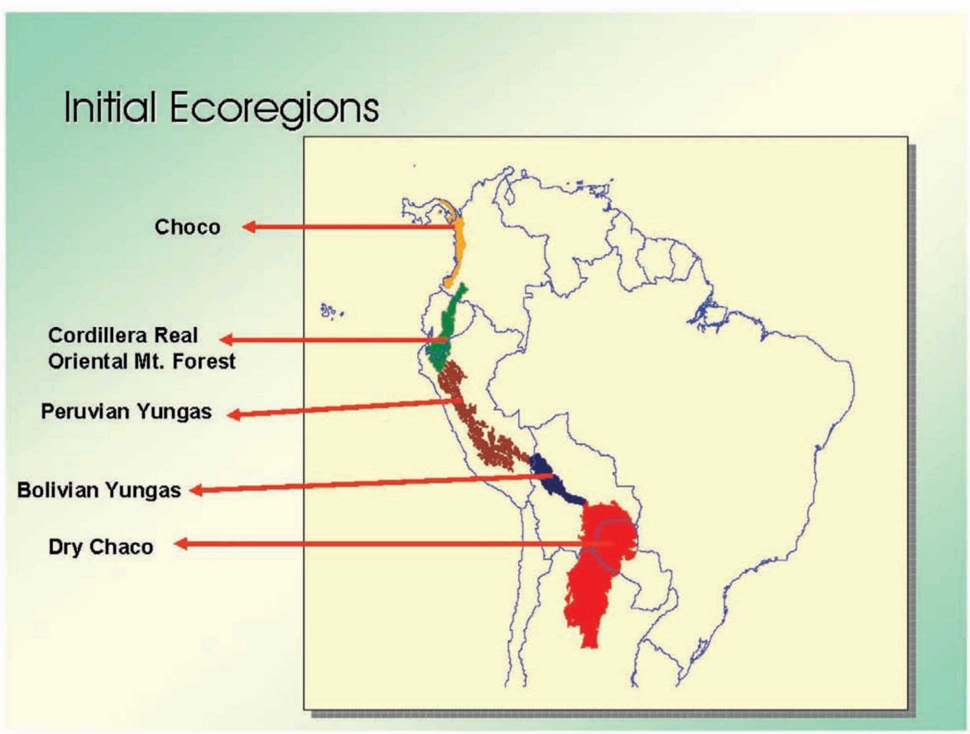
Other objectives will provide to the conservation/science community and to the general public a solid baseline of information about ecosystems, habitats, species, national conservation policies and basic socio-economic information related to the environment in South America.

Ecoregions Proposed

The aim of the Monitoring System is to work in the whole South American continent, although a first iteration of critical ecoregions should be addressed initially. This leads to an organized step-by-step process and the opportunity to test and improve the system before moving to other ecoregions.

A logical starting point is to work with ecoregions that already have solid sets of information, such as the ones that were addressed in the UNEP/GEF Gap Analysis project (UNEP, The Nature Conservancy, NatureServe, 2003) (fig. 1).

Figure 1.



Biogeographic Choco

Tropical humid forest along the Pacific Coast, from southern Panama to northwest Ecuador. Most of the ecoregion is located on the Colombian Coast. This is one of the most biologically diverse ecoregions in the world. The endemism rates are among the highest in continental ecoregions. This ecoregion also includes isolated dry valleys originating in the Andes. Main threats to this ecoregion are logging (both legal and illegal) in northwest Ecuador, and deforestation by the expansion of agriculture.

Eastern Cordillera Real Montane Forest

Cloud forest and forest foothills in the upper reaches of the Amazon Basin, mainly Ecuador eastern Andean slopes. Great variety of habitats, from the lower foothills (800 meters - 2,640 feet) to the highlands treeline (over 3,500 meters - 11,550 feet). High biological diversity. This ecoregion is threatened by clearing for new pastures (livestock) and agriculture.

Peruvian Yungas

Eastern Andean slopes in Peru. Combination of cloud forests and deep valleys (called yungas), some of them running parallel to the Andes. A great variety of habitats as in the previous ecoregion with high biological diversity. Main threats include clearing for new pastures (livestock) and agriculture, as well as coca plantations.

Bolivian Yungas

Similar to the Peruvian Yungas, but located towards the south where greater seasonal climatic variations occurs. Main threats are clearing for new pastures (livestock) and agriculture, and coca plantations.

Dry Chaco

Southern Bolivia and Northern Paraguay. The ecoregion is a combination of several dry ecosystems with unique flora and fauna, including wild peanuts (original genetic bank) and lowland guanacos. Main threats are vegetation clearings for new pasturelands, fires and burning of natural vegetation.

Main Guidelines

Three sets of guidelines are proposed for the Monitoring System database.

Landscape ecology elements

These guidelines include: (1) Vegetation Cover and Vegetation Classification. (2) Fragmentation and Deforestation, including form and size of fragments, location and deforestation rates. (3) Base Map & Main Threats; threats include infrastructure such as new roads and agricultural frontier expansion, logging areas, pipelines, dams, etc. Landscape ecology issues will be based on the most up to date remote sensing images and GIS. Scale for the proposed maps would be 1:500,000.

Biological elements

The Biological Guidelines include 4 main topics: Species Richness, Endemism, Endangered Species and Species of particular interest (including economic value). For this elemnt, all biological indicators (see biological indicators criteria bellow) will have a potential geographic distribution map, based on vegetation cover and habitat types. GIS management of potential distribution maps will show the important areas for biological diversity, endemism, endangered species and species with a particular interest (fig. 2).

Conservation policy & socio-economic elements

These address issues using basic information sets: (1) National Protected Areas Systems (scale 1:500,000); (2) National Environmental Offices and current Contact Representatives (6 month period update); (3) Principal Conservation/Science NGOs and other related organizations (6 month period update); (4) Principal National Projects, such as road construction, pipelines, dams, etc. (1 year period update); and (5) Socio-Economic Database, including several fields, like population (in the selected ecoregions), main economic activities, per capita income, local organizations, principal markets, distribution of products, and related datasets.

Indicator Species

The selection of biological indicators is an important procedure for the development and maintenance of monitoring systems. Several criteria are commonly used for selecting indicators (The Nature Conservancy, 2000). Given the fact that this monitoring system is based on an ecoregional scale, the three main criteria planned to be applied for both plants and animals are:

Representativity

The species selected should be representative of the ecoregions and should integrate well with the elements and topics that will be used in the monitoring system. In this particular case species selected should be representative of the chosen ecoregions (see description above) and of the following topics: endemism (the most important endemic species); endangered species (in this case, critically endangered species, based on IUCN criteria); species with a particular interest (the most important species related to economic activities) and species richness. For this topic, a sufficient number of species (providing

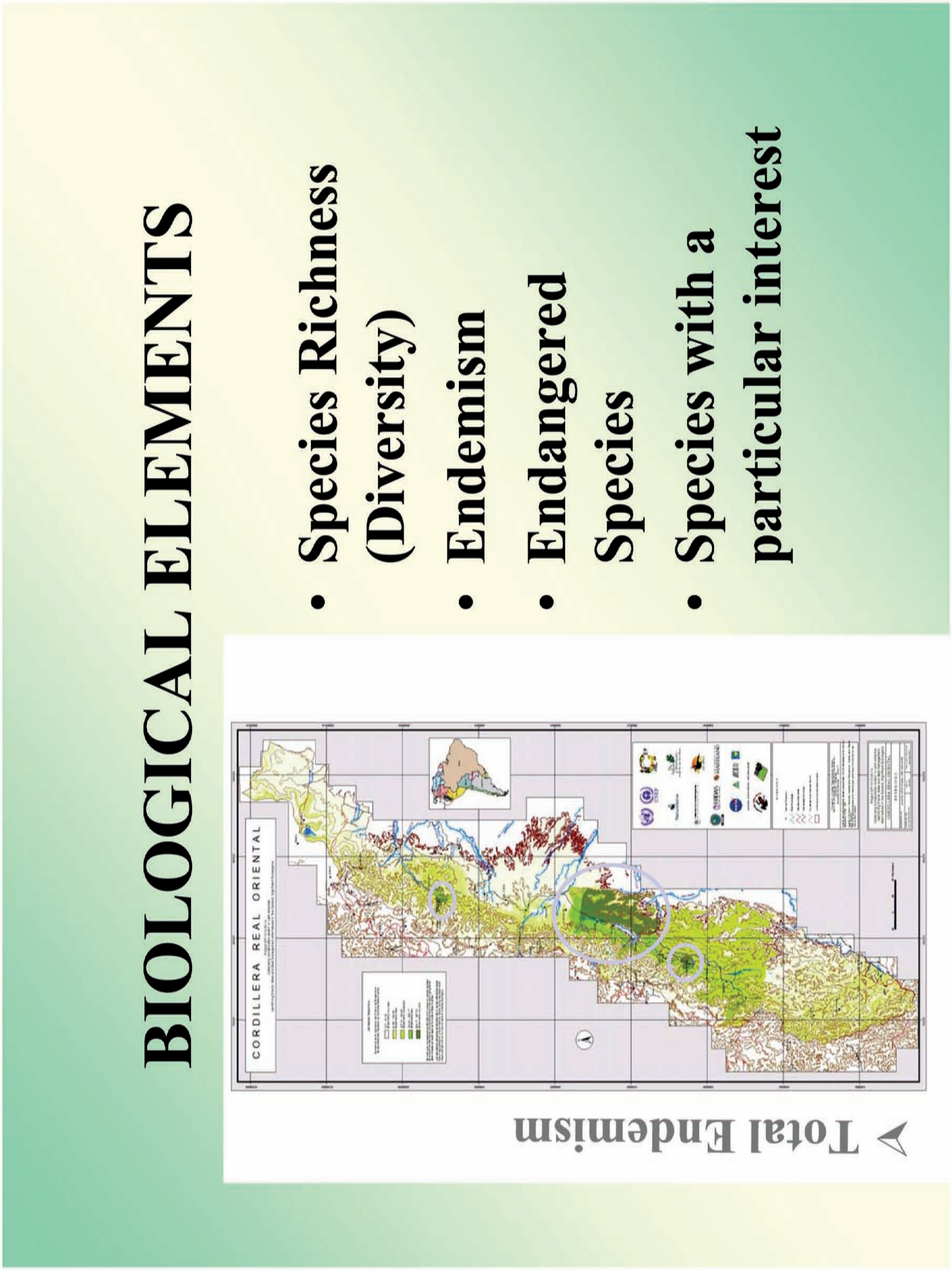

BIOLOGICAL ELEMENTS
• Species Richness (Diversity)
• Endemism
• Endangered Species
• Species with a particular interest
➤ Total Endemism
CORDILLERA REAL ORIENTAL

Figure 2.

statistical value) should be selected, based on the criteria covered by the next point.

Knowledge

The species selected should have a sufficient set of information (based on previous scientific studies and historical data) to provide adequate information on general geographic distribution and habitat preference; and basic ecology like habits, interaction with other species, food, etc. For some animal species there is sufficient baseline information, as in the case of several vertebrates, including most birds and mammals, and some amphibians and reptiles. Invertebrate data (except some insects, such as butterflies) is comparatively poor and not useful for a continental scale system, because of the lack of data. There is a similar situation for plants. Vascular plants have more information than the non-vascular ones.

Ease of observation

Even though some species have good basic information, their accessibility on the field can be difficult. For an ecoregional scale system it is better to choose species that are relatively easy to observe in the field, except perhaps in the case of endemic and endangered species. Basic field observations can be developed for implementation by local peoples, park guards, university students, and scientists.

Organizations and Governance

There are three levels of organizations that need to be considered for the development and the management of the Monitoring System

Executing organizations

These are the organizations that maintain the system's information database at a national level and also develop the early detection process and awareness of environmental problems. The executing agencies are in charge of the following main activities: remote sensing analysis, cartography & GIS, database structure & data population, field work (coordinate with local peoples, park guards, university students, and scientists) and data distribution through web pages and specific information to government agencies. These agencies should be in close contact with other conservation/science organizations, such as NGOs, universities, museums, local groups, etc. For the implementation of the monitoring system, it is suggested that the same five organizations (one in each country) that developed the databases (cartography, species and socio-economic data) for the previous UNEP-GEF gap analysis be utilized (fig. 3).

Recipient organizations

These are the principal organizations where the information should first be routed, especially in the case of an early warning process. Among these organizations, are the government agencies for environmental issues. This includes environmental ministries and other high level government organizations related to the environment, land use planning, agriculture, oil exploration and exploitation, logging and national infrastructure (roads, pipelines, dams, etc.). The proposed national executing agencies have already initiated contacts with these type of organizations in each country. Other recipients of the information are NGOs, local communities, universities and the general public (using internet technology).

Coordinating organization

The Coordinating Organization oversees the general functioning of the monitoring system and has an international communication role. This organizational body provides high level representation to the executing agencies and helps to maintain good relations with the recipient agencies. It also is charged with managing and maintaining a sufficient level of funds for the system's functioning. The coordinating organization interacts with international organizations, such as the World Bank, Inter American Development Bank, Andean Corporation (CAF), Andean Community of Nations (CAN), European Community, and with other organizations developing ecoregional scale databases and monitoring systems; as is the case with The Nature Conservancy, Conservation International, and the University of Maryland for the Amazon Basin.

Discussion

Working on an environmental monitoring system at a continental scale is a very ambitious task, especially in South America where biological and ecological knowledge is still rudimentary in many cases. The system proposed in this paper will follow several iterative steps; the first one is to concentrate activities in key ecoregions, especially the ones that are important because of their biological richness and for their level of threats. The first set of ecoregions selected for the monitoring system all have sufficient baseline information to initiate the monitoring process, thanks to a previous UNEP-GEF gap analysis, from which several indicator species and ecosystems can be chosen. With a current IDB project providing the social and economic follow-up for the ecoregions, integrating socio-economic information is also reinforced.


Proposed Executing Agencies
CVC
CORPORACION AUTONOMA REGIONAL DEL VALLE DEL CAUCA
Corporación Valle del Cauca, Colombia
trópico
Trópico, Bolivia
CDC
Secretaría del Ambiente, Paraguay
CDC - UNALM
Universidad Nacional Agraria La Molina, Perú
Fundación Jatun Sacha
Alianza Jatun Sacha CDC-Ecuador

Figure 3.

Working with a disparate set conservation/science organizations, both at national and international levels, is a challenging task and needs to be considered from the beginning of the system's development. This includes the main national and international conservation/science organizations, universities, museums, and others. Also, recipients of the information, such as government agencies should be active partners of the monitoring system. International agencies, like the World Bank, IDB, European Community and bilateral agencies such as the USAID, need to be involved as well.

A crucial factor for developing the monitoring system as a permanent source of information and early warning detector, is to maintain a high level of professionalism both from the technical side (biological, ecological, socio-economic, informatics) and from the administrative point of view. The executing organizations' experience and technical competence, as well as the coordinating organization and partner's efficiency are key to the development of the system.

Finding resources, including human resources and funds, is another critical task for the development and structuring of the monitoring system. All system's partners and especially the coordinating organization should provide the necessary means to maintain a sufficient flow of resources through the development of relationships with international organizations, local governments and other types of funding organizations.

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An Overview of Inventory and Monitoring and the Role of FIA in National Assessments

W. Brad Smith, Associate National Program Manager for Forest Inventory and Analysis, USDA Forest Service Research & Development, Washington, DC

Abstract—*This paper presents a brief conceptual overview of inventory and monitoring and the role of the Forest Inventory and Analysis (FIA) program in national assessments. FIA has become a focal point of national inventory and monitoring and kept national leadership as well as forest resource research and management professionals apprised, through periodic reports to Congress and others on the status, condition and health of the Nations forests across all ownerships for over 75 years.*

Introduction

The Forest Inventory and Analysis program within the Forest Service is the only inventory and monitoring programs in the U.S. that carries out large-scale descriptive forest vegetation inventory and monitoring across all forest land ownerships with consistent, compatible protocols for landscape scale information reporting. And, these inventories have been the scientifically reliable basis of national assessments of the Nation's forests for more than 5 decades. A general overview of the nature and application of inventory and monitoring will be followed by an overview of specific role of FIA in national assessments.

Nature of Inventory and Monitoring

In simple terms, monitoring is the process of checking or observing something, relative to a standard or baseline, for a particular purpose, followed by interpretation and possible action. The notion of comparison to a baseline explicitly implies repeated measurements when considering inventories. The timing, content, and scale of these measurements must depend on the both the need for the information and the availability of data from other ancillary sources required for possible analysis. Coordination between agency units (State and Private Forestry, Research, and National Forest System) and external partners (public participants; Federal, State, and local agencies, tribal governments, universities, and special interest groups) is mandatory for effective inventory and monitoring activities aimed at addressing issues or policies which cross multiple spatial and legal boundaries. Vegetative inventory and monitoring is considered one of the principal tools the Forest Service will use to assure that the goal of achieving and maintaining sustainable forest ecosystems is being accomplished.

More specifically, inventory and monitoring is defined as the process of repeating vegetative inventories and developing analyses to assess resource trends and provide the basis for broad policy decisions. In this context, inventory and monitoring (referred to as simply 'monitoring' henceforth) can be divided into the broad generic categories of descriptive and prescriptive monitoring (Barnard and others 1985). Descriptive monitoring (also referred to as strategic or landscape-scale monitoring) provides information on an extensive landscape and broad environmental scale for public policy development and analysis. An example of this type of monitoring would be the Forest Inventory and Analysis (FIA) grid inventory. Prescriptive monitoring (also referred to as management or operational monitoring) is much more resource intensive and aimed at providing information for local managerial action. Prescriptive monitoring usually provides detailed information for a limited geographic area and is aimed at developing or evaluating management plans for particular tracts of land. Examples of this type of monitoring include stand exams, wildlife surveys, recreation surveys, etc.

Vegetative landscapes consist of large numbers of individual elements distributed over wide areas making it logistically and economically impractical to use complete census as a monitoring tool of choice. Sampling, in some form, is the only practical solution to obtaining reliable information on the content, structure and condition of the resource. Since trend information over time is important, a process for linked repetition of the sampling, or monitoring, is critical. A key consideration in all types of monitoring is the accuracy level required for the variables of interest, which, in turn, impacts the number and orientation of samples needed.

Statistical sampling of natural resources generally involve three fundamental components 1) area classification or stratification in which relatively homogeneous environments are recognized; 2) direct measurement of observable characteristics of interest; and 3) indirect measurement where characteristics, such as volume or condition, are inferred from models based upon measurements taken in the second component (Barnard and others 1985). Remote sensing and GIS systems are primary tools in the first component; sampling theory, plot design, and collection apparatus dominate the second; and ecological theory, mathematical formulation, and analytical process dominate the third component.

Application of Inventory and Monitoring

The remainder of this paper will focus on descriptive or landscape-scale monitoring. One of the first descriptive inventory estimates for the forests of the U.S. was provided by Franklin Hough (1878-1882). Concerns arose, however, about the subjective method of data collection and reliability of the information. Since that time, foresters in this country have relentlessly pursued better ways to provide statistically reliable information that describe the extent, condition, and trends in the forest resources of the nation. By the turn of the 19th century Graves (1907) described many alternative designs for large-scale forest assessment including plot cruises over extensive forest areas. Later, systematic cruise designs using fixed area plots were recommended by Sewall (1911) and Clark (1913) which would provide greater measurement precision and produce reliable estimates of the resource at low cost. The science of large-scale descriptive forest inventory in the U.S. was being born.

By 1920, several further attempts had been made to estimate the volume contained in the nation's forests (Martin, 1983), but none would yet bear up under the rigors of modern statistical evaluation. This shortcoming, coupled with nagging concerns over the status of the Nation's forests and ongoing depletion of the timber supply, ultimately led to the passage of the McSweeney-McNary Act in 1928 by the federal government. This Act, which also created the federal Forest Research organization in the Forest Service, directed the Secretary of Agriculture "to make and keep current a comprehensive survey of the present and prospective requirements for timber and other forest products in the United States..." This directive became the legal mandate for the national Forest Survey. The new Forest Research organization would use much of the earlier work on sampling as a foundation for more rigorous approaches.

The U.S. Forest Service, under the authority of the McSweeny-McNary Act, initiated FIA (then called Forest Survey) in Oregon, in 1930. Shortly thereafter, in 1931 and 1934, the Southern Forest Experiment Station and Lakes States Forest Experiment Station, respectively, launched forest surveys. In the Northwest the survey statistics were gathered by compilation of existing data with new data collected for areas where information was lacking. In the South (Lentz 1931). and Lake States (Gafvert 1938), a systematic lineplot survey was established. While the Compilation Method and Lineplot method (Lentz 1931) were most common, these early implementations still lacked the desired statistical rigor for the task at hand. And, sampling methods but were generally constrained by terrain and the availability of adequate spatial information (maps or photography) relative to the forests to be measured.

By the late 1930's sampling theory for large-scale inventories had greatly progressed, and with the advent of more widely available aerial photography, the current method of double sampling for stratification began to take shape. This approach, described by Bickford (1952), used aerial photos to determine or stratify the location and extent of the forest and ground plot measurements to quantify and describe strata attributes. The formal theory for this approach, presented by Schumacher and Chapman (1942) and Yates (1949), has survived the rigors of statistical and scientific scrutiny for nearly five decades and continues to form the basis of Forest Service descriptive or landscape-scale vegetative sampling for providing consistent, reliable State, regional, and national assessment information.

By the end of the 1960's, an inventory had been completed in every State except Alaska using this approach. And, while the field plot design and its attendant data measurements have been modified over the years in response to changing information needs and the need to link to new technologies such as satellite and aerial remote sensors, this basic sampling approach continues to demonstrate incredible adaptability and reliability. This relentless pursuit of scientific excellence would position the Forest Service to provide the first reliable national inventory report in the early 1950's (USDA Forest Service 1958), and provide a sound basis for supplying new types of resource information a rapidly changing clientele demanded. In 1967, FIA would codify a standard for consistent monitoring in the Forest Survey Handbook FSH4809.11, which contained core definitions, variables, and tables for reporting timber inventories.

Changing Mandates

During initial Forest Service state-wide inventories and several repeat inventories, under the auspices of the McSweeney-McNary Act, forest conditions deemed less valuable from a timber perspective were often overlooked (Van Hooser 1992). By the 1970's, a growing awareness of the complex interactions among the many forest uses led to the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, The National Forest Management Act (NFMA) of 1976, and the Forest and Rangeland Renewable Resources Research Act of 1978. The RPA required an Assessment of the nation's forest and rangeland resources every decade and development of a long-range program to guide natural resources policy. All three laws expanded the inventory mandate to cover all renewable resources on the nation's forest and rangelands.

FIA responded in the late 1970's by expanding predominantly timber-oriented inventories into broader, multi-resource activities. All forest inventory field units began to gather data on wildlife habitat, recreation, soil, and water resources. An example of the magnitude of the change is reflected in the number of variables now being measured by FIA. Before 1974, most FIA field units collected fewer than 60 timber variables on each plot. Today, more than 150 items may be recorded at each location (VanHooser 1992). More than half of these are related to land use, vegetation structure, and other site descriptors that may have no direct relationship to timber supply. And, since 1980, FIA researchers and cooperators have published hundreds of reports and articles on non-timber resources (Rudis and others 1991).

Environmental concerns about pollution effects on forest condition prompted passage of the Forest Ecosystem and Atmospheric Pollution Research Act of 1988. This Act directs the Forest Service to monitor long-term trends in the health and productivity of forest ecosystems. In response, the Forest Service began establishing a network of "sentinel plots" in cooperation with the Environmental Protection Agency's Ecosystem Monitoring and Assessment Program (EMAP). Information collected at these locations annually is much more detailed than regular FIA forest surveys with collection of soil and foliage samples for detailed analysis as well as other sophisticated indicator measures requiring highly trained ecologists, botanists, entomologists, pathologists, and soil scientists. These sentinel plots, known as the Forest Health Monitoring (FHM) detection network, consists of a grid of plots installed at 1/16th the intensity of the national plot grid maintained by FIA. The FHM detection plot network was integrated into the national FIA grid in 1998.

As inventory focus moved from timberland to all forest land, forests that were reserved, marginally productive for timber, or in proximity to urban areas have been given more attention. In 1992, Forest Service leadership directed that the FIA inventory grid would be extended across all agency forest lands regardless of status or location (Leonard 1992, Reynolds 1996) in order to provide a more comprehensive vegetative inventory. Since this directive was issued, hundreds of plots have been established in Wilderness, National Parks, urban areas, and what were previously deemed marginally productive forest lands from a timber perspective. FIA had become a true 'forest' inventory.

Prior to passage of the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), timber was the main focus of most Forest Service inventories both descriptive and prescriptive. Post RPA, all Forest Service vegetative surveys have taken on a more multi-resource flavor. The primary focus of ecosystem-based inventories is repeatable, objective observations that strive to enumerate and measure basic forest attributes that define ecosystem composition, structure and function. The advent of new technologies in geo-positioning, remote sensing, and geographic information systems (GIS) offers tremendous potential for linking field sample data in a spatially explicit (mapped) way to analyze large landscapes (Powell 1994).

In 1995, an initiative from the White House Office of Science and Technology Policy (OSTP) Committee on Environment and Natural Resources CENR began to take shape that would realize the importance of a network approach to integrated inventory and monitoring of the nation's resources. This effort proposes a framework that builds on existing systematic observations and monitoring of ecological systems; promotes compatible standards, methods and protocols; and provides a strategy developing information for resource assessments at various temporal and spatial scales (OSTP 1996).

The conceptual framework is shown in figure 1. Monitoring is divided into three general classes (starting at the base of the triangle): 1) those that characterize specific properties of large regions by continuous measurement (remote sensing based inventories); 2) those that characterize specific properties of large regions by sampling (for example, FIA); and (3) those that can census properties and processes of specific locations (LTERs, Intensive Ecosystem Monitoring Sites such as Hubbard Brook, etc).

The texture and dynamics of complex forest ecosystems requires information from all three of these levels to efficiently and effectively address the difficult management issues we face today with limited financial and physical resources. At the top of the hierarchy is a

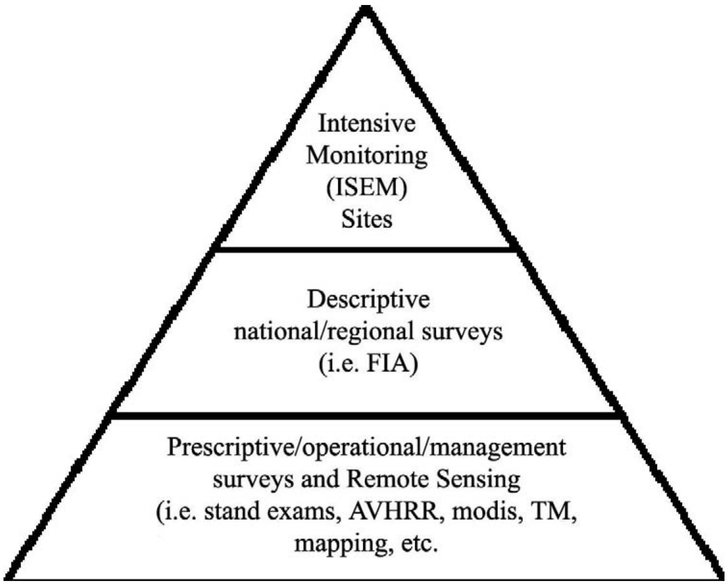

Figure 1. Conceptual framework for achieving the multiple goals of environmental monitoring and research.

small number of intensively monitored sites (index sites) where physical, chemical, and biological measurements of different ecosystem components are measured simultaneously at the same location on a long-term basis. The middle level, ground based regional and national surveys, provide common core data on a large number of locations. This level also provides data to place index site data into a broader context and is useful in calibration and validation of regional/national ecosystem models. At the lower level, inventories utilize linkage variables that allow incorporation of progressively more remote sensing data to develop site specific plans and applications. Information from this tier also provides additional validation information for models developed at the top and middle levels. The primary benefit of such a framework is access to appropriate information that can be utilized across many programs, both public and private, and applied to specific issues and questions at varying scales.

FIA's descriptive inventories provide a basic suite of vegetative data across all landscapes measured in a consistent and compatible manner on the national grid. Simple examination of these data may suggest hypotheses for the geographic distribution of forested ecosystems, associated characteristics and habitats for forest-dwelling species, or trends in regional ecological landscape dynamics and land-use practices (Rudis 1991). In the process of establishing an inventory implementation plan for a given resource area, whether it is wilderness or not, Forest Service researchers work with the principal managers, scientists and publics that are interested in monitoring information from that area to determine if additional data could provide useful indicators of resource condition, health, or change.

A key feature of FIA's national grid inventory is its systematic design which does not predicate sample location on a pre-stratified boundary system (for example, stands, watersheds, ecoregions, etc). The systematic grid allows the user to draw boundaries of interest knowing that a systematic, representative group of plots will be available for analysis. This establishes national grid data as a useful tool to compare or validate other sampling techniques by providing an independent estimate of variables of interest, e.g. using national grid data in global monitoring models (Iverson and others 1990, Lund 1990, Tueber 1990, VanHooser and others 1990).

FIA and National Assessments

Since its inception under the McSweeney/McNary Act of 1928, FIA has been envisioned as the source of consistent, scientifically sound information to guide assessment and management of the Nation's forest resources. The first National Assessment of the Nation's timber resource, based on predominantly amounts of FIA field verified information, was the 1952 Timber Resources for America's Future (USDA Forest Service, 1958) and would set the tone for future efforts. There were earlier reports in 1920, 1932, 1938, and 1945. However, these were based significantly on expert opinion and sparse field data. By 1950, FIA inventories had been completed in 29 States containing 72 percent of the forest land in the 48 States. Since the initial focus of the inventory was on timber, not surprisingly, the 19 missing States were primarily in the Great Plains, interior West, and Northeast.

The success of the 1952 Assessment would spark and all out effort by the Forest Service to complete an inventory the entire U.S. before a second assessment in 1963. The period between 1950 and 1962 would be a golden era for forest inventory in the U.S. with FIA completing inventories in 45 States containing 97 percent of all forest land outside of Alaska and Hawaii. This would include a re-inventory of 20 States. Only Nevada and Alaska would remain with virtually no FIA data in 1963.

A third national assessment would occur in 1970 before the passage of the Forest and Rangeland Renewable Resources Planning Act (RPA) in 1974 which would mandate such assessments with reports to Congress every 10 years.

The RPA legislation requires the Secretary of Agriculture to conduct an assessment of the Nation's renewable resources every 10 years. The original Act had four requirements for the Assessment:

1. an analysis of present and anticipated uses, demand for, and supply of the renewable resources,
2. an inventory,...of present and potential renewable resources…

3. a description of Forest Service programs and responsibilities...; and
4. a discussion of important policy considerations, laws, regulations, and other factors expected to influence… forest, range, and other associated lands.

Subsequent amendments to the RPA added two requirements:

5. an analysis of the potential effects of global climate change on the condition of renewable resources…; and
6. an analysis of the rural and urban forestry opportunities to mitigate the buildup of atmospheric carbon dioxide and reduce the risk of global climate change.

Since the 1930's FIA has supported many of these requirements by providing over 250 Statewide forest inventories; eight national assessments (USDA 1958, 1965, 1973, 1982, Waddell et al. 1989, Faulkner et al. 1993, Smith et al 2001, Smith et al 2004); two national biomass studies (USDA 1981, Cost et al. 1990); three national private forest land ownership studies (Birch 1982, 1996, Butler 2004 in process); a national satellite forest cover map of the U.S. (Zhu and Evans 1994); hundreds of primary mill, utilization, and residential fuelwood studies (May 1998, Smith 1991); hundreds of reports on nontimber issues (Rudis 1991); and online access to FIA data at http://fia.fs.fed.us. And, FHM detection monitoring plots established in the late 1980's are now fully integrated into the FIA grid in 42 States covering 83 percent of the Nation's forests reporting on the health of our forests

Other National Reporting Activities

FIA is responsible for many periodic reporting products associated with status and trends in forested ecosystems. The following needs are presently important. It is expected that other reporting needs will arise in the future. A key attribute of the FIA inventory program is that it contains sufficient scope of data to enable response to new clients and needs as they arise.

State of the Nation's Ecosystems Report

This report, developed for the White House Office of Science and Technology Policy (OSTP) by the John Heinz III Center for Science, Economics, and the Environment to provide indicators of sustainable forestry. Nearly two-thirds of the data for the forestry section of the report comes from FIA.

The National Report on Sustainable Forests

After the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests ("Montreal Process") was formed in Geneva in June 1994 to advance the development of internationally agreed upon criteria and indicators to monitor sustainable forests. A set of indicators of sustainable forests were then set forth in Santiago, Chile in February 1995. This set of seven Criteria and 67 Indicators are known as the "Santiago Declaration" (Canadian Forest Service 1995). The first five Criteria contain 28 biological indicators. FIA provided critical support for 18 of 28 biological indicators to monitor and report on U.S. forest sustainability. The U.S. used these criteria and indicators to develop a national report on sustainable forests (http://www.fs.fed.us/research/sustain).

International Reporting

The FIA responds to many international requests for national estimates of status, condition, and trends, in America's forests. Within the last two decades there has been an increasing awareness of global forestry issues. The Committee on Forestry, FAO has formulated a comprehensive global Forest Resources Assessment (FRA) program consisting of four components: 1) country capacity building, 2) assessments of the multiple benefits of forests, 3) assessment based on existing reliable information, and 4) remote sensing survey. The U.S. participated along with 54 other countries in the Temperate and Boreal Forest Resource Assessment (United Nations, 2000) and the Global Forest Resource Assessment 2000 (http://www.fao.or/forestry).

Conclusion

FIA has evolved over the last 75 years into a premier forest monitoring program working with partners and clients to continuously improve our product. And, while FIA focuses considerable attention on making sure our data are compatible across scales and ownerships within the U.S., we have not ignore the need to pursue similar goals at the international level. Visit FIA's web site at http://www.fia.fs.fed.us for more information or read papers by VanHooser and others (1992) or Gregoire (1992) for more on inventory and FIA history in the U.S.

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Wildfire, Exotic Vegetation, and Breeding Bird Habitat in the Rio Grande Bosque

D. Max Smith, Graduate Student, Department of Zoology, University of Oklahoma and Oklahoma Biological Survey, Norman, OK
Jeff F. Kelly, Assistant Professor of Zoology, University of Oklahoma and Heritage Zoologist, Oklahoma Biological Survey
Deborah M. Finch, Project Leader, USDA Forest Service Rocky Mountain Research Station, Albuquerque, NM

Abstract—*Wildfires in the Middle Rio Grande bosque have likely increased in frequency due to absence of the natural flood regime and current drought conditions. Native cottonwoods (*Populus *spp.) do not tolerate or recover from wildfire as well as exotic vegetation, particularly salt cedar, also known as tamarisk (*Tamarix *spp.). There is concern that this change in the primary disturbance process from flood to fire will shift vegetative succession away from structurally diverse mesic native communities to structurally simple xeric exotic shrub-lands, which provide inferior habitat for riparian-dependent animals. In 2003, we initiated a study to evaluate effects of wildfire on quality of riparian habitat for birds breeding in the Middle Rio Grande bosque. Our research focusing on the effects of wildfire on exotic and native woody plants, arthropods and breeding birds will provide managers with information about post-wildfire dynamics of riparian vegetation and breeding bird use.*

Introduction

For several decades, conservationists have given considerable attention to riparian ecosystems in the southwestern U.S. (Knopf 1988). Riparian corridors may be the most biologically diverse habitats on earth (Naiman 1993), contributing greatly to the biodiversity of the southwestern U.S. deserts (Cartron and others 1999). Unfortunately, anthropogenic activities have largely reduced riparian forests from their former extent (Cartron and others 2000, Postel 2000) by replacing them with exotic vegetation (Lovich and De Gouvenain 1998, Knopf and Olson 1984), altering hydrological regimes (Shafroth 2002), and grazing (Krueper 1996). Southwestern riparian forests are also experiencing increasing frequency of wildfires, considered by many to be a novel and serious factor in riparian forest conservation (Bush 1995).

Cottonwood (*Populus deltoides*) -dominated forests ("bosque") along the Middle Rio Grande were historically shaped by regular flood events. Floods influenced river sinuosity, providing safe sites for native vegetation regeneration (Whitney 1996). Construction of dams, levees, and irrigation ditches in the early twentieth century inhibited regular flooding (Whitney 1996). As a result, cottonwood seedling establishment has nearly ceased within the bosque (Howe and Knopf 1991). Exotic, less flood-dependent vegetation, such as saltcedar or tamarisk (*Tamarix ramossisima*) has proliferated through the understory, out-competing native vegetation (Lovich and De Gouvenain 1998, Sher and others 2000).

Unlike flooding, wildfire was not a common disturbance in the Middle Rio Grande Bosque until modern times (Bush 1995, Stromberg and others 2002). During the last century, conditions within Rio Grande riparian forests have become more susceptible to wildfire due to increased production of salt cedar and other invasive plants (Racher 2003), accumulation of woody debris (Bush 1995), and long-term drought (New Mexico Drought Planning Team 2003). Riparian wildfires also gained public awareness and notoriety when four riparian wildfires burned within the city limits of Albuquerque, New Mexico during the summers of 2003 and 2004.

The inverse relationship between wildfire and frequency of flooding represents a shift in the disturbance regime of the Middle Rio Grande bosque and other riparian forests. It is critical that managers understand the effects of more fire and less flooding on the plant and animal communities inhabiting riparian forests in order to conserve southwestern biological diversity. In 2003, we initiated a study evaluating quality of breeding bird habitat resulting from wildfire along the Middle Rio Grande. The objectives of the study were to document the recovery of native and exotic vegetation following fire, identify changes in food resources for birds, and compare numbers and success of birds breeding in burned and unburned sites.

Methods

A full description of methods is described in our 2003 Annual Report (USDA Forest Service, Rocky Mountain Research Station, and Oklahoma Biological Inventory 2003). We selected four wildfire sites with nearby controls at Bernardo, Rio Grande Complex, Chavez, and San Pedro burns. Starting in 2001, bird point counts, nest searches and monitoring of nest contents were conducted at three of the burn sites during the bird breeding season. In March 2003, a total of 63 nest boxes were distributed among three wildfire sites and nearby unburned gallery forest. In August 2003, nest boxes were placed at the fourth wildfire site, Bernardo, which burned in April 2003; nest boxes were also placed in adjacent unburned forests at this site. Nest boxes were checked regularly to determine use. Four arthropod pitfall traps were installed around nest boxes in order to quantify availability of food resources. Pitfall traps were continuously operated from June to August 2003. In addition, 45 cicada (F. Cicadidae) traps were established in unburned forests and in wildfire areas. To better understand post-fire succession on burned plots, native and exotic re-sprouts were tagged in 2003 and monitored in 2004.

Results

Response of Riparian Vegetation to Wildfire

Native riparian vegetation is primarily adapted to flood disturbance and is not believed to respond well to wildfire. Stuever (1997) found that low intensity fires along the Middle Rio Grande killed 50 percent of cottonwood trees. Moderate intensity fires killed 75 percent of cottonwoods, and all burned cottonwoods died in high intensity fires. In the Middle Rio Grande bosque, we observed that native and exotic tree and shrub species can re-sprout from their roots after fires (table 1). However, many cottonwood root sprouts do not establish following emergence and in some areas, cottonwoods do not re-sprout at all (Stromberg and others 2002). At one of our study sites, we found 60 percent mortality in cottonwood re-sprouts during the first year following a wildfire in 2003 (table 2).

Table 1. Re-sprouting vegetation monitored in wildfire sites in the Middle Rio Grande Bosque (species are listed in order of relative abundance).

Native Plant Species
Rio Grande cottonwood (*Populus deltoides*)
Gooding's willow (*Salix goodingii*)
Seepwillow (*Baccharis glutinosa*)
Coyote willow (*Salix exigua*)
New Mexico olive (*Foresteria neomexicana*)
False indigo (*Lycium torreyi*)
Screwbean mesquite (*Prosopis pubescens*)
Exotic species
Saltcedar (*Tamarix ramosissima*)
Russian olive (*Eleganus angustifolia*)
White mulberry (*Morus alba*)
Siberian elm (*Ulmus pumila*)
Tree of Heaven (*Ailanthus altissima*)

Saltcedar and other exotic species may be more fire-adapted than native species. Following wildfire, saltcedar re-sprouts faster than cottonwood (Stromberg and others 2002), and these re-sprouts flower in as early as three months, while cottonwood re-sprouts take up to eight years to flower (Smith pers obs). One hundred percent of the saltcedar re-sprouts we marked in 2003 survived to 2004. The density of saltcedar foliage was higher at more burned sites (3 of 4) than unburned sites (fig. 1). These observations suggest that salt cedar may be more fire-adapted than cottonwood and can rapidly colonize recent burns.

Despite the effective response of saltcedar to wildfire, native vegetation persisted in our wildfire study sites. Mean height of re-sprouts was greater for cottonwood than for saltcedar at sites that burned at least three years prior (fig. 2 A-D). We also found evidence that survival

Table 2. Percentage of cottonwood and saltcedar stems that survived between 2003 and 2004 at four wildfire sites. Stems were randomly located and marked during the summer of 2003 and re-located during the summer of 2004.

Site	Year of wildfire	2003-2004 % cottonwood survival	2003-2004 % saltcedar survival
Bernardo	2003	40%	100%
Chavez	2002	79%	100%
Rio Grande Complex	2000	100%	100%
San Pedro	1996	83%	100%

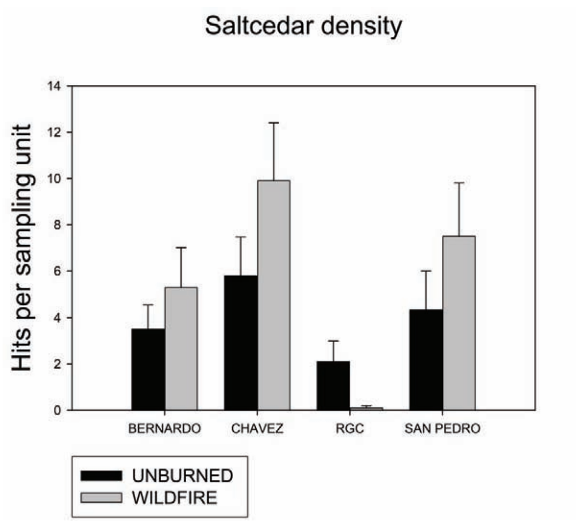

Figure 1. Saltcedar density at unburned and wildfire sites. We counted saltcedar hits against a one inch diameter pole at 4 locations within each vegetation sampling unit. Sampling units were systematically located within wildfire and unburned sites.

of cottonwood re-sprouts might increase in subsequent years following a fire (table 2). We suggest that, where some cottonwood trees persist after a wildfire, management to enhance initial cottonwood re-sprouts might be effective in inhibiting the spread of monotypic salt cedar.

Wildfire, Riparian Areas, and Birds

Riparian forests provide breeding habitat for nearly half of the bird species found in the Southwest (Cartron and others 1999). Bird diversity has been correlated with structural diversity of riparian vegetation and the presence of cottonwoods (Carothers 1974). Vegetation structure has also been shown to influence nesting success in southwestern riparian forests (Powell and Steidl 2000). Scott (2003) showed that structural vegetation diversity and avian diversity are highest when riparian areas experience geomorphic change associated with flooding. Little is known about how riparian breeding birds respond to replacement of flooding disturbance by wildfire because such studies are in their infancy.

The Middle Rio Grande bosque provides habitat for birds in a variety of nesting guilds. Higher numbers of shrub-associated species and lower numbers of cottonwood-canopy species were detected at point-count locations in wildfire sites than in unburned sites (table 3; for scientific bird names, see Finch and others 2003). If post-fire succession results in exotic-dominated shrublands, we hypothesize that populations of widespread, shrub-associated species such as mourning doves (*Zenaida macroura*), yellow breasted chats (*Icteria virens*), and spotted towhees (*Pipilo maculatus*) will

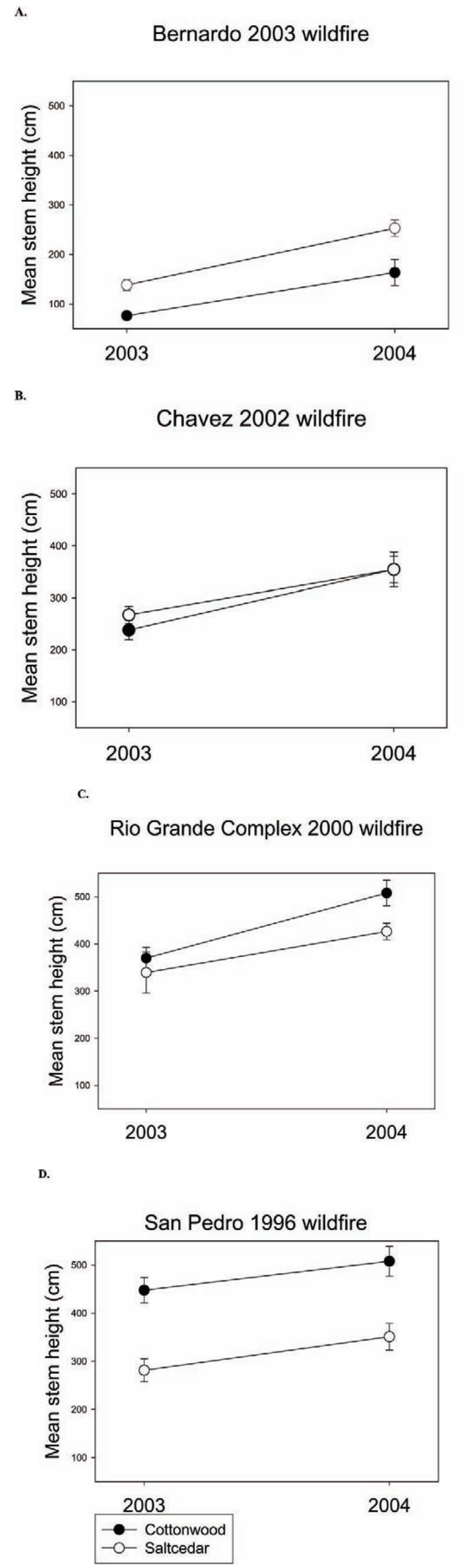

Figure 2 (A-D). Growth of cottonwood and saltcedar re-sprout stems at three wildfire sites. We randomly located and measured the heights of re-sprouted stems in 2003 and re-measured them in 2004.

Table 3. Total and average number (pt. ct. station/5 surveys) of avian species detected at Middle Rio Grande fire effects and control sites.*

Species	# of Individuals Burned	Control	Total	Avg./pt - Burned	Avg./pt - Control
Canada Goose	3	4	7	0.11	0.25
Wood Duck	1	0	1	0.04	0.00
Gadwall	2	0	2	0.07	0.00
Mallard	46	20	66	1.64	1.25
Northern Pintail	3	2	5	0.11	0.13
Ring-necked Pheasant	43	23	66	1.54	1.44
Gambel's Quail	7	1	8	0.25	0.06
American White Pelican	3	0	3	0.11	0.00
Great Blue Heron	3	1	4	0.11	0.06
Snowy Egret	9	0	9	0.32	0.00
Black-crowned Night-Heron	4	0	4	0.14	0.00
Turkey Vulture	40	0	40	1.43	0.00
Cooper's Hawk	7	4	11	0.25	0.25
Swainson's Hawk	2	1	3	0.07	0.06
Red-tailed Hawk	1	0	1	0.04	0.00
American Kestrel	29	2	31	1.04	0.13
Killdeer	8	0	8	0.29	0.00
Spotted Sandpiper	1	0	1	0.04	0.00
White-winged Dove	1	0	1	0.04	0.00
Mourning Dove	242	79	321	8.64	4.94
Yellow-billed Cuckoo	6	1	7	0.21	0.06
Greater Roadrunner	26	1	27	0.93	0.06
Black-chinned Hummingbird	134	140	274	4.79	8.75
Broad-tailed Hummingbird	4	0	4	0.14	0.00
Rufous Hummingbird	1	0	1	0.04	0.00
Ladder-backed Woodpecker	4	4	8	0.14	0.25
Downy Woodpecker	9	6	15	0.32	0.38
Hairy Woodpecker	12	2	14	0.43	0.13
Northern "Red-shafted" Flicker	38	19	57	1.36	1.19
Western Wood-Pewee	32	25	57	1.14	1.56
Dusky Flycatcher	8	0	8	0.29	0.00
Black Phoebe	2	0	2	0.07	0.00
Ash-throated Flycatcher	88	99	187	3.14	6.19
Western Kingbird	43	2	45	1.54	0.13
"Solitary" Vireo	6	0	6	0.21	0.00
Warbling Vireo	1	0	1	0.04	0.00
American Crow	20	20	40	0.71	1.25
Chihuahuan Raven	1	0	1	0.04	0.00
Common Raven	18	17	35	0.64	1.06
Tree Swallow	8	0	8	0.29	0.00
Violet-green Swallow	1	6	7	0.04	0.38
Northern Rough-winged Swallow	2	1	3	0.07	0.06
Bank Swallow	7	0	7	0.25	0.00
Cliff Swallow	17	3	20	0.61	0.19
Barn Swallow	24	6	30	0.86	0.38
Black-capped Chickadee	12	38	50	0.43	2.38
Bushtit	12	9	21	0.43	0.56
White-breasted Nuthatch	25	38	63	0.89	2.38
Bewick's Wren	105	85	190	3.75	5.31
House Wren	1	0	1	0.04	0.00
Ruby-crowned Kinglet	5	0	5	0.18	0.00
American Robin	38	2	40	1.36	0.13
Gray Catbird	20	1	21	0.71	0.06
Northern Mockingbird	2	0	2	0.07	0.00
European Starling	16	1	17	0.57	0.06
Phainopepla	2	0	2	0.07	0.00
Orange-crowned Warbler	1	0	1	0.04	0.00
Virginia's Warbler	2	0	2	0.07	0.00
Lucy's Warbler	11	12	23	0.39	0.75
Yellow-rumped "Audubon's" Warbler	8	1	9	0.29	0.06
MacGillivray's Warbler	1	0	1	0.04	0.00
Common Yellowthroat	43	2	45	1.54	0.13
Wilson's Warbler	6	0	6	0.21	0.00
Yellow-breasted Chat	220	38	258	7.86	2.38
Summer Tanager	35	46	81	1.25	2.88

Table 3. *Continued.*

Species	# of Individuals Burned	Control	Total	Avg./pt - Burned	Avg./pt - Control
Western Tanager	3	0	3	0.11	0.00
Spotted Towhee	195	88	283	6.96	5.50
Chipping Sparrow	10	0	10	0.36	0.00
Lark Sparrow	7	0	7	0.25	0.00
White-crowned Sparrow	4	0	4	0.14	0.00
Black-headed Grosbeak	115	117	232	4.11	7.31
Blue Grosbeak	133	47	180	4.75	2.94
Lazuli Bunting	6	0	6	0.21	0.00
Indigo Bunting	19	0	19	0.68	0.00
Red-winged Blackbird	117	11	128	4.18	0.69
Western Meadowlark	8	23	31	0.29	1.44
Yellow-headed Blackbird	2	0	2	0.07	0.00
Common Grackle	10	1	11	0.36	0.06
Great-tailed Grackle	20	2	22	0.71	0.13
Brown-headed Cowbird	223	46	269	7.96	2.88
Bullock's Oriole	12	5	17	0.43	0.31
House Finch	23	3	26	0.82	0.19
American Goldfinch	1	4	5	0.04	0.25
Lesser Goldfinch	28	22	50	1.00	1.38
Guinea Fowl (exotic)	5	11	16	0.18	0.69
Peacock (exotic)	2	2	4	0.07	0.13
Total Individuals	2475	1144	3619	88.39	71.50
Total Species	86	52	86		

* For bird scientific names, see Finch and others, 2003.

persist. Low detection rates of cottonwood-associated species such as summer tanagers (*Piranga rubra*) in wildfire sites suggest that riparian specialist species may decline following fire. Current research on the success of individual species nesting in burned and unburned sites should provide insight into the suitability of burned riparian forests for all breeding birds.

Along with vegetation, arthropod prey is a critical component of breeding bird habitat (Sherry and Holmes 1995). Insectivorous birds depend on riparian habitat more than those of other guilds (Knopf and others 1988) possibly because of the presence of arthropods (Delay and others 1999). Due to differences in structure and plant-arthropod interactions, exotic and native riparian vegetation support different arthropod densities and communities (Delay and others 1999, Mund-Meyerson 1991). If wildfire alters native and exotic plant densities, it is likely that arthropod communities will be altered as well. To determine if wildfire affects breeding bird habitat by altering arthropod abundance, arthropods important to breeding birds must be identified and sampled in wildfire sites.

Annual cicadas have been identified as an important resource for breeding birds (Rosenberg and others 1982). Like its cottonwood hosts, the cicada (*Tibicen dealbata*), is likely adapted to regular flood disturbance and not wildfire. This cicada emerges in high densities each summer and provides timely food for a variety of birds, including the yellow-billed cuckoo (*Coccyzus americanus*), a species whose breeding may be timed to take advantage of this resource (Rosenberg and others 1982). Our research on the effects of wildfire and exotic vegetation on the density and phenology of annual cicadas will provide insight into the dependability of this resource after wildfire.

Other arthropod groups that warrant research include foliage arthropods and litter arthropods. Wildfires often result in increased abundance of understory vegetation (Stromberg and others 2002). Saltcedar foliage, in particular, increases in density following wildfire (fig. 1). New growth after fire may provide additional resources for foliage-gleaning birds, depending on the abundance and type of arthropods found on re-sprouted stems. In 2003, we observed more foliage-gleaning bird species (6 of 20 observed species) than species of other guilds at wildfire sites. Fewer foliage-gleaning species were observed at unburned sites than burned sites (fig. 3). We found more nests of ground-gleaners (38 of 83 nests) than other guilds at wildfire sites. Fewer nests of ground-gleaners were found at unburned sites than burned sites (fig. 3). Much of the arthropod biomass in riparian forests is found in ground litter (Cartron and others 2003), a foraging substrate that is drastically reduced following wildfires. The cricket, *Gryllus alogus*, is a detritivore that prefers moist leaf litter (Cartron and others 2003) and is frequently fed upon by birds during the breeding season (Smith pers obs). *Gryllus alogus* represents a suite of

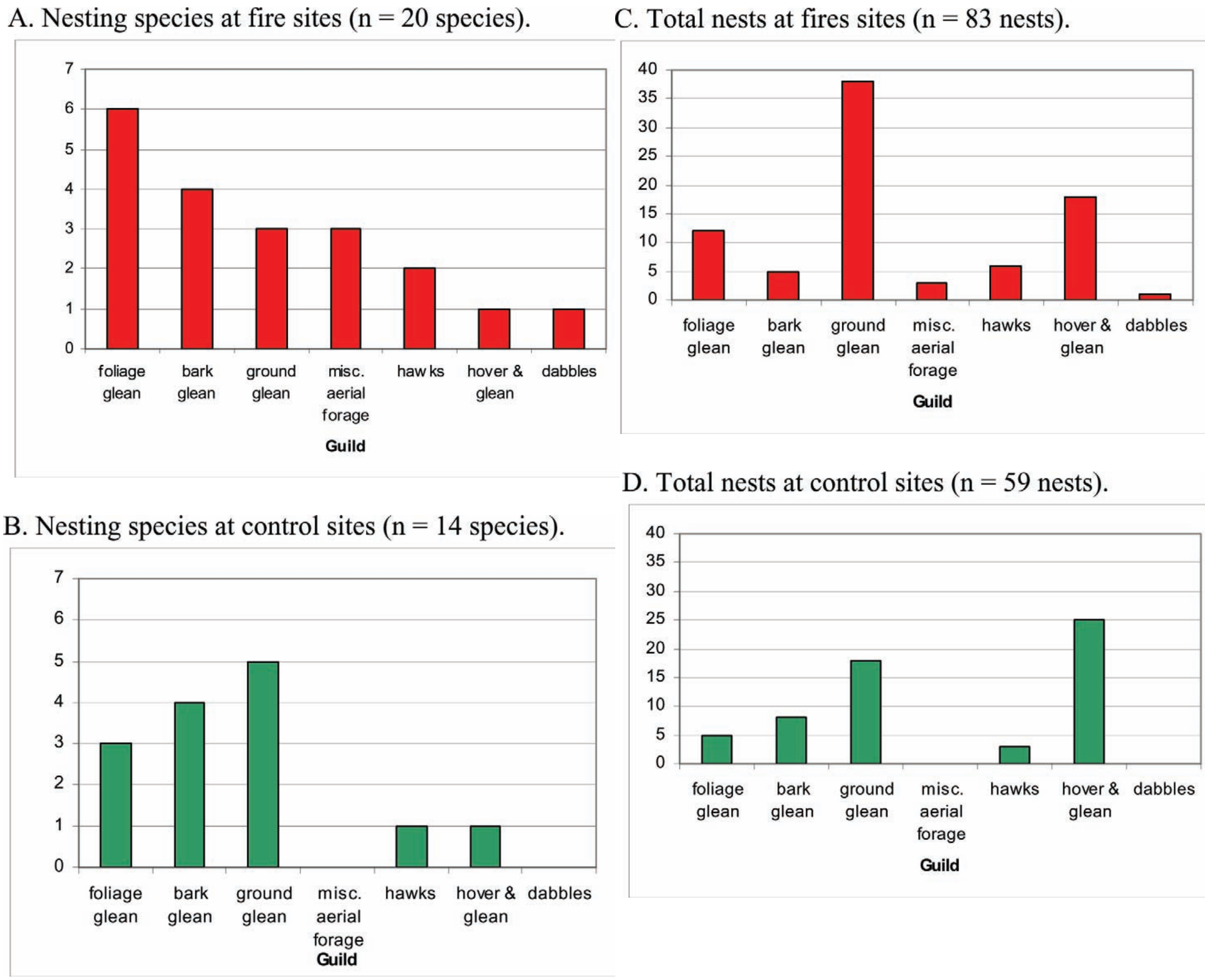

Figure 3 (A-D). Comparison of nesting species at fire and control research sites by Foraging Guild.

arthropods whose reduction following wildfires could have serious consequences for obligate ground-foragers such as spotted towhees and for generalists such as Bewick's wrens (*Thryomanes bewickii*), which forage frequently on the ground.

Conclusions

Wildfire is becoming a frequent disturbance in the Middle Rio Grande Bosque. Riparian trees and shrubs are top-killed during fires and forests typically recover by re-sprouting rather than by seedling establishment. Our data suggest that native vegetation recovers from wildfire with varying success between sites. Native re-sprouts grew from 2003 to 2004 at burned sites, suggesting that native vegetation can survive, at least over the short term. Continued monitoring is necessary to determine the long-term effects of wildfire on the structure of riparian vegetation. The factors that aid the post-fire survival of native trees, such as cottonwoods, must be understood for managers to ensure the persistence of communities tied to this vegetation type. Exotic species, especially saltcedar, appear to be fire-adapted; therefore, exotic vegetation control, controlled flooding, and pole-plantings may be required to maintain native vegetation at sites with low plant survival.

Native vegetation and arthropods are essential habitat requirements for the diverse array of birds found in riparian forests. Low post-fire survival of native vegetation could result in declines of species such as yellow-billed cuckoos and willow flycatchers (*Empidonax traillii*) (Stromberg and other 2002). In this situation, many cosmopolitan species that currently breed in southwestern riparian forests will continue to utilize burned habitat. However, the well-known bird diversity of these forests is likely to decline with the loss of native trees used by canopy-nesting and cavity-nesting species. Further research on the relationships between arthropods, exotic vegetation, and wildfire is needed to evaluate the quality of post-wildfire habitat for riparian birds. In addition, the use of different vegetation types and arthropods by various foraging guilds must be monitored to predict long-term consequences of wildfire for insectivorous birds.

Figure 4. Section of Middle Rio Grande Bosque near Abeytas, NM. This photo was taken four weeks after the fire. Note the saltcedar re-sprouts in the foreground. Native vegetation has not yet re-sprouted. Photo by Max Smith.

Figure 5. Section of Middle Rio Grande Bosque near Abeytas, NM. This photo was taken two years after the fire. The understory is dominated by saltcedar re-sprouts while a few cottonwoods re-sprouts are present. Photo by Max Smith.

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Figure 6. Section of Middle Rio Grande Bosque near Los Lunas, NM. This Photo was taken three years after the fire. Unlike other wildfire sites, this area is dominated by native cottonwood and coyote willow re-sprouts. Photo by Max Smith.

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Saltcedar and Southwestern Willow Flycatchers: Lessons From Long-term Studies in Central Arizona

M. K. Sogge and E. H. Paxton, Researchers, U.S. Geological Survey Southwest Biological Science Center, Flagstaff, AZ
April A. Tudor, Biologist, Arizona Game and Fish Department, Nongame and Endangered Wildlife Program, Phoenix, AZ

Abstract—*The endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*: SWWF) is a riparian-obligate bird that breeds only in dense, typically wet riparian vegetation. Since the mid-1990s, biologists have discovered a substantial number of flycatchers breeding in habitat dominated by exotic saltcedar (*Tamarix ramossisima*) in sites across Arizona, New Mexico, Nevada, and Utah. Today, approximately 25 percent of SWWF breeding sites, supporting one-third of the roughly 1,300 known flycatcher territories, are in saltcedar-dominated sites. A widely held belief is that this saltcedar habitat must be sub-optimal for the SWWF. Therefore, studies were conducted to determine if there are negative effects to SWWFs breeding in saltcedar. Although diet of flycatchers in native and saltcedar habitats differs, dietary differences are not proof that food resources are limiting or insufficient in one habitat compared to the other. Long-term studies of flycatcher physiology, immunology, site fidelity, productivity, and survivorship found no evidence that nesting in saltcedar-dominated habitat is detrimental to Southwestern Willow Flycatchers at breeding sites in central Arizona. It is likely that saltcedar habitats vary with respect to suitability for breeding flycatchers across their range, just as do native habitats; therefore, results from a single study or site may not be applicable across the ranges of the SWWF or saltcedar. Ultimately, multiple long-term studies over a large geographic area must be compared to determine the relative suitability of native and saltcedar habitats at the landscape scale.*

Introduction

The Southwestern Willow Flycatcher (*Empidonax traillii extimus*: SWWF) is a federally-listed endangered species that breeds in dense, typically wet riparian vegetation in parts of the southwestern United States (Sogge and Marshall 2000, USFWS 2002). The fact that SWWFs breed in both native and saltcedar (*Tamarix ramosissima*) dominated habitats has generated much interest, primarily due to perceived conflicts between the control/eradication of saltcedar and the goal of SWWF conservation (DeLoach and others 2000). Some (Hunter and others 1988) have reported that the value of saltcedar as bird habitat varies among bird species and geographic regions. Others (DeLoach and others 2000) hypothesized that SWWF use of saltcedar is limited, and that flycatchers breeding in saltcedar experience inadequate food resources and lowered productivity compared to those in native habitats. Therefore, we examined data from several large-scale and long-term studies being conducted by the U.S. Geological Survey and the Arizona Game and Fish Department, in order to better understand the extent to which flycatchers breed in saltcedar, and the ecological ramifications of their doing so.

Flycatcher Use of Saltcedar: Nature, Geography, and Extent

Within it range, the SWWF is distributed among roughly 150 riparian breeding sites along rivers, streams, lakes, and marshes; currently, the known population is estimated at just over 1,300 pairs (Sogge and others 2003, USGS unpublished data). Based on recent distribution data, the breeding range of the SWWF overlaps greatly with the core range of saltcedar (fig. 1). Given this spatial overlap, the potential for SWWFs to use saltcedar habitats is high.

Some of the first reports of SWWF nesting in saltcedar were from New Mexico in the 1970s (Hubbard 1987, S. Williams pers. comm.), with a few additional records by the late 1980s and early 1990s (for example, Brown

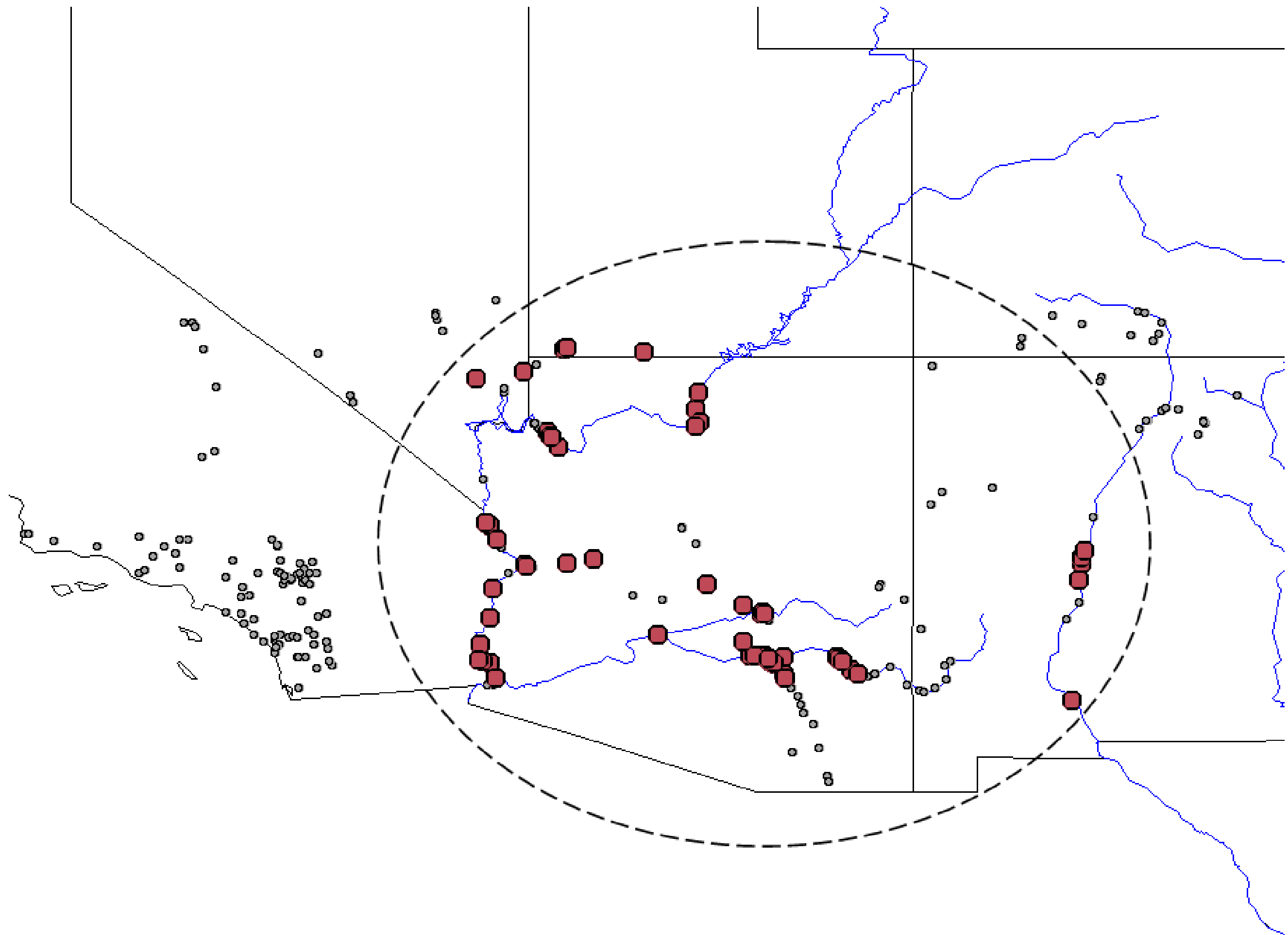

Figure 1. Distribution of known Southwestern Willow Flycatcher breeding sites (circles), and the core geographic distribution of saltcedar (*Tamarisk ramossisima*) in the Southwest (dashed ellipse). The larger circles are flycatcher breeding sites that are dominated by saltcedar vegetation.

1988, Maynard 1994). Today, SWWFs are known to breed in saltcedar-dominated habitats throughout much of the flycatcher's range (Sogge and others 2003, USGS unpublished data, fig. 1), and saltcedar habitats account for 25 percent of breeding sites and approximately 30 percent of known flycatcher territories. Clearly, SWWFs use saltcedar extensively.

SWWFs do not breed in all types of saltcedar habitats—a fact sometimes presented as evidence that saltcedar is "avoided", or is not as suitable as native habitats (DeLoach and others 2000). However, the same is true of native vegetation—not all native riparian habitats or patches are used by flycatchers. Flycatchers typically breed in only a subset of riparian habitats—whether native or saltcedar dominated (Sogge and Marshall 2000, USFWS 2002). In fact, saltcedar vegetation used by breeding SWWFs generally has similar structural characteristics to the native habitats in which they breed—dense structure, high canopy cover, tall stature, and mesic and/or near surface water.

Southwestern Willow Flycatcher Site Selection and Fidelity

Roosevelt Lake, in central Arizona, currently hosts the largest known population of breeding SWWF (USGS unpublished data). Here, flycatchers returning each year from their wintering grounds have an opportunity to choose from a mosaic of riparian habitat types, including native and saltcedar dominated. Over the course of our 1996 to 2004 joint Arizona Game and Fish Department/U.S. Geological Survey study (for example, Newell and others 2003, Smith and others 2004), flycatchers bred in native, saltcedar, and mixed habitats. Each year, some flycatchers settle into saltcedar patches even though potential territory locations are still available in nearby native patches (and are later occupied by other flycatchers). This argues against a hypothesis that saltcedar is only used when native vegetation is not available.

It is commonly assumed that a species can determine the suitability of different habitat types, and choose the "better" habitat (Wiens 1989). If SWWFs are making choices based on suitability of habitat, we would expect higher rates of settlement and site fidelity in the "best" habitat. Based on capture and re-sighting of banded flycatchers (Newell and others 2003), we examined the degree to which SWWFs at Roosevelt Lake returned each year to the type of habitat in which they bred the previous year. From 1996 through 2003, 65 percent of returning adults first encountered (and banded) in native patches (n = 66) moved in subsequent years to saltcedar or mixed patches. However, only 37 percent of returning flycatcher adults first banded in saltcedar habitats (n = 152) subsequently moved to other habitat types. This pattern does not support a hypothesis that flycatchers prefer native habitats (at a local scale), or that saltcedar habitat at Roosevelt Lake is of poorer quality than native habitat (assuming that flycatchers can accurately perceive quality differences).

Ramifications of Saltcedar Use by Flycatchers

Clearly, flycatchers often choose to breed in saltcedar habitat at Roosevelt Lake. DeLoach and others (2000) proposed that flycatchers might use saltcedar even though it is a lower quality habitat. Therefore, we examined several lines of evidence to determine if flycatchers choosing to breed in saltcedar are suffering negative physiological, survivorship, or reproductive consequences.

Flycatcher Diet and Physiology

Drost and others (2001) compared the food habits of SWWFs breeding in saltcedar and native (willow, *Salix* spp.) habitats, and reported a statistically significant difference in diet. This difference has been suggested as evidence that flycatcher diet in saltcedar habitat is of poorer quality than in native habitat (DeLoach and others 2000). However, the fact that there is a difference does not necessarily equate to "better" or "worse," in terms of diet quality. Indeed, flycatcher diet is highly variable overall, with statistically significant differences among years, month, sexes, and even ages (Drost and others 2003, USGS unpublished data).

Physiological studies of blood chemistry provides a way to evaluate whether these diet difference actually impact SWWFs. Fat storage, blood glucose level, hematocrit, and other measures reflect a bird's nutritional and energetic state, and poor nutritional state or high stress can be detected from their immunological condition. A recent study of 13 physiological and immunological parameters (Owen and Sogge 2002) found no evidence that flycatchers breeding in saltcedar are in poorer physiological condition than those in native habitats. This indicates that SWWFs are able to obtain sufficient food in the saltcedar habitats studied, and that dietary differences do not equate to habitat quality differences.

Flycatcher Productivity and Nest Success

DeLoach and others (2000) suggest that, based on their assumption that saltcedar habitats are low quality, flycatcher nest success and productivity will be lower in saltcedar than in native patches. To test this, we calculated female productivity (the total number of young fledged per female per year) for SWWFs breeding at Roosevelt Lake from 2001 to 2003, and found no significant difference in productivity between saltcedar and native habitats (T-test, p = 0.37; table 1).

Table 1. Reproductive success and annual survivorship estimates for Southwestern Willow Flycatchers breeding in native and saltcedar-dominated habitats at Roosevelt Lake, Arizona. Differences in productivity and survivorship are not significant based on T-test (p = 0.37) and confidences interval overlap, respectively.

Variable	Native Habitat	Saltcedar Habitat
Productivity per female per year (2001 – 2003)	Mean = 1.2 ± 0.4 (SE) n = 18 females	Mean = 1.3 ± 0.3 (SE) n = 23 females
Annual survivorship probability: adult (1996 – 2003)	Mean = 0.66 ± 0.05 (SE) 95% CI = 0.55 – 0.75 n = 66 adults	Mean = 0.60 ± 0.03 (SE) 95% CI = 0.54 – 0.67 n = 152 adults
Annual survivorship probability: nestling to adult (1996 – 2003)	Mean = 0.3 ± 0.15 SE 95% CI = 0.11 – 0.64 n = 25 adults	Mean = 0.28 ± 0.09 (SE) 95% CI = 0.14 – 0.48 n = 64 adults

Flycatcher Survivorship

Another way in which saltcedar could prove detrimental to flycatchers is if birds breeding in saltcedar suffer reduced survivorship compared to those in native habitats. Therefore, we estimated the maximum likelihood survivorship rate of adults and nestlings, using the program MARK (White and Burnham 1999), based on the return rates of 429 adults and 249 nestlings banded from 1996 to 2003 at Roosevelt Lake. Neither juvenile not adult survivorship differed significantly between native and saltcedar habitats, with both age groups having nearly identical survivorship in both habitats (table 1).

Conclusions

Our studies found no evidence for a negative effect of saltcedar on SWWFs breeding at Roosevelt Lake. However, saltcedar habitats vary with respect to suitability for breeding flycatchers, just as do native habitats (USFWS 2002). Therefore, saltcedar may prove to be suitable flycatcher habitat in some areas (such as Roosevelt Lake), yet less so or not at all in others - such as in portions of the lower Colorado River, where its structure and micro-climate conditions may preclude flycatcher nesting (DeLoach and others 2000). A similar difference in habitat suitability was reported by Hunter and others (1988), who found that saltcedar was a relatively unimportant habitat for birds on the lower Colorado River, yet consistently among the most important for riparian birds (including the Yellow-billed Cuckoo, Coccyzus americanus) along the Pecos River, NM.

Ultimately, multiple long-term studies over a large geographic area must be compared to determine the relative suitability of native and saltcedar habitats at the landscape scale. The difference in suitability of saltcedar habitats underscores the fact that site-specific details and context are important. Therefore, saltcedar control and/or riparian restoration efforts should be evaluated on a site-specific basis, and pre- and post-action monitoring conducted to determine if ecological goals are being met (USFWS 2002).

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Monitoring Late-Successional Forest Biodiversity in the Pacific Northwest, U.S.A.

Thomas A. Spies, Research Ecologist, USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR
Jon R. Martin, Monitoring Program Manager, USDA Forest Service, Portland, OR

Abstract—*The era of ecosystem management for federal forest lands in the Pacific Northwest began in 1994 with the adoption of the Northwest Forest Plan. This plan was designed to maintain and restore species and ecosystems associated with late successional and old-growth forests on over 10 million ha. of federal lands in Washington, Oregon and California. The plan called for implementation monitoring, effectiveness monitoring, and validation monitoring for a variety of ecological and socio-economic components. Monitoring has become a central part of management of the federal forests in the region and managers and scientists have gained considerable experience in implementing this large and complex program. The components of the monitoring plan include, late-successional/old growth vegetation, northern spotted owls, marbled murrelets, aquatic habitat and social conditions. The monitoring plan is strongly based on vegetation layer created with TM satellite imagery and on a regional grid of forest inventory plots. The lessons learned from the implementation of this monitoring plan include: 1) agencies need to devote considerable resources to insure that effective monitoring will occur at broad scales; 2) aggregation of local monitoring efforts is not a substitute for a designed regional monitoring plan; 3) vegetation structure and composition, measured with satellite imagery and inventory plots, is a cost effective, broad-scale indicator of biological diversity; 4) Some species, such as threatened and endangered species, are not necessarily covered with habitat approaches and may require population monitoring; 5) our scientific understanding of monitoring components will vary widely as will the approaches to data collection and analysis; 6) monitoring requires research support to develop and test metrics and biodiversity models; 7) Links of monitoring to decision making (adaptive management) are still being forged.*

Introduction

The era of ecosystem management on federal forest lands in the Pacific Northwest and northern California began in 1994 with the adoption of the Northwest Forest Plan (NWFP) (FEMAT 1993). This plan was the first comprehensive regional forest ecosystem plan in the world designed to maintain and restore species and ecosystems associated with late successional and old-growth forests and aquatic ecosystems. Covering over 10 million ha. of federal lands, the goal of the plan was set by then President Clinton who asked a team of scientists to develop alternatives that "would attain the greatest economic and social contributions from the forest and also meet the requirements of applicable [environmental] laws and regulations." The alternatives had to meet the following objectives: 1) maintenance and/or restoration of habitat conditions for the northern spotted owl and marbled murrelets that will provide for viability of each species; 2) maintenance and/or restoration of habitat conditions to support viable populations of species known to be associated with old-growth forest conditions; 3) maintenance and/or restoration of spawning and rearing habitat on federal lands to support recovery and maintenance of viable populations of anadromous fish species; 4) maintenance and/or creation of a connected or interactive old-growth forest ecosystem on federal lands.

The scientists developed nine alternatives and the President selected one, option nine, which was almost immediately challenged by lawsuits from both timber and environmental interests. The lawsuits were not successful and one year later, a federal judge found that the NWFP was in compliance with environmental laws but he also warned that "monitoring is central to the (NWFP) validity. If it is not funded, or done for any reason, the plan will have to be reconsidered." Thus began one of the largest regional forest monitoring programs ever attempted.

The plan has been in place for about 10 years now and federal managers and scientists have developed and implemented a comprehensive monitoring strategy that is one of the most comprehensive and largest for any region in the world (Mulder and others 1999). The total budget for the monitoring program in federal fiscal year 2003 was over 6 million dollars. We will review the main components of the plan and discuss some of the lessons learned from the effort to implement the monitoring component.

Components of the Plan

The plan contained three major types of monitoring: (1) implementation--were the standards and guidelines followed?; (2) effectiveness--did the management actions achieve the desired goals?; and (3) validation--are the underlying management and scientific assumptions correct? These three types of monitoring were applied to five components: (1) old-growth ecosystems; (2) the northern spotted owl (*Strix occidentalis caurina*); (3) marbled murrelet (*Brachyrampus marmoratus*); (4) aquatic ecosystems; (5) socio-economic benefits; and (6) tribal relations. Thus, the monitoring plan contained both focal species components and whole ecosystems components, as well as human dimensions. A critical step in the monitoring process was to clearly identify expectations under the original plan and use these to form questions that focus the collection and analysis of data. Coordinated programs were developed for both implementation monitoring and effectiveness monitoring. Validation monitoring, which was seen as largely a research effort by managers and policy makers, was not formally developed into a program. This paper will focus on the major components of the effectiveness monitoring program and identify some of the lessons learned from monitoring in the first decade.

Late-Successional and Old-Growth Monitoring

The central component of the monitoring plan is the measurement of status and trends in late successional (mature and old-growth) and old-growth forests in the region (Hemstrom and others 1998). These forests are defined ecologically based on a variety of structural and compositional elements. For Douglas-fir (*Pseudotsuga menziesii*) forests, mature forest conditions begin around 80 years of age, although there is considerable variation in structure among stands with similar ages. Old-growth forest structures can be found in Douglas-fir stands 150 to over 800 years in age (Franklin and others 2002).

These forests are monitored using two methods: (1) spatial models developed by the Interagency Vegetation Mapping Project (IVMP) using satellite imagery and GIS, and (2) a grid of inventory plots spaced every 5.4 km on public and private lands. These two different methods are complementary. The spatial vegetation models are used to estimate spatial distribution and pattern based on predictive models of canopy cover, composition (conifer vs. hardwood), quadratic mean diameter (QMD) of the upper canopy, and canopy heterogeneity (Cohen and others 2001). The inventory plots are used to provide an estimate of area of forest structure and composition with a known degree of statistical reliability. They are also used to estimate characteristics of forests that can't be measured with satellite imagery, such as dead wood and understory structure and composition. The spatial monitoring is intended to be repeated on a 5-10 year interval and the inventory grid re-measured on a 10 year cycle with a subset measured every year.

Both the spatial and plot-based measurements provide continuous estimate of old forest characteristics. Consequently, it is possible to use different definitions of older forest, a valuable feature since the definition of old growth varies by environment, forest type, and interest group. The flexible vegetation layers also make it possible to develop custom habitat models for other late successional species whose habitat is not well defined by a standard old-growth definition or vegetation classification.

Northern Spotted Owl

The northern spotted owl was listed as a threatened species in 1990 under the Endangered Species Act of 1973. The owl, which finds suitable habitat in mature and old-growth forests in the region, was listed because of extensive losses of its primary habitat throughout its range resulting from logging, development, and wildfire. The northern spotted owl was central to many of the early debates and controversies over logging of mature and old-growth Douglas-fir and the NWFP ecosystem approach evolved out of single species efforts that focused on the owl.

Effectiveness monitoring of the northern spotted owls consists of monitoring populations in eight demographic study areas within the NWFP area and monitoring spotted owl habitat and dispersal habitat using satellite imagery and inventory plots (Lint and others 1999). The long-range plan is to reduce the number of relatively expensive demographic monitoring areas and rely more on habitat monitoring to predict population dynamics. These predictive models are the subject of ongoing research. Early results indicate that reliability of these models may not be high enough to reduce or eliminate direct population monitoring.

The northern spotted owl provides a lesson on the value of monitoring some species populations directly, rather than relying only on habitat. Owl populations are declining in the northern part of the NWFP area (Joe Lint, personal communication) and the cause is hypothesized to be competition from the invading, and more aggressive, barred owl (*Strix varia*), which is spreading into the area from Canada. During this same period, very little cutting of owl habitat occurred on federal lands.

Marbled Murrelet

The marbled murrelet is a small seabird that forages in the near shore environment and nests up to 50 km inland, in the NWFP area, on large branches or branch fans, which typically occur in large diameter trees. The species was federally listed as Threatened in the NWFP area in 1992 due to population declines that were attributed to loss of mature and old-growth forests among other factors.

The effectiveness monitoring for the murrelet consists of at sea population surveys within 8 km of the shore, and monitoring of nesting habitat based on the vegetation modules described above. Predictive habitat models are under development and may be useful to predict murrelet use as a function of forest conditions. As in the case of the spotted owl, the models are in the research stage.

Aquatic and Riparian Resources

The aquatic conservation strategy was intended to conserve and restore processes and habitats that support anadromous fish and other aquatic and riparian dependent organisms (FEMAT 1993). The monitoring approach is based on assessing watershed conditions in 250 randomly selected sixth field watersheds (out of a total of 2,600 watersheds) across the NWFP area (Reeves and others 2004). Watersheds would be sampled on a 5 year interval with 50 watersheds sampled each year. Information collected would include in-channel conditions (for example, frequency of pools), vegetation conditions from the IVMP vegetation layer, and road densities and stream crossings from agency road data bases. The aquatic monitoring program intends to develop a series of models that predict in-channel conditions as a function of upslope and riparian attributes. If these models prove adequate they would allow for the expansion of the monitoring effort to wider landscape conditions using the IVMP layers and physical GIS layers. The watershed scale information is used to assess the condition of a watershed relative to desired conditions that are associated with high quality habitat for fish species. These desired conditions and watershed quality ratings are developed through an expert opinion process that is codified as a network of relationships in a computer model.

Social and Economic Benefits

The NWFP was intended to produce social and economic benefits in addition to the biodiversity goals. This module was developed relatively recently and has not been funded at the level of the other modules. It is intended to determine if predictable amounts of timber and non-timber resources are being produced and to determine if local communities and economies are experiencing positive or negative changes associated with the NWFP. The monitoring is done through collection of data from agency records, community case studies, and the literature.

Lessons Learned

Many lessons have been learned from implementing this monitoring program. These include:

1. Monitoring species and ecosystems requires real institutional commitments and defined programs with individuals and teams who are accountable for accomplishing monitoring objectives. Too often monitoring has not been supported with sufficient people and resources.
2. Regional scale questions require a regional-scale monitoring program. The federal agencies have completed many project and district monitoring efforts in the past but these cannot easily be scaled-up because they lack common questions and measures, randomly assigned samples, and a coordinated data management program.
3. Use vegetation structure and composition as a common denominator. Practicality and cost effectiveness are critical to the success of a monitoring program. It is not practical or scientifically feasible to use a species by species approach for hundreds or thousands of species. A coarse filter approach, using vegetation structure and composition as a surrogate for the bulk of species and ecosystem processes, is a good way for management agencies to deal efficiently with many biodiversity issues.
4. Monitor focal species. Some species, such as threatened and endangered species, and other species with special legal or social values are naturally of great interest and are not necessarily covered with

vegetative approaches. Such species may require population monitoring to deal with stressors that are not related to habitat characteristics.

5. The scientific understanding of monitoring components varies widely as will the approach to data collection and analysis. Some components such as the northern spotted owl have a much more developed scientific basis, more focused questions, and a longer history of ecological study than others. For example, the aquatic and socio-economic components focus on whole systems, which are more difficult to define, and have a much shorter history of scientific research at regional scales. Expert opinion and case studies play more of a role in answering monitoring questions for less-developed subject areas than in studies of the spotted owl and old-forest vegetation.
6. Research is essential to monitoring but research organizations do not have the mandate and resources to implement a large monitoring program. Monitoring typically requires research to help develop and test indicators, models, and protocols. Research and management should work together to prioritize research inputs into monitoring programs. In addition, monitoring really needs to be integrated into management and the best way for that to happen is for managers to do the monitoring.
7. Links of monitoring to decision-making (adaptive management) are still being forged. Monitoring is not just data collection for data collection sake—the questions "what information do you need?" and "what are you going to do with it?" are central. Monitoring needs to focus on a set of management-related questions and be linked to decision-making. The linkage of monitoring to decision-making has not happened yet. The NWFP, which was intended as a 100 year plan, is only 10 years old and we have not yet learned how information from monitoring will find its way into decision-making and plan revisions. Many factors influence a policy maker's decision. The true measure of success is that the decisions of policy makers will be informed by monitoring.

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Alberta Biodiversity Monitoring Program—Monitoring Effectiveness of Sustainable Forest Management Planning

J. John Stadt, Forest Ecologist, Forest Management Branch, Alberta Sustainable Resource Development, Edmonton AB T5K 2M4 Canada
Jim Schieck, Research Ecologist, Integrated Resource Management, Alberta Research Council, Vegreville AB T9C 1T4 Canada
Harry Stelfox, Senior Manager Intergovernmental Relations and Resource Policy, Policy and Planning, Alberta Sustainable Resource Development, Edmonton AB T5K 2G8 Canada

Abstract—*The Alberta Biodiversity Monitoring Program is a rigorous science-based initiative that is being developed to monitor and report on biodiversity status and trends throughout the province of Alberta, Canada. Forest management plans in Alberta are required to monitor and report on the achievement of stated sustainable forest management objectives; however, the effectiveness of these objectives in maintaining biodiversity is not directly addressed in this operational monitoring. The Alberta Biodiversity Monitoring Program will provide this effectiveness function at provincial and regional scales, supporting the ongoing assessment and revision of resource management objectives in an adaptive management process.*

The basic survey design consists of 1650 sites, 20 km apart, evenly spaced on a grid pattern across Alberta. Sites will be sampled over a five-year period at a rate of 350 sites/year. Standardized sampling protocols will be used to cover a broad range of species and habitat elements within terrestrial and aquatic environments, as well as broader landscape-level features. The ABMP will have a 90 percent power to detect a 3-percent yearly change within a region after three visits to a site.

In addition to forest management, the petroleum and agriculture sectors also have significant influences on biodiversity in Alberta ecosystems. Planning regimes vary widely among these sectors creating a significant challenge in managing their cumulative effects on biodiversity. The ABMP is designed to provide a comprehensive monitoring system that will detect changes to biodiversity, act as an early warning system, and help Albertans and various resource sectors make improvements to their management practices.

Introduction

The conservation of biodiversity has become an important component of sustainable resource management. The Canadian Council of Forest Ministers (CCFM 2003) and various forest certification organizations such as the Canadian Standards Association (CSA 2002) have included the conservation of biodiversity in their definitions of sustainable forest management. The forest industry in many parts of Canada, including Alberta, are moving from sustained yield systems in which wood fibre volumes are maximized, to sustainable forest management systems in which a range of forest values, including biodiversity, are co-managed for sustainability.

Any management system, including forest management, requires monitoring to ensure that desired outcomes are achieved. In this paper, we discuss the linkage between sustainable forest management planning and monitoring using Alberta as a case study. This case study will highlight the system of operational forest planning in Alberta and its potential linkage with the Alberta Biodiversity Monitoring Program (ABMP). The challenges of integrating forest planning and biodiversity monitoring systems will then be discussed.

Context

Alberta is a diverse province ecologically and includes Canadian Shield, Boreal Forest, Parkland, Foothills, Rocky Mountain, and Grassland natural regions (fig. 1). This natural diversity supports a wide variety of life and provides internationally significant habitats for migratory birds and large mammals such as grizzly bear and

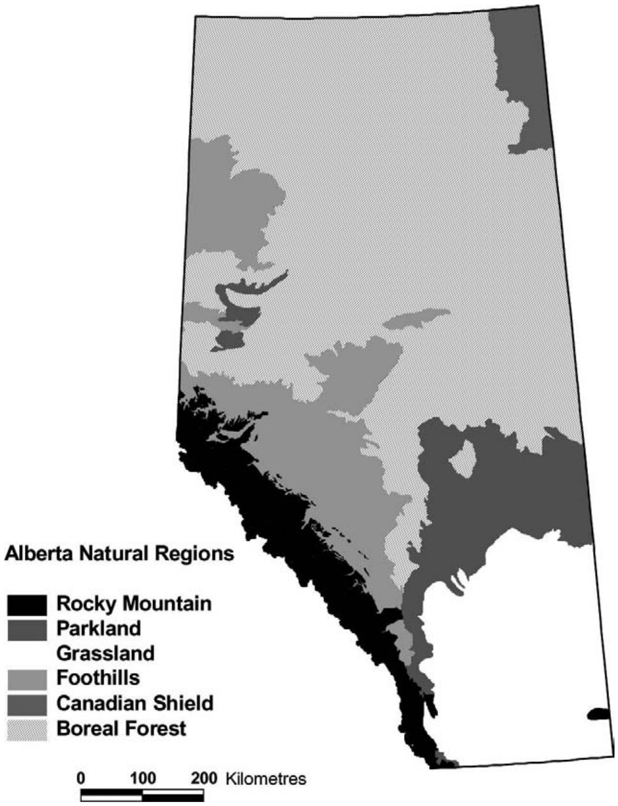

Figure 1. Natural regions of Alberta, Canada.

caribou. Species rare in Canada are seen in the northern reaches of the Missouri watershed. This diversity is part of the "natural capital" that has attracted many people to this part of the world. A growing human population has resulted in significant changes to these ecosystems over the last 100 years. The Grassland and Parkland natural regions have been heavily influenced by agriculture and settlement. The Boreal Forest, Parkland and Rocky Mountain natural regions are experiencing extensive development of their forestry resources. The oil and gas industry is the economic driver of Alberta and is a significant factor in all natural regions in the province. Impacts result from seismic exploration programs, the development of road, wellhead, and pipeline networks, and large oil-sand projects. The pace of oil and gas developments is expected to continue, if not increase, as these resources become more valuable on world markets and new extraction technologies are introduced to access previously inaccessible reserves such as coal bed methane and deep tar sand deposits.

This increasing human intervention in these natural regions has led to more scrutiny over how we manage our natural resources. As a society, we want to benefit economically from these natural resources but also realize that maintaining a healthy society requires maintaining healthy ecosystems. Biodiversity is one important measure and component of healthy ecosystems and therefore managing for biodiversity is crucial to meeting the wide range of human needs and aspirations.

The discussion of how biodiversity can be conserved begins with a look at forest management planning in Alberta. While forestry is only one human activity affecting biodiversity, operational forest planning provides an example of one of the required components of biodiversity conservation. The ABMP is then highlighted as the effectiveness-monitoring component of biodiversity conservation assessing forest management impacts in the larger context of the full suite of human and natural impacts on the landscape.

Forest Management Planning in Alberta

Before describing forest management in Alberta, it must be acknowledged that forest management does not equal landscape or ecosystem management. As noted above, forestry is only one player on the landscape and operates in a context that includes oil and gas, agriculture, and human settlement. True ecosystem management requires a strategic planning framework in which society sets landscape and even region-wide objectives so that tradeoffs can be made to balance environmental, social, and economic values. Strategic planning is a crucial part of management for the conservation of biodiversity (fig. 2); however, the focus in this paper will be on forest management planning and its linkage to biodiversity.

Most of the actively managed forests in Alberta are on crown land and the primary land manager is therefore the Government of Alberta. Through Forest Management Agreements (FMAs), the Government of Alberta has authorized forest companies to manage fibre production in these forests in a manner that maintains other values including biodiversity. The Government of Alberta, through newly proposed forest planning standards, will be providing FMA holders with its expectations for sustainable forest management. The standards place a strong emphasis on forest management by well-defined objectives and measurable results, with a reduced reliance on regulatory constraints. Forest management plans will include the statement of values, objectives, indicators, and targets (table 1). Standards for establishing biodiversity objectives are included in the proposed forest planning policy (table 2). In order to be able to set values, objectives, indicators and targets that will contribute meaningfully to the conservation of biodiversity, an understanding is needed of what we want forests of the future to look like. This requires an understanding of forest dynamics, such as the natural disturbance regime, as well as an understanding of what forest attributes are

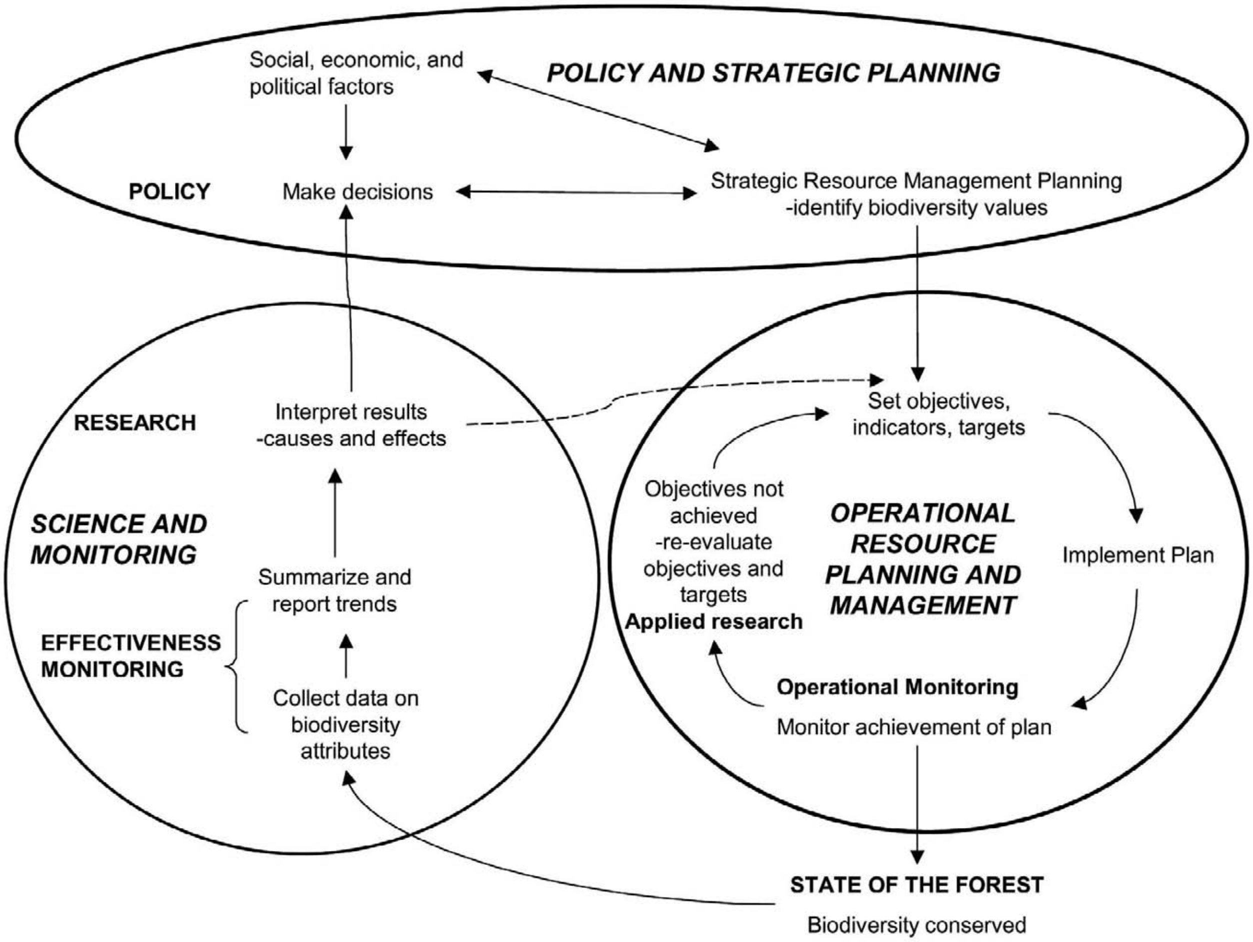

Figure 2. Forest resource planning cycle as it relates to the conservation of biodiversity including operational planning, operational monitoring, biodiversity effectiveness monitoring, and research.

Table 1. Forest Planning Manual Values, Objectives, Indicators and Targets.

Values	Forest area quality considered important
Objectives	Broad statement describing desired future condition or state of a value
Indicators	Variable describing state or condition of a value
Targets	Specific statement describing future state or condition of value, quantified if possible

required to maintain the full suite of forest biodiversity. Scientific research that links a fundamental understanding of forest ecosystems to practical cause-and-effect relationships is therefore crucial for developing objective-based sustainable forest management plans (fig. 2).

Monitoring and Forest Management

Monitoring is an integral and necessary component of any plan and sustainable forest management plans are no different. Alberta's forest planning guidelines require reporting on the achievement of all objectives in 5-year stewardship reports. This operational monitoring assesses the success in achieving the targets set for each objective. Adjustments to operations can then be made if it is demonstrated that current management activities are not achieving certain targets (fig. 2). Operational monitoring will sometimes also trigger a re-assessment of the objectives themselves if it becomes apparent that it is impossible to achieve certain objectives because of unforeseen factors, factors not under the control of the forest manager, or because some of the objectives prove to be mutually incompatible.

Table 2. Proposed Alberta forest planning standards for conservation of biodiversity objectives in forest management plans.

Element	Value	Objective	Indicator
Ecosystem Diversity	Landscape Scale biodiversity	Seral Stage and cover type	Area of old, mature and young forest
		Fragmentation	Patch size distribution of harvest openings
			Area of old interior forest
		Access	Open forestry road density
		Uncommon plant communities	Area/occurrence of community
		Burned and windthrow habitats	Area of unsalvaged burned or windthrow forest
		Riparian areas	Application of required buffers
	Stand scale biodiversity	Stand level structure	Volume/area of standing merchantable trees
			Volume of downed woody material
		Sensitive sites	Number or percentage maintained
		Water crossings	Strategy to minimize
			Compliance with crossing regulations
Species Diversity	Viable populations of identified species	Species habitat or populations	Habitat area or number of individuals
Genetic Diversity	Tree genetic diversity	Wild populations of each species (*in situ*)	Number and area of tree genetic conservation areas
		Ex situ conservation of tree genetic resources	Number of provenance and genetic lines in ex situ gene banks and trials

Operational monitoring cannot determine the effectiveness of a forest management plan's objectives in achieving the broader value of biodiversity conservation. This is a crucial issue in sustainable forest management as it is entirely possible to have successfully achieved all the forest management objectives related to biodiversity and still not be conserving biodiversity at all. How is this possible? One reason may be that the objectives, with their indicators and targets, did not address the full requirements for biodiversity, either because they failed to address certain necessary attributes (missing objectives) or because they did not provide enough of the required attribute (target inadequate). The other possibility is that factors not under the control of forest management practices, and therefore not addressed in forest management plans, are impacting biodiversity. These other factors are diverse and include the impact of other industries on the landscape (for example, seismic lines created by oil and gas), impacts in other jurisdictions outside the forest management area (for example, pesticide use or habitat loss in migratory bird wintering areas), or the effects of natural variability and climate change on species and their habitats.

For these reasons it is clear that operational monitoring is not enough. Biodiversity must be directly measured. This requires a comprehensive monitoring program in which significant trends in biodiversity can be detected. A biodiversity monitoring program would simply show what is happening; it would not be expected to make cause-and-effect conclusions (fig. 3). Such conclusions could only be made through research in which specific cause-and-effect hypotheses are tested. These hypotheses could very well be suggested or inferred by the trend data collected by a biodiversity monitoring program.

In this way a carefully designed biodiversity monitoring program can complete the planning cycle by providing inputs to research which in turn allows planners to set objectives to manage toward a future forest that meets desired values (fig. 2).

Alberta Biodiversity Monitoring Program

ABMP (Shank and others 2002) is designed to be a comprehensive, long-term monitoring program that will directly measure status and trends of biodiversity in Alberta, within the context of multiple resource developments across the province. The program objectives are as follows

1. to develop and implement a scientifically credible, long-term biodiversity monitoring program,

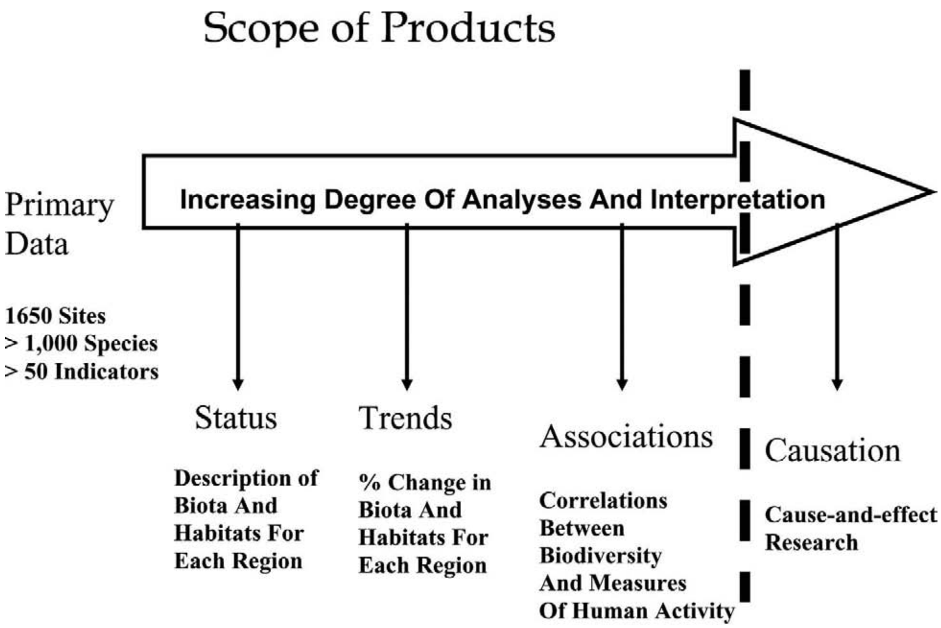

Figure 3. Scope of analysis and interpretation of the Alberta Biodiversity Monitoring Program and its relationship with research.

2. to measure status, differences, and temporal changes in selected measures of biodiversity, habitat, and anthropogenic disturbances at provincial and regional scales, and
3. to provide access to primary data and summary information reports. The ABMP has three phases. Phase 1, completed in 2002, developed the technical design of the program. Phase 2, currently underway and scheduled for completion in 2006, is the prototype testing phase in which the data collection protocols will be refined and the data management and reporting systems developed and tested. Phase 3, scheduled to begin in 2007, is the implementation of the full program across the province.

Survey Design

Before the design of the ABMP is described, it is important to understand the difference between a monitoring program and a research study. In environmental research, the objective is to develop a generalization about the way nature functions. Cause-and-effect relationships can be determined through hypothesis testing in which all factors are controlled for other than the one under consideration. In environmental monitoring, the objective is to determine if some characteristic of nature has changed in a significant way over time at a particular place or region. The primary purpose of monitoring is not to determine why the change occurred. There is no attempt to control for, or necessarily even to understand, the spectrum of causal factors. No generalization is possible outside the area being monitored; a statement is simply made about what has happened within that area. This allows monitoring to be independent of assumptions of cause-and-effect relationships and to detect unanticipated changes (Shank and others 2002). Later in this paper the synergistic relationship between monitoring and research will be described.

The ABMP survey design is a systematic placement of permanent survey locations on a 20-km grid across the whole province of Alberta resulting in about 1650 sites (fig. 4, see http://www.abmp.arc.ab.ca for full documentation). The sampling return interval is five years with 350 sites sampled yearly. This survey pattern and intensity is designed to detect a change in measured attributes of at least 3-percent per year after three visits to a site (Shank and others 2002).

The systematic distribution of sampling sites is an important feature of the ABMP. Alternative sampling regimes include random and stratified networks of sampling sites. However, random site locations were not deemed appropriate for long-term monitoring as concentrations of sites in certain locations of the study area can result in other areas being undersampled. Although stratifying locations based on some pre-determined spatial criteria avoids this problem, other issues then arise. Stratification of locations is inappropriate for long-term monitoring programs such as ABMP because it requires an initial determination of what spatial stratification criteria is most important and this determination will bias the data collected. The boundaries of any zoning framework used to stratify sampling effort are expected to change over the multiple decades that the ABMP is expected to run. Only a systematic system of sampling removes the bias inherent with stratified sampling while providing flexibility to address questions not anticipated today (Shank and others 2002).

Figure 4. Systematic 20-km grid layout of sampling locations in the Alberta Biodiversity Monitoring Program. Boundaries denote Alberta natural regions shown on figure 1.

Development of the ABMP sampling protocols focused on the question of "how does one measure biodiversity?" It is obviously impossible to measure all the attributes of ecosystem, species, and genetic diversity that comprise biodiversity. Therefore, the first task of protocol development involved selecting a suite of ecosystem and species attributes that would provide a reasonable measure of biodiversity in a cost-effective manner. Separate protocols were developed for terrestrial and aquatic habitats. The protocol to be used at a site depends on local site characteristics. A remote sensing protocol was developed to provide a picture of the landscape attributes around each site.

The terrestrial and aquatic protocols require the collection of both ecosystem and species attributes (table 3, fig. 5). The selection of these attributes and species was based on their having a high probability of responding to human disturbances. Some biodiversity monitoring programs select a number of "indicator species" or "key habitat types" to reduce sampling cost and assume that changes detected are indicative of changes in a broad spectrum of species. The ABMP has taken a different approach and instead monitors a large number of species from a wide range of taxonomic and functional groups (table 3). This approach was taken to increase the ability to detect a change that may affect only some species. This approach also limits the need to make a priori assumptions of how systems will respond to environmental change and therefore increases the long-term resilience of the program to monitor and detect unanticipated events and responses.

The remote sensing protocol will use satellite imagery to document status and change in the aerial extent of land cover types at regional and provincial scales. This protocol will also document landscape scale changes in landscape structure to provide a context for interpreting biodiversity data at each site. Large extent imagery (30-1000 m resolution) covering the entire province will be used to monitor broad landscape patterns. Elements monitored here include the area of major land cover types, percentage of forest as coniferous, deciduous and mixedwood, and large human and natural disturbances. Medium extent imagery (1-5 m resolution) centred on each sample site with a 1% provincial coverage will be used to detect smaller scale attributes such as vegetation patches down to 0.1 ha, species composition of vegetation patches, and small human disturbances such as seismic lines.

Data Assessment and Interpretation

The large amount of point and map data generated by the ABMP will be stored in a data management system designed to provide long-term data security while facilitating easy access by many groups. A secure, internet-based, interactive interface is being developed to allow external users access to data and summary information that they require.

Data analysis procedures are currently being developed that will be used to provide management insights that are not obvious within the raw data. For each biotic group, habitat, or landscape metric monitored by the ABMP, researchers are designing analyses that are effective at detecting change over time and describing differences in biodiversity status between geographic areas.

A critical component of making ABMP data useful to a wide audience will be the delivery of quality

Table 3. Summary of terrestrial and aquatic field sampling protocols in the Alberta Biodiversity Monitoring Program.

	Protocol	Description
Terrestrial Sites		
Species Protocols	Low vegetation	Plots
	Tall shrubs and saplings	Transects
	Trees	Plots
	Terrestrial arthropods	Pan and Lindgren traps
	Breeding birds	Point counts
	Winter birds	Point counts and playbacks
	Snow tracking	Transect
	Rare and elusive biota	Transects, plots
	Tree genetic material	Leaf and needle material
Habitat Protocols	Habitat structure	Slope, elevation, drainage, vegetation type, phenology, site origin, photographs
	Soil carbon	Pits
	Down deadwood material	Transects
	Tree canopy cover	Spherical densiometer readings
Aquatic Sites		
Species Protocols	Phytoplankton	Euphotic zone (standing water)
	Zooplankton	Water column (standing water)
	Benthic algae	Scrape sample (flowing water)
	Benthic macroinvertebrates	Corer/grab (standing and flowing water)
	Fish	Gill net (standing water)
Electrofishing (flowing water)		
Habitat Protocols	Water physiochemistry	pH, temperature, dissolved oxygen, conductivity, light attenuation, nutrient characteristics, depth (standing and flowing water), velocity (flowing water)
	Basin/channel characteristics	Surface water width, area, shape (standing and flowing water)
Substrate composition (standing and flowing water)		
Dead wood (flowing water)		

information products at regular intervals. The following baseline products will be created:

- Summaries of data collected and archived during the year.
- Annual reports reviewing program performance measures.
- Five-year reports providing interpretation of, and trends in, biodiversity status.

Data summaries and five-year reports provide a way to report biodiversity stewardship for both researchers and the general public. In this way the ABMP contributes to the public accountability of natural resource managers.

Integration of ABMP into Natural Resource Management

The ABMP is designed to monitor status and trends in biodiversity but does not indicate what causal agents are affecting biodiversity (fig. 3). However, the biodiversity data produced in the ABMP will be correlated to both stand- and landscape-scale attributes that may suggest possible cause-and-effect relationships. These correlations can then provide the basis for generating hypotheses that can be tested in scientific research programs. The result of this linkage between monitoring and research is a more effective way of focusing limited research resources to questions of real significance to biodiversity conservation (fig. 2). Knowing what questions to ask will make research more relevant. The knowledge generated from more focused research will allow strategic and operational planners to develop and refine objectives related to the conservation of biodiversity.

Once cause and effect relationships between human actions and biodiversity are more clearly understood, the ABMP will be able to provide more direct effectiveness monitoring of the success of operational plans in achieving conservation of biodiversity objectives.

Conclusion

The ABMP's systematic sampling design, and its direct approach to measuring biodiversity without a priori assumptions, makes it resilient to unanticipated developments and relevant to planning at both strategic and operational scales. Forest managers will be able to set conservation of biodiversity objectives based on scientific research, which in turn has been directed by a

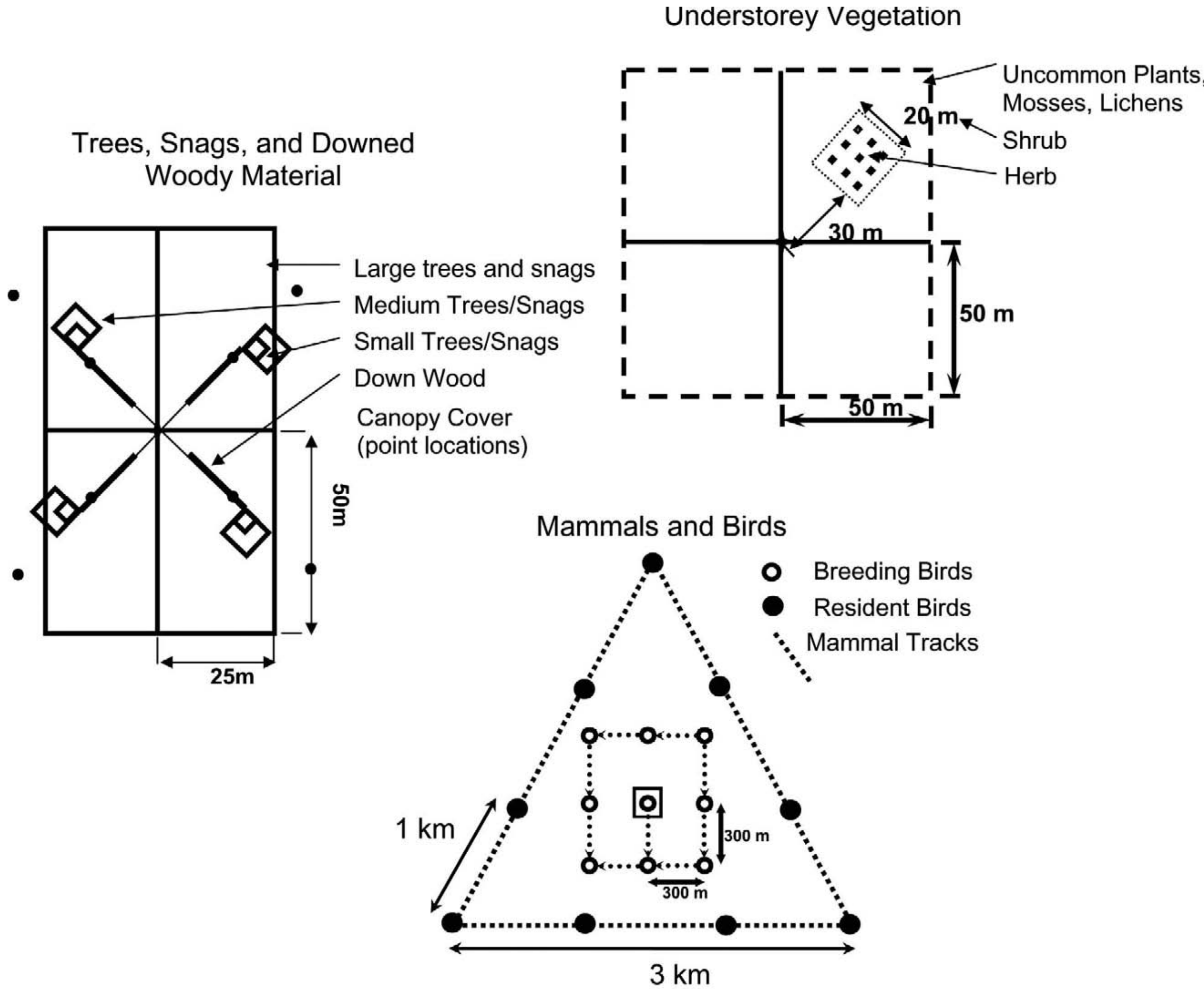

Figure 5. Terrestrial field sampling layout protocols for overstorey and understorey vegetation and for mammals and birds. The three layouts shown above are centred on the same point and therefore would be superimposed in the field.

greater understanding of the status and trends in biodiversity. Effectiveness monitoring will also now complement operational monitoring of these objectives.

The establishment of measurable biodiversity objectives required by Alberta's proposed forest planning standards and the effectiveness monitoring function provided by the ABMP are key links in the forest planning cycle and will therefore contribute to the ultimate goal of conserving biodiversity in Alberta's forests.

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Aerial Treatment of Salt Cedar Within Threatened and Endangered Species Habitat—A Success Story

Nyleen H. Troxel Stowe, Director of Special Projects, Program Manager, Socorro Soil & Water Conservation District, Socorro County Noxious Weed Coordinator, Socorro, NM

Abstract—*The Lower Rio Grande Salt Cedar Control Project treated 7,648 acres of monotypic Tamarisk (Salt cedar) in riparian areas along the Rio Grande in Socorro, Sierra, and Dona Ana Counties in New Mexico. We contracted North Star Helicopters, Inc. to do aerial treatment of these Salt cedar stands. The biggest issue in doing this treatment was the presence of the Southwestern Willow Flycatcher, an endangered bird species that is now nesting in Salt cedar. For this project to be undertaken, we had to ensure the USFWS that no treatment would occur within the ¼-mile buffer radius of the Southwestern Willow Flycatcher's nesting sites. We had ESRI (Environmental Systems Research Institute, Inc.) shape files of the nesting sites with the ¼-mile buffer. These files were uploaded into the on-board Trimble GPS units on the helicopters and marked as exclusion zones. The spray pump could not be activated when the helicopter was within this zone. The on-board GPS units also had real-time differential correction. ESRI shape files of the areas to be treated were loaded into the GPS units. When the helicopter was within the boundaries of these files, the spray pump could be activated. When outside of these boundaries, the spray pump could not be activated. This project was very successful. It was done with several constraints such as the exclusion zones, and the time period allotted for treatment. Current technology allows us to do accurate and safe treatment.*

Introduction

In the spring of 2002, the New Mexico State Legislature appropriated $5 million for Phreatophyte control along the Rio Grande and Pecos Rivers in New Mexico. Again, in the spring of 2003, the New Mexico State Legislature appropriated another $1.2 million for this project. These funds were directed to the Soil & Water Conservation Districts along the Rio Grande and Pecos Rivers with the following provisions: development of management and native vegetation restoration plans, conducting hearings within the local conservation districts to receive public input, carrying out aerial spraying only by helicopter or ground application with prior public notice, monitoring and evaluating the effects of control on wildlife, water quality, vegetation, and soil health, and if control affects threatened or endangered species, the projects proponents will take action to ensure compliance with applicable federal law and conformance to any duly enacted recovery plan. The Lower Rio Grande Salt Cedar Control Project encompasses the Rio Grande River from the Northern Socorro/Valencia County line to the US/Mexico border. There are four Soil & Water Conservation Districts involved in the Lower Rio Grande Salt Cedar Control Project-Socorro, Sierra, Caballo, and La Union.

Within the project boundaries, there are tens of thousands of acres of monotypic Salt cedar and thousands of acres of Salt cedar understory beneath cottonwood/willow stands. The proponents of this project chose these large monotypic stands of Salt cedar as the treatment priority. These areas for treatment were chosen for the following reasons: the fire danger that large monotypic stands pose and the cost of treatment of these large stands. The areas that we treated ranged from 2,000 to 7,000 stems of Salt cedar per acre.

The primary concern and largest obstacle to overcome with this project was the presence of the endangered bird species the Southwestern Willow Flycatcher. This bird is now nesting in Salt cedar. We had to ensure that these nesting sites and habitat of the Southwestern Willow Flycatcher would not be destroyed or degraded. We worked with Ecological Services of the U.S. Fish & Wildlife Service to determine a suitable buffer zone for the Southwestern Willow Flycatcher.

Salt Cedar Control—The First Step

Our first step in restoring the riparian native vegetation along the lower Rio Grande River was the treatment of the large monotypic stands of Salt cedar. This was done by aerial application of the herbicide Arsenal (BASF) from a helicopter. Arsenal is an amino acid synthesis inhibitor of the Imidazolinone family. The chemical in Arsenal is Imazapyr which inhibits the production of the enzyme AHAS (Acetohydroxy acid synthase). AHAS is found only in plants and it converts three key amino acids that are only found in plants (Zaliene, Leucine, and Isoleucine) into protein so that the plant can grow. When this enzyme is inhibited, the plant is then unable to grow and eventually uses up all of its carbohydrates. Imazapyr does not harm vertebrate or invertebrate animal life. Imazapyr also dissipates quickly in the environment, particularly in water. The Socorro Soil & Water Conservation District contracted with North Star Helicopters, Inc. for this aerial application. The contract was awarded to North Star Helicopters, Inc. because they had the capability of taking ESRI (Environmental Systems Research Institute) shape files and uploading them into the on-board GPS (Global Positioning System) units on the helicopters. ESRI shape files of the known nesting sites of the Southwestern Willow Flycatcher with the ¼-mile buffer zone were loaded into these GPS units and marked as exclusion zones.

The areas to be treated were also GPSed using a hand held Trimble III GPS unit. These shape files were differentially corrected and loaded into the helicopter's GPS units. The helicopters had real-time correction. When the helicopter flew into the area that was designated to spray, the GPS unit would allow the helicopter's spray pump to be turned on and thus allowing the pilot control only within the designated boundaries. This was accomplished by creating a prescription file for the onboard GPS for the area to be treated that only allowed the spray to be turned on when within this boundary file. The two helicopters detailed to this project were wired to have automatic shutoff of the spray system when the ¼-mile buffer zone around these sites was reached. This helped assure that the application would not be turned on over the Southwestern Willow Flycatcher areas. This was the first practical application using this technique by North Star Helicopters, Inc; all previous applications were only for the use of testing the system. Not all GPS units have this ability, although they could have similar features, but the pilot could override the feature without even realizing that he was doing so. To ensure that the pilot could not override this feature by accident, North Star Helicopters, Inc. placed the override switch in a hard to reach area of the control panel. This extra feature provided by North Star Helicopters, Inc. allowed for an extremely successful treatment program in the Lower Rio Grande Salt Cedar Control Project area. A total of 436 acres of Salt cedar were effectively treated on the Sevilleta National Wildlife Refuge around the nesting sites and territories of the Southwestern Willow Flycatcher. Another 800 acres of private land were treated next to the Southwestern Willow Flycatcher nesting sites.

The aerial application began on September 5, 2003 on the Rio Salado, a major tributary to the Rio Grande. Aerial application concluded on September 23, 2003 near Rincon in Dona Ana County. North Star Helicopters, Inc treated a total of 7,648 acres of Salt cedar aerially with the use of two helicopters. Nine hundred forty-one acres of Salt cedar on the Rio Salado were treated in partnership with the Bureau of Land Management-Socorro Field Office. They funded this in the amount of $152,200 and 70 gallons of the herbicide Arsenal. Also in partnership with the Bureau of Land Management-Albuquerque Field Office and the Cuba SWCD, another 262 acres of Salt cedar were treated near Cuba, New Mexico. The Bureau of Land Management-Albuquerque Field Office funded this in the amount of $50,000. Twelve hundred acres of Salt cedar were treated on the USFWS-Sevilleta National Wildlife Refuge. Sevilleta National Wildlife Refuge funded this project in the amount of $140,000. Twelve hundred forty-six acres of Salt cedar were treated around Elephant Butte for the Bureau of Reclamation. Sixty acres were treated for the City of Truth or Consequences in Cuchillo Negro Dam. Three thousand nine hundred ninety-eight acres of Salt cedar were treated on private land.

There were no measurements of Arsenal deposition within the ¼-mile buffer zone of the Southwestern Willow Flycatcher nests. The New Mexico Department of Agriculture-Pesticide Division did inspect this job using moisture sensitive placards place within the treatment zones, next to the treatment zones, and outside of the treatment zones. No herbicide application occurred outside of the treatment zones. The New Mexico Department of Agriculture-Pesticide Division was very pleased with the control measures of this project. The U.S. Fish & Wildlife Service also did not require us to test for Arsenal deposition within the Southwestern Willow Flycatcher buffer zones, as they were satisfied with the control measures of this project.

The project was successful with the use of this technology. We worked in partnership with the U.S. Fish & Wildlife Service-Ecological Services and Regional Office, the Bureau of Land Management, the Bureau of Reclamation, the NM State Land Office and North Star

Helicopters, Inc. By pooling our funds and resources, the project was streamlined and more work was completed on the ground.

Salt Cedar Control—The Next Steps

This is our first step and the easiest step in our Salt cedar control. We are currently writing individual conservation plans with each of the landowners, taking into account their desires for their land. Each of the Federal and State Agencies are treated as an individual landowner. Each of these agencies has rules and regulations to follow. This is incorporated into their plans. The re-vegetation of these areas after the removal of the Salt cedar is our most important step. Removal of the dead Salt cedar will be done two to three years after the aerial treatment. The dead Salt cedar will be burned or bulldozed followed by burning of the brush piles. In some instances, such as the Rio Salado, the dead Salt cedar will be left in place as bank stabilization and habitat for Raptor species. We anticipate that the native seed source is still present in this tributary to the Rio Grande and that the seeds will establish once the competition for water has been eliminated.

We must re-establish native vegetation and integrate re-treatment into the plans. The salinity of the soil will determine the type of re-vegetation. The Socorro Soil & Water Conservation District has a Geonics EM 38 soil salinity meter that measures the salinity both vertically and horizontally. In areas with high salinity, plants such as salt grass will have a better chance of establishing. Some areas will require aerial reseeding. This action may have to be repeated. The treatment areas also have no water rights. Therefore, our reseeding process will coincide with our normal monsoon season. Our office will also do re-treatment of Salt cedar sprouts. It is our goal to re-establish a native riparian ecosystem to our portion of the Rio Grande River thus enhancing habitat not only for the endangered species such as the Southwestern Willow Flycatcher and the Silvery Minnow, but for all wildlife. The large monotypic stands of Salt cedar do not provide good habitat for wildlife.

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Sequencing Conservation Actions Through Threat Assessments in the Southeastern United States

Robert D. Sutter, Senior Conservation Ecologist, and Christopher C. Szell, Conservation Ecologist, The Nature Conservancy, Southern U.S. Regional Office, Durham, NC

Abstract—*The identification of conservation priorities is one of the leading issues in conservation biology. We present a project of The Nature Conservancy, called Sequencing Conservation Actions, which prioritizes conservation areas and identifies foci for cross-cutting strategies at various geographic scales. We use the term "Sequencing" to mean an ordering of actions over time and "Conservation Actions" to represent strategies implemented both at and across conservation areas, and from local to global scales. There are three outcomes of the Sequencing Project. The first is the ranking of conservation areas into four sequencing categories based on Relative Biodiversity Value and Relative Threat Status. These categories are: 1) Now, Right Now: conservation areas to be addressed immediately, 2) Now: conservation areas to be addressed in 3-5 years, 3) Soon: conservation areas that can be addressed in 5-10 years, and 4) Later: conservation areas that can be addressed in more than 10 years. The second outcome is the identification of foci for cross-cutting strategies based on common threats. It is around these foci that strategies can be developed. The third outcome compares Relative Conservation Opportunities across priority conservation areas. The results enable a conservation entity to effectively prioritize actions across conservation areas.*

Introduction

The identification of conservation priorities is one of the leading issues in conservation biology. In an effort to effectively preserve the world's biodiversity, conservation priorities have been assessed at the scale of biodiversity hotspots (Myers and others 2000, Reid 1998) with more recent consideration given to zones of ecological transition (Araújo 2002, Gaston and others 2001), reserve networks (Andelman and Willig 2003, Groves and others 2000, Margules and Pressey 2000, Rodrigues and others 2004), and for assessing strategies at conservation areas (Low 2003). However, given the estimated size of the reserve network to conserve the world's biodiversity (11.5% of land area [Chape and others 2003]) and the investments to make it a reality ($3-11 billion per year over the next 30 years [James and others 2001, Pimm and others 2001]), NGOs and agencies are constantly challenged to strategically consider where, when, and how to invest their limited funds to maximize conservation benefits (Meir and others 2004).

Assessing the priority of conservation areas has focused correctly on high biodiversity significance and protection status (Groves 2003, Pressey and others 2000, Ricketts 1999, Scott and others 1996, Smith and others 2002). Such an approach has provided significant influence on conservation efforts by public and private agencies. These studies, however, have not adequately incorporated threats impacting biodiversity, which is the primary temporal influence on conservation action. The more robust approaches have incorporated threats into their assessment process (Neke and du Plessis 2004, Noss 2002, Theobald 2003) and it is becoming increasing recognized that conservation will fail without detailed insights into the threats that are putting species and ecological systems at risk (Lawler and others 2002). Predicting future threats, such as those from population growth (Saterson and others 2001, McKee and others 2003, Rouget and others 2003), invasives (Dirnbock and others 2003), roads, agriculture, forestry and global climate change, can provide a proactive approach to conservation.

We present a project of The Nature Conservancy (TNC), called Sequencing Conservation Actions, which prioritizes conservation areas and identifies foci for cross-cutting strategies (strategies that impact conservation at multiple sites) at various geographic scales (state, ecoregion, region). The Nature Conservancy's mission is to protect biological diversity (Groves and others 2000), thus the conservation focus of this project is the protection of species, natural communities and ecological systems. We use the term "Sequencing" to mean an ordering of actions over time and "Conservation Actions" to represent strategies implemented both at and across conservation areas and from local to global scales.

In the Southeast U.S., the region in which the Sequencing project was developed, there are 1268 conservation areas identified in 11 Ecoregional Assessments. Ecoregional Assessments, done at the scale of ecoregions (Groves and others 2000, Velutis and Mullen 2000), identify targets of biodiversity interest, assess the viability of target occurrences, establish target occurrence and geographic goals, and circumscribe conservation areas of biodiversity significance (Groves and others 2000, Velutis and Mullen 2000). They present the complete set of conservation areas that protect multiple occurrences of the identified targets. Ecoregional Assessments have the added value of identifying multi-site strategies, engaging partners and collaborators, and identifying research and inventory needs. Sequencing Conservation Actions extends these Assessments by identifying the highest priority conservation areas and foci for cross-cutting strategies.

Three parameters were used to sequence conservation actions. First, an assessment of Relative Biodiversity Value, reflecting the significance of species and natural communities (total number of targets, rare targets), was assigned to each conservation area. Second, a Relative Threat Status was determined through the assessment of 30 standardized threats. Last, each conservation area was assessed for their Relative Conservation Opportunities. The first two are based on the characteristics of the conservation area; the conservation targets and the threats to those targets. The third parameter, takes into account the human dimensions of available funding, planning windows, the presence of partners, and project feasibility.

There are three outcomes to the Sequencing Project. The first is the ranking of conservation areas into four sequencing categories based on Relative Biodiversity Value and Relative Threat Status. These categories are: 1) *Now, Right Now:* conservation areas to be addressed immediately, 2) *Now:* conservation areas to be addressed in 3-5 years, 3) *Soon:* conservation areas that can be addressed in 5-10 years, and 4) *Later:* conservation areas that can be addressed in more than 10 years. The second outcome is the identification of foci for cross-cutting strategies based on common threats. It is around these foci that strategies can be developed, supported by the quantitative information gathered for each threat. The third outcome compares Relative Conservation Opportunities across priority conservation areas.

In this paper, we outline the methods used to obtain these outcomes and provide several examples. The results provide a basis for a conservation entity to prioritize conservation areas and a context for site specific actions, including land acquisition, threat abatement, land management and restoration, and influencing public policy or implementing sustainable land uses.

Methods: Description of the Sequencing Process

Parameters

Three parameters were used in the Sequencing Process to assess priorities of conservation areas and cross-cutting strategies.

1. Relative Biodiversity Value

In order to determine the Relative Biodiversity Value of a conservation area we calculated an index of "irreplaceability" (Pressey and others 1994). Used in other efforts to identify conservation priorities (Marshall and others 2004, Enquist and others 2004), this measure is dependent upon the targets represented at a conservation area and the number of conservation areas being considered (for example, scale dependent). Therefore, irreplaceability may be defined as the potential contribution of a target to meeting the conservation goals within the context of other conservation areas. The index changes as targets become more or less represented in conservation areas elsewhere in the Ecoregion (Pressey and others 1994). Targets that have fewer occurrences will have higher index values and contribute greater to a conservation area score (see scoring below). Target occurrence data from Ecoregional Assessments, provided by the Natural Heritage Program Network, was used to calculate the index.

2. Relative Threat Status

Relative Threat Status was obtained through the assessment of 30 standardized and defined threats (table 1) for each conservation area. Threats were defined as activities or conditions that limit the viability of populations or the functionality of ecological systems. They are the factors or sources (development, dams, grazing) contributing to the stresses (habitat destruction, altered hydrologic regime, sedimentation) impacting the targets.

Threats were ranked by two attributes: 1) the *Severity* of the threat – how severe the stresses of the threat are to the conservation targets and 2) *Percent of Ecoregional Target Occurrences Affected*– the proportion of the target occurrences on which the threat is acting at the ranked level of severity. Threats were assessed at the scale of the conservation area, across all the target occurrences. Threats were scored for two time frames, 1) *Active*

Table 1. Standardized Threats by Category.

Forest Threats
Forest Conversion
Incompatible Forestry Practices and Management
Forestry Roads
Agriculture Threats
Agriculture Conversion
Incompatible Agricultural Practices
Conversion to Pasture
Incompatible Grazing Practices
Livestock Feedlots/Production Practices
Resource Extraction Threats
Incompatible Resource Extraction
Proposed/Potential Mineral Resource Extraction
Development Threats
Urban/Suburban Development
Industrial Development
Second Home/Vacation Development
Development of Roads/Utilities
Hydrologic Threats
Operation of Dams/Impoundments
Proposed Dams/Impoundments
Water Withdrawal
Proposed Water Withdrawal
Excessive Groundwater Withdrawal
Channel Modification
Incompatible Water Quality
Other Threats
Invasive Species
Parasites/Pathogens
Altered Fire Regime
Recreation
Overexploitation of Species
Airborne Pollutants/Nutrients
Coastal Threats
Shoreline Stabilization
Sea-Level Rise/Global Climate Change
Global Climate Change

– current or a very high probability of occurring within 10 years or 2) *Historic* – past threats that were no longer active but their impacts were still affecting biodiversity in the conservation area. Ranking was done on an ordinal scale (low, medium, high, very high) as defined in table 2. The ranking of threats was done in expert meetings for each ecoregion involving knowledgeable biologists and land managers. Based on the expertise present at the meeting, the collective "level of knowledge" about each conservation area and its target occurrences was also assigned a rank (table 3).

The collection of experts' intimate knowledge of the conservation areas was the most valuable asset during the threat assessment process. Although quantitative data pertaining to the spatial distribution of conservation areas within an ecoregion and the identification and location of targets was also made available at each expert meeting. These data were derived from Ecoregional Assessments and the Freshwater Biodiversity Conservation Assessment (Smith and others 2002). Spatial layers of roads, managed areas, rivers, and landuse (National Land Cover data 1992) were also provided. Threat maps were generated for selected threats such as population, predicted population growth, livestock facilities, and hydrologic dams and made available during discussions as needed.

3. Relative Conservation Opportunity

The addition of Relative Conservation Opportunities adds the circumstances under which conservation is conducted "on the ground." The scoring of this last component is done from the perspective of the whole conservation community and was also completed in expert meetings involving biologists and individuals knowledgeable about funding sources, public policy, partners, and stakeholders. The final product allows the comparison of the ecologically most important places to work with conservation areas that have the greatest conservation opportunities. Six attributes were used to score this parameter.

Funding Opportunities: presence of funding from any source (private or public) that is available and sufficient to begin implementation of key strategies for the specific conservation area. Sufficient funding is subjectively assessed across the range and cost of key strategies (protection, policy, land management).

Presence of Support in Key Agencies/Partners: the presence, or potential presence, of support within key partner agencies having sufficient competency and will have significant positive influence (directly or indirectly conserving target occurrences) on project success.

Policy and Constituency (Stakeholder) Support: the presence of policy, constituency, both state-wide and local, and the political context that will have significant influence (directly and indirectly conserving target occurrences) on the success of a project.

Feasibility: a measure of how likely conservation success (based on conservation of the majority of conservation targets by implementation of priority strategies) can be obtained at a conservation area. This measure is a combination of the ease of implementation of the project (for example, logistics, number of landowners) and the ecological integrity of the site (for example, how much restoration is needed or how difficult to abate threats such as hydrologic alteration or pathogens).

Unique Opportunity Windows: An unique opportunity window includes infrequent planning windows, a rare opportunity to purchase land, or currently established momentum for conservation. The unique opportunity window must be currently present or exist over the next 2-3 years and taking advantage of the window with focused conservation efforts will have significant conservation

Table 2. Rank definitions for the attributes of Severity and Percent of Ecoregional Target Occurrences Affected.

	Severity Ranks Defined
Very High	the **threat** is likely to destroy or eliminate (irreversible) one or multiple targets within thenext 5 years or currently a less severe threat that if not addressed immediately (invasive species; altered fire regimes) will become a very high rank within the next 5 years – or – **historically, the threat has destroyed or eliminated one or multiple targets**.
High	the **threat** is likely to seriously degrade (possible to restore but difficult and costly) one or multiple targets within the next 5 years or currently a less severe threat that if not addressed immediately will become a high rank within the next 5 years – or – **historically, the threat has seriously degraded one or multiple targets**.
Medium	the **threat** is likely to moderately degrade (possible to reverse) the target within the next 5 years – or – **historically, the threat has moderately degraded one or multiple targets**.
Low	the **threat** is likely to slightly impair (easily reversed) the target within the next 5 years – or – **historically, the threat has slightly impaired one or multiple targets**.
	Percent Ecoregional Target Occurrence Ranks Defined
Very high	the **threat** is likely to impact >50% of the target occurrences at the conservation area - or – **historically, the threat has impacted a majority of target occurrences**.
High	the **threat** is likely to impact one **irreplaceable** (see definition below) conservation target occurrence or 25 - 50% of the target occurrences at the conservation area – or **historically, the threat has impacted a high percentage of target occurrences**.
Medium	the **threat** is likely to impact 10 - 25% of the target occurrences at the conservation area – or – **historically, the threat has impacted a moderate percentage of target occurrences**.
Low	the **threat** is likely to impact <10% of the target occurrences at the conservation area - or – **historically, the threat has impacted a low percentage of target occurrences**.

Table 3. Rank definitions for varying degrees of the experts' level of knowledge about a conservation area and its target occurrences.

Level of Knowledge Defined	
Very High	A very high level of knowledge of the Conservation Area that includes a completed conservation area plan.
High	A high level of knowledge of the Conservation Area with one or more participants having first-hand knowledge of the whole site and over 50% of the targets.
Medium	A medium level of knowledge of the Conservation Area with one or more participants having first-hand knowledge of part of the site and less than 50% of the targets.
Low	A low level of knowledge of the Conservation Area with the participants having no first-hand knowledge of the site and will be making their best guesses for threats and leverage.

impact (directly and indirectly conserving target occurrences) at a single conservation area or across numerous conservation areas.

Opportunity for Significant and Real Leverage: Leverage is defined as investments of conservation resources in conservation action at one conservation area, through direct action or influencing management decisions, that results in or enables threat abatement and restoration across many other conservation areas. For example, this attribute would include exporting new conservation knowledge/approaches developed at one site to other sites.

Scoring

Relative biodiversity value

We calculated an index of "irreplaceability" to represent the Relative Biodiversity Value of a conservation area following the method outlined and incorporated in prioritization efforts by Marshall and others 2004. For each conservation target, the number of conservation areas (for a given ecoregion) at which it occurs was determined and the inverse of that number was calculated to represent the importance of a particular area. For example, a target occurring at 20 conservation areas would have an index of 1/20 and protecting any one of those 20 areas would protect an occurrence of the target (Marshall and others 2004). Targets captured at fewer areas would have higher index values giving them greater weight (for example, 1/2 is larger than 1/20) (Marshall and others 2004). The index values for all targets present for a given conservation area were then summed to give an index of irreplaceability (IRR): IRR = 1/(count of areas with target

Table 4. Threat Rank Matrix: results of Severity and Percent Ecoregional Target Occurrence ranks.

		Percent of Ecoregional Target Occurrence Ranks:			
		VERY HIGH	HIGH	MEDIUM	LOW
Severity Ranks:	VERY HIGH	Very High	Very High	Very High	High
	HIGH	Very High	High	High	Medium
	MEDIUM	High	Medium	Medium	Low
	LOW	Medium	Low	Low	Low

Table 5. Example calculations for determining Relative Threat Status. Very High (VH), High (H), Medium (M), Low (L).

	Tallied Number of Threat Ranks:				**Threat Rank x Log 5 value:**				
Conservation Area	**VH**	**H**	**M**	**L**	**VH = 125**	**H = 25**	**M = 5**	**L = 1**	**Relative Threat Status**
A	7	9	7	0	875	+25	+35	+0	= 1135
B	4	3	0	0	500	+5	+0	+0	= 575
C	3	0	12	0	375	+0	+60	+0	= 435

a) + 1/(count of areas with target a) + 1/(count of areas with target a)…for all targets at a given area.

Relative threat status

The first step towards calculating the overall Relative Threat Status of a given conservation area is to assess the impact of a single threat at the given conservation area. The attributes of *Severity* and *Percent Ecoregional Target Occurrences* were ranked on an ordinal scale (low, medium, high, and very high) and combined according to the matrix in table 4, to obtain a *threat rank* for each threat.

The four *threat ranks* for a given conservation area were tallied and multiplied by its respective log 5 value (for example, number of *very high* ranks multiplied by 125, *high* ranks x 25, *medium* ranks x 5, and *low* ranks x 1, see table 5). Finally, Relative Threat Status is calculated as the sum of all *log values* within a given conservation area (table 5).

Conservation opportunities

Six attributes were also ranked on an ordinal scale (low, medium, high, or very high) for assessing Relative Conservation Opportunities. Ordinal scale values translated into numeric values from 1-4 (low = 1, very high =4) and the attributes of Funding and Opportunity Window were each weighted by 2 (4 x 2 = 8) while the Presence of Key Agencies/Partners was weighted by 1.5 (4 x 1.5 = 6). Subsequently, the highest possible value available for a given conservation area would be 34 (3 attributes x 4; 2 attributes x 8; 1 attribute x 6). Dividing scores into quartiles provided the Conservation Opportunity categories of very high, high, medium or low opportunity (fig. 2).

Example of Sequencing Results

Figure 1 illustrates the output that positions conservation areas along the two axes of Irreplaceability and Relative Threat Status for the South Atlantic Coastal Plain (SACP) ecoregion. The graph provides information on the Sequencing Category (determined by the region of the graph) and the level of knowledge about each conservation area brought to the assessment by experts (the color and size of the points). Action Sites, priority conservation areas subjectively identified in the South Atlantic Coastal Plain Ecoregional Assessment (TNC 2002), have been marked with an asterisk. Thresholds of Relative Threat Status were established on a log 5 scale at the 50 and 250 values. The conservation areas that fall within the region above the 250 threshold contain at least 2 threat ranks scored as very high while those within the region between 50 and 250 had at least 2 high threat ranks. The Irreplaceability index was placed on a log + 1 scale. The thresholds of Soon and Later represent the 50% and 75% quartiles of the largest log value within the data set (1.73 in the case of SACP). Therefore, a conservation area with a Relative Threat Status >250 and an Irreplaceability Index of <1.3 falls within the *NOW* sequencing category.

The Sequencing Categories, from bottom left to top right, are: *Later:* conservation areas that can be addressed in more than 10 years due to low threat and low irreplaceability value; *Soon:* conservation areas that can be addressed in 5-10 years due to low threat and medium to low irreplaceability; *Now:* conservation areas to be addressed in 3-5 years due to a medium to high threat and with a medium to low irreplaceability value; and *Now - Right Now:* conservation areas to be addressed

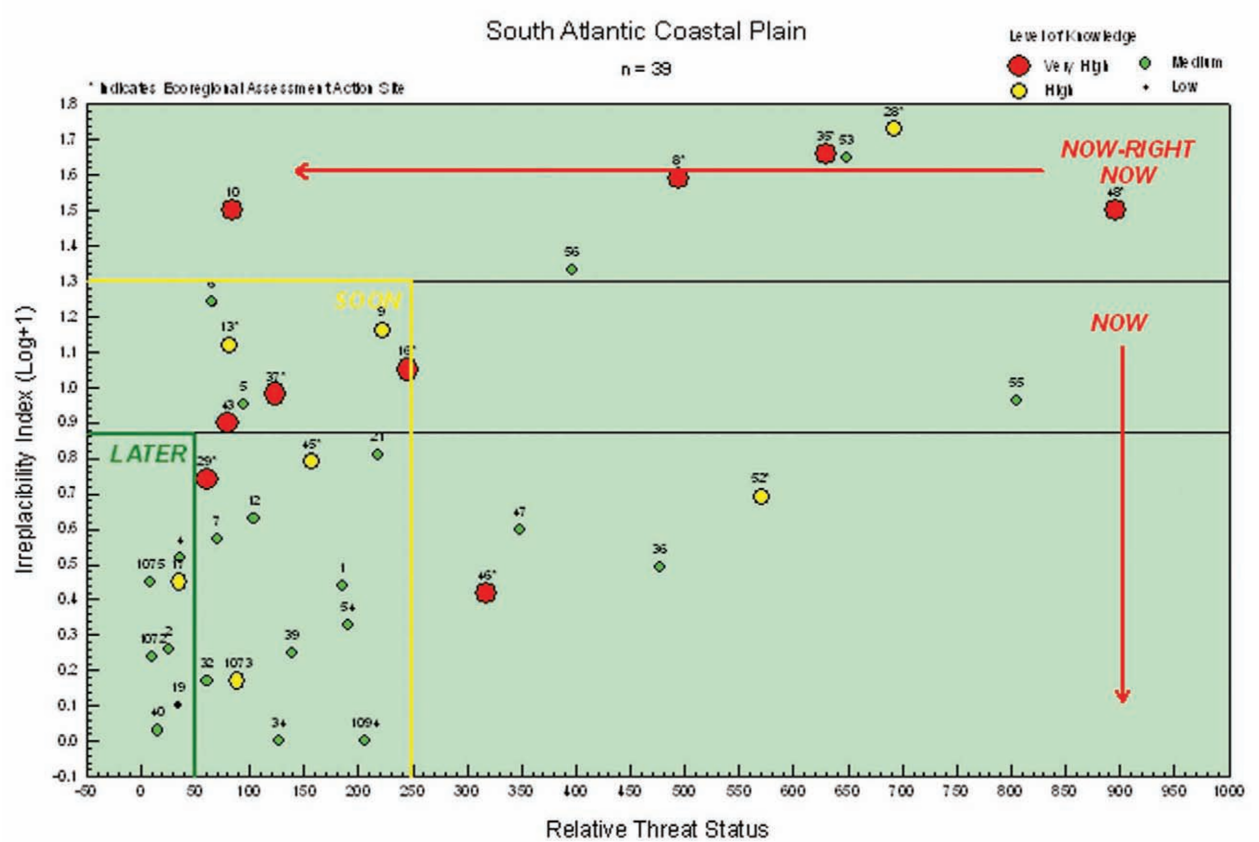

Figure 1. Four levels of Conservation Action for 39 conservation areas in the South Atlantic Coastal Plain Ecoregion. Each point represents a conservation area labeled by the conservation id. Sequencing Category thresholds are indicated by red (Now-Right Now and Now), yellow (Soon), and green (Later) lines. Participants Level of Knowledge about each conservation area is noted by different size and color points. Actions sites identified in Ecoregional Assessments are indicated by an asterisk.

immediately driven by their high irreplaceability value and a range of threat status from low to high. The dimensions of the *Now-Right Now* category reflects the duel desire of conservation entities to protect both high biodiversity areas that have low threat and those that have high threat. Table 6 lists the conservation areas in both the *Now-Right Now* and *Now* categories and provides the scores for Irreplaceability Index and Relative Threat Status.

Figure 2 illustrates the output that positions conservation areas along the two axes of Irreplaceability and Relative Threat Status for the state of Georgia (combination of five ecoregional assessments). The graph provides information on the Sequencing Category and the rank of Relative Conservation Opportunity (the color and size of the points). Note that all of the *Now-Right Now* conservation areas have either a very high or high conservation opportunity, an unusual result among the seven state assessments.

Figure 3 presents threat data for the state of Georgia. Percent occurrence of each of the 30 threats using just Very High and High threat ranks have been graphed. This information provides foci for identifying potential cross-cutting strategies.

All three figures may be graphed at various scales (state, ecoregion, region) and may represent different threats or ownership. For the latter, we have generated graphs for conservation areas in which the USFS and USFWS are primary land owners. Each parameter may also be assigned to a GIS layer and mapped to represent the spatial distribution of each threat or threat rank.

Discussion

The process of Sequencing Conservation Actions highlights several challenges in assessing the priorities across a set of conservation areas. An obvious concern is the completeness and quality of the data. The Southeast U.S. is one of the most thoroughly inventoried and data rich regions of the world. Over the 11 ecoregional plans and 1268 conservation areas, there were 38,000 target occurrences (representing some 3500 species groups and natural communities) and the process was enriched by the involvement of 160 field biologists and land

Table 6. South Atlantic Coastal Plain Conservation Areas with Sequencing Category of *Now-Right Now* and *Now*.

Conservation Area (CA)	State	Level of Knowledge	Targets	IRR[1]	RTS[2]	Sequencing Category
Coastal Islands and Estuaries	GA-SC-FL	High	92	52.94	693	NOW-RIGHT NOW
Altamaha River	GA	Very High	111	44.92	630	NOW-RIGHT NOW
New Trail Ridge	FL	Medium	87	43.81	649	NOW-RIGHT NOW
St. Marys River	FL-GA	Very High	64	30.43	896	NOW-RIGHT NOW
Ixia Flatwoods	FL	Medium	24	8.03	805	NOW-RIGHT NOW
Timucuan/Pumpkin Hill	FL	Very High	25	7.97	1098	NOW-RIGHT NOW
Durbin/Dee Dot	FL	High	15	3.95	570	NOW-RIGHT NOW
Savannah River Basin	SC-GA	Very High	108	37.60	495	NOW
Santa Fe/New River	FL	Medium	37	20.57	397	NOW
Crooked River/King's Bay	GA	Medium	8	2.94	348	NOW
Alapaha River	GA-FL	Medium	9	2.10	477	NOW
Grand Bay/Banks Lake	GA	Very High	6	1.63	318	NOW

[1] IRR = Irreplacibility Index
[2] RTS = Relative Threat Status

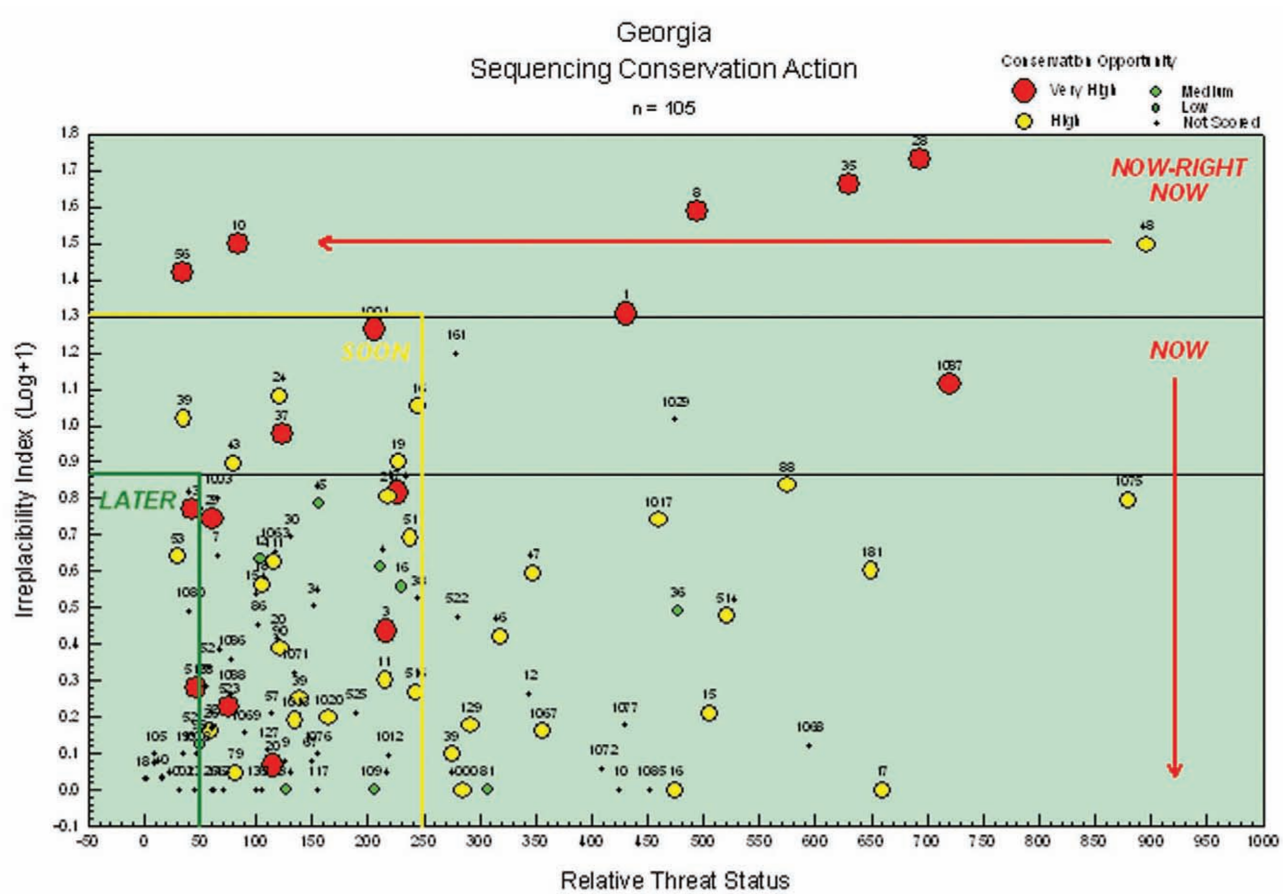

Figure 2. Four levels of Conservation Action for 105 conservation areas in Georgia from 5 ecoregional assessments. Each point represents a conservation area labeled by the conservation id. Sequencing Category thresholds are indicated by red (Now-Right Now and Now), yellow (Soon), and green (Later) lines. Conservation Opportunity is indicated by different size and colored points.

managers. While data was extensive, there are always problems with completeness. Even in well inventoried regions, not all target occurrences are known and within and across ecoregions there were obvious gaps in knowledge. There were also differences among ecoregions and states in compiling data and the involvement of experts. Consistency was greatest at the ecoregional scale. When rolling up data, the inconsistency across plans effects the accuracy of the results.

Developing an appropriate measure for Relative Biodiversity Value involved testing several indices before settling on the Irreplaceability Index. The goal was

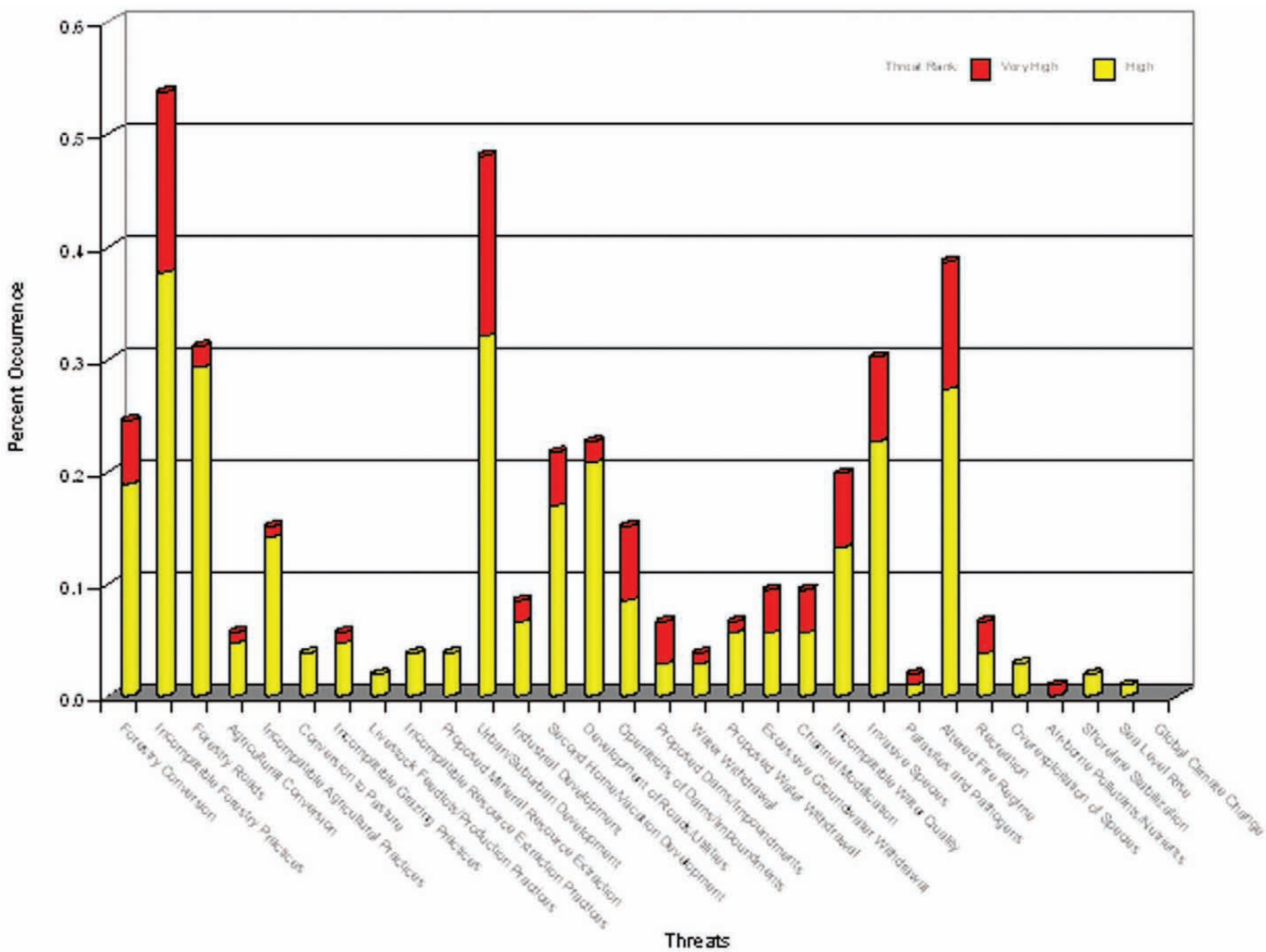

Figure 3. Very high and High Threats Ranks for each of the 30 threats scored for Georgia.

to rank conservation areas by a value representing the significant biodiversity of that area, moderating the bias of larger areas (usually having more targets), and giving additional weight to rare (having few occurrences across their range) and irreplaceable (occurring in only one location) targets. The first index used to represent Relative Biodiversity Value, incorporated the total number of ecoregional target occurrences and the number of globally rare targets (G1 and G2 ranked targets). However, this index did not represent conservation areas with "irreplaceable" targets (G1 targets found only at one conservation area in the ecoregion). Subsequently, conservation areas with an irreplaceable target were queried individually and assigned, by default, to the *Now-Right Now* sequencing category. In doing so, we lost the actual relationship between Relative Biodiversity Value and Relative Threat Status. Comparing the different indices found that each provided similar relational patterns between Relative Biodiversity Value and Relative Threat Status (Sutter and Szell unpublished data).

Enquist and others (2004) chose not to use the Irreplaceability Index, instead they used an index developed from 6 weighted attributes. While the correlation among their three indices were high (all greater than r=.85), they felt that the Irreplaceabiliy Index was more sensitive to sampling bias and the lack of knowledge of the distribution of targets among the conservation areas. We do not see this as an unique issue with the Irreplaceability Index, rather sampling bias will effect all indices in similar ways. With the Irreplaceability Index, only new targets at the scale of assessment (ecoregion, state) or the addition of an occurrences of a target in a new conservation area will have a substantial influence on the index. This, we believe, is outweighed by the simplicity and clarity of the Irreplaceability Index. In addition, the index's dynamic nature allows rapid re-evaluation of the "uniqueness" of a given conservation area as more target data becomes available. One does need to take care of interpreting a score of 1 for the Irreplaceability Index. This suggests that either the conservation area encompasses a target that only occurs at that location (1 of 1 occurrence) or many targets occur at multiple locations so when the many index values for a given conservation area are summed they give an index of irreplaceability (IRR) equal to 1. Thus the index does not guarantee that all very rare targets receive a high IRR score. The data itself (table 6) provides a means of assessing this.

Developing the Relative Threat Assessment measure also presented challenges. First, there was no standardized and comprehensive list of threats that could be adopted. We developed our own list of threats (table 1) from our experience, TNC conservation plans, and published articles (Salafsky and Margolius 1999). The content and structure of the list, as expected, evolved through the process, although we had to continue scoring threats in the categories first chosen. We would recommend others using our more comprehensive list, structured with primary threats and an associated list of threat descriptors (Appendix A, available on ConserveOnline). A standardized list of threats will be essential for studies that assess threats across different scales, assessments, and organizations.

Secondly, the associated time frame for ranking threats is a challenge. Threats can be ranked as historic (past threats that are no longer active but their impacts are still effecting biodiversity in the conservation area), active (current threat or one that has a very high probability of occurring over a selected time frame) and future (a potential threat that is not currently active). Historic threats become the focus of ecological restoration, while active threats need to be first addressed by some level of threat abatement. Some active threats that are scored at lower levels of severity (invasive species) and some future threats (climate change, sea level rise) need to be addressed proactively. For invasive species, control efforts are much more successful at low levels of invasion, before they reach levels that get scored as high severity. Efforts to mitigate the effects of climate change and sea level rise needs to be taken into account in conservation planning. While obvious from the nature of these threats, the scoring did not take these issues into account.

We had extensive input from practitioners into the Relative Conservation Opportunity parameter, for both the identification of attributes and the development of criteria. It was difficult developing a categorized and linear structure for a process that is complex and interrelated. A significant issue is the order in which these parameters are scored. We feel strongly that the biodiversity value and threat status of conservation areas should be assessed before opportunities are overlain. This order makes explicit the primary importance of what is ecologically significant before conservation opportunities are taken into account.

The results of Sequencing are not intended to be absolute, but guidance for conservation entities. The graphs allow the comparison of Relative Biodiversity Value and Relative Threat Status, providing the basis to assess the trade-off in acting at one site over others. As mentioned, where along the threat continuum a conservation entity works, from highly threatened to not threatened, is a matter of choice. The more threatened a conservation area is, the lower the probability of conservation success. Conservation areas scored with a very high Relative Conservation Opportunity in the *Now-Right Now* category, especially in the attributes of funding and opportunity windows, are clearly places for priority action. Conservation areas with low Relative Conservation Opportunity scores in the *Now-Right Now* category are places where opportunities can be developed. Conservation areas scored with a very high Relative Conservation Opportunity in the other sequencing categories challenge conservation entities to assess the trade-off among areas of different biodiversity values and threat status. Going through the process itself is an extremely valuable exercise as it poses important issues that any conservation entity needs to address. Sequencing facilitates a thoughtful approach to establishing conservation priorities.

The Sequencing process makes explicit several significant questions concerning how conservation is implemented. Some of these are: Should conservation entities focus conservation efforts on the most threatened or the best remaining conservation areas? How do conservation entities balance between working deep at a few conservation areas and working on broader, larger scale actions that influence conservation at multiple scales? Should conservation entities focus work on large landscape sites or a mix of spatial scales? Should conservation entities focus on conserving targets nearest to extinction or actions that influences all conservation targets equally? How do conservation entities make decisions between high priority conservation areas and opportunities for conservation at lower priority sites? These questions need wider discussion within the conservation community as NGOs and agencies consider where, when, and how to invest limited funds to maximize conservation benefits.

The results from Sequencing Conservation Actions provides significant insight into establishing priorities for conservation, explicitly showing the relationship of the conservation areas to biodiversity value, threat, and conservation opportunity. The process takes significant but not extensive time to complete and the scoring is straightforward and understandable. The overall benefit is that it provides consistency and transparency to the process of establishing conservation priorities and makes explicit important conservation decisions.

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Monitoring of Biodiversity Indicators in Boreal Forests: A Need for Improved Focus

Ian D. Thompson

Abstract—*The general principles of scale and coarse and fine filters have been widely accepted, but management agencies and industry are still grappling with the question of what to monitor to detect changes in forest biodiversity after forest management. Part of this problem can be attributed to the lack of focused questions for monitoring associated with an absence of null models and predicted effects, a certain level of disconnect between research and management, and recognition that, in the case of forest management, monitoring is research. Considerable research from the past decade has not been adequately synthesized to answer important questions, such as which species might be the best indicators of change, what is the importance, if any, of subtle changes in community structures, and causes of observed changes. A disproportionate research emphasis has been placed on community ecology, and mostly on a few groups of arthropods, amphibians, migratory songbirds, and small mammals, while other species, including soil organisms, lichens, bats, raptors, and larger mammals remain less well-known. Hence, our ability to deal with questions of persistence is limited, and demographic research on key species is urgently needed. Management agencies need to clearly articulate null models for monitoring, focus fine-scale monitoring on key species in key habitats and areas to answer clear questions, and have a protocol in place to adapt management strategies to changes observed. Finally, agencies must have some way to determine and define when a significant change has occurred and to predict persistence of species; this too should flow from a proper null model.*

Introduction

Effectiveness monitoring is the use of indicators to determine achievement of management goals and objectives, while validation monitoring is used to investigate the relationship between an action and an effect as a test of a hypothesis (Mulder and others 1999). These two types of monitoring with respect to forest management should not be considered different, and all biodiversity monitoring should examine objectives in light of expectation, or hypotheses. In other words, monitoring the effects of forest management should be considered a research problem. However, monitoring needs for management evaluation requires ecologists to conduct long-term research without the benefits of experimental manipulation. In this way, ecologists are caught in an experimental time-space warp.

Despite more than 20 years of research into the effects of boreal forest management on animal and plant communities, with few exceptions, management agencies are still uncertain of how to monitor effects (or effectiveness). The broad concepts of coarse and fine filters (Noss 1987, 1999, Hunter 1990), although somewhat modified from the original intent, are generally well accepted, as is the principle that forest management affects biodiversity at multiple scales. A large and varied number of criticisms have been made of the use of indicators to suggest change as a result of forest management (Steele and others 1984, Landres and others 1988, Prendergast and others 1993, Carignan and Villard 2002). Nevertheless, it is impossible to infer sustainability without monitoring something, and all authors agree that a set of indicators is needed (Landres and others 1988, McLaren and others 1998, Lindenmayer 1999, Carignan and Villard 2002).

However, difficulties arise in the development of details, particularly over what to monitor, how often to monitor, what sample sizes are needed, and ultimately how to decide whether or not a measured change is meaningful. In fact the latter issue is rarely considered in monitoring programs. These problems arise for several reasons including a lack of application of research results to management practice, uncertainty about the questions that a monitoring program should answer, and especially the lack of scientific rigor in application of a monitoring program to the problems at hand. There is a need for management agencies to develop clear questions before designing and undertaking monitoring programs. This paper suggests various means to correct some of the problems that have arisen, clouding the intent, design, and interpretation of results from monitoring programs. The paper does not address in a comprehensive manner the selection of indicators or the statistical considerations for designing a monitoring program. For specific discussions of ways to chose indicators, the reader is referred to: McLaren and others (1998), Noss (1999), and Carignan and Villard (2002), and for statistical and power considerations to Link and others (1994), Phillippi and others (1998), Gibbs and others (1998), Pollock and others (2002), Carlson and Schmiegelow (2002), and Rempel and Kushneriuk (2003).

A Need for the Improved Use of Available Research

The catalogue of research studies into the effects of boreal forest management on aspects of biodiversity during the past 20 or more years is impressive. A simple search on "biodiversity + boreal + forest management" in a single forestry-related library database, for 1980 to 2004, produced more than 300 published articles. However, much of the available research is in a published format that management agencies do not or rarely use. Academic researchers view the scientific community as their main "client," and so results are published in scientific journals that managers rarely read and using language that is difficult to read. As a result, much of this information remains obscure and unavailable to management agencies because of a lack of directed and meaningful syntheses, and the inability (or disinterest) of researchers to move their results into management practice. By "meaningful synthesis," I am referring to the need to use the published literature to develop predictive models of effects, which can lead to a strong set of indicators that can be monitored as a test of a hypothesis. Considerable information on which to base monitoring programs is available but remains non-influential, and as a result monitoring programs in boreal forests are somewhat mired in uncertainty.

As an example in boreal forests of Canada, researchers have keyed in on the importance of standing and fallen deadwood with certain characteristics that provides strong predictive capability for breeding by some species (Bonar 2000, Setterington and others 2000, Drapeau and others 2002, Steeger and Dulisse 2002). A synthesis of this information could be used to develop models leading to predictions of when certain species might begin to re-occur in managed forests, for example as was done by Bunnell and others (2002), leading to a hypothesis of effect. Models may also lead to predictions about thresholds of response to particular structures (fig. 1).

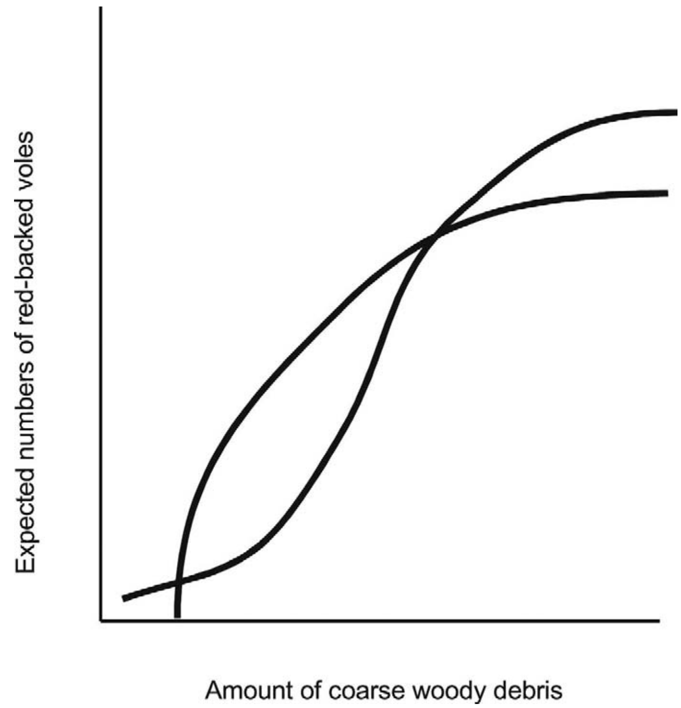

Figure 1. Possible thresholds and responses exist in response of species to structures and amounts of forest, and if properly modeled provides managers with testable hypotheses. In the illustrated case, two possible models suggest responses by red-backed voles (*Clethrionomys gapperi*) in mature boreal forests to the volume of coarse woody debris. Monitoring could be used as a test of the hypothesis that a certain volume of CWD is required for the voles to persist and to examine the suggested thresholds for population. These models are based on unpublished data for dry conifer (exponential) and lowland conifer (logistic) (I. Thompson, Can. For. Serv.).

However, little demographic information and few species-specific studies are available to enable assessment of persistence of species associated with dead wood structures. Nevertheless, models could be developed to predict responses.

Re-focusing Research

There has been excessive study of certain groups of organisms, especially carabid beetles, forest songbirds, and small mammals, yet on the other hand the cryptic and the more difficult-to-study organisms remain obscure as does species-specific information on demography. For example, certain groups of species that have proved to be useful indicators in Scandinavian boreal forests, have not been well-researched in the Canadian boreal forest. These include bryophytes, fungi, saproxylic beetles, and lichens (Esseen and others 1996, Jonsson and Jonsell 1999, Berglund and Jonsson 2001). As a result, even the broad effects of forest management on many potential indicators remain unknown. Other groups of species that remain poorly known in boreal forests include small carnivores, owls, raptors, cryptograms, and all soil organisms. Among the small carnivores, marten and lynx are reasonably well researched, but fisher, red fox, all three boreal weasel species, river otter, and mink have not been adequately studied to predict the effects of forest management.

For the commonly studied groups, researchers have most often decided to examine community-level questions. These studies invariably show a re-ordered abundance of species by forest management treatment, but provide limited information about the causal effects of forest management on species persistence and no information on the effects of such changes on ecosystem function. For example, a recent publication by Work and others (2004) concluded that the community composition of carabid beetles was dramatically different depending on stand origin (fire or logging) and by cover type. Their conclusion was that "…[the species] exist in different mixes and it is not clear that the persistence of all species would be assured [under different management regimes] on the managed landscape." This is the same as saying that they could draw no conclusions with respect to species persistence and so could not comment about the effects of forest management, other than to say that relative abundances had changed. The literature is replete with these kinds of studies, all indicating that differences in relative species abundance had occurred as a result of forest management, but which provided no information about important mechanistic relationships. Lindenmayer (1999) points out that such studies also reveal little about cumulative impacts in space or time. This kind of result has done little to inform management agencies and do not contribute to a monitoring program. However, what these community-based studies can provide is suggestions about species that may be affected and so lead researchers towards subsequent demographic and detailed habitat studies that may reveal causal links to the effects of forest management. Unfortunately, few such studies are available in boreal forests and modeling persistence is not possible for most species, although there are notable exceptions (marten [*Martes americana*], snowshoe hare [*Lepus americana*], and balsam fir [*Abies balsmifera*]). Schumaker and others (2004) developed habitat scenarios for suites of wildlife species but noted their inability to deal with the persistence issue owing to lack of information for most. We need to move past community studies and onto detailed examinations of habitats and demographics of individual species that are predicted to be affected negatively by forest management. Spatially explicit population models can be used to develop population-based predictions of effects that can be examined through monitoring.

What is the Correct Monitoring Question?

Forest management is a large-scale experiment in community ecology, hence monitoring requires research hypotheses that flow logically from this experiment. Logging in the Canadian boreal forest has a relatively young history, beginning in the 1940s, only becoming mechanized in the 1960s, followed by a rapid expansion in area in the 1970s in the east but not until the late 1980s in the west. There are no mechanically-logged second-growth forests that are old enough to compare to natural-origin old forests. Bearing this in mind, simulation modeling is the only tool to enable some perspective about the sustainability of forest management in the long term. However, we can examine younger forests that are comparable in age but were derived from natural and managed disturbances, while maintaining benchmark old forests to enable the longer-term modeling predictions to be tested.

For monitoring to contribute to our understanding of the effects of forest management, it must be viewed as a mensurative science experiment with testable hypotheses. Therefore, in designing a monitoring program, a key need is to formulate the correct questions. The main underlying question is not "how has abundance of species A or forest ecosystem X changed over time in response to a given practice?" Rather, the issue is "has a change occurred in response to a forest management practice that was unexpected and deleterious to the persistence of a population of a particular species?" (In Ontario, for example, the scale is set at the "forest management unit" [FMU, approximately 5000 km^2] because plans are developed at this scale and each plan has to demonstrate sustainability). In other words, "will the species or population continue to survive over the long-term in this forest?" In the ultimate sense, sustainable development is about the preservation of genetic diversity. Thinking at this level, that is, about what might cause the loss of genes from populations, should help to develop a monitoring program that will succeed. There is a need to monitor local populations (in other words, FMU-scale), not just species or elements at a regional scale.

There must be some a priori expectation (hypothesis) against which to measure effect and a means to identify an unacceptable level of impact. In the few instances where management agencies have followed a well-developed plan for a boreal biodiversity monitoring program (the Alberta Biomonitoring Program, Farr and others 1999), there is still no explicit means of determining when to declare that a problem exists. Monitoring programs need to consider observed changes measured under an appropriate null model, and in the light of changes to coarse filters that are also monitored. Null models provide a basis against which to determine that a significant negative effect has occurred. In the absence of a such a model, monitoring is nothing more than counting organisms and assessing trends in time (Krebs 1991, Nichols 1999), but cannot answer the question "when has a sufficient change occurred to warrant corrective management action?"

Appropriate null models are debatable and require considerable thought and various lines of evidence from research to develop properly. In recent years at coarse scales, forest management has moved away from sustained yield towards emphasizing planning that is "close to nature" or that "emulates natural disturbances," at scales from forest stands to large landscapes (Harris 1984, Hunter 1990, Attiwill 1994). In boreal forests, many authors have argued that "natural disturbance emulation" is the appropriate null model because these forests were mostly disturbance-driven, especially by fires (Harris 1984, Haila and others 1994, Bergeron and Harvey 1997). An important issue to understand, as a forest manager, is "will forest communities that result following harvesting converge with those forest communities that result following natural disturbances, and hence maintain associated biological diversity and all the same goods and services?" In other words, we need to know if it is possible to use forest systems while maintaining their ecological integrity, and ensuring their stability (age structure, species composition, structures, and processes) within known bounds (Thompson and Harestad 2004). A monitoring program is meant to suggest whether or not such bounds have been exceeded, and should be developed to test differences between natural and managed forests of similar types on similar sites and of similar ages, for a range of indicators across scales.

There is, of course, considerable debate about the ability of forest managers to emulate natural disturbances, and how appropriate the natural disturbance model may be is open to some question (Hunter 1993, Landres and others 1999, Reich and others 2001). It may be that past landscapes cannot really be true predictors of future landscapes, given that humans have altered even natural processes, for example through suppression of fires, climate change, and the introduction of exotic species. One could argue that an appropriate null model should be based on an expected landscape as designed by humans.

The ability to develop well-informed null models may be limited by knowledge; however, this limitation has been reduced in recent years with an accumulation of studies about boreal forests and their biodiversity. This work has flowed from well-funded research programs under the Canadian Model Forests Network, National Research Council's Sustainable Forest Management Network, Ontario's Living Legacy Trust, Manning Forest Products Research Trust, Fonds québécois de recherche sur la société et la culture, and British Columbia Forest Renewal Program. However, the problem of incorporating these results into monitoring programs remains problematic as noted above.

The Value of a Model-based Monitoring Program

Models can fulfill several roles in the development of a monitoring program including estimating required sample sizes, indicating power, suggesting sample distribution, but most importantly to develop predictions based on previous knowledge. The latter use provides managers with a means to assess success and the ability to estimate the probability of persistence of an indicator. In a more general sense, models also force managers and researchers to examine closely what they understand about causal links between forest management and effects on biodiversity, and lead ultimately to revised management strategies (Walters and Holling 1990) and more focused research.

An Example of Model-based Predictions for Monitoring

Thompson and others (2003) published a review of the impacts of intensive forest management that enabled them to develop predictive probabilistic models of effects on individual species. The species modeled were selected based on an expectation of detectable effects over time in second-growth boreal forest stands, as compared to natural-origin forests of the same age and type. The curves were developed based on published literature and expert opinion and provided testable null hypotheses of probabilistic effect. Relative population changes were modeled for several species based on forest change with harvesting on a 5000 km^2 landscape in boreal eastern Ontario, Canada. Cape May warbler (*Dendroica tigrina*) and Tennessee warbler (*Vermivora peregrina*) are illustrated in figure 2. Species for which predicted effects were distinguishable between treatments (natural vs. managed) at 40-50 years of age could be used as indicators of sustainable forest management, such as in the case of the two warbler species shown. The predicted population changes are hypotheses of effect and monitoring would permit testing against the model. A decline of 20 percent could be selected as severe and would occur for Tennessee warblers by year 48 on this particular landscape, if no post-harvest treatment was done.

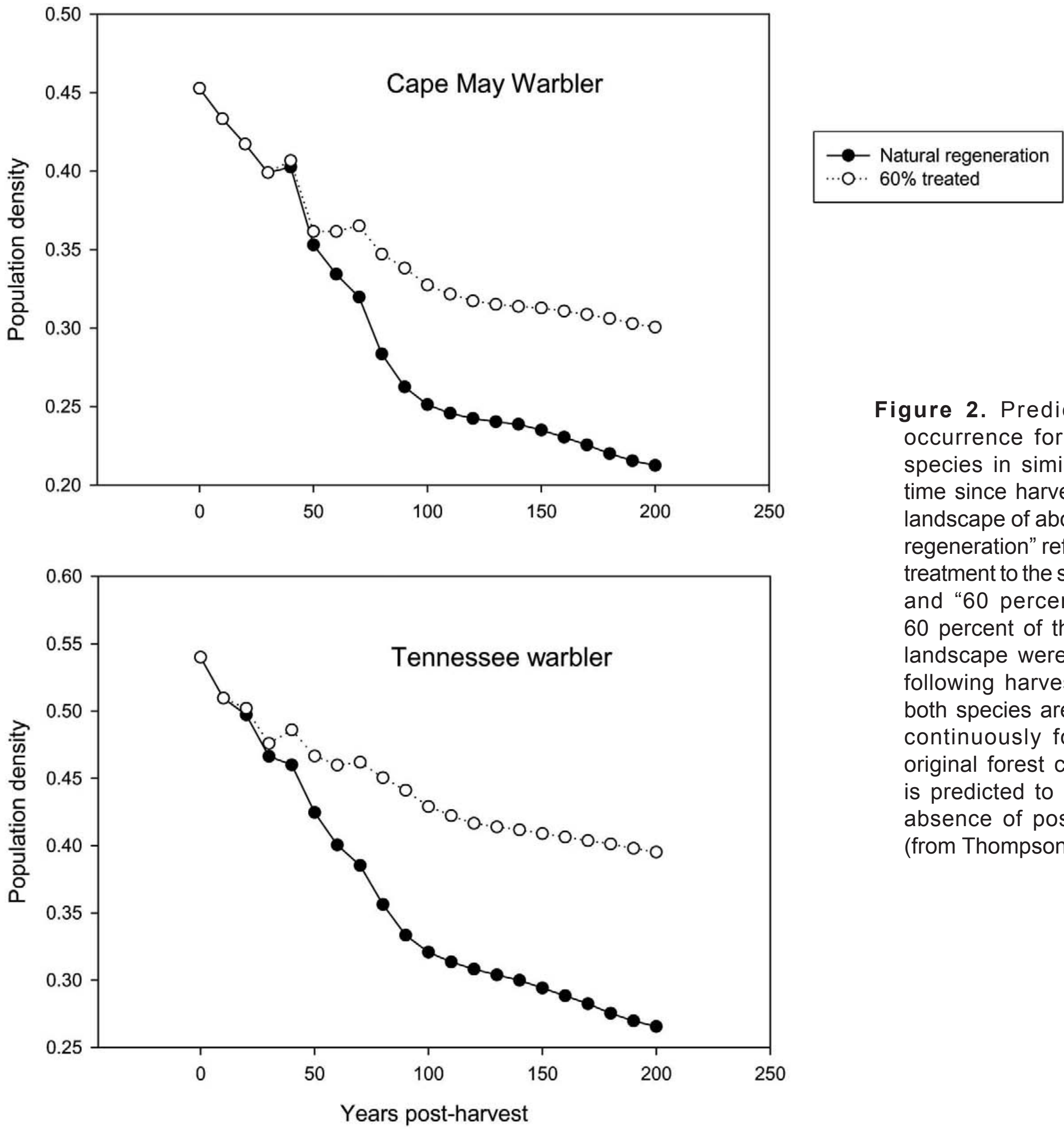

Figure 2. Predicted probability of occurrence for two boreal warbler species in similar forest types over time since harvest for a boreal forest landscape of about 5000 km^2. "Natural regeneration" refers to no post-harvest treatment to the stands post-harvesting, and "60 percent treated" refers to 60 percent of the stands on a given landscape were planted and tended following harvesting. Populations of both species are predicted to decline continuously following removal of original forest cover, but the decline is predicted to be precipitous in the absence of post-harvest treatment. (from Thompson and others 2003)

Some Additional Thoughts on Selecting Indicators

How to select species or elements to monitor is not the focus of this paper, and several excellent publications are available to help managers select indicators (see: Introduction). Nevertheless, some additional ideas to guide the selection of indicators would include: using existing community-based studies to implicate species of particular interest, choosing species for which modeling has suggested both stand and landscape effects (in other words, as predictor variables), including species that require specific forest structures known to change as a result of management, and selecting species that occur in rare or declining habitats (and monitoring the habitats themselves). Hansson (2001) called habitats in which there was a high probability of encountering "red-listed" species "key habitats" and suggested these areas required special consideration. Such areas have not been carefully identified in Canadian boreal forests. Although rare species present several sampling problems (for example, excessive zero plots, high variance, low power to detect change) (Link and others 1994), these species have a high probability of being among the first to become locally extinct, as a result of altered habitats or altered community-related processes, such as predation or competition. Hannon and others (2004) have suggested a protocol for identifying rare avian species in boreal forests. Locally rare species, especially where rarity is related to a rare habitat, warrant special consideration as indicators in a monitoring program. In the case of a rare indicator, concern over high variability among counts, or among years, could be offset by using several lines of evidence to determine change in population. For example, counts on snow transects, counts at scent posts, and camera traps might be used to provide three separate indices of a rare mammal species. Finally, to reiterate an earlier point, until the value as indicators of poorly studied groups of organisms is assessed (lichens, soil organisms, small carnivores), the available choices for indicators remains incomplete.

Conclusion

In the case of monitoring the effects of forest management, we need to be clear that monitoring is long-term research. A proper framework for monitoring programs that includes hypotheses, well thought-out models of effects, and clear objectives with respect to changes in numbers or amounts of indicators is needed for these programs to be effective. Simple arbitrary plans that declines will be detected are insufficient, as is the view that reporting numbers is somehow meaningful. A monitoring program should be seen and developed as a test of hypotheses relating to the experiment of sustainable forest management. Improved use of existing research can be made to develop testable hypotheses under a monitoring program, and future research should concentrate less on community ecology and more on key species and key habitats to understand causal links to the effects of forest management. Finally, in boreal forests considerable research is still needed on many poorly understood species so that indicators can be selected from the range of functional groups in these systems.

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Southwestern Avian Community Organization in Exotic Tamarix: Current Patterns and Future Needs

H. A. Walker, doctoral candidate, Department of Biology, University of New Mexico, Albuquerque, NM 87131 and seasonal Wildlife Biologist, USDA Forest Service Rocky Mountain Research Station, Albuquerque, NM

Abstract—*Tamarisk (saltcedar:* Tamarix*), an invasive exotic tree native to the Eastern Hemisphere, is currently the dominant plant species in most southwestern riparian ecosystems at elevations below 1500 m. Tamarisk alters abiotic conditions and the floral composition of native southwestern riparian ecosystems and, in turn, affects native southwestern animal communities. However, information on the overall effects of tamarisk on avifauna is somewhat conflicting and incomplete. This paper attempts to resolve conflict in the literature by addressing several questions: (1) Are there consistent broad geographic patterns in avian species richness and abundance in tamarisk?; (2) Which groups of birds use tamarisk?; and (3) Which attributes are most useful in predicting avian use of tamarisk? A survey of published literature found that overall avian species richness and abundance in tamarisk are not consistent across broad geographic scales, but vary consistently between the Rio Grande and the Pecos and Colorado Rivers. Examination of geographic variation in food and nesting resources provided by tamarisk-dominated vegetation did not fully explain overall geographic patterns; most groups of birds show consistent use of tamarisk across geographic locations. However, use of tamarisk by cup nesting breeding birds does vary with geographic location. Since most research on avian use of tamarisk has been completed on breeding birds, patterns in breeding birds appear to drive the documented geographic patterns. Overall, avian use of tamarisk is best explained by species-specific nesting and foraging requirements, which in turn covary with vegetation structure and floristics, and are mediated by climatic influences. Since large gaps still exist in the knowledge base, especially for wintering and migrating birds, more research should be completed on both local and regional avian use of tamarisk and a classification system of tamarisk vegetation types should be developed to aid in defining which types of tamarisk are most useful or detrimental to wildlife.*

Background

Evidence that humans impact their local environment dates as long ago as 40,000 years before the present (Drake and others 1989). As human populations on the planet grow, expand, and colonize new landscapes, humans are also beginning to impact the global environment by: 1) increasing concentrations of carbon dioxide in the atmosphere and altering global climatic conditions; 2) producing and releasing persistent organic compounds (for example, chloroflourocarbons); 3) changing land cover; and 4) encouraging the spread of invasive organisms, so-called "biological pollutants" (Coblentz 1990, Soulé 1990, Jobin and others 1996, Vitousek and others 1996, Olson and Harris 1997, Higgins and others 1999, Palumbi 2001). Potential impacts of human activities include local and global species extinctions. Areas where "anthropogenic activities reduce natural habitat in centers of endemism" (Dobson and others 1997:550) are considered "hot spots" of species endangerment. Within the United States, the Southwest is one of several regions designated as such a hot spot (Dobson and others 1997, Flather and others 1998, Abbitt and others 2000). The Southwest includes southeastern California, most of Arizona and New Mexico, southwestern Colorado and southern Utah, and Texas west of the Pecos River (Bogan and others 1998). The region is topographically and climatically diverse, with elevations ranging from sea level to 4,000 m, and temperatures ranging from mild to extreme cold or intense heat. Precipitation and water availability also vary. The diversity of abiotic conditions, combined with elevational and latitudinal gradients, create a multitude of microhabitats, which have contributed to the evolution and maintenance of biological endemism and diversity (Hubbard 1977, Szaro 1980, Bogan and others 1998). Southwestern ecosystems most threatened by human activities are desert shrubland, arid grassland, and, particularly, riparian.

Southwestern riparian ecosystems occur along streams and rivers and are characterized by narrow bands of mesic vegetation embedded in extensive areas of xeric upland vegetation (Szaro and Jakle 1985, Knopf and others 1988). Anthropogenic alteration, degradation, and destruction of native riparian ecosystems have great potential to negatively impact the long-term stability of southwestern wildlife populations. Southwestern riparian areas are one of the few places where plants and wildlife can find surface or near-surface water and, consequently, support a large number and variety of southwestern wildlife species (Stamp 1978, Szaro 1980, Knopf and others 1988, Brown and Johnson 1989). Specifically, southwestern riparian areas support more breeding birds than surrounding uplands and attract higher numbers of migratory birds (Carothers and others 1974, Stamp 1978, Szaro 1980, Szaro and Jakle 1985, Hunter and others 1988, Knopf and others 1988, Ellis 1995, Yong and Finch 1997, Patten 1998, Skagen and others 1998, Yong and others 1998, DeLay and others 1999, Kelly and Finch 1999, Kelly and others 2000).

Although indigenous peoples have inhabited the Southwest for at least 10,000 years (for example, the Anasazi, Mogollon, and Hohokam peoples), large-scale anthropogenic impacts to southwestern riparian ecosystems intensified in the 1870s when the Southwest began to be settled by Anglo-Americans, accompanied by development of irrigation, agriculture, livestock grazing, and, eventually, urban and suburban areas (Carothers 1977, Bogan and others 1998). Threats to native riparian ecosystems include: 1) removal of native riparian vegetation (for example, phreatophyte control); 2) urban and suburban development; 3) groundwater pumping; and 4) river damming, diversion, and channelization (Carothers and others 1974, Carothers 1977, Davis 1977, Johnson and others 1977, Ohmart and others 1977, Knopf and others 1988, Johnson 1989, Howe and Knopf 1991, Marshall and Stoleson 2000). In addition, but perhaps not as widely appreciated, native riparian ecosystems are being altered by the spread and establishment of exotic plants, which can affect ecosystem function and distributions and population dynamics of native species (Knopf and others 1988, Howe and Knopf 1991, Vitousek and others 1996, Westbrooks 1998, Higgins and others 1999, Fleishman and others 2003).

An invasive exotic plant of management concern in the Southwest is tamarisk or saltcedar (*Tamarix*), a long-lived (50 to 100 years) deciduous tree native to arid regions of the Eastern Hemisphere. Plants within the *Tamarix* genus are generally characterized by: 1) deep pink to almost

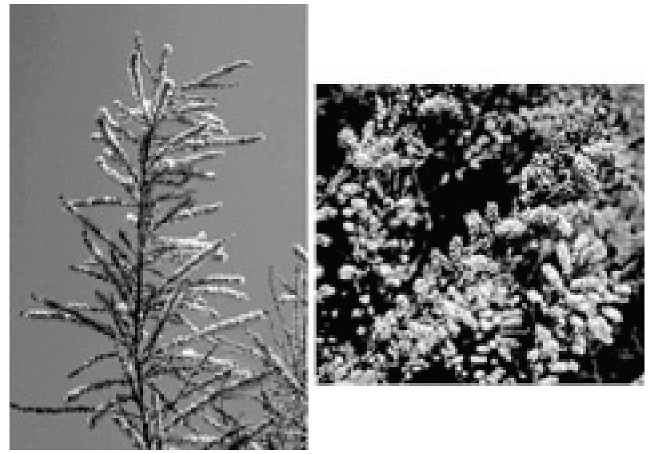

Figure 1. Flowering tamarisk (*Tamarix*). (Photograph reproduced with the permission of the King County Noxious Weed Control Program.).

white flowers (fig. 1); 2) capsule fruit, bearing many tiny seeds; 3) small scale-like leaves with salt-secreting glands; and 4) deep, extensive root systems (up to 100 feet) that extend to the water table. Several species of tamarisk were first introduced into the United States in the early 1800s for stabilization of eroding stream banks and for use as both ornamentals and windbreaks (DeLoach 1997, Westbrooks 1998). By the 1930s, tamarisk had successfully invaded riparian areas throughout the western United States (Anderson and others 1977a, Ohmart and others 1977, Brown and Johnson 1989, DeLoach 1997). Initial spread of tamarisk along such rivers as the Gila, Salt, Pecos, Colorado, and Rio Grande was encouraged by the construction of dams and flood control structures, which disrupted natural hydrologic cycles and decreased the competitive ability of native plant species that depended on flood-created regeneration sites (Marshall and Stoleson 2000). Subsequently, tamarisk has successfully invaded riparian areas and ephemeral wetlands (for example, playas, arroyos, and alkali flats) that are relatively undisturbed by human activities. Introduced tamarisk is now the dominant plant species in most southwestern riparian ecosystems at elevations below 1500 m, where it often forms large monotypic stands to the exclusion of native plants.

The success of tamarisk in replacing native riparian plant species in the Southwest is partially due to its ability to alter ecosystem functioning and create unsuitable growing conditions for other plants. In particular, tamarisk: 1) increases soil salinity above the tolerance level of native plants by secreting a salty exudate from its foliage; 2) reduces water availability by drawing down ground water with its deep root systems to depths below root systems of native plants; and 3) increases fire frequency by shedding its foliage and creating thick, fire-prone ground cover (Anderson and others 1977a, Cohan and others 1979, Livingston and Schemnitz 1996, DeLoach 1997). Tamarisk is able to further limit growth of native plant species due to the fact that it: 1) has a 5-month fruiting period that allows it to exploit suitable germinating conditions over a longer period than many native plant species (Howe and Knopf 1991); 2) produces a large seed bank that allows it to out-compete many native plant species for germination sites (Cohan and others 1979, Howe and Knopf 1991, Westbrooks 1998); 3) in the absence of scouring flows, forms thick stands that shade native plant germination sites; and 4) establishes opportunistically (in both saturated and dry surface soils) after flood disturbance (Stromberg 1997).

By altering abiotic conditions and the floral composition of native riparian ecosystems, tamarisk also affects native southwestern animal communities (DeLoach 1997). However, information on the overall use of tamarisk by wildlife is conflicting and somewhat incomplete. Some authors have reported preferential use of tamarisk vegetation by certain animal species, while other authors have reported that, like many exotic plant species, tamarisk establishment alters animal species compositions and reduce biodiversity (DeLoach 1997, Olson and Harris 1997). Similar debate exists in the literature regarding the value of tamarisk specifically for avifauna. It is generally accepted that initial spread and establishment of tamarisk in native southwestern riparian ecosystems, and corresponding loss of native vegetation, resulted in population reductions in many riparian bird species (Carothers 1977, Ohmart and others 1977, Cohan and others 1979, Hunter and others 1985, Hunter and others 1987, Hunter and others 1988). However, there is evidence that birds are adjusting to the expansion of tamarisk and are utilizing tamarisk-dominated vegetation for both nesting (Hunter and others 1988, Brown and Trosset 1989, Fleishman and others 2003) and foraging (Yard and others 2004). Unfortunately, determining the value of tamarisk to avifauna has been confounded by the fact that bird/tamarisk relationships vary with geographic location (Livingston and Schemnitz 1996).

It is estimated that at the current rate of spread exotic plants will dominate all southwestern riparian ecosystems within 50 to 100 years (Howe and Knopf 1991). Therefore, knowledge of the effects of tamarisk on native organisms will become substantially more relevant as tamarisk becomes the predominant vegetation type available and as the need for habitat management increases (Anderson and others 1977a, Ohmart and others 1977). In this paper, I examine several questions concerning the value of tamarisk to avifauna: (1) Are there consistent broad geographic patterns in avian species richness and abundance in tamarisk?; (2) Which groups of birds use tamarisk?; and (3) Which attributes intrinsic and extrinsic to tamarisk are most useful in predicting avian use? Answers to these questions will help to determine which groups of birds respond most negatively and positively to tamarisk establishment and whether tamarisk can provide avian habitat functionally similar to native riparian vegetation. Such information will inform management practices that seek to control or eradicate exotic vegetation and protect southwestern bird species. In addition, since bird species can be good indicators for other taxa (Dobson and others 1997), knowledge of the effects of tamarisk on avifauna can also help to guide conservation efforts on other taxa.

Geographic Patterns in Avian Use of Tamarisk

In trying to resolve debate regarding the value of tamarisk to avifauna across the Southwest, I attempted to glean broad predictive patterns from the published literature. However, it became immediately apparent that most research investigating avian use of tamarisk was biased towards riparian ecosystems that were historically dominated by native cottonwood (*Populus*), willow (*Salix*), and/or mesquite (*Prosopis*) along the Rio Grande and Pecos and Colorado Rivers in New Mexico, Texas, and Arizona. Furthermore, it also became apparent that geographic location is a strong determinant of avian use of tamarisk and associations of bird species with tamarisk vary consistently between the three southwestern river valleys. Specifically, tamarisk-dominated vegetation along the lower Colorado River supports a depauperate riparian bird community compared to tamarisk vegetation along the Rio Grande and Pecos River (Hunter and others 1985, Hunter and others 1987, Hunter and others 1988). This pattern can be seen at both the species and the community level.

Two species that illustrate geographic variability in species-specific use of tamarisk are Bell's Vireo (*Vireo bellii*, State Threatened in New Mexico) and Yellow-billed Cuckoo (*Coccyzus americanus*, Federal Candidate Species). The Bell's Vireo avoids monotypic stands of tamarisk along the lower Colorado River, but readily uses similar stands along the Rio Grande and at higher elevations along the Colorado River (Hunter and others 1985, Brown and Trosset 1989, Rosenburg and others 1991). Similarly, the Yellow-billed Cuckoo tends to be restricted to cottonwood-willow groves on the lower Colorado River, but is found extensively in tamarisk along the middle Pecos River (Hunter and others 1985, Hunter and others 1988, Rosenberg and others 1991, Livingston and Schemnitz 1996).

When species-specific patterns are summarized into total densities and species richness values, the total number of individuals and species supported by tamarisk relative to native vegetation also differs among the three river valleys (fig. 2). Tamarisk vegetation along the lower Colorado River supports lower avian densities and species richness than native vegetation types, while, along the middle Pecos River, where a substantial riparian woodland was absent prior to establishment of tamarisk, total densities and species richness in tamarisk surpasses that of the native Chihuahuan grassland and shrub (Anderson and others 1977a and 1977b, Cohan and others 1979, Anderson and Ohmart 1984b, Hunter and others 1985, Hunter and others 1988, Rosenberg and others 1991, Livingston and Schemnitz 1996). Tamarisk invasion has even promoted expansions of several bird species within and into the Pecos Valley (Hunter and others 1988, Livingston and Schemnitz 1996). On the Rio Grande, several published studies report that avian densities and species richness are lower in tamarisk relative to native vegetation (Anderson and Ohmart 1984b, Hunter and others 1988, Kelly and Finch 1999), while other studies report that avian densities and species richness are either similar or higher in tamarisk (Hunter and others 1985, Ellis 1995, Livingston and Schemnitz 1996, Kelly and Finch 1999). Despite conflicting results within the Rio Grande, evidence suggests that tamarisk vegetation generally supports more birds along the Rio Grande than along the lower Colorado River (Hunter and others 1985, 1988).

Avian use of tamarisk also varies geographically among bird communities classified by residency status (Anderson and Ohmart 1977a, Hunter and others 1985, Hunter and others 1987, Hunter and others 1988). There are four principal residency groups: 1) residents (also called permanent residents), which tend to be present in southwestern riparian ecosystems throughout the year; 2) summer residents (also called summer visitors or summer breeders), which are only present in the ecosystem during late spring and summer; 3) winter residents (also called winter visitors), which are only present for varying lengths of time between September and April; and 4) transients (also called en route migrants), which are only present for narrow time periods during fall and spring migration (Szaro 1980, Hunter and others 1985, Hunter and others 1987, Hunter and others 1988, Finch and others 1995). Most research on use of tamarisk by residency groups has focused on residents and summer residents during the summer breeding season. Little research has been completed on winter residents and even less on transients.

Studies on residents and summer residents during the breeding season indicate that peak timing of egg laying

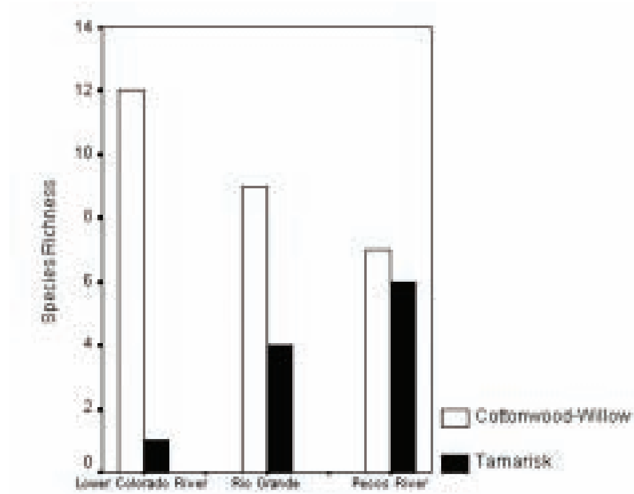

Figure 2. Number of bird species (N=13), common to the Rio Grande and the Pecos and lower Colorado Rivers, with more than fifty percent of their detections in either cottonwood-willow (*Populus-Salix*) or tamarisk (*Tamarix*) vegetation, when evaluating presence only in those two vegetation types. Adapted from data published in Hunter and others 1985, 1988.

is a confounding determinant in breeding bird use of tamarisk (Hunter and others 1985, 1988). Use of tamarisk by early summer breeders generally increases from east to west (Hunter and others 1985, 1988). In contrast, most midsummer breeders are largely restricted to native vegetation on the lower Colorado River, but they occur in greater or equal densities in tamarisk as native vegetation on the middle Pecos River, the Rio Grande, and higher-elevation stretches of the Colorado River (Anderson and others 1977a, Cohan and others 1979, Hunter and others 1985, Hunter and others 1987, Hunter and others 1988). Research during the winter season indicates that avian densities and species richness in tamarisk also follow geographic patterns; densities and species richness of wintering birds are generally lower in tamarisk than in native vegetation types on the lower Colorado River and Rio Grande, while wintering birds use tamarisk heavily on the middle Pecos River (Anderson and others 1977a, Cohan and others 1979, Anderson and Ohmart 1984b, Hunter and others 1988, Rosenberg and others 1991).

There is some evidence to suggest that, as with breeding and wintering birds, use of tamarisk by transients is also site-specific. However, the only published studies that specifically addressed use of tamarisk by transients were from the middle Rio Grande. I found no published studies on transient use of tamarisk on the Pecos River and the few studies that measured avian use in tamarisk during the spring and/or fall migratory periods along the lower Colorado River provided little specific information on migrating birds. The lack of work on transient use of tamarisk makes conclusions problematic. Nevertheless, it appears that transients use tamarisk along the middle Rio Grande, sometimes in equal numbers to the native vegetation (Leal 1994, Ellis 1995, Yong and others 1998, Kelly and Finch 1999, Kelly and others 2000, Yong and Finch 2002), while both spring and fall birds (of all residency groups, not just transients) avoid tamarisk along the lower Colorado River (Anderson and others 1977a, Cohan and others 1979, Anderson and Ohmart 1984b).

Confounding Variables: Explaining Geographic Variation in Avian Use of Tamarisk

Geographic variation in avian use of tamarisk appears to pose an obstacle to drawing sweeping region-wide conclusions about the value of tamarisk to avifauna: few region-wide generalizations can be derived from information based on only one river valley. However, geographic variation in avian use of vegetation is not unique to tamarisk. It reflects the interaction between the life histories of particular bird species and geographic variation in physical and biological environmental factors necessary for survival and reproductive success (Szaro 1980, James and others 1984, Rosenberg and others 1991). Interspecific competition also plays a role in determining species' occurrences, but it is difficult to quantify over broad geographic regions (Carothers and others 1974, James and others 1984).

Geographic variation in both physical and biological environmental factors is apparent in tamarisk-dominated sites. Due to its ability to tolerate a wide range of environmental conditions, tamarisk can flourish along both permanent and ephemeral water sources and in a wide variety of soil types (saturated and dry), elevations, and climates. In addition, both the structure of tamarisk vegetation and the floristics of adjacent and associated vegetation are variable (Brotherson and others 1984). As a result of differences in environmental features among tamarisk vegetation across local and broad geographic scales, tamarisk provides a variety of abiotic microclimates, food resources, and foraging and nesting substrates. Thus, variation in environmental features must be examined in relation to avian life history requirements in order to tease apart the factors that confound region-wide patterns in avian use of tamarisk (James and others 1984, Sogge and Marshall 2000).

In the following paragraphs, I will evaluate the extent to which food resources, nesting substrates, vegetative structure, and climate underlie the following two somewhat consistent patterns in avian use of tamarisk: 1) tamarisk vegetation along the lower Colorado River supports fewer total species and individuals of midsummer breeding and wintering birds than tamarisk vegetation along the Rio Grande and middle Pecos River; and 2) early summer breeders are more abundant in tamarisk along the lower Colorado River than in tamarisk along the Rio Grande and the middle Pecos River.

Confounding Variable: Food Resources

Food acquisition is important for survival during all phases of a bird's annual cycle and influences seasonal patterns in habitat use. Not all birds use tamarisk to meet food-related requirements and some forage largely or exclusively in adjacent vegetation. Nevertheless, many bird species appear to forage in tamarisk. Few studies investigating the value of food resources in tamarisk to birds used direct measures such as observations of foraging behavior or analyses of stomach and fecal contents. Instead, correspondence between presence of avian diet guilds and abundance of food types is used as a proxy indictor of whether tamarisk vegetation provides necessary food resources. Five primary diet guilds are discussed in the literature: granivores, frugivores, timber-drillers and timber gleaners (which are often considered to be foraging, rather than diet, guilds, but will be included here), nectivores, and insectivores.

Little geographic variability is evident in use of tamarisk plants by granivores, frugivores, timber-drillers and timber gleaners, and nectivores. Granivorous bird species prefer or do not avoid tamarisk, while frugivores, timber-drillers and timber gleaners, and nectivores appear to avoid tamarisk (Anderson and others 1977a, Cohan and others 1979, Brush 1983, Anderson and Ohmart 1984b, Rosenberg and others 1991, Ellis 1995). Consistent use of tamarisk by granivores is due to the fact that, though affected by age and water availability, all tamarisk plants produce copious amounts of seeds (up to 100 million seeds per year) from mid-spring to fall. Its lack of fleshy fruits and dense, hard wood result in consistent avoidance of tamarisk by frugivores and timber-drillers and timber gleaners, respectively. Tamarisk floral morphology apparently limits the ability of nectivores to utilize the large numbers of nectar-laden tamarisk flowers available from mid-spring to fall.

In general, the large number of 1) pollinator species (for example, Cotinus beetles) attracted to flowering tamarisk; 2) the exotic leafhopper (*Opsius stactogalus*) accidentally introduced with tamarisk; and 3) Apache cicadas (*Diceroprocta apache*) are good sources of arthropod prey for insectivorous birds in tamarisk vegetation during spring and summer (Rosenberg and others 1982, Glinski and Ohmart 1983, Glinski and Ohmart 1984, Andersen 1994, Drost and others 2003, Yard and others 2004). However, unlike in the above four diet guilds, use of tamarisk by insectivorous birds has been found to vary with location and season; some studies have found that insectivorous birds showed no selection against tamarisk (Anderson and others 1977a, Rosenberg and others 1991, Ellis 1995), while others have found the reverse (Cohan and others 1979, Anderson and Ohmart 1984b). Variability in tamarisk use by insectivores is partially explained by differences in: 1) adjacent vegetation, such as mesquite, which can be good sources for arthropod "tourist" species that move into tamarisk-dominated vegetation; 2) the composition and diversity of major arthropod taxa between tamarisk and native vegetation and between locations (for example, Apache cicadas are less abundant and Orthopterans are more abundant in tamarisk on the middle Pecos River than on the lower Colorado River); and 3) timing of emergence of Apache cicadas, which better matches the timing of bird migration and peak nesting in cottonwood-willow vegetation than it does in tamarisk vegetation, at least along the lower Colorado River (Cohan and others 1979, Hunter and others 1988, Rosenberg and others 1991, Andersen 1994, Mund-Meyerson 1998, DeLay and others 1999, Drost and others 2003).

Since granivores, frugivores, timber-drillers and timber gleaners, and nectivores (though locally variable) are either consistently absent or present in tamarisk, these four diet guilds do not explain differences between tamarisk avian communities along the lower Colorado River compared to those along the Rio Grande and the Pecos River. In contrast, differences in the presence of insectivores, corresponding to differences in arthropod resources, partly explain why tamarisk vegetation supports fewer birds along the lower Colorado River than along the Rio Grande and Pecos River. However, these differences alone do not fully explain geographic patterns in avian use of tamarisk, since: 1) arthropod diversity in tamarisk does not appear to differ markedly between the Pecos and Colorado Rivers; and 2) the low numbers of midsummer breeders along the lower Colorado River cannot be attributed entirely to differences in Apache cicada availability. Furthermore, arthropod prey abundance apparently does not differ consistently between the Pecos and Colorado Rivers; a large number prey items are consistently abundant in tamarisk along both rivers.

Confounding Variable: Nest Sites

In addition to food resources, the availability of nest sites, which directly affects reproductive success, is an important determinant in habitat selection (Hunter and others 1987). The ability to nest in tamarisk is partly related to nest type (for example, cavity, cup, platform) and the availability of suitable nesting substrates. Cup nesters (including riparian obligates) are able to use tamarisk vegetation in many areas and sometimes nest predominately in tamarisk even when native vegetation is available (Hunter and others 1988, Brown and Trosset 1989, Rosenberg and others 1991, Brown 1992, Ellis 1995). However, a number of species are generally unable to meet their nesting requirements in tamarisk vegetation, including ground nesting charadriiformes (for example, Least Tern [*Sterna antillarum*], Snowy Plover [*Charadrius alexandrinus*]), large raptors, and cavity nesters (for example, woodpeckers, nuthatches) (Anderson and others 1977a, Cohan and others 1979, Brush 1983, Hunter and others 1987, Rosenberg and others 1991, Ellis 1995, Koenen and others 1996, Taylor 2003). Large raptors might be absent from tamarisk due to the lack of tall, large trees needed for placement of platform nests (Hunter and others 1985). Cavity nesters might be absent from tamarisk because (1) tamarisk wood is too hard to excavate, (2) the body sizes of North American woodpeckers (and required cavity sizes) generally exceed the maximum size of tamarisk trunks and limbs, and (3) the absence of woodpeckers affects secondary cavity nesters that require woodpeckers for cavity excavation (Anderson and others 1977a, Brush 1983). A notable exception is the Ladder-backed Woodpecker (*Picoides scalaris*), which was the first New World woodpecker to be documented breeding in tamarisk, most likely due to the fact that it is the smallest and best excavating woodpecker in the range of introduced tamarisk (fig. 3, Brush 1983).

Use of tamarisk by ground nesting charadriiformes, platform nesters, and cavity nesters is generally consistent among river valleys. Use of tamarisk by cup nesters, on the other hand, is variable and evidence suggests that midsummer breeders with open cup nests are less likely to use tamarisk than are birds with insulated nests (for example, sphere nests or cup nests with shade structures) on the lower Colorado River (Hunter and others 1988). This pattern cannot be explained by the lack of suitable nesting substrates for open cup nesters on the lower Colorado. Therefore, nest type alone does not explain why avian use of tamarisk tends to differ between river valleys.

Confounding Variable: Vegetative Composition and Structure

The vegetative structure (physiognomy) and floristics (species composition) of tamarisk-dominated areas is perhaps more useful in explaining geographic variation in avian use of tamarisk than variation in food resources or nest site availability alone. Both vegetative structure and floristics influence the types and availability of food

Figure 3. Cavity nesting birds generally avoid tamarisk (*Tamarix*) and are restricted to native vegetation. A notable exception is the Ladder-backed Woodpecker (*Picoides scalaris*). The Ladder-backed Woodpecker (left photographs) was the first New World woodpecker to be documented breeding in tamarisk, which is most likely due to the fact that it is the smallest and best excavating woodpecker in the range of tamarisk. Note the stout bill morphology of the Ladder-backed Woodpecker compared to that of the Red-shafted Flicker (right photograph: *Colaptes auratus cafer*). (Photographs by Santigo Guallar, Steven Ogle, and John Puschock.).

resources and of foraging and nesting substrates (Szaro 1980, Fleishman and others 2003), and therefore, are proxies for a large number of environmental factors necessary for birds to fulfill their life history (MacArthur and MacArthur 1961, Robinson and Holmes 1984, Szaro and Jakle 1985, Allison and others 2003, Fleishman and others 2003).

There is disagreement in the literature as to whether vegetative structure of tamarisk is most closely correlated with avian diversity, density, or species richness. However, tall, dense tamarisk stands that are structurally diverse are generally most often used by birds (Carothers and others 1974, Anderson and others 1977a, Stamp 1978, Szaro and Jakle 1985, Rosenberg and others 1991, Farley and others 1994, Livingston and Schemnitz 1996). Furthermore, tamarisk vegetation with similar physiognomy as native vegetation generally supports similar avian densities and species richness (Brown and Trosset 1989, Livingston and Schemnitz 1996, Fleishman and others 2003). Thus, in some situations, riparian communities dominated by tamarisk can be the structural or ecological analogs of native communities that are the required habitat of native riparian birds. Compared to physiognomy, floristics are more important in determining avian species composition. Avian species composition is generally more similar when floristics are more similar (Anderson and others 1977a, Fleishman and others 2003). Therefore, tamarisk stands that contain some attendant native plant species are more likely to support unique avian species that are usually closely associated with the native vegetation (Ellis 1995). In addition, floristics of adjacent plant species influence avian species composition, abundance, and diversity in tamarisk vegetation by increasing availability of food and nesting substrates (Carothers and others 1974, Szaro and Jakle 1985). Due to the affect of floristics on avian communities, many studies suggest that addition of native trees and shrubs that provide high quality nesting and/or foraging substrates enhances the value of tamarisk vegetation to birds (Beidleman 1971, Anderson and others 1977a, Cohan and others 1979, Glinski and Ohmart 1983, Hunter and others 1987, Hunter and others 1988, Brown 1992, Livingston and Schemnitz 1996, Kelly and Finch 1999).

Both the vegetative structure and the floristics of tamarisk vegetation vary with location (fig. 4). Structure of individual tamarisk plants can vary from thin-stemmed shrubs to multi-trunked trees and from ground cover seedlings to trees of 10 meters or more in height (Brotherson and others 1984). In addition, tamarisk-dominated vegetation can vary from mixtures of native and exotic plant species to stands comprised solely of tamarisk. Furthermore, vegetation adjacent to tamarisk stands can vary from native woodland to grassland or agricultural fields. Though few consistent structural and floristic differences exist between tamarisk vegetation of the Rio Grande and the Pecos and Colorado Rivers: 1) tamarisk stands on the lower Colorado River tend to be lower-statured and sparser than along the Pecos River, the Rio Grande, and upper elevations of the Colorado River and 2) a larger number of adjacent shrubs and annuals are present along the middle Pecos River. This variability in

Figure 4. The vegetative structure (physiognomy) of tamarisk can vary with location. Individual tamarisk plants can vary from thin-stemmed shrubs to multi-trunked trees and from ground cover seedlings to trees of 10 meters or more in height. (Photographs by Kenneth Lair and Hira Walker.).

physiognomy and floristics of tamarisk vegetation partly explains geographic variability in avian communities in tamarisk. Specifically, the higher availability of food resources provided by associated shrubs and annuals along the Pecos River is responsible for the relatively high number of granivorous and wintering insectivorous bird species in tamarisk on the Pecos River compared to the lower Colorado River and Rio Grande (Hunter and others 1988). However, geographic differences in physiognomy and floristics alone are probably insufficient to explain geographic patterns in avian use of tamarisk.

Confounding Variable: Climate

Birds select among available habitats using information on both physical and biological environmental attributes to meet energetic and reproductive needs and to maximize fitness: vegetation composition alone does not determine whether a bird will be present in a particular area. Thus, although availability of food resources and nesting substrates, which covary with vegetative structure and floristics, help to explain patterns in avian use of tamarisk, the physical environment is also an important causal factor. In the southwest, elevation increases and temperatures decreases from west to east (for example, from the Colorado River to the Pecos River) and from south to north. These gradients influence abiotic environmental features extrinsic to tamarisk-dominated sites and help to explain the conflicting patterns seen in breeding birds (i.e., why midsummer breeders are absent in tamarisk on the lower Colorado River while early summer breeders rarely use tamarisk on the middle Pecos River).

Along the lower Colorado River, June and July temperatures frequently exceed 42 ^{o}C. Such high temperatures are detrimental to developing eggs and young. Since tamarisk stands along the lower Colorado River tend to be lower-statured and sparse, it has been hypothesized that they might not provide adequate foliage cover for eggs and young during midsummer months (Anderson and others 1977a, Hunter and others 1985, Hunter and others 1987, Hunter and others 1988, Rosenberg and others 1991, Marshall and Stoleson 2000, United States Fish and Wildlife Service 2001). This hypothesis is supported by the fact that midsummer breeders with insulated nests are more likely to use tamarisk on the lower Colorado River than are open cup nesters (Hunter and others 1988).

Opposite to summer temperatures, winter severity increases from west to east. Hunter and others (1985, 1988) hypothesized that the low numbers of early breeding residents in tamarisk along the middle Pecos River and Rio Grande are due to the fact that tamarisk might provide suboptimal habitat for wintering early breeding Sonoran or Chihuahuan bird species in western Texas and eastern New Mexico. Physiological stress and associated mortality might prevent resident species from spreading into tamarisk and surviving to breed the next year.

Synthesis of Current Patterns

Southwestern riparian bird populations are affected by a complex set of interacting factors, including competition, diet preference, nesting requirements, psychological preferences for habitat attributes (for example, vegetative structure, plant species composition, patch size), and physiological tolerance to microclimatic factors of the physical environment (Szaro 1980, James and others 1984, Sogge and Marshall 2000). Since factors necessary for the survival and reproductive success of birds fluctuate spatially and temporally, discussion of distributions and abundances of species and species assemblages in tamarisk must involve biogeographic considerations.

Absence or negative relationships are the clearest patterns to document; several groups or assemblages of birds generally avoid tamarisk across the Southwest simply because tamarisk does not provide specific food resources or nesting substrates. These birds include frugivores, timber-drillers and timber gleaners, nectivores, ground nesting charadriiformes, platform-nesting raptors, and cavity nesters. Positive relationships are more difficult to quantify. Granivorous bird species generally prefer or do not to avoid tamarisk regardless of locality, while use by other guilds is more complex. Geographic variability in use of tamarisk by these species often impedes attempts to determine the value of tamarisk to birds. However, biogeographic comparisons elucidate the following two predictive patterns: 1) tamarisk vegetation along the lower Colorado River supports fewer total species and individuals of both midsummer breeding and wintering birds than tamarisk vegetation along the Rio Grande and middle Pecos River and 2) early summer breeders are more abundant in tamarisk along the lower Colorado River than in tamarisk along the Rio Grande and the middle Pecos River.

Breeding birds (especially midsummer-breeding summer residents) are the most abundant group of birds in riparian areas (Szaro and Jakle 1985) and are the most well documented. Therefore, patterns in breeding bird use of tamarisk drive the patterns that have been described for total species densities and richness. Since distributions of breeding birds are most limited by nesting requirements, the depauperate midsummer breeding bird community in tamarisk along the lower Colorado River is attributed to lower nesting success. Specifically, the lower-statured and spares stands of tamarisk along the lower Colorado

River do not provide sufficient foliage cover to protect eggs and young of open cup nesters from high midsummer temperatures. In addition, the timing of Apache cicada emergence in tamarisk stands along the lower Colorado River makes cicadas unavailable as a prey source for migrating or breeding riparian birds.

There are few substantiated explanations for the lowered number of wintering birds on the lower Colorado River, largely because less research has been completed during this period than during the breeding season. Wintering birds are generally more limited by physiological stress and mortality. Winters tend to increase in severity from west to east. However, information is lacking as to why exactly early breeding residents (as opposed to other groups of birds) are unable to survive winters in tamarisk vegetation along the middle Pecos River and Rio Grande. Hunter and others (1988) hypothesized that tamarisk vegetation in western Texas and eastern New Mexico provides suboptimal wintering habitat for Sonoran or Chihuahuan bird species (which are often early summer breeders). This conflicts with findings that wintering birds are generally more abundant in tamarisk on the middle Pecos River due to the higher availability of winter food resources from adjacent food-producing habitats), which allows for higher winter survivorship on the middle Pecos River.

Overall, documented patterns in avian use of tamarisk are best explained by species-specific nesting and foraging requirements, which in turn covary with the vegetation structure and floristics, and are mediated by climatic influences. Tamarisk vegetation most used by birds generally occurs as tall, dense, structurally heterogeneous stands. Such stands tend to have more nesting and foraging substrates, provide cover from thermal stress and predation, and support more food resources.

Future Needs

Despite the numerous studies that have been published on avian use of tamarisk, large gaps exist in our knowledge base:

1. Most research has focused on the lower Colorado River, which is vegetatively and climatically distinct from tamarisk-dominated sites elsewhere. As a result, broad conclusions made on the value of tamarisk to avifauna would be erroneous if based solely on data from the lower Colorado River (Brown and Johnson 1989). More studies are needed not only from the Rio Grande and the Pecos River, but also from associated tributaries and other major southwestern river systems (Hunter and others 1985).
2. The majority of research has been completed during the breeding season. Although some information exists for wintering birds, there is much left to discover regarding tamarisk use by migrating birds.
3. Use of tamarisk by insectivorous birds has been found to vary with location and season, but little information is available to explain the observed variability. Studies are needed comparing insect biomass and availability of foraging substrates to foraging behavior and diet requirements.
4. Published literature on avian use of tamarisk has been largely limited to inventory – that is, simply recording the presence or absence of bird species in tamarisk vegetation. However, occupancy of a habitat alone does not imply optimality, only that the habitat meets the selection criteria for those species present (Sogge and Marshall 2000). Ultimately, the suitability of a habitat must be measured by reproductive success and survivorship (Sogge and Marshall 2000). The suitability (in terms of productivity and survivorship) of tamarisk-dominated vegetation to avian species in the Southwest is not well studied and has been mostly limited to work on one species, the Federally Endangered Southwestern Willow Flycatcher (Sogge and Marshall 2000). Notable exceptions are studies by Yong and others (1998) and Kelly and Finch (1999) that looked at energetic condition (for example, fat scores and mass) of transients on the middle Rio Grande, New Mexico. Additional studies quantifying survivorship and reproductive success should better determine the value of tamarisk habitats and should resolve whether tamarisk habitats are sinks for southwestern bird populations.
5. More studies (particularly experimental studies) are needed to tease out which factors delimit avian use of tamarisk at local and regional scales. Hunter and others (1985, 1987, 1988) and others have put forth several hypotheses to explain observed patterns in avian use of tamarisk, but no studies have attempted to determine their validity. More data are needed to determine whether, for example, the relative insulation properties of tamarisk, availability of food resources, and/or vegetative structure limit bird use of tamarisk along east-west gradients.
6. Tamarisk vegetation is variable in structure and floristics. Hunter and others (1985) suggests that, in order to better quantify avian value of tamarisk, bird communities should be surveyed in a large range of tamarisk vegetation types. However, the diversity of tamarisk vegetation types hampers discussion of the types of tamarisk most preferred or avoided by birds. I propose that a classification system be developed for tamarisk vegetation based on such attributes as

plant species composition, structure, and hydrology. Similar classification systems have been developed for streams (Rosgen 1985), riparian forests (Brown and others 1979, Szaro 1980), and tamarisk structural types (Anderson and others 1977a). Only by formulating standardized terminology can the complexity of tamarisk vegetation types be addressed by both managers and researchers.

Discussion

Riparian ecosystems in the Southwest provide mesic sanctuaries from surrounding arid and semi-arid landscapes for a host of wildlife species (Patten 1998). Although riparian ecosystems represent only 1 percent of the total area in the southwestern United States, they support 75 to 80 percent of southwestern wildlife species (Knopf and others 1988). Specifically, riparian ecosystems support more breeding bird species than surrounding uplands (Johnson and others 1977, Hunter and others 1988, Knopf and others 1988, Ellis 1995, DeLay and others 1999, Kelly and Finch 1999) and, according to Hunter and others (1988), over 40 percent of all the bird species found in southwestern river valleys depend, either partially or entirely, on riparian vegetation. In addition, southwestern riparian areas attract high concentrations of migratory passerines en route to their wintering or breeding grounds (Yong and Finch 1997, Skagen and others 1998, Yong and others 1998, Kelly and others 2000).

Over the last century, an estimated 90 percent of native riparian habitats in Arizona and New Mexico has been lost or degraded due to anthropogenic land clearing, habitat fragmentation, river damming and impoundment, overgrazing, and addition of fertilizers and agricultural chemicals (Howe and Knopf 1991). Native cottonwood/willow (*Populus*/*Salix*) riparian forest is now considered one of North America's rarest forest types (Johnson 1989). Resulting from and compounding these anthropogenic changes is the widespread establishment of exotic plant species (Westbrooks 1998). It has been estimated that at the current rate of spread exotic plants will dominate all southwestern riparian ecosystems within 50 to 100 years (Howe and Knopf 1991).

A particularly successful exotic in the Southwest is tamarisk or saltcedar (*Tamarix*), an exotic tree from the Eastern Hemisphere that was introduced to the United States in the early 1800s for stabilization of eroding stream banks and use in wind breaks (DeLoach 1997). Tamarisk is quickly becoming the dominant vegetation type in southwestern riparian ecosystems (Hunter and others 1985, Brown and Johnson 1989) and it is thought that potential increases in average global temperatures and aridity will only further the spread of tamarisk and the decline of native plant species (Marshall and Stoleson 2000). Introduced tamarisk alters the abiotic environment of southwestern riparian ecosystems by changing soil salinity, ground water availability, and fire frequency (Cohan and others 1979, Brotherson and others 1984, DeLoach 1997, Lovich and DeGouvenain 1998). In addition, tamarisk introduction, and associated loss of native riparian vegetation, is affecting faunal communities and could potentially result in the loss of approximately half of the avian species that breed in the Southwest (Knopf and others 1988).

In order to curtail future negative impacts of tamarisk on native ecosystems, many federal, state, and tribal agencies are undertaking aggressive campaigns to reduce or eradicate tamarisk in the Southwest through mechanical, chemical, and biological control (Fleishman and others 2003). However, many such efforts are being undertaken on a site-specific basis without sufficient quantitative data on the value of tamarisk to wildlife, specifically avifauna. Although development of broad management guidelines is difficult due to the variability of tamarisk habitats and the scale of infestation (Szaro 1980, Knopf and others 1988), site-specific data and management policies can lead to erroneous conclusions regarding the desirability and efficacy of tamarisk removal programs across the Southwest (Knopf and others 1988). In this paper, I recommend that more research be completed on the local and regional use of tamarisk by avifauna and that a classification system of tamarisk vegetation types be developed to aid in defining which types of tamarisk are most useful and detrimental to wildlife. However, tamarisk control actions already underway or planned for the near future cannot wait for the results of future scientific projects. For those control programs, results from this paper suggest that monotypic stands of tamarisk that are sparse and lower-statured should be a priority for removal, while stands that are structurally and floristically diverse can function as temporary replacements for native vegetation for a number of riparian bird species. Regardless of which types of tamarisk are removed, intensive tamarisk removal projects that eradicate tamarisk and leave areas bare of woody overstories and/or understories, without restoring native vegetation in the near term, might threaten the local persistence of many native birds. At the very least, tamarisk removal projects should be accompanied by studies of birds and other organisms. Such studies are essential to determine whether tamarisk control projects achieve their targeted goals.

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Monitoring the Relationship Between the Public and Public Lands: Application to Wilderness Stewardship in the U.S.

Alan Watson, Research Social Scientist, Aldo Leopold Wilderness Research Institute, USDA Forest Service, Rocky Mountain Research Station, Missoula, MT
William Borrie, Associate Professor, College of Forestry and Conservation, Department of Conservation and Society, The University of Montana, Missoula, MT

Abstract—*Stakeholders in wilderness, and other public lands, have varying opinions on how well the land management agencies reflect their values and respond to their needs in management, and they therefore vary in their level of commitment and attachment to these places and the activities that occur there. Establishing baseline measures and monitoring indicators of the relationship between the public and wilderness lands can provide efficient evaluations of many management activities. Examples include protection of traditional relationships for indigenous people, and the enhancement and protection of relationships between the resource and both local and distant populations of stakeholders.*

Most social science monitoring by wilderness managers in the U.S. has focused on either visitors' perceived quality of experiences or a small set of commonly used indicators of threats to those experiences (Watson and Williams 1995). Measures of satisfaction, perceptions of crowding, number of encounters with other visitors while traveling and at campsites, perceptions of recreation visitor impacts to soil and vegetation, and other commonly used social science indicators imply a customer orientation between the agency and the public. The primary evaluation of how well public land managers are doing in their stewardship responsibilities is reflected through the quality of these transactions. That is, public land managers have been judged by their ability to provide particular conditions utilized during a visit.

Recent research has, however, suggested that stewardship responsibilities may also be evaluated through indicators of the relationship that is created, protected or restored through public lands management activities (Alessa and Watson 2002, Shroyer and others 2003). This approach, described as public purpose marketing by Borrie and others (2002a) and Watson and Borrie (2003), emphasizes understanding relationships, in addition to monitoring transactions, as the primary stewardship responsibility of public land managers. The purpose of this paper is to describe why wilderness monitoring programs should include protocol for monitoring relationships between people and wilderness.

Public Purpose Marketing

Watson and Herath (1999) surmised from recent research on public lands recreation fees that support for fees is strongest when the fees are to be used for the public purpose of the place visited. For instance, visitors to the Desolation Wilderness in California most support use of fees to maintain or restore wilderness conditions (Vogt and Williams 1999). Also, in a national sample of U.S. residents, less than half supported fees for providing restroom facilities on any public lands (Bowker and others 1999). Winter and others (1999) found that the level of trust people had in the administering agency was the most significant predictor of general attitudes towards, and amounts respondents were willing to pay for, daily and annual recreation passes. This research suggests that many things besides what the visitor encounters on a single visit influences how the visitor evaluates management policies. Borrie and others (2002a) suggested a focus on the relationship between the public and public land as a guide to marketing in the public sector. This relational framework can also guide monitoring to determine success in stewardship of relationships with wilderness.

Relational Marketing

For the purposes of marketing in the public sector, a focus on relationships between the managing agency and the public as primary stakeholders (both customers and partners) has been proposed as a feasible and appropriate conceptual framework (Borrie and others. 2002a, Watson and Borrie 2003). A transaction with a customer is said to have a distinct beginning, short duration, and sharp ending (Dwyer and others 1987). A relational exchange, on the other hand, builds from previous contacts, is longer in duration and reflects an ongoing process. When providing services for the public through the development of programs on public lands, the more appropriate view of "customer service" would probably be the development or fostering of a relationship between the members of the public and the places that have been established on their behalf as public lands, such as wilderness.

Morgan and Hunt (1994) emphasize theoretical and empirical research on commitment and trust as the primary indicators of successful relational marketing. Support for public agency actions also depends on confidence in efforts that recognize responsibility to current and future generations and efforts to meet the public purpose (legislation or policy mandates), versus vested-interest demands (Watson and Borrie 2003).

Anderson and Narus (1991) acknowledge that not everyone desires the same relationship with a producer of goods or services. They suggest that an organization may need to pursue both transactional and relational marketing simultaneously, and that customers may exist on a continuum of transactional to collaborative exchanges. In the public sector, however, members of the public are, by definition, involved in a collaborative relationship with the stewardship agency taking responsibility for implementation of public policy. While we are suggesting that a collaborative relationship exists for all people, we do acknowledge that the level of commitment or involvement with the services provided by an agency and the level of trust instilled among members of the public may vary substantially. Relational marketing suggests that a focus on understanding variation in trust, commitment, and personal values will be paramount in developing and implementing public policy to meet the mandates or purpose of public lands (Garbarino & Johnson 1999, Morgan & Hunt 1994, Moorman, and others 1993, Watson 2000).

Trust

Trust is widely viewed as an essential ingredient for successful relationships (Berry 1995, Dwyer and others 1987). Trust is one of the underlying foundations of any form or action of government. Without trust, public agencies operate with weakened mandate and support. The public grants the right for any public organization to operate. Putnam (2000) found that trust and engagement in the public arena go hand in hand. Conversely, if communities believe they are not fairly and truthfully represented there is great potential for withdrawal of political and social support (Miller 1974).

Until very recently, studies of trust in organizations or institutions were virtually unknown (Earle and Cvetkovich 1995). Two dominant views of trust for organizations have emerged recently, however. The more traditional view is that trust is based on confidence in competence, objectivity, fairness, consistency or predictability and caring, or the perception of good will. In recognition that this traditional view requires a generally unattainable level of knowledge of complex social systems, Earle and Cvetkovich (1995) suggest an alternative view: people judge the similarity of values they hold to those expressed by an organization. Trust is then quantified in terms of perceptions of shared values, direction, goals, views, actions and thoughts (Winter and others 1999).

Commitment

Another strong influence on relationships between organizations and stakeholders is level of commitment, which is defined by Gundlach and others (1995) as having three components: 1) an instrumental component or level of investment, 2) an attitudinal component or level of psychological attachment, and 3) a temporal dimension or length of time of the commitment. Interestingly, in an application to wilderness, Williams and others (1999) found that more trips to wilderness, more trips to Desolation Wilderness, and residing closer to Desolation Wilderness (suggesting high temporal commitment, high investment and high attachment) all tend to be associated with weaker support for camping fees at Desolation Wilderness by visitors there. Commitment varies with evaluation of this particular policy and understanding commitment can help us understand public response to this policy.

Social responsibility and public values

Even in corporate America, the concept of social responsibility can take on a new emphasis in development of products and in research on customer attitudes

(Drumwright 1994). The adoption of non-economic criteria in customer decision making (criteria other than price, or relationship between price and quality) has led to greater understanding of how some purchase decisions pose social dilemmas and prompt moral reasoning (Drumwright 1994). Samli (1992) also describes social responsibility in the private sector and those who want to make a profit but who also care. In the public sector, it is mandated that the government agency respond to stakeholders and the public purpose of the places and resources it manages.

In the public sector social responsibility is a mandate in the delivery of services and carrying out of the legislation and policy that guide a public agency. Recent research on wilderness visitors (Glaspell and others 2003, Patterson and others 1999) and local communities (Watson and others 2004, Whiting 2004) suggests there are many aspects of relationships people have with wilderness beyond the ones specified in the Wilderness Act. The public purpose of these areas often extend well beyond what is officially described in legislation and policy, but falls within the responsibility of the public land manager for stewardship. More information about the meanings and values people ascribe to these public lands can help public lands management respond to all stakeholders.

A Framework for Marketing and Monitoring

The use of marketing principles by public land management agencies poses both a threat and a promise to the people who depend on wilderness for pleasurable outdoor experiences or have deep relationships with wilderness. The most serious threat is from a focus towards on-site experiences as a transaction between the agency and a visitor, and the temptation to focus too much on measures of on-site satisfaction and repeat visitation as an indicator of success in meeting the public purpose of those places. Although it has been previously suggested that "… the goal of government … service agencies is to provide satisfaction to their client groups, which is exactly the same goal pursued by private sector organizations" (Crompton and Lamb 1984, p. 37), we suggest that marketing or monitoring focused on a simple transaction with the public as a customer is too narrow. Not only are there methodological concerns with satisfaction measures, they may yield little information on the quality of the visitor experience or on relationships with the public lands (Borrie and Birzell 2001). Instead, a focus on the relationship between the public and those public recreation land management agencies, with emphasis on trust, commitment, social responsibility, and public values should be a guiding principle when employing marketing principles and developing monitoring protocols in the public sector.

Applications to Wilderness: Aspects of Relationships to Monitor

Following the conclusions of Shroyer and others (2003), we suggest that all potential wilderness values are likely not received by all people at all places. Nor should we expect them to be. Not only is there no such thing as the 'average camper' (Shafer 1969), but a diversity and multiplicity of values are an important feature of protected areas (Borrie and others 2002b). There are multiple types of relationships with wilderness, commonly ranging from neighboring communities to urban residents to recreation visitors, and extending to international communities and future populations (Shroyer and others 2003).

The following sections describe research efforts aimed at measuring and monitoring the previously described dimensions (trust, commitments, and public values) for the relationship with wilderness.

Trust

Monitoring the levels of trust that the public has in wilderness managers requires an understanding of the underlying components of trust. Initially, the public must feel that managers fairly understand and represent their values and norms of behavior. Secondly, the public must be willing to allow managers to operate on their behalf. And lastly, the public needs confidence in the managers ability to produce suitable results. Without these levels of trust, the agency has little license to operate.

A recent research project has been initiated to measure levels of trust held by residents of the wilderness-proximate Bitterroot Valley of Montana towards the U.S. Forest Service (Watson and others 2004). Using a telephone survey, three components/precursors of trust (shared norms/values; contingent consent; and expectation of outcomes) were measured and used to classify residents into high- and low- trust groups. Significant differences were found between high- and low- trust groups, for example, based on length of time resident in the valley, proximity to wilderness and forest boundaries, and whether or not they live in the wildland-urban interface.

Establishing this baseline measure of trust and its underlying components provides an opportunity to judge future relationships between the public and the wilderness managers. The changing composition of high- and low- trust groups will be indicative of whose relationship to government is strengthening and whose is weakening. In addition, overall levels of trust among residents can be indicative of the perceived success of management initiatives. And finally, the relative change in levels of the underlying components of trust can be used to identify areas needing attention in order to improve relationships with the public.

Commitment

Level of investment (and return)

People invest in wilderness and wilderness yields an investment to communities surrounding it. Some special provisions in wilderness legislation were aimed at pre-existing uses of land and water resources. Without these acknowledgements, many of those areas would not have been included in the National Wilderness Preservation System or the added units would have been much smaller. While economic values associated with these "non-conforming" uses are hard to associate with wilderness designation, they nonetheless do originate within the National Wilderness Preservation System.

Other local economic benefits have been found to accrue from outfitted and guided uses, and nearby service industries (hotels, motels, restaurants, etc.) that are used by wilderness visitors before or after a wilderness visit. Because these businesses are substantially in the service industry, there is substantial contribution to local economies. There is also a small contribution to local economies from sale of retail goods to wilderness visitors. Loomis and Richardson (2001) estimate that wilderness users spend a total of about $30 per each day of a wilderness visit.

Power (1996) has found other economic benefits to local communities from wilderness designation, and those come in the form of increased tax revenue originating from increasing property values of communities with high natural amenities. High quality natural environments draw people and businesses to an area. Power (1996) suggests that wilderness protection does not impoverish communities, but rather it protects the economic future of communities by preserving high quality natural environments that are increasing in demand across the nation. Florida (2004) similarly describes how quality of place, including quality of the natural environment, attracts members of the 'Creative Class' including scientists, engineers, architects, educators, artists, musicians, and other knowledge-based professionals to a community. Florida suggests that it is this class who will be the engine for future economic growth and prosperity. Place he says is "the key economic and social organizing unit of our time" (2004, p. xix).

Attachment

There has not been a great deal of research to document the more emotional relationships with wilderness. Clayton (2003) offers a definition of environmental identity as a "sense of connections to some part of the nonhuman, natural environment based on history, emotional attachment, and/or similarity, that affects the ways in which we perceive and act toward the world" (p. 45) Williams and others (1992) explored emotional and symbolic attachment to place among wilderness visitors, and concluded that describing visitors' attachments to wilderness places can capture the connections between people and geographic areas directly. This direct type of indication of a relationship is much more preferable than more indirect indicators such as use and user characteristics.

There are many different forms of attachments to wilderness, some of which are long held traditions or representations of heritage. While the Wilderness Act was most likely referencing activities like horse packing, canoeing, and camping, historical activities may or may not be referred to today as traditional. In addition to the activities of hunting, fishing, and gathering (berries, mushrooms, medicinal plants, etc.) of indigenous and other rural people of Alaska, there are other historic attachments to wilderness.

Relationships to wilderness mean more than just a single transaction or visit. Indeed, in the Frank Church – River of No Return Wilderness, a study of jet boat users on the Salmon River, a use allowed under the Central Idaho Wilderness Act of 1980, revealed respondents who resented being called visitors to the area (Watson and others 2004a). Instead, deeply rooted historical bonds cause them to organize their lives around this place. Respondents acknowledged that their ability to do physically demanding activities in this wilderness may diminish over time, but their interest in spending time where they have enjoyed all their lives will not, and jet boats were seen as a means to having this experience (Patterson 1999).

Other emotional values often lie at the heart of relationships with wilderness lands. The Qikiktagrugmiut expressed the emotional values they attach to the Western Arctic Parklands Wilderness (Whiting 2004) as including spiritual, emotional and physical health and humility. In Ravalli County, Montana, local residents expressed an emotional attachment to the Bitterroot Front because of its unique physical features that they have easy access to (Gunderson and others 2004). This wilderness landscape was also found to create identity for the people who live there. The documentation of all these attachments (emotional, symbolic, traditional, and historical) is necessary for a full accounting of the management of wilderness lands.

Temporal commitment

Watson and others (1991) suggested that some of the key indicators of temporal commitment may be measures of past experience in wilderness and at the particular place. Commonly used measures of past experience which differentiate among current wilderness visitors (Watson and Cronn 1994) include the number of years a person has been going to wilderness, the number of trips they have taken and the number of trips they normally take per year. At a specific place, it is common to ask about the number of previous visits and the length of time since the first visit.

In a rare attempt to understand the temporal relationship between a population of visitors to a place, instead of case studies which commonly focus on only users during a study time frame (usually the summer heavy use season), Watson and others (2004a) considered the whole population of jet boat users on the Salmon River in the Frank Church – River of No Return Wilderness in Idaho. Insight from this population provided understanding of displacement and substitutions past visitors have made as use and the resource changed over time. While levels of temporal commitment may remain relatively constant, the form and location of visits change.

Public values

Two approaches for the monitoring of public values towards wilderness and other protected areas are current. Borrie and others (2002b) and Johnson and others (2004), for example, have taken psychometric, survey-based methods, while Shroyer and others (2003) and Williams (2000) have adopted a more social constructionist, interview-based approach. Both strive to identify the qualities of wilderness that are most important to, and valued by, the public. Managers have a responsibility to understand and map these values, partially as a demonstration of a commitment by the agency to the public.

In Ravalli County, Montana, a project to understand local values associated with the Bitterroot Front (which is dominated by the Selway-Bitterroot Wilderness) found descendants of white settlers expressing strong traditional or historic values associated with this landscape (Gunderson and others 2004). But these places also have historical value to the Salish-speaking (indigenous) people who were removed to the Flathead Indian Reservation. In Alaska, research was recently initiated to obtain a better understanding of the local values the native Inupiaq people of Kotzebue (the Qikiktagrugmiut) attach to the Western Arctic Parklands Wilderness. From interviews with those in the village currently active in hunting and gathering activities on these lands, Whiting (2004) described the economic values of self-sufficiency and survival (personal and family). The Qikiktagrugmiut described these traditional values as identity (personal and community), traditional way of life, and personal growth.

Public values of wilderness extend well beyond the boundaries, with many off-site benefits. For example, there are local economic benefits associated with agricultural uses of water originating within wilderness. While there are many negative ecological effects of disturbing the hydrologic connectivity of wilderness watersheds (Pringle 2001), there are also some positive economic benefits from impoundments within wilderness (Cook 2003). In the Bitterroot Valley of Montana, an area which is classified as a high desert environment, the annual precipitation is only 12.3 inches. Since the mid-1800s, agriculture has been a highly productive industry in the valley. In the late 1800s and early 1900s, farmers constructed dams in the Bitterroot Mountains, in what is now the Selway-Bitterroot Wilderness. The dams capture the spring runoff from snow melt and store it until late summer for irrigation purposes. In the Bitterroot Valley, the area's groundwater supply would not sustain the county's population levels without the additional water added to the groundwater from irrigation (Finstick 1986). Therefore, these wilderness dams not only sustain local agriculture, they are crucial to the growing suburban development and quality of life there. The available groundwater is an important contributor for not only domestic uses such as drinking and bathing, but also for recreation, residential sprinklers, and livestock watering.

Conclusions

Visitors to wilderness have a variety of types of relationships with wilderness. If we are interested in these relationships and acknowledge our mandated responsibility of stewarding these relationships, we need to monitor indicators of it to understand how we are doing. Historically, wilderness research has focused on stewardship of the transactions people have with the wilderness resource, mostly those who travel as visitors to these places. Methods have been developed to monitor visitor perceptions of resource conditions, of their reaction to social conditions encountered, and obtain reactions to interactions with managers of the areas and their policies. Only recently was it seen that many evaluations of wilderness policy are rooted in larger contexts than just individual visits to a wilderness.

Local communities are not excluded from consideration in the primary values of wilderness listed in the original Wilderness Act, though sometimes they feel that way. Studies of local resident and visitor reactions to wilderness recreation fees revealed that these reactions were most closely related to the level of trust the public had in an agency's ability to manage an area within the public purpose designated for that place (Borrie and others 2002a). And, in post-fire assessments of social impacts at the community level in the Bitterroot Valley in 2000, a major issue expressed by the public was the lack of trust in the agency's ability to make decisions that reflect local values. Local community members felt that decisions were made according to policies developed elsewhere, that outside organized groups were forcing decisions on agency managers that were not reflective of local values, or that even some agency decisions made locally were made by temporarily assigned managers from elsewhere and that they did not understand local values associated with wild lands.

The Qikiktagrugmiut of Alaska worry that someday their relationships will become the one described in the Wilderness Act, that of "a visitor who does not remain" (Whiting 2004). Jet boat users on the Salmon River have relationships with the wilderness resource that extend well beyond the time wilderness protection was extended to these lands and waters, going much longer and deeper than most recreational visitors. And the people who live in Ravalli County, Montana, are who they are partly because of the Wilderness which is so accessible to them.

A new era of stewardship is facing us, with not only expectations of stewarding our public lands, but also deeply cognizant of our role in stewarding the relationship between the public and public lands. Local communities are vocal in their assertion that we need to understand the values they receive from wilderness and other lands and demonstrate to them that we consider these values in making decisions, while also meeting the primary intent of the legislation and policy that guide us in our management decisions.

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The Politics and Science of Tamarisk

Philip Westra, Professor, Weed Science, Colorado State University, Ft. Collins, CO

Abstract—*Tamarisk is a woody invasive weed of riparian areas which has galvanized an amazing array of scientists, politicians, ranchers, farmers, tribal people, and many other interested parties because of its devastating impacts on natural ecosystems and valuable water ways in the west. Rarely has a single plant become such a catalyst for so many people to use as a "poster child" for a variety of interesting issues. Among these issues are water resource issues, soil quality, land use issues, wildlife habitats, access to federal funds to support local community initiatives, and support for research on a plant with an amazing ability to invade and alter natural habitats. This collective effort to understand and manage a major water robbing plant in riparian ecosystems is due to the efforts of many people, many organizations, and to the vision provided by a group such as the tamarisk coalition. The science of tamarisk is currently focused primarily on genetic diversity, biological, chemical, and mechanical control, mapping of tamarisk infestations, flooding impacts on tamarisk dynamics, wildlife impacts, and ecosystem restoration. Because tamarisk is spreading at such a large scale, significant resources will be required to halt the negative impacts causes where it invades.*

Political action by congress and many agencies suggest that the necessary resources to support tamarisk science, education, and management may help in the battle to control this invasive weed. Tamarisk is providing a novel and revealing project around which both rural and urban citizens can rally for economic, environmental, and recreational benefits.

The Problem

The plant genus *Tamarix* includes several weedy species that have proven to be very successful invaders of prime riparian habitats in much of the western United States. They primarily invade the banks of rivers, streams, and reservoirs, but in some places they are moving into adjacent upland areas where they displace native vegetation. These foreign plants originated in Eurasia and Africa in semi-arid environments where their unusual biological characteristics developed. There are approximately 54 species in the genus *Tamarix*; of these approximately 10 have been introduced into the United States. It now appears that several of these species can interbreed to form new hybrid forms of saltcedar. Since they were introduced to the United States, they have been able to colonize millions of acres due to their aggressive invasive abilities and a lack of natural enemies which might have kept their spread in check.

The most commonly encountered Tamarix plants include *Tamarix ramosissima* (saltcedar), *T. chinensis* (Chinese tamarisk), and *T. parviflora* (smallflower tamarisk). Of these, *Tamarix ramosissima* is the most widespread and the weed which attracts the most research attention although saltcedar and Chinese tamarisk appear to be very closely related.

The negative impacts of salt cedar have been documented by various researchers in various regions where salt cedar has successfully colonized significant amounts of riparian ecosystems. These negative impacts include the following:

1. Luxury water consumption by this invasive weed is cited as a universal threat across the region to sustainable stream and river flows, to reliable water supplies for irrigation in agriculture, and for water demands by increasing urbanization which is occurring in many areas where salt cedar is found. Salt cedar can have a profound negative impact on stream and underground hydrology, to the point where streams or reservoirs can dry up due to water use by salt cedar.
2. Salt cedar, which was originally introduced for stream bank stabilization, has often done too good a job of stabilizing stream banks to the point where channel characteristics have been dramatically altered. In severe cases, flood plains surrounding streams have silted in due to the impediment salt cedar presents to flowing water, thereby forcing the streams into ever narrower channels. In some unusual cases, salt cedar becomes so dense that water flow ceases.
3. Salt cedar accumulates salt in its scale-like leaves, and when they drop to the soil surface, these leaves increase the salt contents of surface soil layers to the

point where many native species cannot germinate or thrive.

4. Salt cedar commonly creates dense monoculture stands which exclude desirable native species, thereby altering riparian biodiversity and adversely impacting recreational use of riparian areas for hunting, fishing, and camping. Heavy salt cedar stands can be prone to intense fires which can themselves alter the plant community. Once salt cedar becomes established, it is very difficult for other desirable species to penetrate and dominate such degraded plant communities.

The Politics of Salt Cedar

Many scientists and people knowledgeable about riparian ecosystems have known for more than 20 years that salt cedar was an aggressive invader that presents serious challenges for management. Over the past 4 years, many people have helped make politicians and policy makers aware of the threats salt cedar poses to both rural and urban populations. Much of the increased political interest in salt cedar is driven by drought, water conservation, and water law concerns. Managing salt cedar in infested water ways is seen as a cost effective way to improve water use efficiency while improving the environment of riparian ecosystems. Groups such as the Tamarisk Coalition from Grand Junction, CO, have helped educate and inform members of congress of the seriousness of the salt cedar issue. In particular, Tim Carlson of the Tamarisk Coalition has been instrumental in educating people at many levels about salt cedar issues, and in bringing different groups together to attack salt cedar. Researchers and citizens from Texas and New Mexico have also had a major impact on getting politicians to support salt cedar legislation. Both houses of congress have now passed salt cedar management legislation and once funding is appropriated to support these efforts, up to $100,000,000 may be available to support management and research efforts on salt cedar. Because of its strong negative impact on water issues, salt cedar has become a "poster child weed" for and amazing coalition of groups and organizations who all hope to work together to battle salt cedar. While some states have dedicated commendable dollars to combat salt cedar, management at a regional level will require substantially bigger sums of financial support. Ongoing political activities must be targeted at getting funding appropriated to support salt cedar management and research activities.

In the weed science community, increased interest in salt cedar research and management has been evident in the 2004 Salt Cedar Symposium sponsored by the Western Society of Weed Science in Colorado Springs, CO. Many of the PowerPoint presentations from this symposium will be posted at the www.invasivespecies.gov website. In March of 2004, Team Tamarisk held a workshop in Albuquerque, NM, to bring together researchers and land managers at a national level to discuss and coordinate salt cedar mapping and management activities. The compiled results of this important meeting, attended by nearly 400 people, is now available at their web site.

The national Weed Science Society of America has appointed a special "salt cedar committee" to coordinate research, education, and management options developed by the weed science community. Our activities include collaborations with plant ecologists, precision mapping experts, biocontrol experts, and molecular biology scientists who bring special skills to the complex family of species in the genus *Tamarix*. Integrated multi-scale mapping of salt cedar in the United States is being coordinated through the USGS program of Dr. Tom Stohlgren in Ft. Collins, CO. This effort is a web based effort to allow people to input salt cedar monitoring data into a centralized data base showing where salt cedar occurs. Researchers from Colorado State University and the Denver Botanical Gardens have teamed up with the Colorado state weed coordinator Eric Lane to launch an ambitious salt cedar project on the upper Arkansas River, where the integrated effects of mechanical, chemical, biological, and ecological control will be evaluated over several years. While each of these four major control tactics has its strengths and weaknesses, it likely will require an integrated approach to provide long term salt cedar management. In the process, it will be important to support on going salt cedar research with the hope of developing new tools to combat this invasive weed.

Selected informative salt cedar web sites:

http://www.invasivespecies.gov/education/workshop-Jun96/index.html

http://www.tamariskcoalition.org/

http://www.montana.edu/wwwpb/pubs/mt9710.html

http://invasivespecies.gov/profiles/saltcedar.shtml

http://www.invasivespecies.gov/teamtam/

http://squall.nrel.colostate.edu/cwis438/tmap/index.html

Changes in Riparian Vegetation Buffers in Response to Development in Three Oregon Cities

J. A. Yeakley, Associate Professor, Environmental Science, C. P. Ozawa, Professor of Urban Studies and Planning, and A. M. Hook, Research Associate, Environmental Science, Portland State University, Portland, OR

Abstract—*Riparian vegetation buffer loss was investigated for three cities with contrasting local regulatory controls in urbanizing northwest Oregon. The cities examined were Hillsboro, Oregon City and Portland, all having experienced high rates of population increase in the 1990s. All cities are covered under Oregon's land use law that provides goals for the protection of open space and natural resources. On the municipality level, regulatory controls in Portland included a system of environmental zoning for riparian area protection, while regulatory controls on development in riparian areas in Hillsboro and Oregon City were less stringent. Digital aerial photographs covering buffer areas within 200 m of all permanent streams for these cities were digitized for the years 1990 and 1997 using criteria including minimum inter-patch distance of 5 m for adjacent classes and minimum patch area of 20 m^2. Cover classes were divided into vegetation areas adjacent to stream and total, as well as woody and unmanaged vegetation areas. Banding analysis was performed for these vegetation coverages for several buffer widths out to 100 m from streams. Results for the 1990 to 1997 period showed larger losses for unmanaged adjacent vegetation 100 m from stream for Hillsboro and Oregon City (≥1.5 percent/year) than for Portland (<1 percent/year). For adjacent tree vegetation within a 100 m buffer width, again Hillsboro and Oregon City had higher rates of loss (>1 percent/year), while Portland lost trees in the 100 m buffer at a lower rate (<1 percent/year). Factors explaining these lower rates of riparian buffer loss for Portland may include both a higher amount of riparian area in public ownership and more stringent local regulatory controls on development in riparian buffers. These results also demonstrate that vegetated riparian buffers continue to be lost due to development in growing Oregon municipalities regardless of the level of regulatory protection.*

Introduction

Growing populations exert increasing pressure in urban areas to develop urban land uses, which can create observable impacts on that natural environment that can degrade ecosystem conditions. Our research seeks to better understand the interplay among social systems, regulatory processes, land cover change and ecosystem functions in areas undergoing urbanization (fig. 1). We have focused on a specific ecosystem attribute, vegetated riparian buffers, in urban areas, with the overall goal of clarifying the linkages shown in figure 1. This paper presents results on vegetated buffer loss in three cities that experienced significant population growth over a 7-year period in the Pacific Northwest of the USA, and discusses regulatory and geographic constraints that are likely related to the resource losses observed.

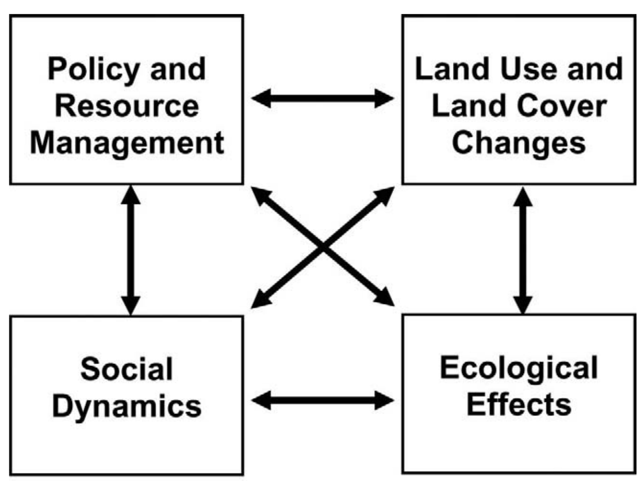


Figure 1. Research Context. Linkages among boxes represent relationships under investigation in this research overall.

Vegetated Riparian Buffers

Generally, riparian buffers can be disconnected, compressed and eliminated by urban development. Riparian areas are particularly susceptible to impacts associated with development (Budd and others 1987). Conservation of riparian zones in urban and industrial areas has usually been limited to narrow borders along streambanks, if at all (Naiman and others 2000). Protection of riparian buffers has been singled out for protective policy in the Portland metropolitan region (Furfey and others 1997). Conditions of the vegetated zone along stream banks are positively related to stream water and wildlife habitat quality. Studies have concluded that minimal buffer widths necessary to maintain stream water quality, native vegetation and wildlife habitat range from at least 20 m to as much as 200 m (Lowrance and others 1984, Castelle and others 1994, Naiman and Decamps 1997, O'Neill and Yeakley 2000, Hennings and Edge 2003).

Regulatory Framework

Oregon is distinguished by its passage of one of the USA's first statewide land use planning laws in 1973. Among the law's 19 goals are provisions to limit the expansion of urban areas and to protect the state's open areas and natural resources. The law sets a framework for local governments to address stream bank protection through comprehensive planning (Abbott and others 1996). The 24 cities and towns and three counties in the Portland metropolitan area (fig. 2) develop comprehensive plans independently, but are expected to act consistently with guidelines set by Metro, the regional planning authority. Considerable discretion with respect to management strategy to protect stream banks remained in the hands of local planners and decision makers until 1998, when Metro assumed a more aggressive stance toward riparian buffers. Through functional plans pertaining to water quality and flood management, Metro set explicit standards to which the region's cities and counties were given a specific period of time to amend their local plans. By 2002, not only were cities expected to be in compliance, but land use changes that resulted from decisions prior to the amendments were expected to have been fully implemented.

Vegetation Losses in Northwestern Oregon

In spite of this relatively progressive regulatory state-level land use framework to curb the degradation of natural and agricultural areas in Oregon, it is becoming clear that enormous losses of vegetated land have yet occurred in urbanized areas of the Willamette Valley over past decades. A study recently concluded by American

Figure 2. Locations and Stream Networks of the Three Study Cities. Shown is the greater metropolitan area of Portland, Oregon, including the urban growth boundary (UGB). Permanent streams and city boundaries are shown for Hillsboro, Oregon City and Portland.

Forests found that tree vegetation in urbanized areas of western Oregon has declined by 56 percent over the period from 1972 through 2000. Clearly such losses are not only occurring in general, but also in critical riparian corridors. While it is likely that increased regulatory measures as described above have slowed the rate of loss of riparian buffers, regulations on the books alone are not sufficient to prevent the degradation of ecosystems in urban areas. For example, during one field visit, we encountered a recent example where the review process failed to enforce the 7.5 m riparian buffer restriction on new development for that municipality. In the planning and permit decision making process, the protection of natural resources is only one among several competing objectives. Therefore, provisions are made for a balancing to occur on a case-by-case basis through the use of "exceptions" or "variances." Such features in the regulatory system indicate that losses of riparian ecosystems will likely continue in spite of increased regulation.

Study Objective

Our overall goal is to better elucidate the linkages among social dynamics, regulatory effectiveness, land cover changes and ecological functions, as shown in figure 1. In this paper we show some of the initial results of our research regarding riparian buffer losses for three Oregon municipalities with varying regulatory strategies over a 7-year period of high population growth.

Approach

Municipalities Selected

We selected three municipalities in the greater Portland, Oregon metropolitan region for intensive study: Oregon City, Hillsboro and Portland. Portland was chosen as the largest city in Oregon and a city with an aggressive approach to protecting natural resources. Hillsboro and Oregon City were chosen due to their comparably rapid population growth rates during the 1990s (table 1), their physical locations that roughly "bracket" the urban growth boundary (UGB) of the metropolitan area (fig. 2), as well as their anecdotal reputations as communities respectively less and more progressive in their attitudes toward resource protection. Regulatory controls varied among the cities. As discussed in Ozawa and Yeakley (2004), by 1990, Portland had instituted a system of environmental zoning (E-zones) for riparian area protection, which depending on location relative to stream, either outright forbid any new building development or only allow construction of structures that follow strict criteria (for example, a low percentage of disturbed area allowed, replacement of vegetation, special construction practices). Hillsboro and Oregon City, however, had far less stringent regulatory constraints on riparian area development. At the county level during the 1990s, Hillsboro riparian areas became subject to a regulation that prohibited development within 7.5 m of streams (although with exceptions that could allow developers to encroach within 4.6 m). Oregon City had no outright restrictions on riparian development from 1990 to 1997; rather development in that municipality was guided by a series of "overlay districts," each relating to specific resources and/or landscape conditions and hazards (for example, water quality, unstable slopes, flood management).

Table 1. Comparative Data for the Three Study Cities.

	Oregon City	Hillsboro	Portland
1990 Population	14,698	37,520	438,802
2000 Population	25,533	69,883	529,121
Population Increase Rate	74%	86%	21%
Municipal Area	22.1 km^2	56.5 km^2	375.6 km^2
Stream Length	34.0 km	63.5 km	475.8 km

Analysis

Our approach for documenting riparian vegetation changes over time in each of the three municipalities consisted of digitizing aerial photographs into four riparian vegetation classes for all permanent streams at two points in time, 1990 and 1997. We then performed a banding analysis where riparian vegetation coverage was measured at several buffer widths out to 200 m from streams and changes over time were compared in the context of differing regulatory strategies. Our data sources included (a) the Metro RLIS database for stream locations and city boundaries (Metro 2002), (b) 1997 color orthorectified aerial photographs at 1.22 m resolution from Metro, and (c) 1990 gray scale photographs at 0.30 m resolution. The 1990 aerial photographs were purchased as raw digital scans and orthorectified to 1997 photos (x and y coordinates) and USGS digital elevation maps (z coordinates) using ERDAS Imagine 8.3 software. For each photo, at least 12 ground control points were used and the total root mean square error was maintained below 1.0. We digitized vegetation using ArcGIS 8.x software, from 0 m to 200 m from permanent streams and wetland features, into four classifications:

- Adjacent woody (= trees and shrubs, within 5 m distance of a stream and/or other adjacent woody cover)
- Adjacent unmanaged (= adjacent woody, plus unmanaged grasses within 5 m distance of a stream and/or other unmanaged adjacent vegetation cover)

- All woody (= adjacent woody plus non-adjacent trees and shrubs)
- All unmanaged (=adjacent unmanaged, plus non-adjacent unmanaged vegetation cover)

We maintained a consistent viewing scale of 1:1500 while digitizing. Our patch delineations followed Schuft and others (1999), and used a minimum inter-patch distance of 5 m for the adjacent classes, and a minimum patch area of 20 m^2 (based on a circular crown diameter = 5 m). We implemented the "adjacent" versus "all" vegetation distinction to track potential changes to riparian corridor habitat quality to account for connectivity (Naiman and DeCamps 1997). We included unmanaged vegetation in the analysis to account for all vegetation changes within our specified buffer widths. We conducted a banding analysis of the digitized vegetation classes (Schuft and others 1999) for the following distances (followed by the corresponding regulatory significance where applicable): 7.5 m (25 ft – Washington County buffer regulation); 15 m (50 ft – proposed Metro Title 3 minimum); 22.5 m; 30 m (100 ft – corresponds to 50x100 ft lot dimension max); 45 m; 61 m (200 ft – proposed Metro Title 3 maximum); 100 m; and 200 m (total). Our quality assurance steps included: (a) alignment of streamline locations provided by Metro were cross-corrected with USGS quadrangles and Metro contour maps; (b) if a stream formed a city boundary, streamline was snapped to the boundary; (c) shadows truncated from photos where determination was possible; (d) field checks were conducted for several dozen ambiguous features; and (e) digitizing interpretations cross-checked between two observers with error < 3 percent. Also, we interpreted 1997 changes while referring directly to 1990 digitized vegetation polygons to minimize interpretation error between years. The analysis was conducted exhaustively for all streams in the three study municipalities (rather than based on a sample or fraction of the streams) to account for all landscape changes in riparian buffers in these cities from 1990 to 1997.

Results

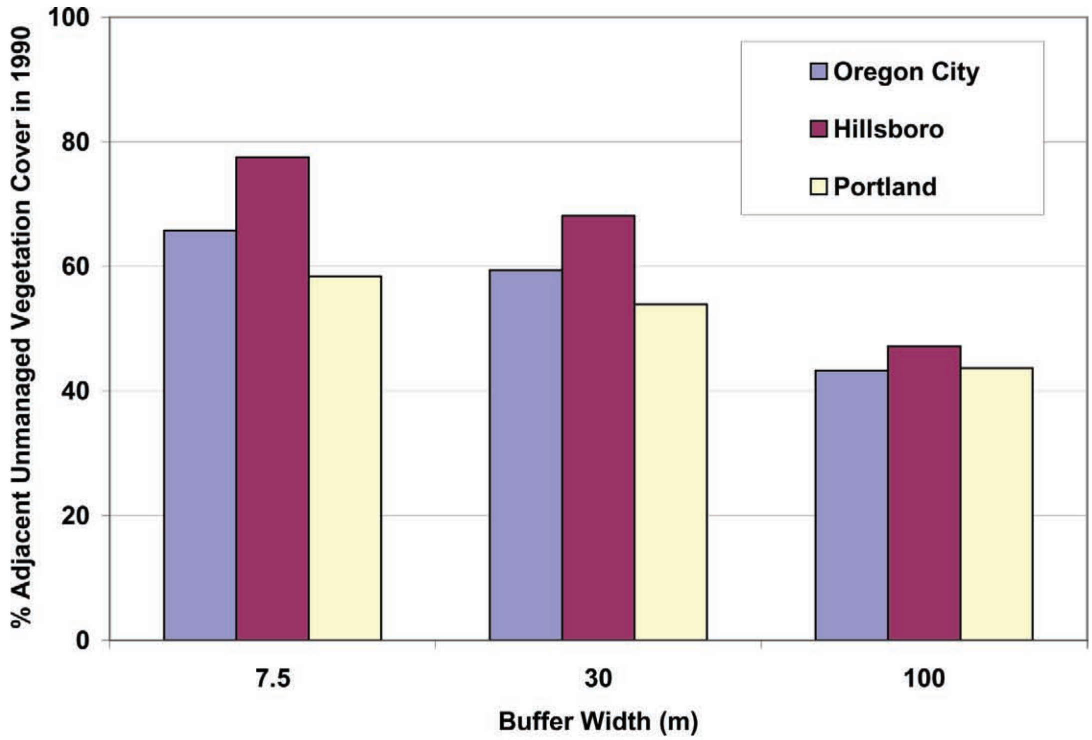
At the beginning of the study period, in 1990, significant portions of adjacent riparian vegetation remained on the landscapes of these three cities (fig. 3). Unmanaged riparian vegetation ranged from approximately 40 percent cover in Oregon City and Portland at 100 m buffer width to nearly 80 percent cover within 7.5 m in Hillsboro. Adjacent riparian tree vegetation resources also remained, ranging from above 30 percent cover at 100 m to 60 percent cover at 7.5 m. It should be noted that these figures do not include historical streams that have been entirely removed and replaced by culverts, as has happened to much of the streams that once existed on the east side of Portland.

For all unmanaged vegetation (trees, shrubs, grasses), losses tracked in this study from 1990 to 1997 ranged from just over 1 percent total in Hillsboro at 7.5 m to over 11 percent riparian cover lost in Hillsboro at 100 m (fig. 4). Losses were slightly higher in adjacent vegetation (fig. 5) compared to all vegetation within the buffer (fig. 4) for most buffer widths examined. For example, in Portland for all buffer widths for both tree and unmanaged vegetation, adjacent losses (fig. 5) were approximately a percentage point higher than for losses of all vegetation in the riparian buffer (fig. 4). Adjacent unmanaged vegetation losses topped 12 percent in Hillsboro at 100 m. Adjacent and all vegetation losses were, however, roughly equivalent in Oregon City for most buffer widths (figs. 4 and 5). On a percentage basis, losses in both adjacent riparian tree and unmanaged vegetation cover within 61 m were highest in Oregon City (figs. 4 and 5). Portland and Hillsboro were roughly comparable closer in, but Hillsboro had the highest losses of all three cities at the largest buffer width (100 m).

At 100 m from stream, larger losses were observed for unmanaged adjacent vegetation for Hillsboro and Oregon City (≥1.5 percent/year) than for Portland (<1 percent/year). For adjacent tree vegetation within a 100 m buffer width, again Hillsboro and Oregon City had higher rates of loss (>1 percent/year), while Portland lost trees in the 100 m buffer at a lower rate (<1 percent/year).

Discussion

Generally, the two cities with lower regulatory stringency experienced larger losses of riparian vegetation at all buffer widths. Oregon City experienced the greatest losses, signaling that their approach of suggestive overlay districts to protect land-based natural resources was not as effective as the more prescriptive approaches of Portland or Hillsboro. Hillsboro was a tale of two types of vegetation loss during the study period. At short distances from streams, Hillsboro experienced the lowest loss of all three cities – in part likely due to a county level ordinance implemented midway through the 1990s that prohibited most development within 7.5 m. At the largest distance from stream, however, Hillsboro experienced the greatest loss, possibly due to its higher construction rates (number of permits relative to total land area) during the 1990s. Portland generally experienced the lowest percentage of riparian loss. There are two potential explanations for Portland's relative success. The more hopeful explanation is that the environmental zoning implemented in



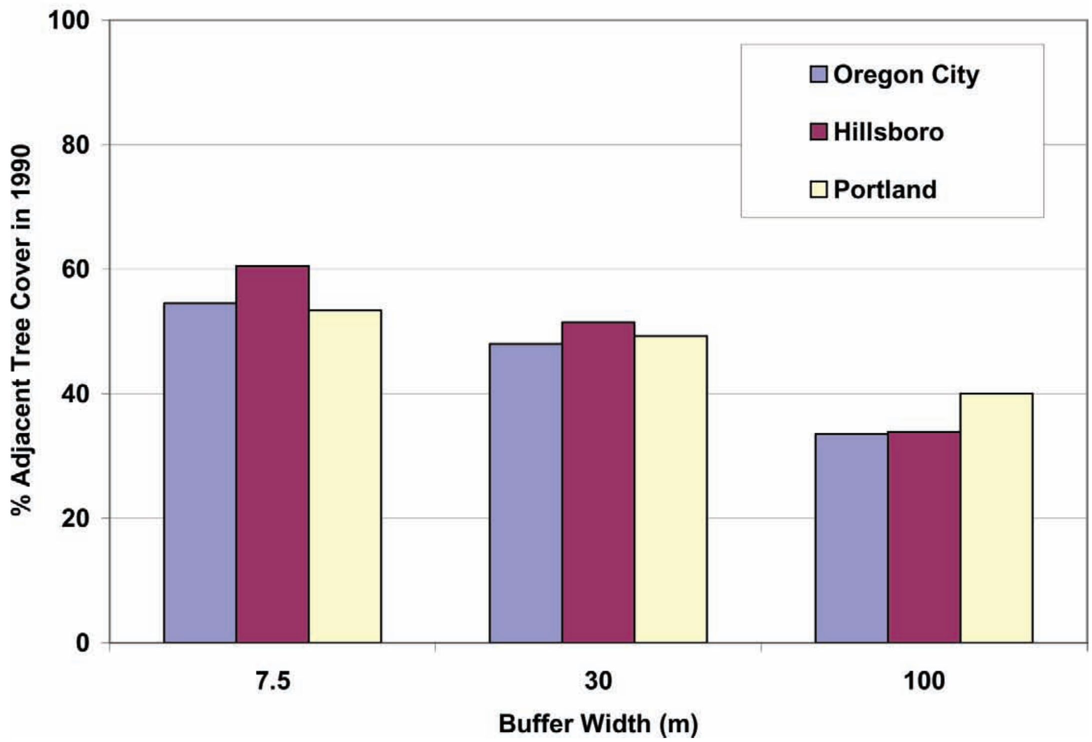


Figure 3. Adjacent Riparian Vegetation Cover in 1990. Shown in the upper graph is percent cover for adjacent unmanaged riparian vegetation cover at 3 buffer widths (or band widths) in 1990. Shown in the lower graph is percent cover for adjacent riparian tree cover at 3 buffer widths in 1990.

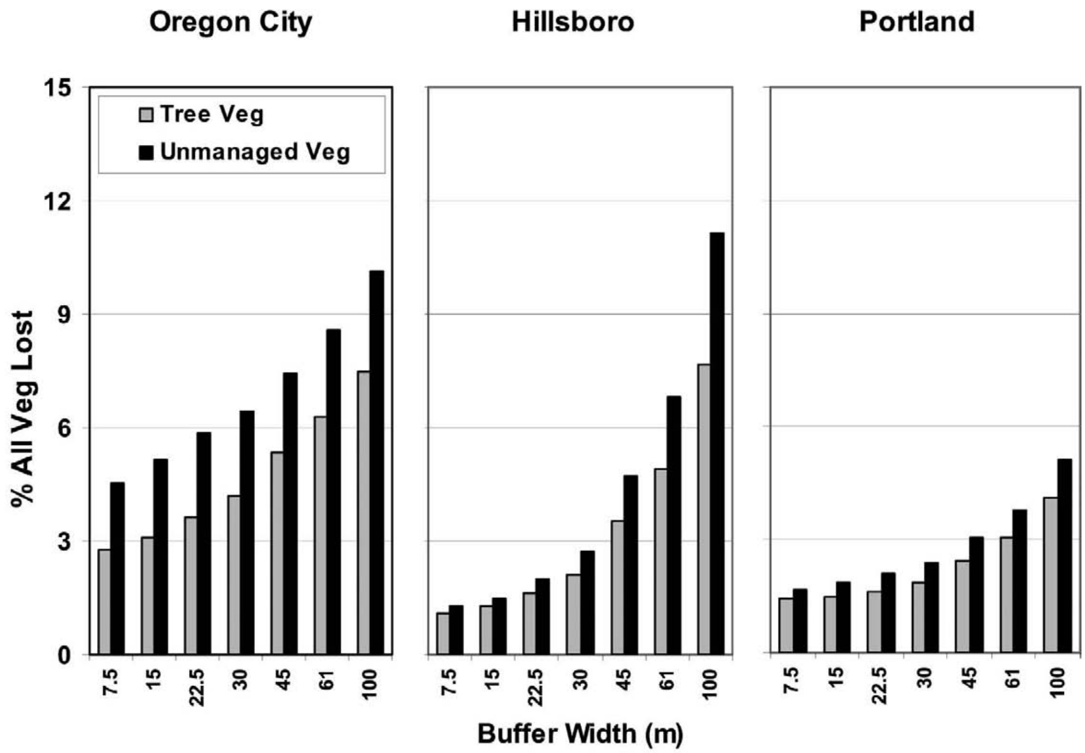


Figure 4. Percent All Riparian Vegetation Lost from 1990 to 1997. Shown in each graph are percent riparian area lost for both all tree and all unmanaged vegetation from 1990 to 1997 for the cities of Oregon City, Hillsboro, and Portland.

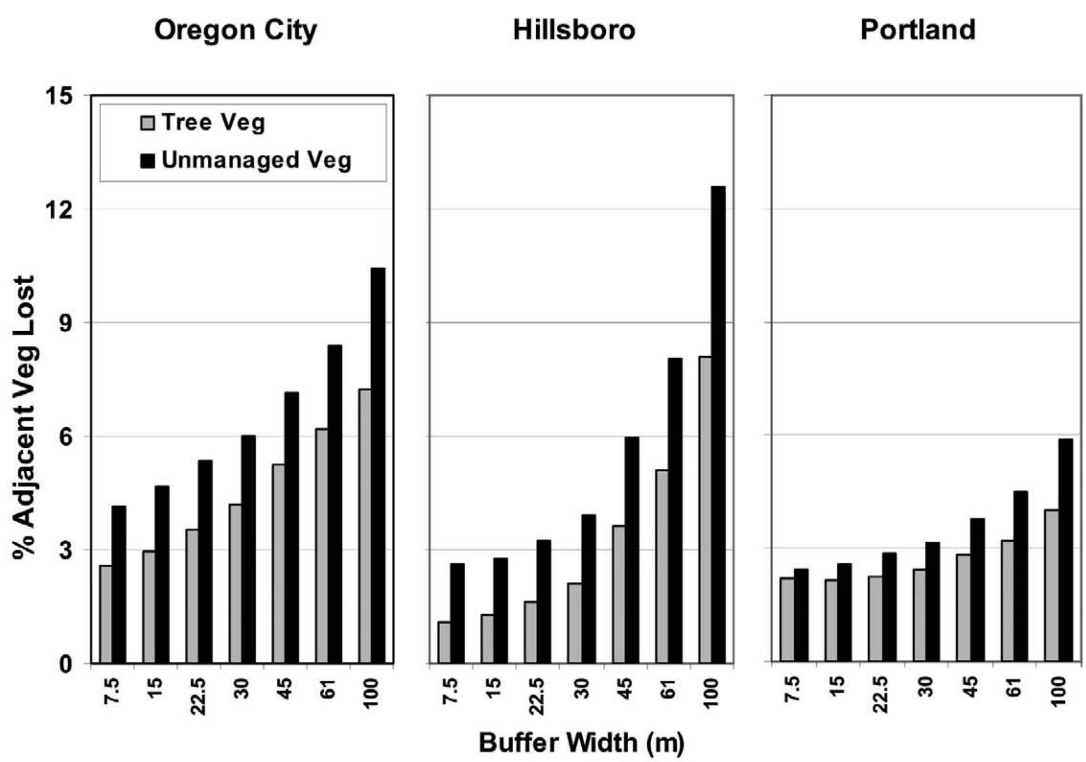


Figure 5. Percent Adjacent Riparian Vegetation Lost from 1990 to 1997. Shown in each graph are percent riparian area lost for both adjacent tree and adjacent unmanaged vegetation from 1990 to 1997 for the cities of Oregon City, Hillsboro, and Portland.

1989 (Ozawa and Yeakley 2004) was actually effective at lowering riparian losses. A secondary possibility is that Portland's streams were protected due to having a large number of streams located on public park land (for example, the ca. 2000 ha Forest Park, located in the northwest part of the city, fig. 2). Further analysis is necessary to determine which factor was more important to Portland's success, but we suggest that both factors (environmental zoning, streams located in public parks) were in play. It should be noted that our analysis does not include streams that have been permanently removed, and here Portland has suffered the most historical loss of streams among the three cities.

While our comparison of the three cities shows differential amounts of loss, an overriding result is that riparian buffer loss occurred regardless of either state or local regulatory efforts. Riparian vegetation loss appears to be an unfortunate consequence of population growth and development activities, and municipalities have yet to factor in the ecological or economic costs of such losses in terms of ecosystem services (Daily and others 1997). We are well underway with an effort to further document losses for these cities from 1997 to 2002, and our preliminary findings indicate that these loss trends have continued. Thus, while Portland shows hopeful signs of stemming the loss of riparian vegetation resources, our results show that the regulatory tools employed to date will likely be only partially successful at best.

Future research that controls for topographic, economic, land use and ownership factors may clarify the relative effectiveness of different regulatory approaches. Additionally, refining our understanding of the types, distribution and patterns of riparian vegetation that satisfy ecological functions, such as habitat connectivity, may enable us to develop more targeted management tools, focus implementation investments, and thereby increase overall effectiveness. Also promising and not to be overlooked are the pro-active efforts of both citizens groups and municipalities to restore riparian vegetation areas. Each of these approaches suggests compelling avenues for research to inform management strategies for preventing riparian resource losses during development.

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Hydrosphere Systems and Processes

Regional Monitoring of Coral Condition in the Florida Keys

William S. Fisher, Deborah L. Santavy, William P. Davis and Lee A. Courtney, research biologists with the United States Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL

Abstract—*Tropical reef corals have experienced unprecedented levels of bleaching and disease during the last three decades. Declining health has been attributed to several stressors, including exposures to elevated water temperature, increased solar radiation, and degraded water quality. Consequences of coral bleaching and disease vary; some recover, while others lose tissue, die, and succumb to algal overgrowth. In 2000, a regional monitoring project documented disease prevalence and bleaching across 41 km² of coral reefs in the Florida Keys. Thirty sites were randomly selected from a spatially-balanced grid. A radial belt transect (113 m²) was surveyed at each site and 100-300 colonies were encountered in each transect. The coral species and health status was recorded for each colony. No site had greater than 13 percent disease prevalence and ~80 percent of the reef area had <5 percent disease prevalence. The survey will be repeated in 2005, but with additional measurements to estimate colony size, percent living tissue, and living surface area. These added endpoints are expected to provide information on the consequences of bleaching, disease, and other stressors on coral communities. Data will be compiled to characterize community composition, abundance, age class structure, and survival of different species across the Florida Keys reef tract. During a pilot study in 2003, living coral tissue on large colonies of elkhorn coral* Acropora palmata *was considerably less than on small colonies, possibly indicating a major mortality event (for example, hurricane or bleaching) that occurred prior to recruitment of the smaller colonies.*

Introduction

Tropical reef-building corals have declined to unprecedented levels during the last three decades (Antonius 1973, Gardner and others 2003, Glynn 1984, Hughes and Tanner 2000). Multiple stressors have been identified that could have led directly, or interactively, to bleaching, disease, and decline in condition. Among these is elevated water temperature, increased exposure to solar radiation, and degraded water quality, each related in some manner to global climate or land use changes. Consequences of bleaching and disease vary, depending on the severity of the stressors and the coral species affected. Some corals recover from a bleaching episode, while others may not. Both bleaching and disease can lead to loss of living coral, algal overgrowth, and eventual disintegration of the calcified skeleton.

Linkages between coral bleaching and global climate change are compelling. Massive episodes of coral bleaching have accompanied the last several El Niño phases of the Southern Oscillation (ENSO). These events have occurred world-wide, irrespective of other impacts from local anthropogenic stressors (Hoegh-Guldberg 1999, Wilkinson and others 1999). Greater frequency, intensity, and spatial extent of bleaching have been documented since the 1982-1983 ENSO. An exceptionally strong 1997-1998 ENSO exhibited record sea-surface temperatures and coincided with the most geographically widespread and severe bleaching in history (Glynn 1984, Wilkinson 1998). Up to 95 percent of the living coral reefs from the central Indian Ocean and its margins were bleached, and bleaching occurred along the margins of the Caribbean Sea, the Indian Ocean and the Pacific Ocean. Although ENSO phases are determined by conditions measured in the Pacific Ocean, climate and weather patterns are altered worldwide (Wellington and others 2001). In the Caribbean, ENSO phases generate higher sea water temperatures and calm, stratified water conditions (doldrums) that allow increased penetration of solar radiation. These conditions are optimal for coral bleaching.

Many corals rely on photosynthetic energy derived from algal symbionts found within the polyps, or colonial units of the coral. Since photosynthesis requires solar radiation, these corals are confined to shallow coastal waters penetrated by sunlight. Coral reefs are located in tropical and sub-tropical oceans that are exposed to the most intense solar radiation on Earth (Madronich and others 1998). This distribution, however, places corals at risk from exposure to ultraviolet light (UV), particularly the damaging UV-B wavelengths (Anderson and others 2001, Shick and others 1996). Increased penetration of UV-B to the earth's surface has been attributed to a decline in UV-absorbing ozone in the stratosphere. Although stratospheric ozone depletion in the tropics is not as great as at the poles, there is concern that any increase in the high levels already experienced could affect coral health. The most variable aspect of coral exposure to UV-B is its penetration through the water above reefs. Many local variables such as water quality and weather can influence attenuation of UV-B with depth. For example, dissolved organic matter absorbs UV-B and reduces its penetration, whereas hot, windless conditions create thermal stratification of the water column and allow greater UV-B penetration (Zepp and Schlotzhauer 1981).

The highly complex three-dimensional structures formed by calcified coral skeletons provide a physical habitat to support high diversity and abundance of marine organisms. It is estimated that a million different marine species are dependent upon or utilize coral reef ecosystems. This diverse biota supports numerous subsistence and commercial fisheries and is a major attraction for tourists. Perhaps even more important is the role that coral structures play in coastal shoreline protection. Some have estimated that wave and current dissipation by coral reefs have protected shorelines at a value ten times greater than all other coral ecosystem services provided (Costanza and others 1997). The economic and ecological benefits of coral reefs are substantial, and much of this value can be credited directly to their physical presence.

The U.S. Environmental Protection Agency's Global Change Program includes research to facilitate and conduct assessments of global change effects on aquatic ecosystems to improve society's ability to respond to future consequences. Global change stressors include climate variability and change, land use change, and ultraviolet radiation. Each of these stressors is believed to contribute to the decline of coral reefs, which appear particularly sensitive to environmental changes. Because coral reefs have survived thousands of years in a relatively unchanged physico-chemical environment, their potential as a sentinel ecosystem is high.

Regional Monitoring of Disease and Bleaching

The Florida Keys coral reef tract provides an opportunity to investigate the causes and effects of global change on coral reefs. It is the third largest barrier reef complex in the world and contains reefs in both remote areas and near human population centers. Major declines in coral health and coral cover have occurred during the last thirty years on these reefs. A Coral Reef Monitoring Project has been supported by US EPA Region 4 since 1996 to compare coral coverage at 160 permanent stations in the Florida Keys National Marine Sanctuary (FKNMS). From 1996-2000, a 38 percent decline in live coral coverage has been documented (Jaap and others 2000, Porter and others 2002, Wheaton and others 2001). Much of this loss has been attributed to mortality caused by hurricane damage, coral bleaching, and coral diseases (Antonius 1981, 1985, 1988, Dustan and Halas 1987, Richardson and others 1998, Santavy and Peters 1997, Santavy and others 1999, 2001, 2004).

A similar survey was conducted by US EPA, Gulf Ecology Division (GED) to document the frequency and distribution of coral disease and bleaching across the entire reef tract in August 2000. Performed in collaboration with FKNMS, 30 stations in the Upper, Middle, and Lower Keys; New Grounds; and the Dry Tortugas in South Florida were surveyed. An EMAP-type sampling protocol was used to select site locations (Summers and others 1995). The probability-based design produced unbiased estimates of the spatial extent of ecological condition with a quantifiable level of uncertainty which measured both the distribution and frequency of coral disease in the Florida Keys Tract. The design was implemented in three steps: a regional stratification was developed, a hexagonal grid was overlaid on the sample frame, and then multiple sites were randomly selected within the grid cells (Santavy and others 2004). The original study area encompassed a nearly 10,000 km^2 area within the boundaries of the FKNMS, Biscayne National Park (BNP), and the Dry Tortugas National Park (DTNP). Areas were eliminated from the sample frame were if they were determined by professional judgment to contain only dead or geological reef structure. After exclusion of these reef areas, the total study area was approximately 45 km^2 (4100 ha).

A radial belt transect (113 m^2) was used to examine, count and identify fifteen coral species, eleven diseases, and three bleaching conditions (Santavy and others 2001). The distribution of the coral disease was

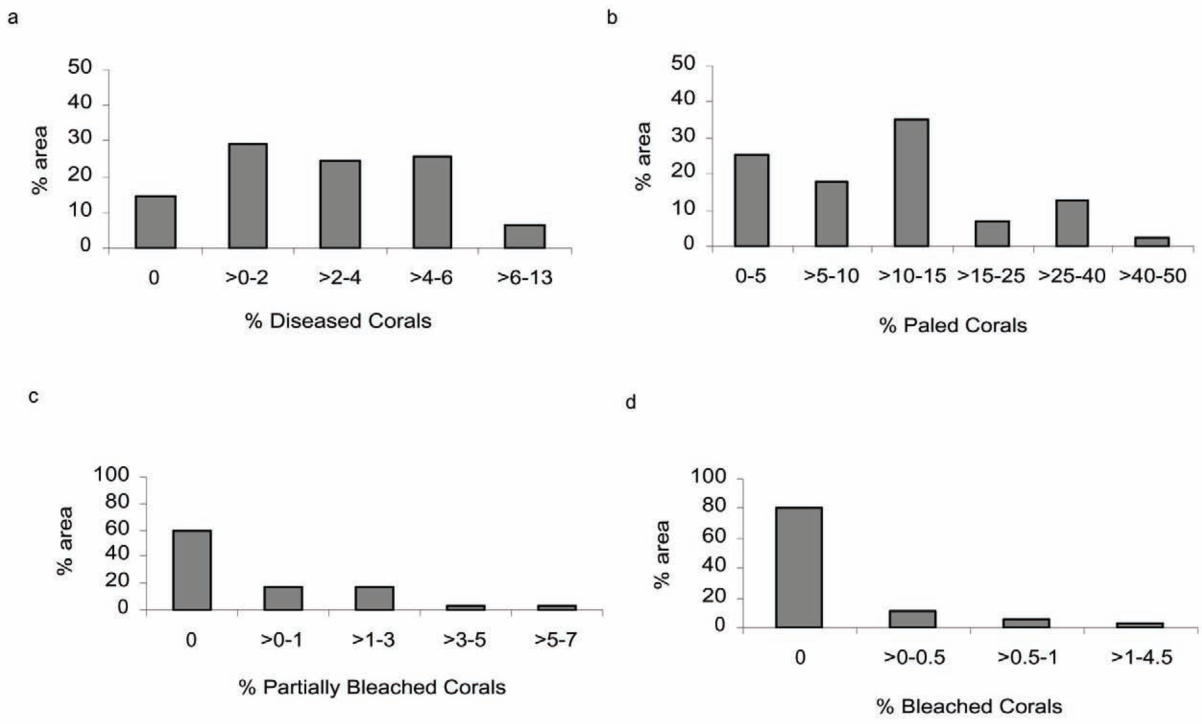

Figure 1. Distribution of the coral health indicators as a function of the frequency of occurrence throughout the area sampled in 2000. The following coral health indicators included: a) coral disease, b) coral paling (light bleaching), c) partially bleached corals affecting 10-50 percent of the total colony, and d) bleached corals affecting greater than 50 percent of the total colony.

determined by presence or absence at each site, and prevalence of disease and bleaching were determined by the percent of the susceptible coral community affected at each site (fig. 1). Diseases were present in 85 ∀ 9 percent (95 percent confidence intervals) of the area sampled, and were widely distributed throughout South Florida. While the distribution of disease was widespread, the prevalence was generally low. Maximum prevalence at any one site was 13 percent, with 2.2 percent of the sampling area containing this maximum level. Approximately 31 percent of the area had 0.4 percent-2 percent prevalence, 28 percent had 2 percent-4 percent prevalence, and 24 percent had 4 percent-9 percent prevalence. Future surveys will be used to document trends in the distribution and frequency of coral disease in South Florida.

Disease prevalence across the Florida Keys reef tract was considerably less than previous reports. Lower prevalence could be a consequence of coral losses documented during this period (Santavy and others 2001, 2004a, 2004b). Other studies have also reported high (38 percent) coral losses (Porter and others 2002, Wheaton and others 2001). Of particular concern has been the dramatic decline of the once dominant reef-building elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) corals (Patterson and others 2002).

With continued declines in South Florida corals, the EPA research effort has expanded to include characterization of coral condition. New measurements have been added to evaluate the cumulative consequences of bleaching and disease, as well as other stressors on coral individuals and populations. Reef-to-reef comparisons of disease prevalence are sometimes confounded by different taxonomic composition (for example, some sites do not have susceptible host species). The new condition measures are unrelated to taxonomic composition and will allow direct comparisons across reefs and geographic areas.

Indicators of Coral Condition

Surveys for prevalence and distribution of disease across the region provided one measure of coral condition and a baseline for detecting trend. An expanded approach was needed to evaluate the consequences of disease and other stressors to coral populations. This required development of condition indicators that would reflect population-level parameters: survival, growth, and reproduction. At the same time, application to a regional assessment required that numerous sites be surveyed, so the amount of time that could be spent at each site was limited. Three coral condition indicators were proposed that required adding only two observations to the existing disease survey protocol. These were estimates of total coral surface area (TSA; based on size class) and percent living coral tissue (%LC).

The new measurements provided meaningful end-points. Estimates of TSA indicated coral reef structural size and complexity (rugosity) and the habitat value that accompanies greater surface area. It also afforded a record of the cumulative, or historical, capacity of the habitat to grow, and sustain corals. Estimation of %LC provided a comparison of living tissue vs. dead coral skeleton, and can be used to examine potential associations of tissue loss with disease and other stressors. Living surface area (LSA) represented the existing capacity of the environment to sustain corals. Also, LSA estimated the actual amount of living coral (m^2) available for growth and reproduction.

Although TSA, %LC, and LSA can provide useful insight to status and trend of coral populations, it is imperative for future management action that declining condition is ultimately linked to causes. For coral reefs, a major obstacle to establishing causal associations has been the variability in reef species composition. For example, disease occurrence is not easily compared across reefs that vary in host density. Estimation of TSA, LSA, and %LC overcome this obstacle because the measures are independent of species composition. They can be used to compare reefs across geographical regions, reef types, water quality, human influences, and occurrence of bleaching and disease. Differences in condition among reefs or study areas can then be used to draw associations with potential stressors (causative factors) that may be degrading corals. Several of these potential stressors were measured but not discussed here.

A pilot project was performed in autumn 2003 to generate an operational survey plan and to illustrate potential interpretations from the candidate indicators. Five stations in the Key West area near anthropogenic activity and five stations in the more remote Dry Tortugas were surveyed. Total Surface Area was estimated through classification of corals in size classes (volumetric) and assignment of a surface area equal to five times the size of one side of a cube containing the size class volume. Estimates of %LC were in 20 percent ranges (0-20 percent, 21-40 percent, etc.).

Data from these ten stations showed greater coral abundance and total surface area (TSA) at Key West stations (table 1), but considerably lower %LC than at Dry Tortugas. In fact, despite a dramatically higher TSA at Key West (240.9 *vs* 175.9 m^2), the actual living coral (LSA) at each study area (fig. 2) was quite similar (136.9 *vs* 140.0 m^2). The two study areas also differed in species diversity, size distributions and the contribution of different species to total coral surface area (tables 2 and 3).

Table 1. Number of coral colonies, total estimated surface area (TSA), calculated surface area of living coral (LSA) and the estimated percent of living coral (%LC) for all colonies encountered within the transects at each of five stations in the Dry Tortugas and Key West study areas. Totals were determined from combined data of all stations in each study area.

	Number of Colonies	TSA (m^2)	LSA (m^2)	%LC
Dry Tortugas				
BK06	178	42.4	32.4	76.4
BK07	94	33.1	26.7	80.8
LR05	149	33.4	26.2	78.6
LR06	165	38.1	32.0	84.1
LR07	104	29.0	22.7	78.2
Total	690	175.9	140.0	79.6
Key West				
SK01	240	73.8	44.4	60.1
SK02	350	85.1	41.8	49.2
SK03	162	26.5	17.7	66.8
ED01	155	25.8	15.5	59.8
WS03	90	29.6	17.4	58.6
Total	997	240.9	136.9	56.8

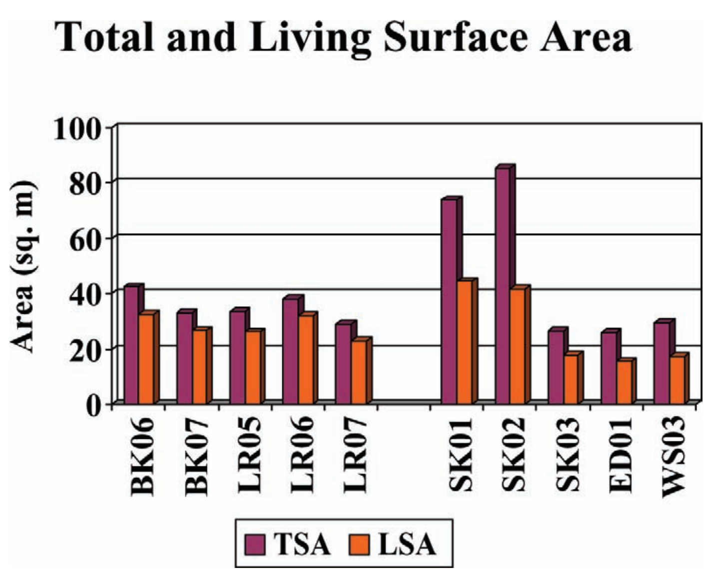

Figure 2. Total coral surface area (TSA) at each station in Dry Tortugas (left side) and Key West (right side) compared to living coral surface area, which was calculated from TSA and %LC (2003 survey).

The TSA metric provided an alternate perspective for taxonomic distribution. Traditionally, the number of colonies of each species provides information on species richness. In contrast, TSA provides the relative contributions of different species to community habitat. *Agaracia agaracites* was numerically the dominant species in Key West, but because it is a physically small species, the surface area contribution was limited in comparison

Table 2. Count, size distribution (5 classes) and estimated surface area contribution of 15 species recorded from transects at five stations at the Dry Tortugas study area in 2003. Percentage contribution to colony number and total surface area of all colonies recorded in Dry Tortugas is also shown.*Species not recorded for Key West study area (table 3).

	Dry Tortugas Study Area								
	Colonies		Size Distribution (L)					Surface Area	
Genus species	**(#)**	**(% of total)**	**1**	**10**	**50**	**100**	**200**	**(m²)**	**(% of total)**
A. cervicornis	25	3.6	10	10	5	-	-	6.2	3.5
A. agaricia	1	0.1	1	-	-	-	-	0.1	0.1
C. natans	1	0.1	-	1	-	-	-	0.2	0.1
D. clivosa	234	33.9	119	60	44	9	2	62.8	35.7
D. labrynthiformis	2	0.3	-	1	1	-	-	0.9	0.5
D. strigosa	59	8.6	28	11	14	3	3	21.8	12.4
D. stokesii	6	0.9	4	2	-	-	-	0.7	0.4
M. alcicornis	116	16.8	46	51	16	2	1	28.9	16.4
M. annularis	2	0.3	1	-	-	1	-	1.1	0.6
M. cavernosa	14	2.0	2	4	6	1	1	7.9	4.5
M. faveolata	24	3.5	3	1	4	2	14	29.2	16.6
P. astreoides	150	21.7	130	20	-	-	-	11.1	6.3
P. porites	46	6.7	44	2	-	-	-	2.7	1.5
S. siderea	9	1.3	5	2	2	-	-	2.1	1.2
Solenastrea sp.*	1	0.1	-	1	-	-	-	0.2	0.1
	690	**100**	**393**	**166**	**92**	**18**	**21**	**175.9**	**100**

Table 3. Count, size distribution (5 classes) and estimated surface area contribution of 22 species recorded from five stations at the Key West study area in 2003. Percentage of contribution to colony number and total surface area of all colonies recorded in Key West is also shown. *Species not recorded for Dry Tortugas study area (table 2).

	Key West Study Area								
	Colonies		Size Distribution					Surface Area	
Genus species	**(#)**	**(% of total)**	**1**	**2**	**3**	**4**	**5**	**(m²)**	**(% of total)**
A. cervicornis	3	0.3	-	1	1	1	-	6.2	3.5
*A. palmata**	57	5.7	16	6	7	10	18	8.5	20.1
A. agaricia	252	25.3	233	19	-	-	-	16.1	6.7
C. natans	9	0.9	5	1	-	2	1	4.3	1.8
D. stokesii	10	1.0	5	5	-	-	-	1.4	0.6
D. clivosa	7	0.7	4	1	1	-	1	2.8	1.2
D. labrynthiformis	8	0.8	6	1	-	1	-	1.6	0.7
D. strigosa	8	0.8	4	1	1	1	1	3.9	1.6
*M. meandrina**	3	0.3	-	1	-	1	1	3.0	1.3
M. alcicornis	199	19.9	156	30	13	-	-	3.6	9.8
*M. complanata**	28	2.8	20	4	2	1	1	6.1	2.5
M. annularis	3	0.3	-	2	-	1	-	1.5	0.6
M. cavernosa	72	7.2	22	21	15	8	6	5.0	4.5
M. faveolata	32	3.2	3	12	1	9	7	5.3	10.5
*M. franksii**	7	0.7	-	5	2	-	-	2.5	1.0
Mycetophelia sp.*	1	0.1	1	-	-	-	-	0.1	0.1
*M. danaana**	2	0.2	1	1	-	-	-	0.3	0.1
*M. ferox**	2	0.2	1	1	-	-	-	0.3	0.1
P. astreoides	175	17.5	109	55	11	-	-	25.7	10.7
P. porites	30	3.0	18	10	1	1	-	5.0	2.1
S. siderea	77	7.7	24	32	10	6	5	30.4	12.6
*S. michelini**	12	1.2	7	5	-	-	-	1.5	0.6
	997	**100**	**635**	**214**	**65**	**42**	**41**	**240.9**	**100**

Table 4. Average percent living coral (%LC) for each species encountered at five stations in Dry Tortugas and Key West in 2003. The number of colonies included in each average is denoted in parentheses; N/a denotes no colonies at that study area.

Genus species	Dry Tortugas	Key West
A. cervicornis	95.0 (25)	76.0 (3)
A. palmata	N/a	37.4 (57)
A. agaricia	99.0 (1)	98.2 (252)
C. natans	70.0 (1)	76.2 (9)
D. stokesii	94.5 (6)	66.7 (10)
D. clivosa	88.4 (234)	94.9 (7)
D. labrynthiformis	99.0 (2)	88.1 (8)
D. strigosa	86.3 (59)	68.4 (8)
M. meandrina	N/a	76.3 (3)
M. alcicornis	94.2 (116)	90.2 (199)
M. complanata	N/a	91.0 (28)
M. annularis	65.0 (2)	83.3 (3)
M. cavernosa	83.9 (14)	69.5 (72)
M. faveolata	64.4 (24)	67.8 (32)
M. franksii	N/a	70.0 (7)
Mycetophelia sp.	N/a	99.0 (1)
M. danaana	N/a	99.0 (2)
M. ferox	N/a	99.0 (2)
P. astreoides	94.6 (150)	89.5 (175)
P. porites	88.6 (46)	85.0 (30)
S. siderea	79.4 (9)	60.1 (77)
Solenastrea sp.	90 (1)	N/a
S. michelini	N/a	78.8 (12)

to *Porites astreoides* and *Siderastrea siderea*. In Dry Tortugas, *Diploria clivosa* was greatest in abundance and surface area.

Because data were collected on individual colonies, relationships could be examined at the regional, reef and even species level. For example, differences in %LC among species (Table 4) could indicate whether a particular species has lost more tissue than other species in the same area, or whether the same species has lost more tissue in one study area than another. Two species, *Colpophyllia natans* and *Montastrea faveolata*, had low %LC at both study areas, whereas *Diploria clivosa, Porites astreoides* and *P. porites* exhibited high %LC at both study areas. Several species had lower %LC in Key West than in Dry Tortugas, including *Acropora cervicornis, Dichocoenia stokesii, Diploria strigosa, Montastrea cavernosa*, and *Siderastrea siderea* (table 4).

Size estimates also provided useful insights. At both study areas, there were high numbers of small individuals and declining abundance with increasing size (fig. 3). However, TSA and LSA for each size class varied between the study areas. For Dry Tortugas, the greatest surface area was contributed by coral in the mid-size range and in Key West, by corals in the large-size

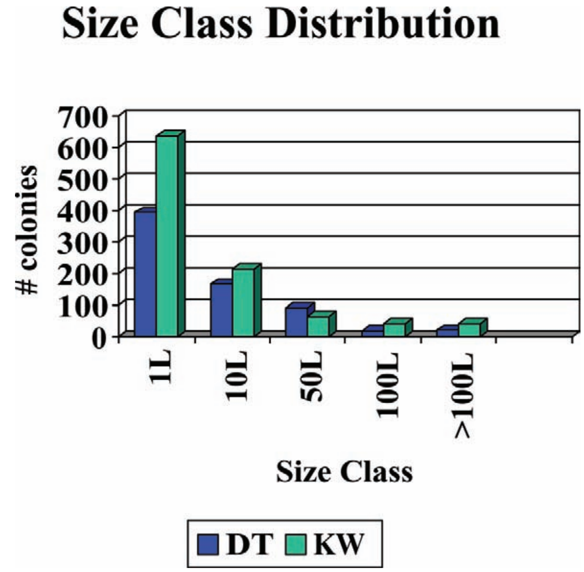

Figure 3. Distribution of coral colonies from Dry Tortugas and Key West across five different size class estimates (2003 survey).

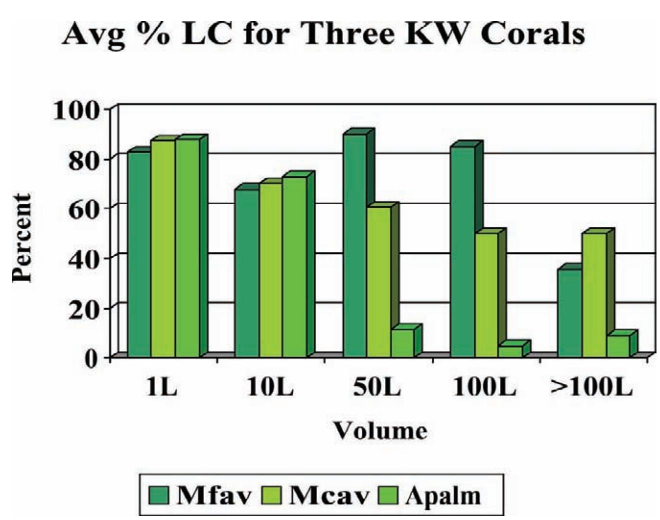

Figure 4. Average percent living coral (%LC) for *Montastrea faveolata, M. cavernosa*, and *Acropora palmata* from Key West stations observed in different size classes (2003 survey).

range. Most species, like *D. clivosa* at Dry Tortugas, showed a decline in percent living coral for the larger size classes. This could be due to chronic losses over added years of existence. The %LC for *Acropora palmata* was substantially different from two other large coral species in Key West, *Montastrea faveolata* and *M. cavernosa*, when examined by size class (fig. 4). Colonies greater than the 10L size class exhibited less than 10 percent living coral whereas the Montastreids retained substantially higher living tissue in even the highest (>100L) size class.

Estimating Surface Area from Size Classes

Estimates of TSA are an integral component of this approach to coral condition. Yet, surface areas estimated from volumetric size classes do not account for the structural complexities unique to each species (for example, branching). Nonetheless, a generic, first-order estimate was made with the assumption that a cube-shaped coral will fill the entire volume of its size class. This is reasonable because most corals in a size class will actually be smaller than the entire volume, a concession balanced by the lack of any consideration for physical complexities that would increase surface area.

Refinements to the first-order surface area estimates are being made through analysis of digital images of coral colonies, similar to the technique described by Bythell and others (2001). A series of nine or more photographs were taken from various angles around individual colonies of various species and size classes. Scale bars and billiard balls were placed around the base of a colony (fig. 5) as static orientation reference points for generating the computer model. The different images were reconciled using a computer software program (PhotoModeler7 Pro 5) designed to produce accurate 3-dimensional models from overlapping still photographs. Points were visually selected along the natural contours of the specimen and linked to produce curved lines that delineated colony topography and generated a 3-dimensional model. The surface area of the model is automatically calculated by the computer as the sum of the component contours. Surface area determinations are more accurate with greater numbers of points, curves, and surfaces used to define the coral structure. Optimization of the technique is being examined through comparison of model output with highly accurate surface areas determined by laser scanning.

As expected, preliminary analysis of the 3-dimensional models indicates that surface areas for hemispherical coral colonies (for example, brain corals) were generally overestimated by the assigned values whereas branched colonies (for example, *Acropora* spp.) were underestimated. Once more accurate estimates for each species and size class are available, new surface areas can be substituted for the currently assigned values.

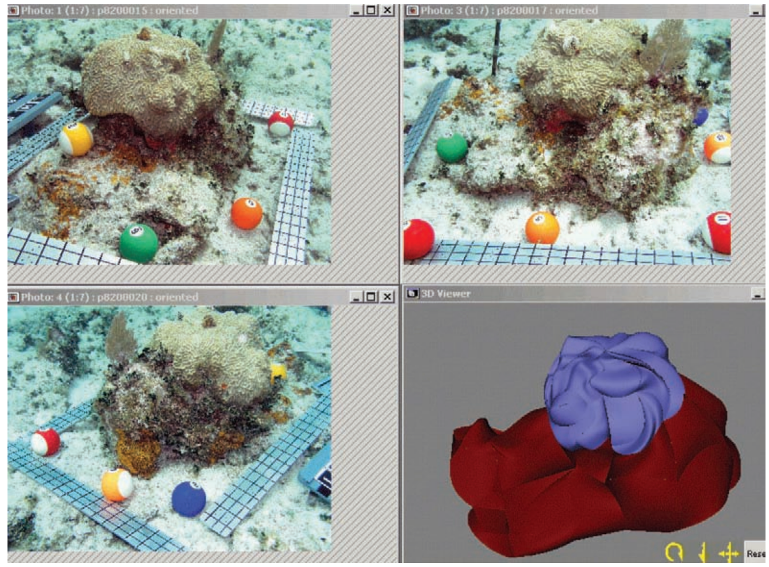

Figure 5. Coral colonies were photographed with gridded scales and pool balls as reference points to develop a 3-D computer model that depicts contours of the coral surface. Surface area of both living (blue) and dead (red) coral is determined using commercially-available computer software.

Acknowledgments

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Use of EMAP Freshwater and Marine Data in EPA Region 10

Gretchen A. Hayslip, C. Lorraine Edmond, and Lillian G. Herger, U.S. Environmental Protection Agency, Seattle, WA

Abstract—*The Environmental Protection Agency (EPA) designed the Environmental Monitoring and Assessment Program (EMAP) to provide tools to monitor and assess the condition of the nation's ecological resources. Since 1993, EPA Region 10 has worked with the States in our region to demonstrate the application of the ecological indicators and statistical designs developed by EMAP to freshwater and marine assessments.*

To illustrate the types of assessment questions that can be addressed with EMAP data, we present an example study of the Western Cascades Ecoregion of Oregon and Washington. In 1999-2000, Washington Department of Ecology (DOE) and Oregon Department of Environmental Quality (DEQ), with assistance from EPA Region 10, collected biological, physical habitat, and selected water column chemistry parameters in small streams of the Ecoregion. An overall assessment of the streams in this region using in-stream biological, physical and chemical data will be presented. In addition, a discussion of how these results might better inform Clean Water Act decisions will be presented.

As a second example, the estuaries of Oregon and Washington will be examined using EMAP Coastal data. Washington DOE and ODEQ, with assistance from National Marine Fisheries Service (NMFS) and EPA Region 10, collected water column chemistry, sediment characteristics, and chemistry, benthic organisms and fish trawl data. A discussion of how this data relates to EPA Regional reporting will be presented.

Introduction

The Environmental Protection Agency (EPA) designed the Environmental Monitoring and Assessment Program (EMAP) to provide tools to monitor and assess the condition of the nation's freshwater and coastal systems. This program was developed by EPA's Office of Research and Development (ORD). EMAP examines associations between these indicators and natural and anthropogenic stressors. The two major features of EMAP are the random, probability based sample site selection and the use of ecological indicators. In 1994, Region 10 began a partnership with the EPA ORD and the States to begin to use an EMAP-type sampling approach in selected areas for rivers and streams. These projects are called Regional EMAP (R-EMAP), and they use the same indicators and sample design as other EMAP projects, but at a smaller geographic scale. Table 1 shows the R-EMAP projects for Region 10.

In 1999, Western EMAP was initiated to focus on the aquatic systems and landscape features of the states encompassed by EPA Regions 8, 9 and 10. There are three major components of the Program - Coastal, Surface Waters (rivers and streams), and Landscapes. The Western EMAP is a partnership between EPA, the States, and others. All field data for Western EMAP in EPA Region 10 is collected by the state and tribal environmental agencies.

Overview of EMAP Surface Waters in Region 10

Western EMAP applies tools developed by ORD to monitor and assess rivers and streams across the contiguous western States. Water chemistry, physical habitat, benthic macroinvertebrate, fish, and periphyton data are combined to describe the current river and stream conditions. Idaho Department of Environmental Quality (IDEQ), Oregon DEQ, Washington DOE, and the Nez Perce Tribe have conducted most of the sampling for Western EMAP in Region 10.

The Western EMAP surface water component evaluates the ecological condition of rivers and streams at two scales (table 1). The broad scale assessment is useful for evaluating the overall condition of rivers and streams for each State and the entire Region. For this scale assessment, approximately 150 stream sites are in the process

Table 1. Freshwater monitoring projects in EPA Region 10 using EMAP design and indicators.

Geographic Scope	Year	Number of Sites	Agency Conducting Sampling
Regional EMAP Projects			
Coast Range ecoregion	1994-1995	104	Washington DOE and Oregon DEQ
Upper Chehalis basin	1997	26	Washington DOE
Upper Deschutes basin	1997	30	Oregon DEQ
Western Cascades Ecoregion	1999-2000	79	Washington DOE and Oregon DEQ
Western EMAP - Statewide scale			
Idaho	2000-2004	50	Idaho DEQ
Oregon	2000-2004	60	Oregon DEQ
Washington	2000-2004	50	Washington DOE
Western EMAP - Focus Studies:			
Deschutes/ John Day Basins	2000-2004	96	Oregon DEQ
Medium to large rivers of Idaho	2000-2004	45	Idaho DEQ
Wenatchee Basin	2000-2004	54	Washington DOE
National State Monitoring, Assessment, and Reporting Program Grants (EMAP design and indicators)			
Yukon (Tanana) basin	2004-2005	50	Alaska DEC and University of Alaska

of being sampled in Idaho, Oregon, and Washington over a four to five year period, beginning in 2000. Over the same time period, approximately 50 river sites will also be sampled across these three States.

The second scale of evaluation is smaller and more localized. This smaller scale is useful for more intensive assessments of particular geographic areas or resource types. These areas will be sampled over the same four year period as the broad scale sample sites. For streams, we will be intensifying the EMAP sampling effort in three focus areas: the John Day and Deschutes basins of Oregon, the Wenatchee Basin of Washington, and the medium to large sized rivers of Idaho. The sampling of the John Day and Deschutes and Wenatchee basins began in 2000. The river sampling in Idaho began in 2002.

During the summers of 2003-2004, as part of the National State Monitoring, Assessment, and Reporting Program Grants, 50 wadeable streams will be monitored in Alaska. Water chemistry, physical habitat, benthic macroinvertebrate, and periphyton assemblage data will be collected using EMAP field protocols. Alaska Department of Environmental Conservation (DEC) has selected the Yukon River Lowlands/Yukon Tanana Uplands (Hydrologic Assessment Unit number 1904) as the study area. This unit is located in interior Alaska, north of the Alaska Range. It extends from Denali National Park and Preserve east to the Yukon Territory border. The project will be managed by Alaska DEC in collaboration with the University of Alaska Environmental and Natural Resources Institute, Alaska Cooperative Fish and Wildlife Research Unit and the U.S. Geological Survey, Alaska office.

Overview of Coastal EMAP in Region 10

The coastal component of Western EMAP applies EMAP's monitoring and assessment tools to create an integrated and comprehensive coastal monitoring program of the west coast. Water column measurements, sediment characteristics and chemistry, benthic organisms, and data from fish trawls are combined to describe the current estuarine condition.

Sampling has focused on a different type of estuarine resource each year (table 2). The Washington DOE and the Oregon DEQ sampled small estuaries in 1999. Oregon sampled a second set of small estuaries in 2001. Sampling of larger systems (Puget Sound, Columbia River Estuary) was completed in 2000. An intensified study of Tillamook Bay, Oregon was also conducted in 1999.

In 2002, samples were collected from the south central coast of Alaska (called the Alaskan Biogeographic Province), which includes both Cook Inlet and Prince William Sound. The Alaska DEC managed this effort with support from the Cook Inlet Regional Citizens Advisory Council (CIRCAC). The Oregon and Washington intertidal zone, including low salt marsh, intertidal flats, and shallow subtidal habitats of estuaries, was also sampled in 2002.

In 2003, the National Oceanographic and Atmospheric Administration (NOAA), EPA, and partnering west coast states (WA, OR, CA) combined efforts to conduct a survey of ecological condition of aquatic resources in

Table 2. Coastal monitoring projects in EPA Region 10 using EMAP design and indicators.

Year	Project area	Sites	Agency conducting sampling
1999	Small estuaries of Oregon and Washington	100	Oregon DEQ, Washington DOE, NMFS
1999	Tillamook Bay, Oregon	30	Oregon DEQ
2000	Large estuarine systems of Puget Sound and the Columbia River	71/ 50	Washington DOE, Oregon DEQ and NMFS
2002	South Central Alaska, including Cook Inlet and Prince William Sound	50	CIRCAC and Alaska DEC
2002	The intertidal zones of Oregon and Washington	100	Oregon DEQ and Washington DOE
2003	The continental shelf off Oregon and Washington	100	Oregon DEQ and Washington DOE
2004	Small estuaries of Oregon and Washington	100	Oregon DEQ, Washington DOE and NMFS
2004	SE Alaska estuaries	50	CIRCAC, NMFS and Alaska DEC

near-coastal waters along the U.S. western continental shelf. Sampling was conducted at approximately 50 stations along the coast of each western coast state, for a total of approximately 150 stations. This survey provided the data necessary for this first-ever comprehensive assessment of ecological conditions of near-coastal waters (30-120 m depth) along a major portion of the U.S. western continental shelf, from the Straits of Juan de Fuca in Washington State to the Mexican border. The survey included stations in all five of NOAA's National Marine Sanctuaries on the west coast, thus providing an opportunity to assess condition in sanctuaries as compared to non-sanctuary areas of the shelf.

Examples of Uses of EMAP Data—Example 1: Freshwater

The data summarized below was collected in the Western Cascades ecoregion of Washington and Oregon as part of the R-EMAP (Hayslip and others 2004). The project was a cooperative effort between EPA ORD, EPA Region 10, Washington DOE, and Oregon ODEQ. Washington DOE and Oregon DEQ conducted all field sampling for this project in 1999-2000. R-EMAP provides States and EPA Regional offices opportunities to use EMAP indicators to answer questions of regional interest.

Geographic Scope

The Western Cascades ecoregion is located in the Cascade Mountain Range in Oregon and Washington. Most of the ecoregion is between 2,000 and 7,000 ft in elevation and is densely forested (Pater and others 1998). The Western Cascades ecoregion is 10,859 square miles in area. It supports forest dominated by Pacific silver fir, western hemlock, mountain hemlock, Douglas fir, and noble fir (Omernik and others 1987).

The predominant land cover type in the Western Cascades ecoregion is forest (87 percent). The next most common land cover type is transitional, which is defined as areas with sparse vegetation (<25 percent) that are dynamically changing from one land cover to another often due to land use activities (for example, forestry clear cuts, construction) and natural processes (for example, fire, flood). There is no urban land cover and very limited agriculture (1 percent) in the Western Cascades ecoregion. Timber harvest is the major industry in this area and the primary land ownership is Federal. In Washington, the federal land ownership is primarily the U.S. Forest Service (41 percent) followed by the National Park Service. In Oregon, the U.S. Forest Service (58 percent) is also the primary federal landowner, followed by the Bureau of Land Management.

Site Selection

Environmental monitoring and assessments are typically based on subjectively selected stream reaches. Peterson and others (1998, 1999) compared subjectively selected localized lake data with probability-based sample selection and showed the results for the same area to be substantially different. The primary reason for these differences was lack of regional sample representativeness of subjectively selected sites. Stream studies have been plagued by the same problem. A more objective approach was needed to assess overall stream quality on a regional scale.

EMAP uses a statistical sampling design that views streams as a continuous resource. This allows statements to be made in terms of length of the stream resource in various conditions (Herlihy and others 2000). Sample sites are randomly selected using a systematic grid based on landscape maps overlaid with stream traces. The EMAP systematic grid provides uniform spatial coverage, making it possible to select stream sample locations in proportion to their occurrence (Overton and others 1990). This design allows one to make statistically valid estimations from the sample data to the entire length of stream in a study area (the Western Cascades ecoregion), such as estimates of the number of stream miles or kilometers that are in "poor" condition.

Study sites were selected from a stream population of all mapped (1:100,000 scale) 2nd and 3rd order streams in the Western Cascades ecoregion, using EMAP-Surface Water protocols (Herlihy and others 2000). There are approximately 19,489 total km (12,100 mi) of streams in the Western Cascades ecoregion. The 2^{nd} and 3^{rd} order streams represent 26.8 percent or 5224 km (3,246 mi) of streams in this ecoregion.

The EMAP probability design was used to select a random sample of the target population. In this study, the "target" population was 2nd and 3rd order streams. A total of 108 sites were evaluated for field sampling. Of these, 79 were selected as "target sites" (useable sample sites). Sites determined to be useable or "target" sites if they were 2^{nd} and 3^{rd} order streams that were accessible, wadeable, perennial, and free of manmade physical barriers. Each of 79 sites was sampled at least once during the 1999-2000 field season. Sites were sampled July 5^{th} through October 19^{th}.

In addition to the 79 sites selected using the EMAP probability design, an additional 22 sites were hand selected and sampled to determine reference condition. The reference condition represents the biological potential or goal for the waterbody. The reference condition establishes the basis for making comparisons and for detecting impairment. The most common way to establish the reference condition is to collect field data from a number of sites that represent condition with minimal human disturbance. The data is then aggregated from these sites to develop a reference condition for that area, ecoregion, or class of waterbody.

For this project, the reference condition for each indicator metric is the average value calculated from these 22 sites. The reference sites were selected by the state environmental agencies (Oregon DEQ and Washington DOE) from 2^{nd} and 3^{rd} order streams in the Western Cascades ecoregion to represent minimal human disturbance. The reference sites were sampled using the same field methods as the probability selected sites, therefore these data are compatible with the probability dataset.

Ecological Indicators

The objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. To implement the Clean Water Act, States adopt water quality standards. These standards are designed to protect public health or welfare, enhance the quality of water, and protect biological integrity.

In general terms, a water quality standard defines the goals of a waterbody by designating the use or uses to be made of the water (such as aquatic life, coldwater biota, or salmonid spawning), setting criteria necessary to protect those uses, and preventing degradation of water quality. Therefore, in order to assess the nation's waters, it is important to measure water quality (stream water parameters), physical habitat (watershed, riparian and in-stream measurements), and biological (vertebrate and invertebrates communities) condition. EMAP uses ecological indicators to quantify these conditions. EMAP field methods were primarily used and additional detailed information is available in Lazorchak and others 1998.

Summary

The often complex results of environmental data analyses must be communicated in a straightforward manner to water resource managers and the public. In order to determine the extent of the 2^{nd} and 3^{rd} order streams in the Western Cascades ecoregion that are in good, fair, and poor condition, we measured chemical, physical, and biological indicators in a statistical probability sample of stream reaches (probability sites).

Stream water chemistry

For stream water chemistry indicators, we compared these results to water quality criteria for Oregon and Washington or literature values where no criteria existed (fig. 1). Over 90 percent of the 2^{nd} and 3^{rd} order stream length in the Western Cascades ecoregion was in "good" condition for pH, phosphorus and nitrite-nitrate.

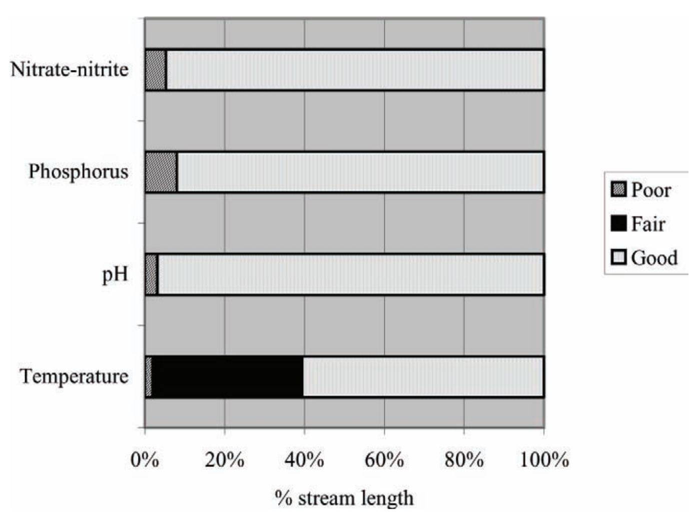

Figure 1. Quality of selected water chemistry indicators.

Streams were determined to be in "good" condition for pH between 6.5-8.8, below 0.1 mg/L for phosphorus and below 0.3 mg/L for nitrate-nitrite. For temperature, 61 percent of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "good" condition. We defined "good" as below 12°C. Thirty-seven percent of the stream length was in "fair" condition (between 12°C and 16.0°C). Only 2 percent of the stream length was in "poor" condition (warmer than 16°C). However, the use of a single measurement is unlikely to catch peak stream temperatures.

Physical habitat and biological indicators

For physical habitat and biological assemblages, we compare the results of the ecoregion-wide assessment (using probability sites) to that of the reference condition (using reference sites) as there are no applicable numeric water quality criteria. The range of scores at reference sites for each habitat and biological indicator represents a distribution that we used to define reference condition. Although the reference sites are minimally disturbed by human influence, however some level of human disturbance has occurred at least at some of these sites. Therefore, we have set our scoring criteria conservatively. The 25th percentile of this reference distribution is the criteria that we used to distinguish probability sites in "good" condition from those in "fair" condition (Barbour and others 1999). The 5th percentile value of reference separates sites in fair condition from those in "poor" condition (figs. 2 and 3). These criteria provide a margin of safety, as they would designate 5 percent of the reference sites in "poor" condition.

Generally, Large Woody Debris (LWD) was more prevalent in the reference sites in all categories, including the large class. For the amount of LWD in the large and very large size classes, 23 percent of the of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "poor" condition as compared to the reference sites. An additional, 49 percent of the stream length was in "fair" condition for large and very large LWD (fig. 2).

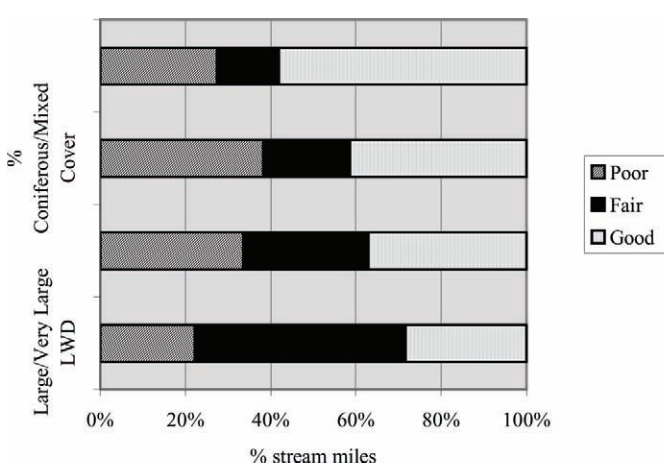

Figure 2. Quality of selected physical habitat indicators.

The amount of mid-channel shade was fairly high for both the probability and reference sites. However, 34 percent of the of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "poor" condition for percent mid-channel canopy cover as compared to the reference sites. An additional 30 percent of the stream length was in "fair" condition for mid-channel shade (fig. 2).

Mixed cover was the most common type of riparian canopy cover for both reference and probability sites. For the probability sites, the next most common riparian cover was deciduous. For the reference sites, the next most common riparian cover was coniferous. Thirty-seven percent of the of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "poor" condition as compared to the reference sites for percent coniferous plus mixed canopy cover types (fig. 2).

Cobble-sized (<64 to 250 mm) substrate was the most common surface substrate for both the probability and reference sites. The percent of fines-sized (.06mm) substrate was relatively abundant in the Ecoregion. Compared to the reference condition, 27 percent of the of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "poor" condition for percent fine-sized substrate. An additional, 16 percent of the stream length was in "fair" condition for percent sands or fines (fig. 2).

Salmonids were common in both with ecoregion-wide sites having slightly higher salmonid species richness than reference sites. Coldwater guild species were the dominant temperature guild in both site types. Reference sites differed from the probability sites in that they had higher amphibian species richness. For total vertebrate richness, 8 percent of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "poor" condition as compared to reference sites (fig. 3). The reference sites also had higher relative abundance of sensitive aquatic vertebrate guild species. Twenty-seven percent of the 2nd and 3rd order stream length was in "poor" condition as compared to the reference sites for sensitive aquatic vertebrate species relative abundance. Overall, vertebrate species diversity based on the Shannon-Weiner diversity was "poor" in 16 percent of the 2nd and 3rd order stream length in the Western Cascades ecoregion as compared to the reference sites (fig. 3).

For benthic macroinvertebrates (fig. 3), three indicators were considered (1) the percent of the individuals in the sample that were from the orders Ephmeroptera,

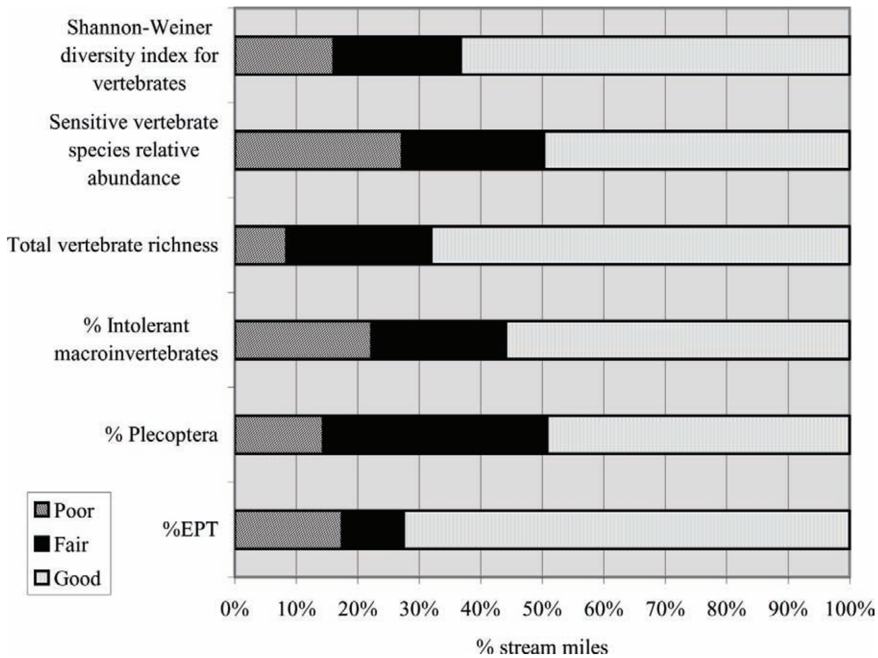

Figure 3. Quality of selected biological indicators.

Plecoptera, Trichoptera (EPT); (2) the percent Plecoptera individuals; and (3) the percent intolerant macroinvertebrates. For all three indicators, metrics values were lower for the probability sites as compared the reference sites. For the percent of individuals in the sample that were EPT (percent EPT), 17 percent of the 2nd and 3rd order stream length in the Western Cascades ecoregion were in "poor" condition as compared to the reference sites. Fourteen percent of the of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "poor" condition as compared to the reference sites for the percent of Plecoptera individuals.

For the percent of individuals in the sample that are intolerant individuals, 22 percent of the of the 2nd and 3rd order stream length in the Western Cascades ecoregion was in "poor" condition as compared to the reference sites. An additional 21 percent of the stream length was in "fair" condition for percent sensitive (fig. 3).

This project was designed to evaluate the overall condition of 2nd and 3rd order streams in the Western Cascades ecoregion. In this assessment we used direct measurements of the biota themselves as indicators of ecological condition. The organisms that live in a stream integrate many of the physical and chemical stressors and factors that are acting in, and on, the stream ecosystem. Information on the stream biota is supplemented by indicators of stress, which are measurements of other stream characteristics or factors that might influence or affect stream condition, especially stream water chemistry and physical habitat.

In conclusion, very few (3-8 percent) of the of the 2nd and 3rd order stream kilometers in the Western Cascades ecoregion were in "poor" condition using stream water indicators. However, physical habitat indicators showed a greater extent of the 2nd and 3rd order stream length in the Western Cascades ecoregion in "poor" condition (22-38 percent). The biological indicators (fish, amphibians, and macroinvertebrates) are likely responding to physical habitat conditions, as 8-27 percent of the 2nd and 3rd order stream kilometers in the Western Cascades ecoregion were in "poor" condition based on these biological indicators.

Examples of Uses of EMAP Data—Example 2: Coastal

The data described below were collected in the estuaries of Washington and Oregon as part of the coastal component of Western EMAP in 1999 and 2000. This project applied EMAP's monitoring and assessment tools to create an integrated and comprehensive coastal monitoring program along the west coast. The project is a cooperative effort between EPA ORD, EPA Region 10, NMFS, Washington DOE, and Oregon ODEQ. Washington DOE and Oregon DEQ conducted all field sampling in Region 10, with assistance from NMFS, for this project in 1999-2000.

In Coastal EMAP, water column measurements are combined with information about sediment characteristics and chemistry, benthic organisms, and data from fish to describe estuarine conditions. The first year's effort (1999) constituted an assessment of the condition of the small estuarine systems (< 250 km^2) in Oregon and Washington, using 100 randomly selected sites. Also in 1999, 30 sites were selected in Tillamook Bay, Oregon, to demonstrate the EMAP design at a smaller scale.

In 2000, EMAP samples were collected from 50 locations in the lower Columbia River estuary and 71 locations in the Puget Sound. While a great deal of data was collected during this project, only a small portion of the information will be described below.

An important part of making policy and management decisions is understanding the relative magnitude and extent of current stressor to aquatic systems. Estuaries are threatened because of the numerous ways that humans use them and use the land areas, or watersheds, that drain into them. Under the Clean Water Act, States are required to report on the condition of the states' waters, including estuaries. There are many stressors that influence the ecological condition of estuarine waters in Region 10.

For example, an excess of nutrients, such as nitrogen and phosphorus, from runoff can lead to euthrophication, a condition in which blooms of algae rob oxygen from other organisms. Dissolved oxygen (DO) is a fundamental requirement for estuarine biota. Another common stressor to estuarine systems comes from potentially toxic substances that reach estuaries from industrial and municipal sources and storm water runoff. These toxic substances bind to particles in the water and settle to the bottom, contaminating sediments.

Non-indigenous species are another estuarine stressor, but are rarely addressed in state or regional monitoring studies. The term "non-indigenous species" (NIS) can refer to any plant, animal, or other viable biological material that enter an ecosystem beyond its historic range. They are also called "invasive species," "nonnative species," "aquatic nuisance species," "introduced species," "exotic organisms," and other terms as well. Invasive species can successfully invade any terrestrial or aquatic ecosystem, and may enter through a wide variety of introduction mechanisms. Human activities, both intentional and non-intentional, are the chief cause of invasive species introductions. Non-indigenous aquatic species impact biological and economic resources and can also impact human health. NIS disturb native species through predation or displacement, clog intake pipes for water supplies, and pose serious human health risks. Not all non-native species become pests, or even survive, in new locations. But when they do, they often displace a whole suite of native species to become dominant.

EMAP coastal data will be used to develop an indicator for NIS for possible inclusion in future reporting and strategic planning. The extent of NIS will be compared to other, more traditional stressors, dissolved oxygen and sediment toxicity. The data that follows is from the 1999-2000 EMAP study of the estuaries of Oregon and Washington.

The three stressors that are compared are dissolved oxygen, sediment toxicity, and NIS. For dissolved oxygen, any location with less than 2.0 ppm DO fails, or is considered in "poor" condition. For sediment toxicity, condition is evaluated using a combination of several different approaches including sediment contaminant concentrations, organic carbon concentration, and amphipod survival in toxicity tests. If the site fails any one of the criteria, it is considered to be in "poor" condition for sediment toxicity. For non-indigenous species, a site with NIS comprising 25 percent or more of the individuals **or** of the species fails or is or is considered in "poor" condition, for NIS.

In the estuaries of Oregon and Washington, only 0.5 percent of the estuarine sites failed the dissolved oxygen cut-point and 15 percent of the sites failed the sediment toxicity cut-points. However, 48 percent of the sites in the estuaries of Oregon and Washington failed the NIS cut-point. Yet, NIS is not typically included in reports showing the condition of estuarine waters. We will be using this data to demonstrate the importance of including NIS in our regional and state reporting on the condition of the estuaries of Region 10.

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From Marshes to the Continental Shelf: Results of the Western Component of the US EPA National Coastal Assessment

W. G. Nelson, H. Lee II, J. O. Lamberson, Pacific Coastal Ecology Branch, Western Ecology Division, National Health and Environmental Effects Laboratory, U.S. Environmental Protection Agency, Newport OR

Abstract—*The National Coastal Assessment of the US EPA began field work in the Western US in 1999-2000. Probabilistic sampling for biotic and abiotic condition indicators was conducted at 381 stations within estuaries and coastal embayments of Washington, Oregon and California. In 2002, intertidal and low salt marsh habitats were sampled at an additional 190 stations. As part of the intertidal effort, pilot evaluations of landscape indicators of coastal wetland condition were carried out in California. Pilot studies were also conducted in south central Alaska and in the Hawaiian Islands. In 2003, sampling for many of the same condition indicators was conducted on the continental shelf of the west coast from the Strait of Juan de Fuca to the Mexican border. By 2003, NCA-West had completed the field work for assessing the condition of soft sediment, estuarine habitats including low salt marsh, intertidal flats, and subtidal bottom, as well as continental shelf habitats down to a depth of 120 m, for the entire west coast. During summer 2004, NCA-West re-sampled estuarine systems of WA, OR, CA, AK, HI and conducted pilot sampling in the territory of Guam. NCA-West data will ultimately provide area estimates of western coastal, soft-sediment benthic habitat (exclusive of beaches) with degraded benthic conditions due to the impacts of sediment contaminants and other stressors. Results from the 1999-2000 survey for condition indicators indicate that only a small percentage of area of Western estuaries has levels of sediment contamination of either metals or organic compounds potentially toxic to benthic organisms. Water quality indicators for Western estuaries were generally good, although PO4 was high at many sites, perhaps due to natural factors. Nonindigenous species may be a more spatially widespread form of disturbance to benthic infaunal communities than sediment chemical contaminants, although the ecological consequences of these invasions are not yet known.*

Introduction

The U.S. Environmental Protection Agency, through the Environmental Monitoring and Assessment Program (EMAP), initiated in 1999 a six-year research effort as part of the National Coastal Assessment (NCA) to develop monitoring protocols for the coastal resources of the western United States. The goal of the NCA is to create an integrated, comprehensive monitoring program among the coastal states to assess ecological condition of estuaries and near-coastal waters.

The specific objectives of the NCA-West program are: to assess the condition of estuarine resources based on a range of indicators of environmental quality using an integrated survey design; to establish a baseline for evaluating how the conditions of the estuarine resources of the Western states change with time; to develop and validate improved methods for use in future coastal monitoring and assessment efforts in the Western states; and to transfer the technical approaches and methods for designing, conducting and analyzing data from probability based environmental assessments to states and tribal environmental organizations.

NCA-West involves the cooperation of numerous organizations. The project is principally funded by the U.S. Environmental Protection Agency, Office of Research and Development. The following organizations provided a wide range of field sampling, analytical and interpretive support in their respective states through individual cooperative agreements with EPA: Washington Department of Ecology, Oregon Department of Environmental Quality, Southern California Water Resources Research

Project (SCCWRP). The Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration provided field support and analysis of fish pathologies through an interagency cooperative agreement with EPA. Moss Landing Marine Laboratories provided the field crews for collection of samples in California under contract to SCCWRP. The U.S. Geological Survey, Columbia Environmental Research Center, through the Biomonitoring Environmental Status and Trends (BEST) Program, provided analyses for exposure of fish to planar halogenated hydrocarbons. Through their Marine Ecotoxicology Research Station, BEST also provided results from two sea urchin bioassays on sediment porewater toxicity.

NCA-West has focused on different coastal resource components each year. The first phase involved a two-year (1999-2000) comprehensive assessment of soft sediment habitats of all estuaries of Washington, Oregon, and California (Nelson and others 2004). In 2001, NCA-West conducted field work only in Oregon estuaries, while the NOAA Status and Trends Program conducted additional sampling in San Francisco Bay. While not formally a part of the original NCA-West assessment design, the NOAA 2001 data will also be incorporated into the NCA-West assessment database.

In 2002, NCA-West conducted a pilot assessment of condition of intertidal estuarine wetlands of Washington, Oregon, and California which included specialized study efforts focused on development of marsh condition indicators for San Francisco Bay and Southern California. Pilot assessments of estuarine and coastal indicators were also successfully conducted in south central Alaska and the state of Hawaii with the collaboration of the Alaska Dept. of Environmental Conservation, the Cook Inlet Regional Citizens Action Committee, the University of Alaska, and the University of Hawaii.

In 2003, NCA-West moved to an assessment of the condition of soft sediment habitat on the continental shelf of Washington, Oregon, and California between a depth of 30 and 120 m. In addition to the group of state partners from Washington, Oregon, California, and Alaska, the shelf assessment efforts included cooperation with NOAA National Marine Sanctuary (NMS) programs for sampling within the Olympic, Cordell Banks, Gulf of Farallones, Monterey Bay, and Channel Islands NMS.

During the summer of 2004, NCA-West re-sampled the estuarine and near-coastal systems of WA, OR, CA, AK, HI and conducted pilot sampling in the territory of Guam. Additional participants in the sampling program for 2004 include the Hawaii Department of Health and the Guam Environmental Protection Agency.

NCA-West 1999-2000 Estuarine Assessment Sample Design

NCA utilizes a probability based sampling design to develop estimates of status and trends of condition of environmental resources. To demonstrate the general design approach, the sampling design for the 1999-2000 study will be described in some detail. The sampling frame for the NCA-West was developed from USGS 1:100,000-scale digital line graphs and stored as a GIS data layer in the ARC/INFO program. A series of programs and scripts (Bourgeois and others 1998) was written to create a random sampling generator (RSG) that runs in ArcView. Site selection consisted of using the RSG to first overlay a user-defined sampling grid of hexagons over the spatial resource which consisted of all estuaries of the west coast. The area of the hexagons was controlled by adjusting the distance to hexagon centers, and by defining how many sample stations were to be generated for each sampling region. After the sampling grid was overlaid on the estuarine resource, the program randomly selected hexagons and randomly located a sampling point within the hexagon. Only one sampling site was selected from any hexagon selected. The program determined whether a sampling point fell in water or on land, and sites that fell on land were not included. The RSG was run iteratively until a hexagon size was determined which generated the desired number of sampling sites within the resource (Bourgeois and others 1998).

Specific details of the 1999-2000 West Coast sampling design are provided in Nelson and others (2004). In brief, the sampling effort in 1999 consisted of 210 sample stations located within the smaller estuarine systems of Washington, Oregon, and California, while 171 locations in Puget Sound, San Francisco Bay and the main channel of the Columbia River up to Bonneville Dam were sampled in 2000 (fig. 1). In 1999, 50 stations were sampled within each state. There were also two regionally focused sampling efforts of 30 stations each for Tillamook Bay, Oregon and for a group of small, northern California estuaries. Approximately equal numbers of stations within the 150 stations of the basic sample effort were partitioned among estuaries of <5, 5-25 and >25 km^2 to ensure some level of sampling across the entire range of estuarine sizes.

The 2000 sampling designs for Puget Sound and San Francisco Bay were produced to allow collaboration with surveys being conducted by the NOAA National Status and Trends Program. For Puget Sound, the NCA-West sample grid was extended to include

Figure 1. Location of NCA-West survey sites in 1999 -2000.

Table 1. Core environmental indicators for the NCA-West assessment of estuarine and near-coastal condition.

Habitat Indicators
Salinity
Water depth
pH
Water temperature
Total suspended solids
Chlorophyll *a* concentration
Nutrient concentrations (nitrate, nitrite, ammonia, & phosphate)
Secchi depth
Percent silt-clay of sediments
Percent Total Organic Carbon (TOC) in sediments
Benthic Condition Indicators
Infaunal species composition
Infaunal abundance
Infaunal species richness and diversity
Demersal fish species composition
Demersal fish abundance
Demersal fish species richness and diversity
Percent Light Transmission
External pathological anomalies in fish
Nonindigenous species
Exposure Indicators
Dissolved oxygen concentration
Sediment contaminants Metals, PAHs, PCBs,
Pesticides, Hydrocarbons (AK only)
Fish tissue contaminants
Sediment toxicity (Ampelisca abdita, Eohaustorius estuarius, Hyallela azteca acute toxicity tests)

Canadian waters at the north end of Puget Sound, and then was overlaid on the existing probability based, randomized NOAA monitoring sites. If a NOAA site fell within a grid cell, the site was designated as the NCA-West sampling point. If not, a random site was selected based on the NCA-West protocols. There were 41 stations selected based on the NOAA sampling stations, in addition to 30 new EMAP stations, of which 10 were associated with the San Juan Islands. Similarly, in San Francisco Bay, NOAA Status and Trends used a probability based design to characterize condition of the sub-estuaries within San Francisco Bay. To insure complete coverage of the bay for the NCA-West study, the NOAA design was augmented with a sampling design which generated 31 sites in the open bay and 19 sites in smaller surrounding systems.

The 2000 sampling design for the Columbia River partitioned the main channel up to Bonneville Dam into 20 stations within the lower, saline portion and 30 stations within the upper, freshwater portion. Side channels of the Columbia River were sampled in 1999 as part of the small system survey. No alternate sites were selected as part of the 1999-2000 sampling design, and thus any sites which could not be sampled were not replaced.

NCA-West Assessment Indicators

The environmental condition indicators used in this study (table 1) included measures of: 1) general habitat condition (depth, salinity, temperature, pH, total suspended solids, sediment characteristics); 2) water quality indicators (chlorophyll a, nutrients); 3) pollutant exposure indicators (dissolved oxygen concentration, sediment contaminants, fish tissue contaminants, sediment toxicity); and 4) benthic condition indicators (diversity and abundance of benthic infaunal and demersal species, fish pathological anomalies).

2002 NCA-West Intertidal Wetlands Sampling Design

Because the principal focus of the 1999-2000 NCA-West estuarine assessment was on subtidal soft sediment habitat, the 2002 assessment was directed towards intertidal wetlands (habitat between mean lower low water and mean high water) to develop a more complete picture of estuarine condition. Thirty sites were randomly

Table 2. List of environmental condition indicators for the 2002 NCA-West intertidal wetlands assessment study.

Tidal water temperature, depth, salinity	Infaunal abundance
Sediment pore water salinity	Infaunal species richness and diversity
Sediment bulk density	Emergent macrophyte species richness
Sediment percent organic carbon	Emergent macrophyte species diversity
Sediment grain size	Emergent macrophyte species maximum stem or shoot length
Sediment inorganic contaminants	Percent of macrophyte species as nonindigenous species
Sediment percent phosphorus	Submerged aquatic vegetation or macroalgal percent cover
Infaunal species composition	Submerged aquatic vegetation maximum shoot length

Table 3. List of environmental condition indicators for the 2002 intertidal wetlands intensification studies in San Francisco Bay and Southern California.

Plant community composition and percent cover for drainage system	Habitat connectivity of tidal marsh patches
Wrack line trash composition for drainage system	Percent attenuation of spring tide range
Threatened/endangered species for habitat patch	Intertidal channel density for habitat patch
Nonindigenous species plants for habitat patch	Total acreage for habitat patch
Management objectives for habitat patch	Total perimeter for habitat patch
Number of recreational facilities and annual visitors for habitat patch	Shoreline development index for habitat patch
Presence of man made water control structures and levees	Shape index for habitat patch
Total annual POTW, industrial and power plant discharge to wetland watershed	Adjacent land cover for habitat patch
Human population density for watershed	Size class distribution for all habitat patches
Human population age structure for watershed	

allocated along the California coastline, and 30 sites were randomly allocated within each of the two intensification regions. All indicators in table 2 were measured at the 90 sites, allowing for a statewide assessment of intertidal wetland condition as well as independent assessments of Southern California (Point Conception to the Mexican border) and San Francisco Bay. The list of condition indicators was modified to reflect the intertidal habitat focus (table 2) and included a variety of plant community indicators.

The intensification studies in southern California and the San Francisco Bay area provided the opportunity to examine additional indicators (table 3). The use of additional indicators allows NCA to broaden its focus beyond an emphasis on sediment contamination to include issues specific to the intertidal wetland habitats, such as habitat fragmentation, threatened and endangered native species, the spread of nonindigenous species, modification of tidal flushing, and the impacts of land use alteration on wetlands.

In the intensification areas, a double randomization design based on the sample frame was employed. Thirty systems were randomly sampled from the list of all wetland systems within a region, with a random sampling point then chosen from the intertidal area of each of the 30 wetland units selected. The advantage of this approach is that it allows condition estimates based on percentage of systems, while at the same time also allowing for the areal extent estimates of condition that have been the basis for all other NCA-West activities.

2002 NCA-West Surveys in Alaska and Hawaii

A survey of the ecological condition of Alaska's near-coastal resources in the south-central region of the state (Alaskan Province) was completed in 2002. The south-central region of the state was selected for the first Alaskan survey because of the importance of the major estuarine resources in the region (Prince William Sound and Cook Inlet) to the local and state economy, as well as to aquatic living resources. The survey design included 50 core sites and 25 alternate sites, of which 55 stations were successfully sampled. The indicators collected during the survey are the same as those collected by the western states in 1999-2000, with the additional inclusion of analysis of petroleum hydrocarbons in sediments.

2003 NCA-West Continental Shelf Assessment Survey

NCA-West conducted a probability based assessment of condition of soft sediment benthic resources of the continental shelf of the west coast in summer of 2003. NOAA was a major partner in the study effort, contributing ship time on the R.V. McArthur II to the assessment effort. Fifty stations per state were sampled in the depth range between 30 and 120 m for the majority of the indicators listed in table 1, although sediment toxicity test and fish community indicators were omitted for a combination of cost and logistical issues. In order to allow development of an assessment of condition in the west coast NMS, 30 stations were selected within the Olympic NMS, and 30 stations were randomly selected within the Cordell Banks, Gulf of Farallones, Monterey Bay, and Channel Islands National Marine Sanctuaries. The remaining 90 stations were distributed in the area on the shelf of Washington, Oregon, and California north of Pt. Conception that was not included in a NMS. The shelf region between Pt. Conception and the Mexican border was sampled for most of the same condition indicators used by NCA-West during summer 2003 as part of the Bight '03 study by a consortium of agencies led by SCCWRP. The Bight '03 data will be integrated with the NCA-West data to provide the overall assessment of condition of the continental shelf of the West Coast.

2004 NCA-West Surveys

During 2004, NCA-West conducted a reassessment of estuarine resource condition in Washington, Oregon and California, using essentially the same sample frame that was used for the 1999-2000 sample effort. One change was the restriction of the sampling the Columbia River to the marine portions of the river system. Alaska conducted a second assessment in southeastern Alaska, a different biogeographic region of the state. Hawaii conducted its second state wide assessment of condition, but revised the sample frame to include not only estuaries and restricted coastal bays, but all state marine waters within the 60 foot depth contour. The territory of Guam conducted its first probability based assessment of marine waters, also using the 60 foot depth contour as the basis for the sample frame.

Selected 1999-2000 Assessment Results

The control corrected mean survivorship of the amphipods in toxicity tests of sediments collected (fig. 2) ranged from 0 percent to 109.9 percent, across the 306 stations that were included in the analysis. Approximately 17 percent of the area of West Coast estuaries had survivorship < 80 percent, indicating sediments that were toxic to amphipods due to some factor.

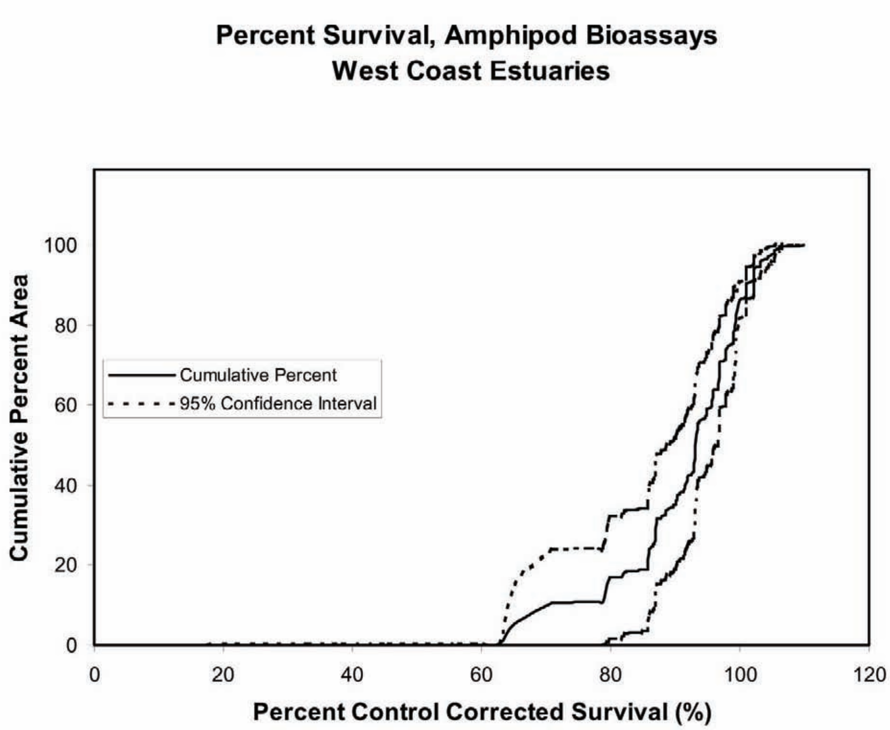

Figure 2. Percent area (and 95 percent C.I.) of West Coast estuaries vs. percent control corrected survivorship of the amphipod crustaceans (*Ampelisca abdita, Hyalella azteca* in the freshwater Columbia River).

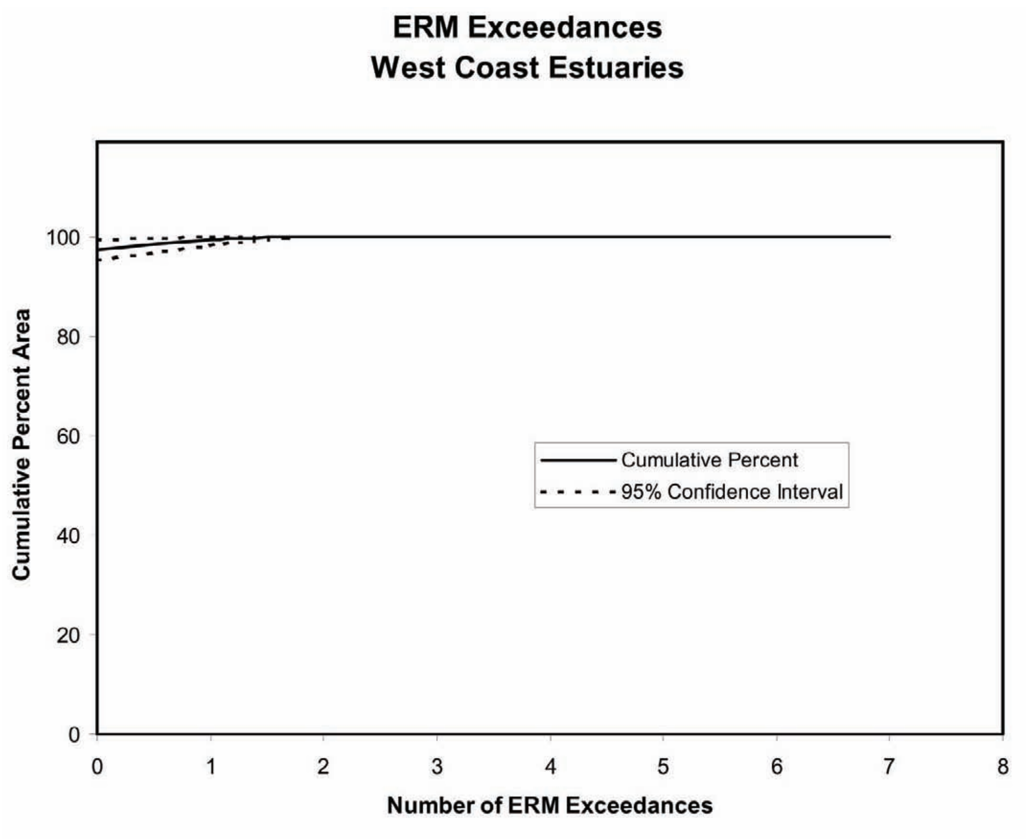

Figure 3. Percent area (and 95 percent C.I.) of West Coast estuaries vs. exceedances of the ERM concentrations for sediment contaminants.

Excluding nickel which has a low reliability for West Coast conditions, sediment concentrations exceeded their respective Effects Range Median (ERM) values at 24 stations, representing 3percent of the estuarine area (fig. 3). Twenty of these sites were in California, four in Washington, and none in Oregon. In California, all of the concentrations that exceeded the ERMs north of San Luis Obispo Bay were due to chromium, mercury, or copper. In Southern California, the exceedances were due to DDT, with the exception of the Los Angeles Harbor, which had high concentrations of several metals and PAHs. In Washington, three of the sediment concentrations that exceeded the ERMs occurred in harbors and bays within the Puget Sound system; one was in the Columbia River. All of these exceedances were due to either PAHs or PCBs.

Of the 18 stations with poor amphipod survivorship, there were five stations, all in California, which also had exceedances of at least one ERM. Therefore factors besides sediment toxicity may be responsible for the low survivorship observed at the remaining 13 sites.

The benthic infaunal community data from 2000 for the large estuaries are not yet finalized. However, the 1999 data indicate that the soft-bottom benthos in the smaller West Coast estuaries are diverse, with a total of 852 non-colonial taxa and an average of 22.3 taxa per grab (N=187). The two most abundant species were the native amphipods *Americorophium spinicorne* and *A. salmonis*, which reached densities as great as 397,000 m^2 in Northern California river mouth estuaries. Overall, nonindigenous species were moderately abundant, constituting almost 13 percent of both the native abundance and the native species (53 nonindigenous compared to 421 native species). The remaining taxa were either cryptogenic (104 species) or indeterminate (274 taxa), where cryptogenic species are species of uncertain origin (Carlton, 1996) and indeterminate taxa are those not identified to a sufficiently low level to classify as native or nonindigenous (Lee and others 2003). A more telling indicator of the extent of invasion in these small West Coast estuaries is that 124 of the 187 grabs (66 percent) contained at least one nonindigenous species, representing 74.5 percent of the area of the small estuaries (fig. 4).

Summary

NCA-West has primarily utilized indicators of biotic condition, physical and chemical characteristics, and exposure to pollutants, but is evolving to include indicators of landscape condition and hydrology. At the conclusion of the program in 2005, NCA-West will provide an integrated assessment of coastal condition of the west coast states in soft sediment habitat from the intertidal low marsh to 120 m depth. In addition, NCA-West has

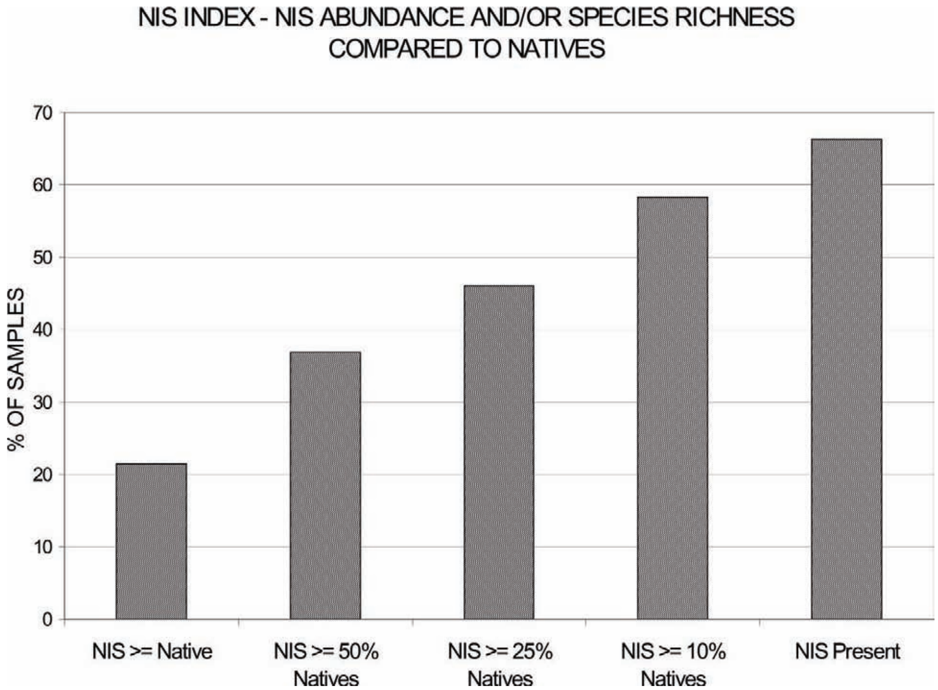

Figure 4. Percentage of benthic infaunal samples (N=187) with either abundance or species richness of nonindigenous (NIS) species that exceed various levels relative to native species abundance or species richness. The percentage of samples with NIS present is also shown.

developed methods for sampling the highly varied coral, coral rubble and soft sediment habitats of the tropical Pacific islands. In Alaska, NCA-West has assessed two of five biogeographic provinces, but still faces major challenges in completing a complete assessment in a state with more shoreline than that of the other 49 states combined.

Analysis of results from the 1999-2000 assessment effort shows an elevated mortality in amphipod sediment toxicity tests at 18 stations representing 17 percent of estuarine area. Two thirds of these sites with sediment toxicity had no measured chemical contaminants at concentrations above the ERM. In contrast, data from 1999 showed that nonindigenous species were present at a majority of sites and comprised 13 percent compared to the native abundance. The results of the NCA-West assessment suggest that at least within western small estuaries, nonindigenous species may be a far more widespread form of disturbance to benthic communities than sediment chemical contaminants.

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An Integrated Monitoring Approach Using Multiple Reference Sites to Assess Sustainable Restoration in Coastal Louisiana

Gregory D. Steyer, senior Wetland Ecologist, U.S. Geological Survey, National Wetlands Research Center, Coastal Restoration Field Station, Baton Rouge, LA
Robert R. Twilley, Director, Wetland Biogeochemistry Institute, Louisiana State University, Baton Rouge, LA
Richard C. Raynie, Coastal Resources Scientist Manager, Louisiana Department of Natural Resources, Coastal Restoration Division, Baton Rouge, LA

Abstract—*Achieving sustainable resource management in coastal Louisiana requires establishing reference conditions that incorporate the goals and objectives of restoration efforts. Since the reference condition is usually considered sustainable, it can be a gauge to assess the present condition of a (degraded) system or to evaluate progress of management actions toward some target system state (the reference or desired conditions).*

In 2003, the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) Task Force and the Louisiana State Wetlands Authority adopted the "Coastwide Reference Monitoring System – Wetlands*" (CRMS–*Wetlands*) for Louisiana. This system will provide data from multiple reference sites to explore the properties of a sustained reference condition. CRMS–*Wetlands *provides links between project-specific and system-wide objectives, criteria for selecting reference sites or conditions, a more robust statistical design, and critical monitoring variables. In addition, a system-wide assessment and monitoring plan (SWAMP) is being developed that incorporates and evaluates existing monitoring efforts (to the extent possible) within a system-wide experimental design. The SWAMP will integrate monitoring of biological, chemical, physical, and climatological variables in four modules: wetlands (CRMS–*Wetlands*), barrier islands, inshore waters and rivers, and nearshore coastal waters. Data and information collected under SWAMP will contribute to developing a systems-synthesis model for coastal Louisiana.*

Regional restoration project leaders in coastal Louisiana acknowledge the mutual dependence of monitoring and modeling the coastal landscape. For example, experiments or measurements should not be conducted independently of modeling and vice versa. Assessment should be directed at reducing scientific uncertainty to improve confidence in modeling and monitoring tools and ultimately to assist management actions. An adaptive environmental assessment and management process prescribes modeling, monitoring, and research activities to be conducted from initial stages of restoration planning to optimize the ability to assess and achieve sustainable restoration.

Introduction

The Mississippi River Deltaic and Chenier Plains of coastal Louisiana consist of diverse geomorphological basins with distinct vegetation zones and patterns of landscape development. Within each of these geomorphological basins are ecological habitats that can be distinguished by the adaptation of plants to soil fertility, relative water levels, and salinity (Buresh and others 1980, DeLaune and others 1989, Gosselink and others 1998). Marshes in coastal regions that differ in geomorphology and nutrient (fresh water and sediments) loading have evolved different plant strategies in response to resource availability and abiotic stressors (Hopkinson and Schubauer 1984, White and Howes 1994), resulting in different patterns of marsh stability. Although this coastal landscape is one of the most productive and biologically diverse in the contiguous United States, it is also suffering from one of the greatest environmental problems in North America—catastrophic wetland loss. Louisiana has the highest rate of coastal wetland loss in the nation, reaching a peak of 108.4 km^2/yr in the 1970s (Barras and others 2003, Gagliano and others 1981, Turner and Cahoon 1987). Although the rate has declined since the 1980s (Britsch and Dunbar 1993), nearly half of the wetlands present in the 1930s, an area equal to the size of Rhode Island (Boesch and others 1994), have been lost. This recent net loss of coastal landscape contrasts with the historical fluctuation of coastal area, which depended on a balance between the progradational processes of active delta formation and degradational processes during river abandonment, that lead to stable coastal landscapes.

There are several factors in the environmental setting of coastal Louisiana that contribute to the present inability of wetlands to maintain surface elevation causing an unstable landscape. These factors include: (1) high rate of regional subsidence (Penland and Ramsey 1990); (2) reduced sediment load in the Mississippi River (Kesel 1988); (3) elimination of spring overbank flooding of the Mississippi River and direct delivery of river sediment to floodplain marshes (Day and others 1997, Templet and Meyer-Arendt 1988); and (4) extensive landscape and hydrologic alterations from human activities, including energy related activities such as the construction of canals and navigation channels (Turner and Cahoon 1987). Determining the relative significance of these causal mechanisms to controlling surface elevation (such as mineral vs. organic matter accumulation; waterlogging vs. salinity stress) is important in developing the conceptual framework and hypotheses of a restoration or rehabilitation program.

Restoring functionality to hasten ecosystem rehabilitation is simply the manipulation of ecological succession to obtain a specific goal or purpose. Knowledge of the ecological theory that pertains to ecosystem development fosters more effective restoration planning that is less expensive, can be effectively implemented, and gives a more desirable final result (Christensen and others 1996). Ecosystem restoration can demonstrate much about how ecosystems work, provided we compare the effectiveness of system response to original hypotheses of causal mechanisms (Ewel 1987). In order to increase our knowledge of ecosystem dynamics it requires diagnostic capabilities that are based on ecological theory of succession and ecosystem development. These diagnostic capabilities are presently limited by the ability of scientists to: (1) anticipate ecological responses of ecosystems to specific manipulations or site conditions; (2) monitor responses of ecosystems at sufficient space and time scales to validate the responses; and (3) modify or prescribe new operations of rehabilitation projects according to the response of the ecosystem to attain specific goals. One of the most difficult tasks in restoring ecological systems is the selection of the proper set of criteria for site manipulations that will rehabilitate habitats and result in a specifically defined structure and function comparable to some reference condition. Thus, a fundamental need of restoration programs is to develop practical tools and approaches that can be used to predict, monitor, and validate the response of ecosystems to rehabilitation criteria.

Louisiana has been at the forefront of coastal wetland restoration and rehabilitation efforts for the past two decades. The passage of the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) in 1990 provided the necessary authorization and funding to accelerate construction of restoration projects throughout coastal Louisiana. From 1990 to 2003, the CWPPRA program has constructed 68 projects that are expected to create, restore, or protect 29,000 ha of wetlands. These projects address localized problems (for example, saltwater intrusion, flooding) and are primarily associated with hotspots of wetland loss within the coastal landscape.

The focus of CWPPRA is limited to project-specific approaches to restore coastal Louisiana and does not address evaluation of larger scale deltaic processes of ecosystem sustainability. In December 1998, the Coast 2050 Plan, the first ecosystem approach for restoring coastal Louisiana's wetlands and associated waters (LCWCRTF 1998), was completed. The strategic goals of the plan are to: (1) assure vertical accumulation to achieve sustainability; (2) maintain estuarine gradient to achieve diversity; and (3) maintain exchange and interface to achieve system linkages. To be sustainable, Louisiana's marshes require organic and inorganic soil accumulation sufficient to keep pace with sea level rise and subsidence, a dynamic salinity gradient, and effective coupling of subsystems in the estuarine landscape that exchange energy and materials. Theories of ecological succession and ecosystem development have provided the conceptual framework of how a delta works, but the challenge is to implement and evaluate these ecosystem concepts. Particular difficulty is in understanding the natural variability of functional processes within coastal wetland ecosystems in deltaic environments. A regional monitoring program was needed to provide comprehensive measurements of the major forcing functions at sufficient spatial and temporal scales to validate our conceptual framework of ecosystem dynamics in a deltaic setting. Additionally, tools were needed to predict trajectories in structural and functional ecosystem attributes in space and time to assess sustainability. In 2002, the Louisiana Coastal Area (LCA) Ecosystem Restoration Study (USACE 2004) developed conceptual and numerical models to integrate ecosystem attributes into measures that can be used to evaluate the effectiveness of restoration actions. Without both monitoring and modeling capabilities, it would be difficult to design or evaluate restoration projects that are intended to achieve ecosystem-level goals of the Coast 2050 plan.

This paper describes the regional monitoring and modeling tools and technologies that have been developed under the CWPPRA and the LCA Plan. The proposed integration of ecosystem attributes that is critical to assess sustainable restoration at ecosystem scales has also been discussed.

Regional Monitoring

Wetland restoration efforts under CWPPRA require an evaluation of the effectiveness of individual projects, as well as a measure of the cumulative effects of all projects in restoring, creating, enhancing, and protecting the coastal landscape. In 1994, a monitoring program was established to evaluate project-specific goals and objectives over each project's 20-year lifespan by using sound scientific procedures. This monitoring program relied heavily on the establishment of paired reference sites or areas. By 1998, the effectiveness of this approach was declining because of: (1) the inability to find comparable reference areas for the large number of restoration projects implemented, (2) the inability to discern the cumulative effects of all restoration projects conducted under multiple mandates, and (3) the inability to assess coastwide status and trends due to inconsistency of the variables measured across multiple projects. Recognizing the benefits of a comprehensive and flexible monitoring program and also realizing the increasing limitations of identifying paired reference sites, the CWPPRA Task Force and the Louisiana State Wetlands Authority adopted the Coast-wide Reference Monitoring System (CRMS-*Wetlands*) in 2003 as the future protocol for CWPPRA monitoring.

The CRMS-*Wetlands* will provide an avenue to evaluate the effectiveness of the Coast 2050 plan, and determine whether entire coastal ecosystems are being restored, rather than just the areas directly affected by individual projects. The focus of the CRMS-*Wetlands* program is to establish monitoring sites in both project and non-project (reference) areas, with reference sites spanning an entire range of structural and functional response characteristics. Reference sites will therefore have similarities as well as differences with project sites and through assessments over time will determine the degree of ecological variation that was restored. The distribution of these sites will also allow ecological comparisons within and between hydrologic basins to evaluate temporal changes at an array of spatial scales ranging from vegetation types to entire geomorphic regions.

CRMS-*Wetlands* was designed to maximize its analytical flexibility while providing information across a representative subsample of the major vegetation types in coastal Louisiana wetlands. A total of 700 stations were identified representing combinations of geomorphology, hydrologic basin, project/non-project areas, and vegetation type. The experimental design (with identifying stratification, sample size, and sample distribution) is described in Steyer and others (2003). Within each strata, locations were randomly selected and the sites were allocated to represent each marsh type to facilitate the evaluation of the stability of the entire ecosystem and the effectiveness of the restoration program on a large, ecosystem scale. The selection of monitoring variables was based on our conceptual understanding of the dominant stressors and the response variables that form our coastal landscape. Because of resource constraints, however, the selection of variables needed to be further narrowed. Following the recommendations by Rapport (1992) and Schindler (1995), only those variables that are thought to be most critical and are the targets of management actions (such as the objectives of the CWPPRA program and Coast 2050 plan) are selected. The selected variables are crucial in determining the effectiveness of the CWPPRA program and include water level, surface salinity, sediment elevation, soil organic matter and bulk density, vegetation cover and species composition, and pore water salinity. Aerial photography will also be collected and analyzed on a 1-km^2 area surrounding each site to document changes in land and water areas over time and calculate rates of land loss or land gain. Sampling methodologies for these variables are described in Steyer and others (1995).

The added values inherent in this design (Steyer and others 2003) are that many of the selected stations represent a 35-year history of vegetation change, and that the transects on which the design is based have been used by the Louisiana Department of Wildlife and Fisheries (LDWF) not only for vegetation surveys, but also for alligator, nutria, muskrat, and water bird surveys. These historical survey data from the reference sites provide valuable information on past conditions and degrees of variability. The monitoring variables that will be collected under CRMS-*Wetlands*, combined with LDWF coast-wide datasets, will provide information on the response of vegetated wetlands and the habitats they support. Using geographic information system's analytical applications, resource managers have the flexibility to characterize and compare ecological change, from the project scale to the entire coast. Resource managers will also be able to compare the effects of a specific type of restoration effort such as diverting freshwater or sediment in a certain basin, or across the coast.

The multiple reference design will provide an understanding of natural variability of the functional processes within coastal wetland ecosystems. Achieving sustainable restoration requires reference conditions that embody the goals and objectives of restoration efforts. Reference conditions can be considered a gauge to assess the present condition of a system or to evaluate progress of management actions toward some target system state (the reference or desired condition). Establishing reference conditions for restoration is a critical component of managing for sustainability, since the reference condition is usually considered to be sustainable. Unfortunately, limitations arise, in many large-scale ecosystem restoration projects or programs, due to insufficient data and information on the temporal and spatial variability of ecosystems.

In addition to the direct benefits of the CRMS-*Wetlands* design to the CWPPRA monitoring program, this integrated approach will also provide information on areas that are currently outside of CWPPRA restoration projects which may one day be included within project boundaries. By establishing a history of data collection at these sites, background data will readily be available to speed up the process and provide information which could improve the design and effectiveness of future projects.

Although project evaluation was a significant impetus for the development of CRMS-*Wetlands*, an equally important benefit is the interdependence of CRMS-*Wetlands* data with the development of ecosystem and hydrodynamic models. CRMS-*Wetlands* will provide the necessary data to select and scale variables to be used in developing, validating and refining functional models of response to project-influenced environmental changes. In this manner, CRMS-*Wetlands* will provide a database that will aid in understanding the way the coastal system operates and how it will change in the future.

LCA Conceptual and Numerical Models

Models are conceptual or numerical approximations of systems depicting key structural components and system drivers that assist us when considering the context and scope of the processes that effect ecological integrity (Karr 1991). They also provide a heuristic device to expand our consideration across traditional discipline boundaries (Allen and Hoekstra 1992). Conceptual models thereby provide a framework for understanding the relationships between physical form and ecological function. In the case of restoring deltaic processes, conceptual models provide a framework to integrate

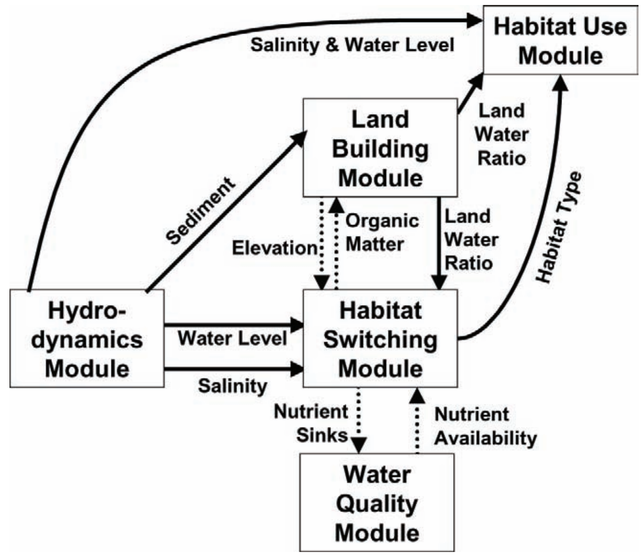

Figure 1. The current ecosystem model for coastal Louisiana developed under LCA. Solid arrows reflect current linkages among the different modules. Stippled arrows reflect known linkages that are currently not incorporated in the model.

physical processes, geomorphic features, and ecological succession (Twilley 2004).

During the planning phase of the LCA, conceptual and numeric models (fig. 1) were developed under the Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) program (Twilley 2004). CLEAR developed tools to evaluate the degree to which different restoration alternatives, that utilize strategies of reintroducing historical flows of fresh water, nutrients and sediments to coastal wetlands, will achieve the Coast 2050 goals. Developing and evaluating restoration alternatives of the LCA to achieve these goals required linking the changes in environmental drivers (processes such as riverine input) to specific restoration endpoints (hydrodynamic, ecological and water quality) using a variety of modeling approaches. These modeling efforts were designed to evaluate how various combinations of conceptual restoration features would reduce ecosystem stress, and identify ecological benefits spatially across the deltaic and chenier plains. This was accomplished by combining existing conceptual models of delta evolution and ecological succession. Assumptions of causal mechanisms and expected responses were used to forecast site conditions necessary to render ecosystem state change.

The conceptual models (developed for hydrodynamics, land building, habitat switching, habitat use and water quality) identified the key ecosystem properties (drivers, stressors and response variables) that control ecosystem development (table 1). These conceptual models represented the inputs and outputs to various numeric models used to estimate benefits of several restoration alternatives at a regional scale.

Table 1. Variables included in the LCA ecosystem model.

	Module				
Variable	Hydro-dynamics	Land Change	Water Quality	Habitat Switching	Habitat Use
Wind speed and direction	Input				
Initial water level	Input				
Initial salinity	Input	Input			
Initial temperature	Input				
River temperature	Input				
Historic land change rates		Input			
River sediment load		Input			
Sediment retention factor		Input			
Bulk density of deltaic soils		Input			
Initial land area	Input	Input			
Bathymetry	Input	Input	Input		
Land elevation	Input	Input	Input	Input	Input
Diversion flows	Input	Input	Input		
River nitrogen			Input		
Nourishment factor	Output	Input			
Salinity	Output		Input	Input	Input
Water level	Output		Input	Input	Input
Water residence time	Output		Input		
Water temperature	Output		Input		Input
Wetland area		Output	Input	Input	Input
Habitat type				Output	Input
Nitrogen removal			Output		
Water primary production			Output		
Wetland primary production				Output	
Habitat quality alligator,					Output
Habitat quality dabbling duck					Output
Habitat quality mink					Output
Habitat quality muskrat					Output
Habitat quality otter					Output
Habitat quality Atlantic croaker					Output
Habitat quality brown shrimp					Output
Habitat quality gulf menhaden					Output
Habitat quality largemouth bass					Output
Habitat quality oyster					Output
Habitat quality spotted sea-trout					Output
Habitat quality white shrimp					Output

Restoration planning also requires a monitoring program that measures actual system responses to evaluate the assumptions of model development and to assure the basic elements of adaptive environmental assessment and management (AEAM). Therefore, the monitoring of system responses should be based on indicators that reflect the key ecosystem properties (drivers, stressors and response variables) highlighted in the ecosystem model. The outputs of the LCA ecosystem model can serve as some of the performance measures that must be identified in AEAM protocol.

Future Directions

Effective monitoring programs can benefit the process of numerical modeling by providing descriptions of system response (fig. 2). This process is required to adequately test causal hypotheses of system degradation upon which restoration measures are designed. This feedback provides a strategic process in performing adaptive environmental assessment and management. Sensitivity analyses during model development provide science programs insights as to what parameters may be the most significant ones to system behavior. These exercises can also provide insights as to the most cost-effective monitoring variables to include in evaluating ecosystem response. Uncertainties in model simulations not only depend on the natural variability of the ecosystem, but also on the lack of knowledge in selecting parameters and model development. Monitoring programs can help reduce the knowledge-based uncertainty by providing data on those parameters that can improve simulation capabilities. This feedback improves numerical models and reduces scientific uncertainty in understanding causal mechanisms associated with system degradation (fig. 2).

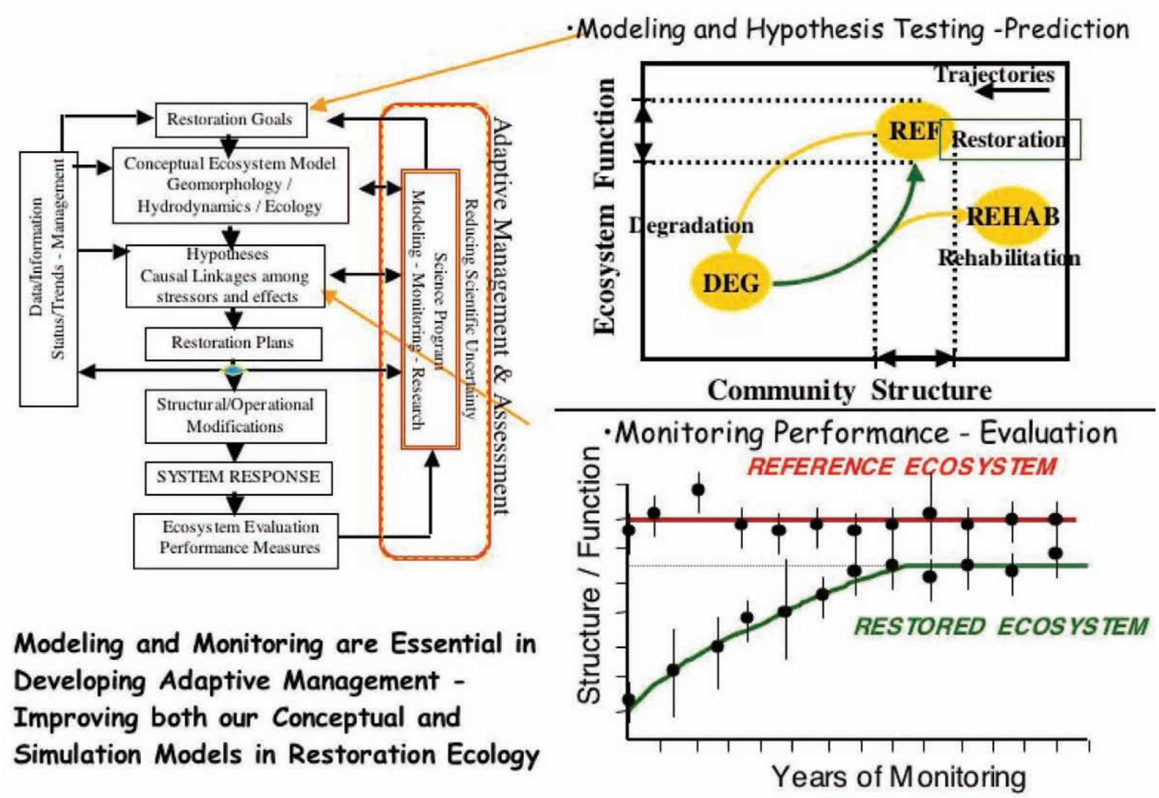

Figure 2. The linkage of modeling, monitoring and research programs in an integrated adaptive environmental assessment and management structure.

The ability to predict how ecosystems will respond to prescribed changes in environmental settings will be much improved with rigorous numerical modeling exercises as the initial stages of restoration planning. This modeling process is critical since it contributes to the development of ecological theory that can be immediately used in developing restoration strategies and provides a direct link between science and management.

System-wide Assessment and Monitoring Plan

A System-wide Assessment and Monitoring Plan (SWAMP) is proposed that will evaluate the key processes and system linkages assumed to be causal mechanisms of system degradation in the LCA conceptual models. SWAMP will expand upon existing monitoring and modeling efforts within a system-wide experimental design by monitoring biological, chemical, physical, and climatological variables in four modules: wetlands (CRMS-*Wetlands*), barrier islands (Barrier Island Comprehensive Monitoring [BICM]), inshore waters and rivers, and nearshore coastal waters (fig. 3). The variables monitored will include those necessary to assess restoration project performance measures, as well as those variables identified through modeling efforts to be most critical to document the long-term restoration of Louisiana's coastal ecosystems. The first of these modules, CRMS-*Wetlands*, as discussed earlier, was designed under the CWPPRA monitoring program and is

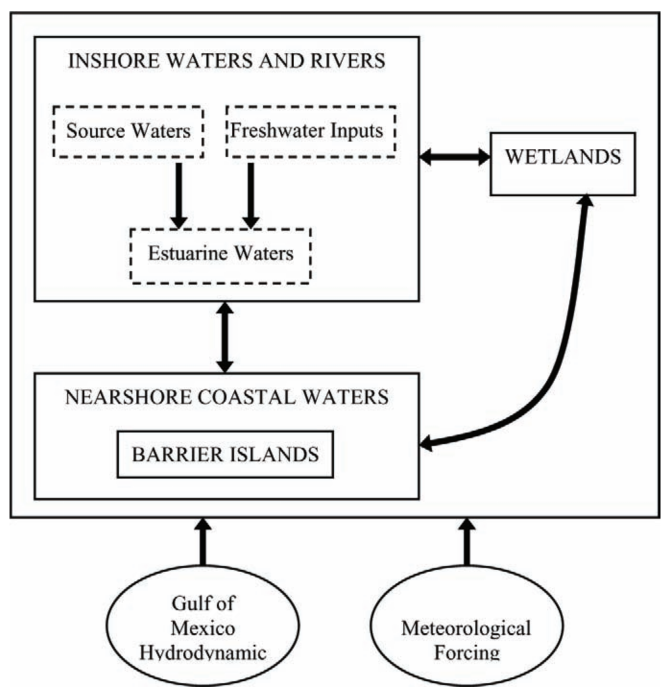

Figure 3. A proposed conceptual model for system-wide integration of monitoring in coastal Louisiana.

compatible with the conceptual framework utilized in the LCA modeling effort (fig. 1). The BICM Plan is currently in development and incorporates variables that are important to monitor and model barrier island changes. This plan was developed to incorporate variables necessary for barrier island project design, monitoring, evaluation, and predictive model development, and includes such variables as topography (LiDAR surveys), bathymetry, habitat classification, sediment properties, geophysical data (wave, current, water level, meteorological data) and vegetation composition.

The LCA Study and SWAMP have integrated the monitoring and modeling needs for coastal Louisiana to support refinement of ecological, hydrodynamic, and water quality models as well as restoration assessment (fig. 2). In addition to the integration of monitoring and modeling, however, a successful program needs an ongoing AEAM program to facilitate the continued feedback and institutional learning necessary to advance restoration science and improve the efficiency of wetland restoration and rehabilitation. In 2002, CWPPRA initiated an AEAM review on constructed restoration projects that incorporated input from multiple disciplines from state and federal agencies and academia. This review resulted in 51 project-specific recommendations, 94 lessons learned, 25 recommendations for improvement by project-type, and several recommendations to improve the overall program, illustrating the need for this approach to continue program advancement (Raynie and Visser 2002). The AEAM approach has also been embedded into the LCA Plan to ensure that the advancement of science continues and the implementation and management of restoration and rehabilitation projects improves with time.

The data gathered under CRMS-*Wetlands* and the other SWAMP modules will provide the robust datasets needed to improve the parameter quality and reduce the uncertainty associated with model development. Perhaps a major challenge facing the LCA Plan lies in the inherent uncertainty of how well a proposed restoration effort will work. This is particularly relevant for the LCA Plan since it depends on the results of a complex suite of hydrodynamic and ecological simulation models. Given the physical complexity of the Louisiana coastal ecosystems, the predictive abilities of such models are far from perfect. Climatic, hydrologic, and ecological data used as model inputs and boundary conditions are usually available at limited spatial and temporal sampling resolutions. Thus, the LCA recognized the critical need for integrated monitoring and modeling capabilities at a regional scale, and the need for an AEAM framework to support decision-making. The challenges for restoration monitoring in Louisiana are in deciding which attributes of ecosystems to monitor, in determining which of the changes in attributes observed represent significant departures from expected natural variability, and in using that information to make the best informed management decisions.

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Assessment of Eutrophication in Estuaries: Pressure-State-Response and Source Apportionment

David Whitall and Suzanne Bricker, staff scientists, National Oceanic and Atmospheric Administration National Centers for Coastal Ocean Science Center for Coastal Monitoring and Assessment, N/SCI SSMC4, Silver Spring, MD

Abstract—*The National Estuarine Eutrophication Assessment (NEEA) Update Program is a management oriented program designed to improve monitoring and assessment efforts through the development of type specific classification of estuaries that will allow improved assessment methods and development of analytical and research models and tools for managers which will help guide and improve management success for estuaries and coastal resources. The assessment methodology, a Pressure-State-Response (PSR) approach, uses a simple model for determination of Pressure and statistical criteria for indicator variables (where possible) to determine State. The Response determination is mostly heuristic although research models are being developed to improve this component. The three components are determined individually and then combined into a single rating.*

In addition to the PSR approach, it is also valuable to identify and quantify the anthropogenic nutrient input sources to estuaries so that management measures can be targeted for maximum effect. Since nitrogen is often the limiting nutrient in estuarine systems, the sources of nitrogen have been determined for eleven coastal watersheds on the U.S. east coast using the WATERSN model. In general, estuaries in the Northeastern U.S. receive most of their nitrogen from human sewage, followed by atmospheric deposition. This is in contrast to some watersheds in the Mid-Atlantic (Chesapeake Bay) and South Atlantic (Pamlico Sound) which receive most of their nitrogen from agricultural runoff.

Introduction

Nutrient pollution has recently been identified as the greatest threat to U.S. coastal water quality (Boesch and others 2001, CSO 1999, NRC 2000). Sources of nutrients include atmospheric deposition, groundwater, and point and non-point sources. Potential consequences of nutrient enrichment range from ecological changes to socio-economic impairments (for example, fisheries) to serious human health threats (fig. 1).

Symptoms of eutrophication include low dissolved oxygen, nuisance and toxic algal blooms, shifts in algal community composition, and losses of submerged aquatic plants that serve as habitat for fish species important to coastal fisheries. These impacts cause economic losses to tourism, and to commercial and recreational fisheries (Lipton 2003, Lipton and Hicks 1999, 2003). Additionally, weakening or destroying native flora and fauna provides the opportunity for colonization by invasive species.

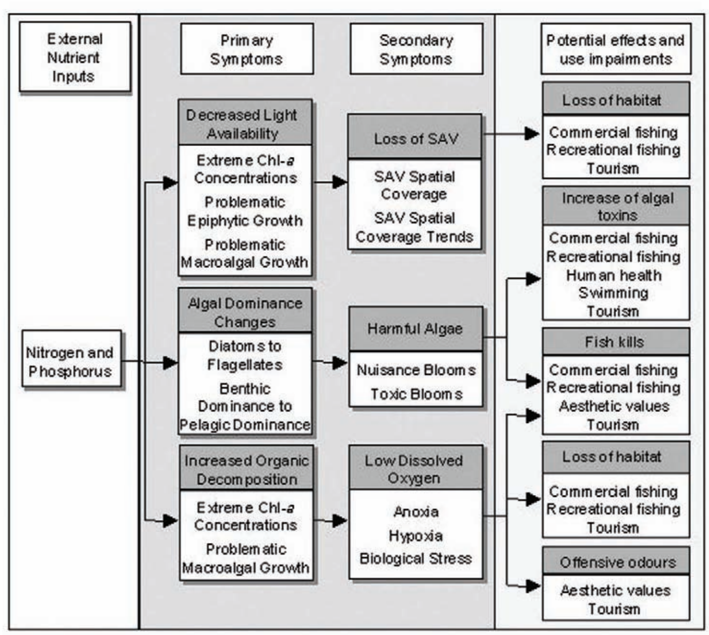

Figure 1. Conceptual model of eutrophication.

The National Estuarine Eutrophication Assessment (NEEA) Update Program is a management oriented program designed to improve monitoring and assessment efforts through the development of type specific classification of estuaries that will allow improved assessment methods, development of analytical and research models and tools for managers which will help guide and improve management success for estuaries and coastal resources.

The objectives of this paper are to describe the NEEA methodology and the program plan for update of the assessment that was recommended at the National Estuarine Eutrophication Assessment Update Workshop in September, 2002 (Bricker and others 2004) and to link nitrogen (N) source apportionment modeling to this assessment work.

NOAA's Estuarine Eutrophication Assessment

The intent of the NEEA update is to develop a monitoring and assessment program for periodic assessment updates that will inform managers, researchers, and politicians about the success of legislation and management measures designed to address eutrophication issues. This program is meant to be a companion program to the National Research Program for Nutrient Pollution in Coastal Waters (Howarth and others 2003) and interactive with European Commission efforts such as the Water Framework Directive 2000/60/EC (WFD, for example; Coast 2003) and OSPAR (2002).

In the early 1990s in response to the knowledge that some estuaries were showing signs of nutrient related degradation as evidenced by hypoxia in Long Island Sound, Chesapeake Bay and Mobile Bay (Welsh 1991) and the concern that this might be a wide spread problem, NOAA conducted a nationwide assessment to discern the magnitude, severity and location of eutrophic conditions. The intent was to learn whether these problems were local, regional or national in scale, to determine probable causes, and to provide this information to managers such that observed problems could be addressed at the appropriate level (national, state or local legislation). The National Estuarine Eutrophication Assessment (NEEA) involved about four hundred participants from academia, state, federal and local agencies who provided information and data for one hundred thirty eight U.S. estuaries and coastal waters (NOAA 1996, 1997a, b, a, 1998). Assessment results show that nutrient related water quality problems occur on a national basis (Bricker and others 1999, fig. 2).

Since the release of the NEEA there has been interest in an update of the assessment given the expected increase in problems in the future as coastal populations, use of fertilizers and fossil fuels continue to increase (Bricker and others 1999, NRC 2000). There is interest in improvement of the accuracy and applicability of the methodology including:

- update of the assessment to learn whether the systems that were expected to become worse have done so,
- the use of data to complement and inform "expert knowledge,"
- development of a type classification to improve the accuracy of the assessment methods,
- improvement of assessment methods to include, for example, type specific selection of indicator variables and variable thresholds,
- development of a socioeconomic indicator to complement the existing indices and to establish a meaningful framework for assessing impairments to human uses and specifying appropriate responses,
- development of tools and predictive models that are useful to resource managers and can help them to make informed decisions and to assess alternative management strategies,
- apportionment of nutrient sources to support implementation of appropriate management measures.

The NEEA/ASSETS Assessment Methodology

The NEEA model (Bricker and others 1999), and recent modifications described in the Assessment of Estuarine Trophic Status (ASSETS; Bricker and others 2003), uses a Pressure-State-Response framework to assess eutrophication in three component parts:

- Overall human influence (OHI) on development of conditions (Pressure),
- Overall eutrophic conditions (OEC) within a water body (State), and
- Determination of future outlook (DFO) for conditions within the system (Response)

The original method is described here in brief, as are recent improvements and modifications made by ASSETS (Bricker and others 2003). A full description of the original method can be found in Bricker and others (1999) and details for modifications can be found in Bricker and others (2003) and Ferreira and others (submitted).

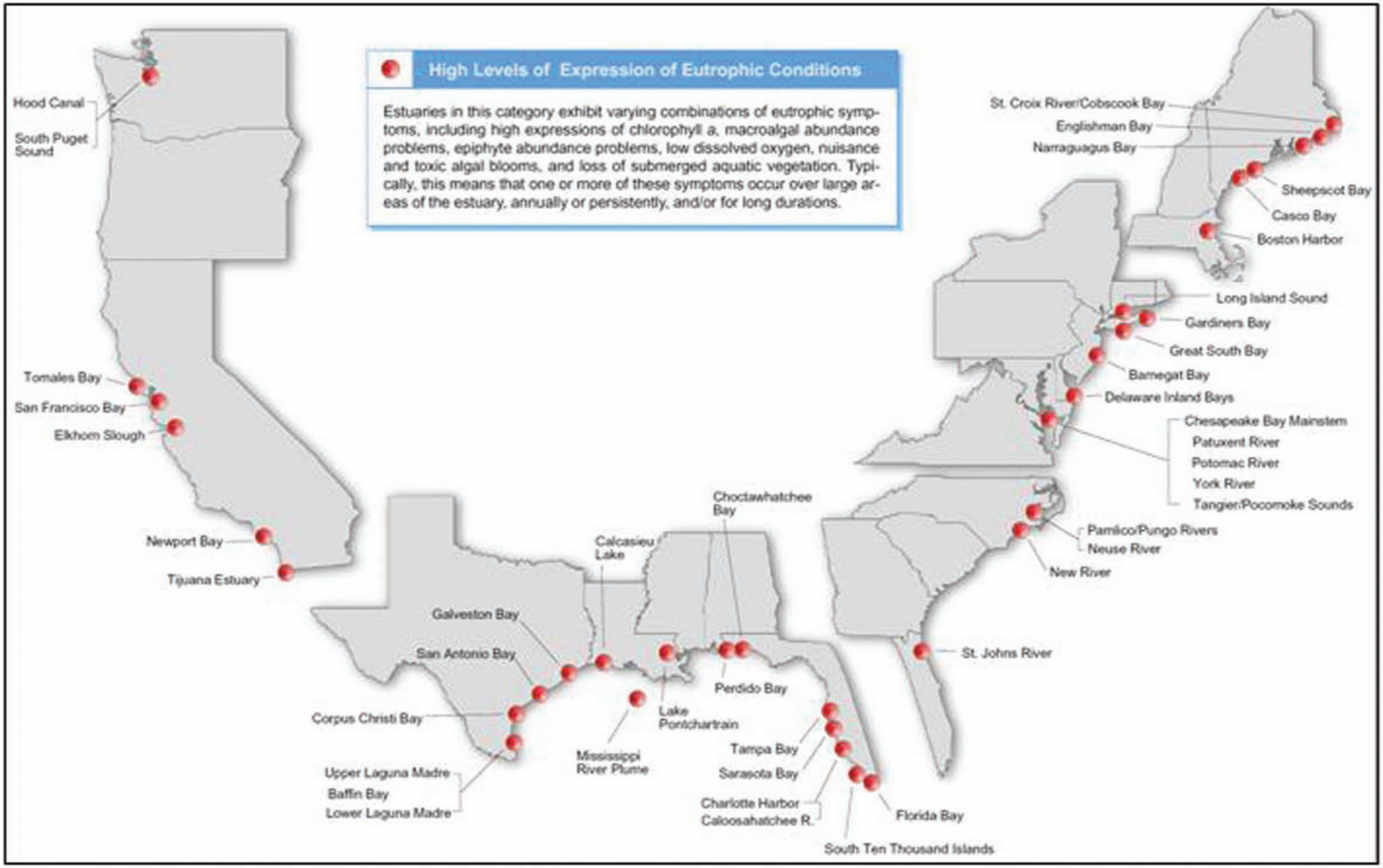

Figure 2. Map showing U.S. estuaries with “High” levels of eutrophic expression (from Bricker and others 1999).

Determination of pressure—Overall Human Influence (OHI)

Pressure is determined by combining in a matrix an estimation of susceptibility of a system which is based on the ability of a system to dilute and flush nutrients from the system and the level of nutrient inputs from the watershed. Participants in the NEEA used watershed nutrient model estimates (SPARROW; Smith and others 1997), watershed population density and other demographic data in the Coastal Assessment and Data Synthesis (CADS 1999) to estimate inputs, and hydrologic and physical data from CADS (1999) to determine susceptibility.

In ASSETS, improvements were made to the original methodology by applying a simple model to compare anthropogenic nutrient loading and natural background concentrations. The model also factors in potential nutrient inputs from oceanic sources thus addressing the question of whether management measures would be successful. For a full description of model development see Bricker and others (2003) and Ferreira and others (submitted).

Determination of state—Overall Eutrophic Condition (OEC)

Six variables were selected from the original 16 used in the NEEA (Bricker and others 1999) for determination of OEC. These were divided into two groups, primary or early stage symptoms (chlorophyll a, epiphytes, macroalgae) and secondary (dissolved oxygen, SAV loss, harmful algal bloom occurrence) or well developed eutrophication symptoms. Statistical criteria are used for quantifying chlorophyll a and dissolved oxygen (90th percentile for chlorophyll and 10th percentile for dissolved oxygen; Bricker and others 2003). Additional improvements to the original "expert knowledge" methodology have been proposed for macroalgae, epiphytes and submerged aquatic vegetation based on comparison of potential area of colonization and effective colonized area. Presently these are still determined heuristically.

An area weighted estuary wide value for each variable is determined based on concentration, spatial coverage, and frequency of extreme occurrences. The primary symptom expression level is determined by averaging the three estuary level of expression values, while the highest of the three secondary symptoms is selected. These values are combined in a matrix to determine an overall ranking of eutrophic conditions for the estuary.

Determination of response—Determination of Future Outlook (DFO)

Response is determined by a matrix that combines susceptibility of the system with expected future changes in nutrient loads. Predictions of nutrient loading (increase, decrease, unchanged) are based on predicted population increase, planned management actions and expected changes in watershed uses.

Synthesis—grouping of pressure, state and response indicators

An additional modification to the original methodology (ASSETS; Bricker and others 2003) combines the OEC, OHI, and DFO into a single overall score falling into one of five categories: high, good, moderate, poor or bad. These categories are color-coded following the convention of the EU Water Framework Directive (2000/60/EC), and provide a scale for setting eutrophication related reference conditions for different types of systems.

Additional modifications: NEEA update program

Further modifications that are presently being pursued in the NEEA update program include: the development of a type classification based on physical and hydrologic characteristics using the Deluxe Integrated System for Clustering Operations (DISCO) tool (Smith and Maxwell 2002). Preliminary results are promising (Smith and others 2004) and will be used to determine type specific reference conditions and thresholds for desirable/undesirable conditions for indicator variables. Additionally, indicator variables are being evaluated by type to ensure that all types of estuaries are assessed with indicators that are relevant. For instance, in types where there is no SAV under natural conditions, an alternative indicator will be used.

A socio-economic/human use indicator is being developed where changes in fish catch rate are related to changes in water quality in the manner of Lipton and Hicks (1999, 2003) and Mistiaen and others (2003). Preliminary analysis of Long Island Sound data shows that as nitrogen inputs decrease, dissolved oxygen and recreational catch of striped bass increase. The increase in catch is shown to be related to changes in oxygen when other influences (for example, fishermen avidity and experience, temperature, changes in fish stock) are accounted for (Mason and others 2004).

In addition to the assessment and typology activities of the NEEA, the quantification of the relative importance of various sources of nutrient pollution to estuaries is considered to be a critical step for coastal management.

Source Apportionment

Primary productivity in aquatic ecosystems is most often limited by either nitrogen or phosphorus. In most estuarine systems, nitrogen is the limiting nutrient, in contrast to freshwater systems where phosphorus limits production. This study focuses on identifying the sources of nitrogen pollution to eleven watersheds on the U.S. east coast.

Nitrogen inputs to coastal systems originates from both point and non-point sources. Point sources include: wastewater treatment plants (WWTP) and industrial discharges. Non-point sources include: agricultural runoff, septic systems, and urban and suburban runoff. Atmospheric deposition of N (AD-N) has also been identified as a potentially important source of N for many coastal ecosystems (Nixon 1995, Paerl and others 2002, Valiela and others 1992, Whitall and others 2003).

Quantitatively describing the sources of nitrogen pollution to an estuary is necessary for the implementation of appropriate and effective management strategies for reducing nitrogen loading, and ultimately, the effects of eutrophication.

WATERS N Model Description

A useful approach for quantifying the relative importance of each source of nitrogen to coastal receiving waters is a numerical watershed model. The model used in this study was the Watershed Assessment Tool for Evaluating Reduction Strategies for Nitrogen (WATERSN, fig. 3). The mass balance approach of this model has been presented previously (Castro and others 2000, Castro and Driscoll 2002, Castro and others 2003, Whitall and others in prep) but is described briefly here.

This model estimates the amount of N available for transport to estuaries from lands in agricultural production (crops, orchards, and pastures), urban areas, and forests. The quantity of N exported from agricultural lands to the surface waters of the watershed is estimated as the difference between N inputs and N outputs. Nitrogen inputs for the agricultural budgets include:

- N fertilization (fertilizer sales data by county),
- N fixation (unique values by crop; Castro and others 2000),
- livestock waste (the difference between feed imports and production of meat, milk, and eggs), and
- atmospheric deposition of NH4+ and NO3- (from National Atmospheric Deposition Program/National Trends Network data).

Outputs from agricultural lands include:

- crop harvest (agricultural census data),
- pasture grazing (agricultural census data),
- volatilization of NH3 (10% of fertilizer and atmospheric deposition, 15% of animal waste; Schlesinger and Hartley 1992) and
- denitrification (10% of inputs; Meisinger and Randall 1991).

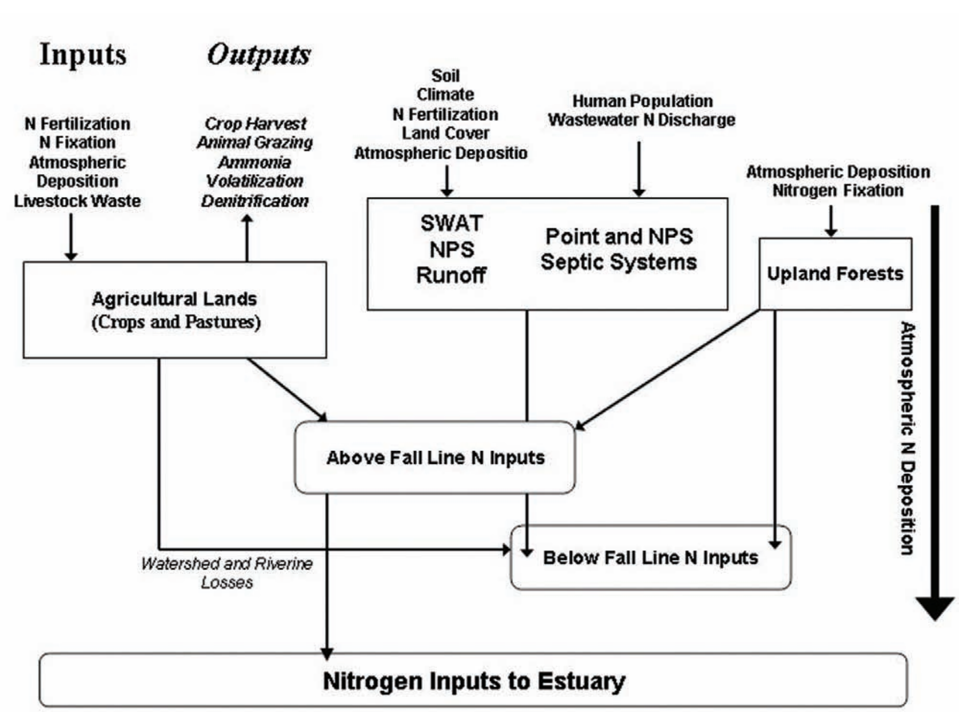

Figure 3. Conceptual diagram of Watershed Assessment Tool for Evaluating Reduction Strategies for Nitrogen (WATERSN) model.

Nitrogen export from urban areas includes:

- wastewater treatment plant effluent (point sources),
- leachate from septic systems and
- non-point source runoff (from SWAT model predictions; Neitsch and others 2001) from pervious and impervious surfaces in urban areas.

Atmospheric deposition of inorganic N and non-symbiotic N fixation were assumed to be the only N inputs to forests. The contribution made by AD-N to the total N runoff from upland forests was assumed to be the same proportion that AD-N made to the total N inputs. N export from upland forests is estimated using a non-linear regression relationship between wet deposition of NH4+ and NO3- and stream water N export of dissolved inorganic N (NH4+ and NO3-) using results of numerous forest watershed studies in the U.S.(Driscoll unpublished data, Neitsch and others 2001). Dissolved organic N contribution to the total N loads is assumed to be equal to 50% of the inorganic N load exported from forests (Castro and Driscoll 2002). Rates of in-stream N loss were based on literature values and calibrated by comparing predicted and measured riverine fluxes. Castro and others (2003) calibrated the model against U.S. Geological Survey (USGS) National Stream Quality Accounting Network (NASQAN) for 18 watersheds in the eastern U.S. by adjusting the watershed and riverine N sinks. The calibrated model loadings agreed well (slope=0.995, r^2=0.9997) with USGS loading values.

It is important to note that all biogeochemical models, no matter how complex, are simplifications of the natural world and are therefore limited in their predictive capacities. With an understanding of the imperfections of any given model, it can be used as a tool to address questions of interest to environmental managers.

WATERSN Results—Northeastern and Middle Atlantic United States

The WATERSN model was used to determine the sources of nitrogen for Casco Bay, Great Bay, Merrimack River, Buzzards Bay, Massachusetts Bay, Narragansett Bay, Long Island Sound, Raritan Bay, Delaware Bay, Chesapeake Bay, and Pamlico Sound (fig. 4). The results presented here compare well with independently published SPARROW model results (Smith and others 1997).

For the purposes of this study, the Northeast has been operationally defined as Delaware Bay and north. Chesapeake Bay and Pamlico Sound are defined as Mid-Atlantic estuaries. Patterns in sources of nitrogen to east coast estuaries vary by region with striking differences between the Northeast and the Mid-Atlantic.

In the Northeast, human sewage is the major source of N loading for all estuaries (36-81%). In addition, runoff from atmospheric deposition (14-35%), urban areas (<1-20%), agricultural systems (4-20%) and forest lands (<1-5%) contributes N to these coastal ecosystems. Atmospheric N deposition, either through direct deposition to the estuary surface or through watershed runoff of atmospheric deposition, was generally the second highest source of N. A notable exception to this pattern is Delaware Bay, where the second highest source of N was agricultural runoff.

In the Chesapeake Bay and Pamlico Sound, agricultural runoff dominates the N loading (55% and 79%, respectively) with wastewater effluent (21% and 12%) and atmospheric deposition also contributing significant loads (22% and 8%, respectively). Loadings from urban (2% and <1%) and forest runoff (1% and <1%) made up smaller portions of the total N load to these systems. This difference in patterns between regions reflects both the differences in watershed populations, which drives the sewage flux, and differences in land use (agricultural vs. non-agricultural).

It is also important to note that the nitrogen pollution that contributes to the atmospheric depositional flux originates from a variety of sources. It is difficult to determine exactly what portion of the deposited nitrogen originates from each source, but the relative sources of atmospheric emissions can be quantified. The airsheds, or atmospheric pollutant source areas, for estuaries on the eastern U.S. seaboard have been delineated previously (Paerl and others 2002). The sources of nitrogen oxide (NOx) emissions for the airsheds of the eleven study estuaries vary by airshed and include:

- on-road mobile sources (31-38%),
- non-road mobile sources (12-21%),

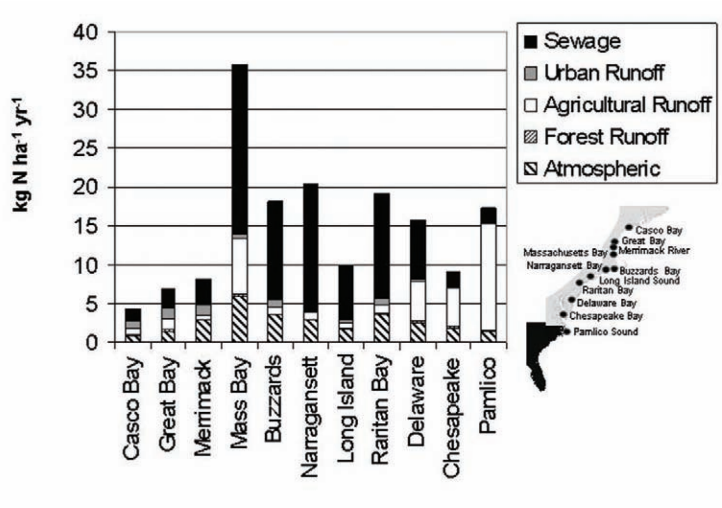

Figure 4. Nitrogen source apportionment for 11 U.S. east coast estuaries. Location of estuaries (inset).

Table 1. Watershed and Estuary characteristics.

System	Watershed Area[1] (km²)	Estuarine Area[2] (km²)	Total N load to estuary[1] (kg N ha^{-1} yr^{-1})	% Ag[1]	% Sewage[1]	% AD-N[1]	OEC[3]
AD-N[1]	OEC[3]						
Casco Bay	2188	427	4.2	5	41	35	MH
Great Bay	2491	47	6.9	19	36	20	MH
Merrimack River	12458	16	8.2	5	70	19	U
Massachusetts Bay	2089	768	35.8	5	81	14	M
Buzzards Bay	1021	639	18.1	20	62	17	ML
Narragansett Bay	4018	416	20.3	8	70	18	ML
Long Island Sound	40774	3259	9.8	6	70	19	MH
Raritan Bay	36114	799	19.1	4	75	16	M
Delaware Bay	30792	2070	15.7	34	47	17	ML
Chesapeake Bay	160765	5470	9.0	55	21	22	H
Pamlico Sound	25090	452	17.3	79	12	8	U

The sum of percentages equals less than 100% because forest runoff and urban runoff make up minor parts of the nitrogen budget for each of these systems. Please see figure 3 for their contributions.

[1] From Whitall and others (in prep). "Ag" is agricultural runoff; "AD-N" is atmospheric nitrogen deposition.
[2] From S. Smith 2004. Preliminary NOAA estuarine typology database, August 2003.
[3] From Bricker and others 1999. "OEC" is overall eutrophic condition. ML = moderate low; M = moderate; MH =moderate high; H = high; U = unknown.

- area sources (9-28%),
- fossil fuel combustion from electric utilities (19-23%) and
- industrial sources (9-12%) (USEPA 1998).

Anthropogenic emissions of ammonia (NH3) also vary between airsheds and include:

- agricultural animal waste (60-73%),
- chemical fertilizers (13-16%),
- domestic animals (4-7%),
- human breath and perspiration (3-7%),
- sewage treatment plants and septic systems (3-6%),
- industrial point sources (2%) and
- mobile sources (1-2%) (Strader and others 2001).

Conclusions

In summary, the intent of the National Estuarine Eutrophication Assessment Update Program is to improve monitoring and assessment efforts through the development of type specific classification of estuaries. This will allow for the improvement of assessment methods and the development of analytical and research models and tools for managers which will help guide and improve management success for estuaries and coastal resources.

An important component of the NEEA Update Program is identification and quantification of nutrient sources to estuaries that are sensitive to eutrophication. Here, nitrogen sources to eleven east coast estuaries have been reported. There are stark regional differences between watersheds in the Northeast (dominated by human sewage followed by atmospheric deposition/agriculture) and the Mid-Atlantic (dominated by agricultural runoff followed by atmospheric deposition/human sewage). These regional differences highlight the need for the sort of typology work (DISCO cluster analysis) that is being conducted as part of the NEEA Update Program. These differences will dictate the appropriate management strategies that will be most successful in protecting and remediating waterbodies that are sensitive to and degraded by nutrient inputs. Generally, these results suggest that sewage related nutrients should be further reduced in the Northeast region while reductions in agriculturally related nutrients should be the focus of management efforts in the Mid Atlantic region. Both regions would also benefit from efforts to reduce/limit atmospheric nutrient sources.

These results show that the WATERSN model can be applied to most estuaries and is a useful tool for resource managers. A similar modeling approach could be used to quantify the phosphorus loading to P sensitive estuaries to provide the basis for development of a comprehensive nutrient management plan that includes both P and N.

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Rhizosphere Systems and Processes

Use of Data Layering to Address Changes in Nitrogen Management Zone Delineation

D.W. Franzen, Extension Soil Specialist, North Dakota State University, Fargo, ND
T. Nanna, graduate student, North Dakota State University

Abstract—*Use of N management zones appears to be a practical method of revealing dominant patterns of residual soil nitrate in North Dakota crop fields, where fall soil nitrate sampling is a common N management tool. Delineation of zone boundaries to date has been a largely subjective process. A weighted, classified method of delineating nitrogen management zones is presented. Soil electrical conductivity sensor measurements, aerial color photography, Landsat 7 satellite NDVI imagery, and yield maps were divided into five classes using natural break algorithms to separate data into classes. Five zones of topographic relief, and Order 1 soil surveys were also used as classes. Soil sampling was conducted in a 33-m grid in a 12.5 ha field. Areas within zones produced from classification were given residual soil nitrate values based on mean zone interior nitrate sampling. The resulting meta-data was compared with a base 33-m sampling grid nitrate analysis for the 12.5 ha field. Layers of data were also combined, classified into zones, and compared with the base grid. Combinations of layers were generally superior in correlation values, compared with individual layers.*

Introduction

An alternative to dense grid soil sampling for delineating residual soil N levels or N availability is a zone sampling approach. The zone approach assumes that soil N patterns are logically linked to some inherent causal effect, either natural or man-made. A number of delineation methods have been examined, including apparent soil EC (Kitchen and others 1999), yield mapping (Taylor and Whitney 2001, Diker and others 2002), topography (Franzen and others 1998), aerial imagery (Williams and others 2002, Sripada and others 2002), satellite imagery (Shanahan and others 2000), use of soil survey (Franzen and others 2001), organic matter (Fleming and Buchleiter 2002), and grain protein (Long and others 1998).

Extensive research has been conducted on the best predictors for determining optimal nitrogen management zones in site-specific farming (Bausch and others 2002, Fleming and Buchleiter 2002, Franzen and Nanna 2002, Hendrickson and Han 2000, Lund and others 2002, Stenger and others 2002). A number of studies have begun to investigate the use of multiple data layers to improve delineation of nutrient management zones (Whelan and others 2002, Kitchen and others 2002, Chang and others 2002). Various statistical tools have been used, including cluster analysis (Jaynes and others 2003, Kitchen and others 2002, Ralston and others 2002) and neural networks (Drummond and others 2002, Gautam and others 2002) group data and delineate management zones.

The objective of our work is to investigate the application of a classified, weighted method to determine patterns of residual soil N. The resulting zones can then be sampled in preparation for an N fertilizer application. Several types of data layers, including yield maps, satellite and aerial imagery, Order 1 soil survey, apparent soil EC and topography, were compared individually, and grouped together to determine whether one method was superior to others, and whether a combination of layers would better delineate soil N patterns.

Materials and Methods

The study site was a 12.5 ha field located near Valley City, North Dakota, 46.87495° north and 97.91001° west. Data collection that took place during 2001 and 2002 consisted of soil and plant sampling, referenced with a DGPS (differentially corrected global positioning system) unit. Soil samples were taken in a 33-m systematic grid, for a total of 144 samples, and then analyzed for nitrate-N at the 0-60 cm depth and organic matter at the 0-15 cm depth. Apparent soil electrical conductivity readings were obtained using a Veris 3100™ sensor, driving in passes approximately 16 m apart. Elevation was measured with a laser beam survey emitter and detection pole, with readings at approximately the same locations as the soil samples. The Order 1 soil survey (1-8,000 scale) was produced by Dr. D. H. Hopkins, a registered soil surveyor and Assistant Professor in the NDSU Department of Soil Science. Yield maps were developed using data from a John Deere Greenstar® yield monitor.

Remotely sensed images, consisting of aerial photographs and Landsat 7 satellite images were also obtained for the 2001 and 2002 crop seasons. Aerial pictures of the field were taken using Ektochrome color film, flown at about 1,650 m elevation and then scanned and saved as TIFF images with red, blue, and green bands. The Landsat 5 and 7 satellite images used in this study are composed of blue, green and red bands in the visible part of the spectrum, as well as three bands in the near and mid infrared and one band in the thermal infrared part of the spectrum. The Normalized Difference Vegetation Index (NDVI) from the satellite images were calculated using the Idrisi32© and the ArcGIS 8.2© software.

NDVI, derived from reflectance measurements in the red and infrared portions of the spectrum (NDVI= (IR – red)/ (IR + Red)), is useful in describing the relative amount of green biomass on the field and is a good indicator of healthy and dense vegetation (Sah and others 2002). Minitab© was used to perform statistical analysis on the data. Surfer 8© was used to interpolate soil data, using inverse distance squared, with eight nearest neighbors to develop an interpolation grid, then to convert from grid to raster images and generate the zone maps.

Weighted Classified Method

This methodology consists of: 1) Classification of data; 2) assigning weights to different types of data, based on residual nitrate correlation between base soil nitrate grid and N zones; and 3) comparing the final nitrogen zones against actual soil residual nitrate data. Various criteria can be used for assigning weights according to the best candidates; however, when several layers of different types of data are involved care must be exercised.

Jessop (2003) recommends three techniques for assigning weights to candidates: 1) sensitivity analysis, which consists of assessment under a number of alternative scenarios; 2) robustness, which looks for the most superior alternative among a group; and 3) risk aversion, which seeks the alternative that is least inferior to others. Correlation and regression analysis can be applied at each scale to quantify the relationship between the different types of data (Long 1998) and identify the appropriate scale for modeling, as well as the effect that scaling has on the data.

The first step in detecting patterns for nitrogen zone delineation is classification of all datasets into performance zones, such as low, medium low, medium, medium high, and high. We have found in our study that if we compile zones out of a few large blocks of data, the patterns tend to reflect less variability of residual nitrate in the field than do more detailed zone patterns. For example our correlation values between topography and residual nitrate increased from about 5 to about 41 percent, when we further subdivided concave and convex slopes into various transitional categories. Therefore, we recommend compiling at least five zones for each type of data, in order to capture the maximum variability for the field, as shown in figure 1.

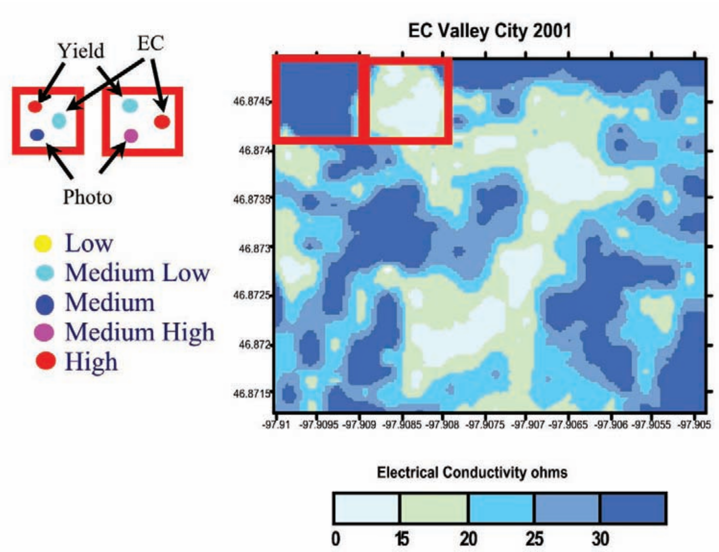

Figure 1. Data are classified into five performance zones and recorded at each sampling grid cell.

Next, an average nitrogen value is assigned to these different zones by selecting soil samples located at the center of each zone, which have been analyzed for residual nitrate. Figure 2 shows the layering of residual nitrate against spring wheat yield from data collected in 2002. The red polygons in figure 2 indicate the soil samples that will be chosen to calculate the average nitrogen for each zone. Select only the center samples, avoiding field corners and zone boundaries. Next assign the N average value to all the other points of the zone as shown in figure 3.

The next step in construction delineation zones consists of performing simple linear regression analysis for each type of data, where the averaged N values are compared against the actual soil nitrate values. At this point, weights can be assigned to each type of data according to those correlations, in order to form patterns that will predict future delineation zones for nitrogen. A final map is compiled by combining all the selected data multiplied by the appropriate weights into one map using the expression: Zones = (data-1 * R-1) + (data-2 * R-2) + …+ (data-n * R-n). Regression analysis is then once again performed, but this time it will be correlating the final patterns against residual nitrate. At this stage,

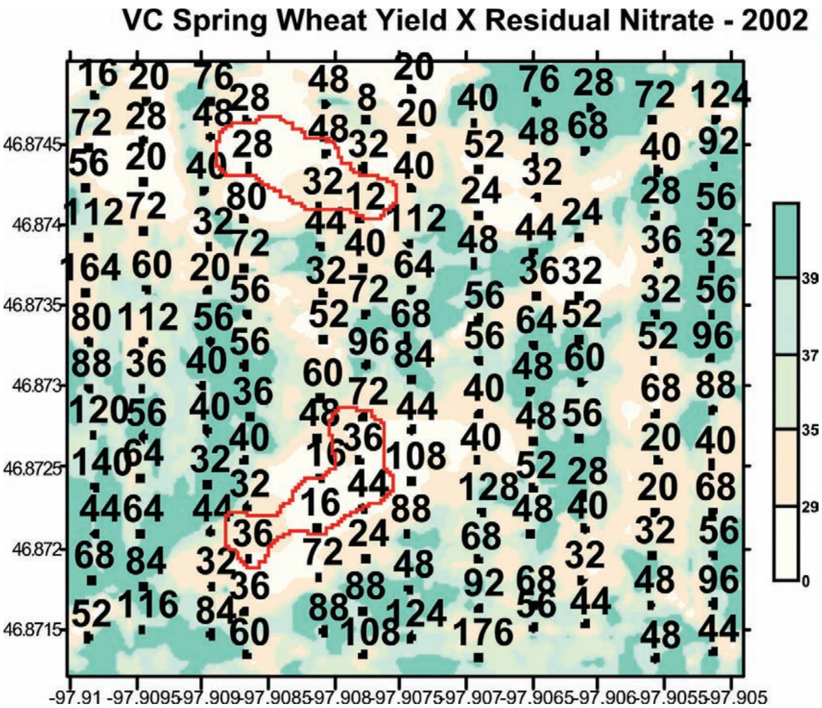

Figure 2. Residual nitrate is overlaid against the yield map, then the samples located within the interior of each zone are selected (two examples shown in red polygons). Values at the edge of the zone are not considered.

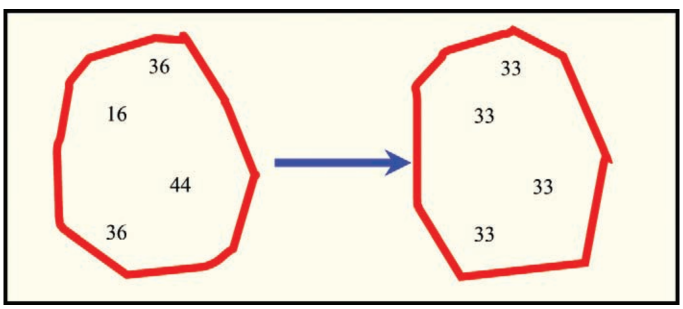

Figure 3. Mean nitrate-N values are assigned at sampling locations within each zone.

we recommend trying different combinations of smaller datasets or comparing data from different years, if available, to strengthen the model and detect consistent trends. Analysis of trends is an invaluable tool for building a reliable model. Rather than obtaining a perfect correlation with the nitrogen data, the main goal is to provide an overall pattern that characterizes the key zones of nitrate homogeneity in the field.

Multiple combinations of data were compared first by normalizing the data, then by assigning a weight to each data layer based on the correlation of individual data layers with nitrate. At each grid point, the normalized, weighted value of the one layer is multiplied by the other normalized, weighted layer or layers of data to create a new zone map. The average nitrate values within each of the five zones produced were determined as explained above and regression analysis was conducted against the point sampled nitrate data set.

Results

Nitrogen zones at the Valley City research site were delineated in both years 2001 and 2002. By ranking the data according to correlations (tables 1 and 2) the nitrogen delineation maps for 2001 and 2002 were obtained (fig. 4).

The patterns expressed from our data in 2001 and 2002 are similar. The northwest corner has consistently showed low residual nitrate for both years, while the northeast and southeast corners have presented higher levels of nitrate-N. Since this site has pronounced differences in elevation between those corners, it is possible that slope position and landform can greatly help explain nitrogen distribution. Studies by Franzen and others. (1998) have shown that in North Dakota topography patterns may be related to residual nitrate patterns. Nitrate responds to water movement on and within the landscape. Even though nitrate is a mobile nutrient, it usually moves to the same slope positions in the landscape. In addition, the northwest corner appears to be a location where limited drainage frequently causes ponding and plant growth is poor. Figure 5 shows the distribution of nitrogen over the research site terrain for both 2001 and 2002.

All comparisons of zone delineation methods were significantly correlated with the base nitrate sampling grid at the 5 percent probability level or less. Methods with r values less than 0.3 were 2001 EC, 2002, EC, 2001, Order 1 soil survey and 2002 aerial photograph (table 1). The 2002 aerial photograph may have been lower than 2001 because the photograph taken was an infrared digital photograph, compared to the Ektochrome color photograph taken in 2001. Direct correlation with EC data was evident in both years. Low EC values are common in both low nitrate areas and areas with apparent lateral water flow over a sloping argillic horizon, which results in an area lower in total salts, but higher in nitrate. Higher r values were obtained with topography, yield, 2001 Order 1 soil survey, 2001 aerial photography and satellite imagery in both years.

Consistency of correlation between years would probably be important for any delineation method, since most commercial applications would not have as robust a data set to compare and evaluate their zone strategy choice.

Table 1. Correlation of zone delineation method with base nitrate results from a 110 ft. systematic grid sampling, Valley City, ND, 2001 and 2002.

Comparison – Method vs. nitrate sampling data	Correlation (r)
2001 topography	0.39
2002 topography	0.41
2001 yield	0.47
2002 yield	0.36
2001 EC	0.28
2002 EC	0.24
2001 Order 1 survey	0.24
2002 Order 1 survey	0.46
2001 Satellite image	0.41
2002 Satellite image	0.35
2001 Aerial photo	0.38
2002 Aerial photo	0.16

Table 2. Comparison of zone delineation method combination on correlation with sampling base nitrate data, Valley City, ND, 2001 and 2002.

Comparison	Correlation (r)
2001 Topography + EC	0.44
2002 Topography + EC	0.39
2001 Topo + EC + Satellite	0.49
2002 Topo + EC + Satellite	0.45
2001 Topo + EC + Yield	0.49
2002 Topo + EC + Yield	0.46
2001 Topo + Yield + Satellite	0.52
2002 Topo + Yield + Satellite	0.48
2001 All methods	0.54
2002 All methods	0.37

Topography, yield and satellite image had the most consistent r values in a higher range than other comparisons between years. Topography, as depicted in figure 5, seems to show some promise in correlation with residual nitrate distribution at this study site, with the best crop production areas concentrated in the mid- slopes and areas of water recharge. Areas in the field where water stands and ponds were found to be low in nitrogen probably due to leaching. In addition, a sandy ridge located next to the northwest corner of the field presented soil conditions with low nitrogen levels both in 2001 and 2002. The research field has various depressions, some low, and some perched, that cause drainage problems with stagnant water when rain accumulates. Furthermore, the sandy ridges in the field can cause rapid infiltration of water, which serves for the transport of mobile nutrients downward and laterally.

The r value of EC comparisons across years was consistent, but with a lower r value than other methods. This may be the reason for poor correlation between soil electrical conductivity (EC) and residual nitrate (28 percent and 24 percent for 2001 and 2002, respectively). Electrical conductivity is known to be influenced by different factors, such as terrain curvature, soil texture, water content, and levels of salts in the soil (Franzen 1999). Soil texture at this site is widely variable, with textures ranging from fine-loamy to loamy sands (Franzen and others 2002). It is clear in this study that EC should not be used as a direct measure for residual nitrate-N. However, because of its interactions with so many other soil parameters, it is a good nitrate pattern indicator.

Order 1 soil survey presented the best correlation with residual nitrate in 2002 (table 1). However, we were not able to reproduce the same results for the 2001 dataset. Yield, crop reflectance, and topography, on the other hand, had very reproducible results between the two years. Analysis of infrared or multi-spectral image can reveal plant vigor due to nitrogen and, therefore, it may be deduced that it is one of the best candidates for consistent nitrogen prediction. Similarly, yield data was better correlated with residual nitrate when determining patterns for nitrogen delineation. However, neither crop reflectance nor yield data should be used as sole means of prediction (table 2). Yield maps may not be reliable enough to consistently identify nutrient zones in a single year (Franzen 1999, Strock 2000) because crop yields are so dependent on various factors, such as insects, disease, weed infestation, soluble salts, and cultural practices. Also nitrogen delineation zones that are based on a single satellite image might miss significant within-field variability. To avoid this problem, some studies (Bergerou and others 2002, Locke and others 2000) suggest averaging crop reflectance from multiple satellite images, taken at key stages of crop development.

Correlation of multiple data-layer comparisons of topography and EC, topography, EC and satellite image, topography, EC and yield, and topography, yield and satellite imagery with soil nitrate data is shown in table 2. A combination of topography, yield, and satellite imagery had the highest correlation values compared to other combinations, although all combinations were consistent between years and generally had higher values than their individual parts. Although one might expect EC to pull the correlations down compared to the better individual correlation of topography, yield, and satellite image, it did not. Generally r values were somewhat higher with combinations of zone delineation methods than topography alone. Perhaps one of the reasons that a combination of topography with EC did not hurt the correlation was that EC received about half the weight as topography and yield. Previous investigations with unweighted comparisons resulted in reduced correlations of multiple comparisons.

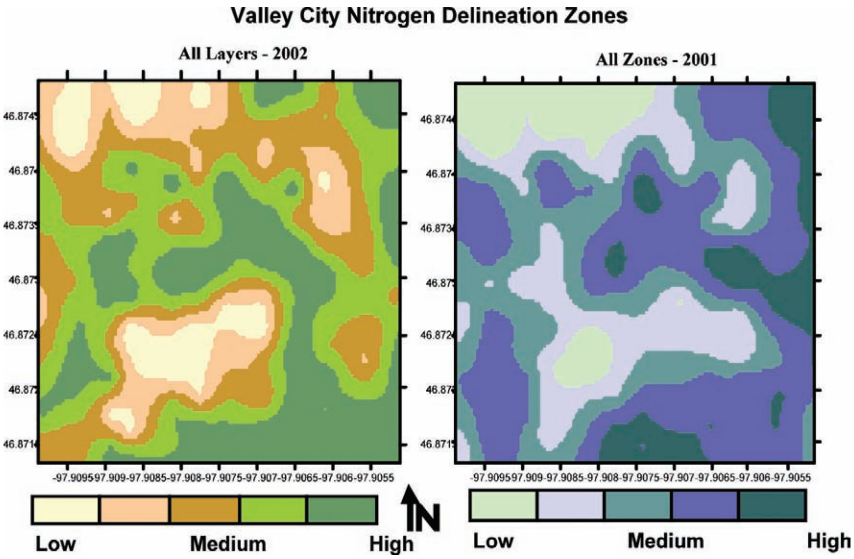

Figure 4. Zones of nitrogen delineation for 2001 and 2002, developed with multiple data layers.

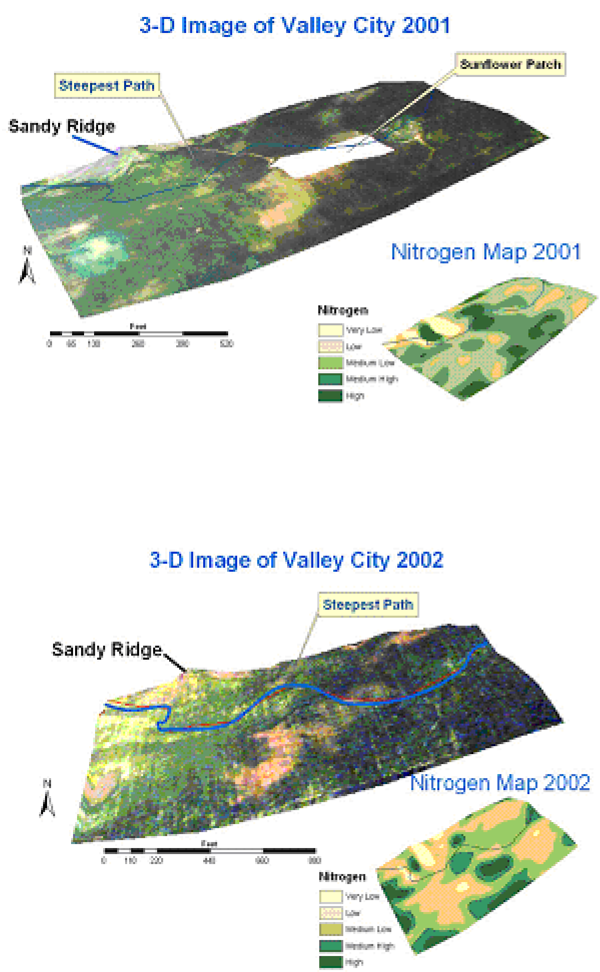

Figure 5. Nitrogen distribution according to topography in 2001 and 2002.

The exception to higher correlation using multiple comparisons appears to be using all methods, which perhaps illustrates a danger in adopting a "shotgun" type of approach to delineation methods.

Summary

Six nitrogen zone delineation methods, topography, yield, Order 1 soil survey, aerial photography, satellite imagery and apparent soil EC, were compared with a sampling base of soil nitrate. All methods were significantly correlated with the base nitrate patterns. Zones for each delineation method were produced using a classified data approach. The highest, most consistent correlations were achieved with topography, satellite imagery, and yield mapping. Combinations of methods using weights based on relative correlation of each method individually resulted in generally higher correlations than any method used alone. Patterns for nitrogen zone delineation can be determined from various remotely sensed and field collected data. However, in order to build a sound model, each type of data has to be individually classified and analyzed in order to determine its contribution to the overall patterns relevant to nitrogen management. Our findings show that it is important to compile nitrogen zones from a variety of data to safeguard against data patterns that might change from one planting season to another. In addition, it is also important to examine trends over multiple years. For example in 2002 the best predictor of nitrogen was Order 1 soil survey, however, we were not able to reproduce the same result for 2001 and when comparing multiple years, topography, yield, and NDVI from satellite images have been much more reproducible than the detailed soil survey. It is, therefore, important not only to have good predictors, but also consistent predictors that set a trend over several crop seasons. From this work, multiple layers of data together provide a combined consistency. When one method is not as highly correlated as expected, the combination with other layers still resulted in a highly correlated zone delineation.

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Contributions to Improve Fallow System in Yucatan State Mexico

Gabriel Uribe Valle, M.C., Investigador INIFAP-CIR-Sureste C.E Uxmal. Apdo .Post # 50 Unidad administrativa # 4. Mérida Yucatán, México
Juan Jiménez-Osornio, Ph D. Jefe Del Departamento De Manejo Y Conservación De Recursos Naturales Tropicales. Facultad de Medicina Veterinaria y Zootecnia. Universidad Autónoma de Yucatán. Apdo. Post. #28 Cordemx 97110. Mérida Yucatán, México
Roberto Dzib Echeverría, M.C. Investigador INIFAP-CIR-Sureste C.E Uxmal. Apdo .Post # 50 Unidad administrativa # 4. Mérida Yucatán. México

Abstract—*More than 25 percent of earth warming can be attributes to deforestation practices such as crop rotations performed in southeast part of Mexico. In the Yucatan peninsula 20 percent of staple foods such as maize and beans are produced under slash and burn system. It has been practiced for many centuries by native Mayans however population pressure and food scarcity made short fallow periods. Thus soil fertility decline and farmers used to changed to new fertile areas slashing and burning about 250 thousand per year. Natural degradation is a problem in this region therefore a project to contribute to fallow system was developed to try to assure grain production in the same deforested land for more years than the farmers do.*

A field study was conducted in the field station "Uxmal" belonging to the National Institute on Forestry, Agriculture and Animal Husbandry Research on a Luvisol rodic *soil in the state of Yucatan. From 1996 to 2003 two legumes, spontaneous weeds, and continuous cropping using fertilizer treatments were established. It was concluded that is possible to return to same area in short periods using at least two years, also produce maize continuously in this soils for more than three years. Variations on yields are due to rainfall than soil fertility conditions.*

Introduction

Farmers in the Yucatan Peninsula have been used crop rotation systems for many hundred of years. More than 25 percent of earth warming can be attributed to this type of agriculture. 17 millions of ha-1 are lost by deforestation actions in the world. Latin America contributes with 40 percent of total area and Mexico is ranked fourth with 700 thousand ha-1 (Bandy, et. al., 1994). Yucatan state rendered 20 percent to basic crops under slash and burn system (SAGARPA 2001).

Therefore this paper can be regard as a contribution to improve the knowledge about fallow systems in Yucatan state and the possibility to stay in the same area growing maize.

Methodology

The study was conducted at the field station "Uxmal" (latitude 20° 25' N, longitude 89° 46' W) belonging at the National Institute on Forestry, Agriculture and Animal Husbandry Research (INIFAP) located in the Yucatan State in the southeast of Mexico. The soil of the study area was a *Luvisol rodic* (FAO system), and experimental area is 50 m above sea level. Annual rainfall average is 900 mm and mean temperature is about 26 ° C. Rainy season starts in June and lasts until the end of October a period of about five months.

The treatments were replicated four times in the study that had a randomized block, split plot design using plots of 12 X 26 m. Treatments using *Mucuna pruriens*, *Leucaena leucocephala*, spontaneous weeds and continuous cropping were assigned to the main plots (table 1).

Sub plots were sown with maize and fertilized with treatments 20-50-0, 40-100-0 of nitrogen, phosphorus and potassium respectively also a control plot without fertilizer was included.

In 1996 experimental area was slash and burned in order to start the experiment for two and four years treatments regarding both as zero year. *Mucuna pruriens* was sown at 1m between rows and plants and *Leucaena*

Table 1. Treatments description of improved fallow and growing seasons.

Treatments	Years							
	1996	1997	1998	1999	2000	2001	2002	2003
Leucaena 2 years fallow	CC	CC	MC	F	F	CC	CC	CC
Leucaena 4 years fallow	MC	F	F	F	F	CC	CC	CC
Mucuna 2 years	CC	CC	MC	F	F	CC	CC	CC
Mucuna 4 years	MC	F	F	F	F	CC	CC	CC
Spontaneous weeds. 2 years	CC	CC	MC	F	F	CC	CC	CC
Spontaneous weeds. 4 years	MC	F	F	F	F	CC	CC	CC
Continuous cropping(maize)	C C	CC	CC	CC	CC	CC	CC	CC

C C = continuous cropping, M C= Maize cropping and legume sowing, F = Fallow

leucocephala at 1m between plants and 2 m between rows. Sowing distance of maize was 1m between rows and 50 cm between plants leaving two by hole.

Soil samples were taken at a depth of 30 cm before and after burn the experimental area. Analysis for pH, OM, P, K, Ca Mg, Fe, Zn, Cu and Mn were done following the usual methods. Soil moisture disturbed samples were collected weakly all over the years making determinations by the gravimetric method. Annual rainfall was also registered from a meteorological station located at field station from sowing to harvest maize. From 2001 to 2003 spontaneous weeds were measured taking the population density. Legumes biomass was also registered after fallow period in 2000 year using a squared frame of 0.5 X0.5m (10 samples per plot) and no analysis of variance was performed for these data. Maize yield was evaluated all the years. In 2002 year a hurricane affected the yield of maize and the original condition of the experiment. Therefore analysis of variance was not performed for some data. Analysis of variance was performed for population density of spontaneous weeds, legumes contribution to yield of maize and grain yield of maize under fertilizer treatments. Mean separation was made using L.S.D test.

Results and Discussion

Results of chemical characterization are shown in table 2. According to data without burn organic matter and phosphorus are at medium level and very high for potassium and calcium pH is slightly alkaline. With burn organic matter is high as well as phosphorus, potassium, calcium and the pH.

It thus appears that low CEC can regard as limiting factor to yield of maize. Similar results of organic matter content increase, agreed these data (Perez, 1975; Navarrete, 1977; Sanchez y Salinas, 1981; Uribe, 1982; Nair. 1984).

Table 2. Soil analysis content before and after burn experimental area. INIFAP.2003.

Soil parameter	Soil management	
	Before burn	After burn
Organic mater (%)	2.96	3.37
Phosphorus ppm	24.28	26.25
Potassium ppm	306.78	348.93
Magnesium ppm	465.36	461.43
Calcium ppm	2446.07	2492.86
pH	7.09	7.39
CEC meq/100 gr	17.55	17.26

Soil moisture content data with *Mucuna pruriens* were slightly higher than those registered with *Leucaena leucocephala* mainly in dry season due to organic matter contribution which keeps the soil moisture content (Campos and others 1983; Ramirez and others 2001) (table 3).

No significant differences were found for plant population of spontaneous weeds (table 4). *Mucuna pruriens* had a slightly depressive effect on spontaneous weed population compared to *Leucaena leucocephala* in 2001 year. In 2002 year spontaneous weed were damage by hurricane. The recover started in 2003 year without a clear tendency among treatments, may be due to previous damage above cited.

Even though no significant differences were found with the use of legumes a tendency to improve the yield of maize was observed with *Leucaena leucocephala* in both 2001 and 2203 years (table 5). Quantity of biomass contribution and a fast decomposition to organic matter can be regard as important factors that show the tendency observed.

Mucuna pruriens contribution of biomass was better than the other treatments in both 2 and 4 fallow years due to a mulch of leaves left in the soil without decomposition (table 6). Similar results are reported by Ramirez and others (2001) in Quintana-Roo state in the same type of soil (*Luvisol rodic*). On the other hand *Leucaena*

Table 3. Soil moisture content in improved fallow system for two seasons. INIFAP 2003.

Treatments	Dry season S.M %	Wet season S.M %	Annual average
Leucaena leucocephala 2 years	22.88	31.33	27.10
Leucaena leucocephala 4 años	22.32	30.83	26.57
Mucuna pruriens 2 years	23.81	32.05	27.93
Mucuna pruriens 4 years	24.67	31.97	28.32
Spontaneous weeds 2 years	23.03	31.73	27.38
Spontaneous weeds 4 years	23.68	31.45	27.56
Continuous cropping(maiz)	21.83	31.37	26.60
Average	23.17	31.53	

S.M% = Soil Moisture %

Table 4. Plant population density of spontaneous weeds. INIFAP 2003.

	Years/thousands/plants/ha			
Treatments	01	02	03	Average
Leucaena leucocephala 2 years	2101	666	1373	1380
Leucaena leucocephala 4 años	2191	860	2100	1717
Mucuna pruriens 2 years	2083	730	1820	1544
Mucuna pruriens 4 years	2014	630	2056	1567
Spontaneous weeds 2 years	2103	711	1353	1389
Spontaneous weeds 4 years	2032	593	930	1185
Continuous cropping (maiz)	1914	743	1306	1321

Table 5. Treatments contribution to grain yield of maize after fallow. INIFAP 2003.

	Years /t/ha		
Treatments	2001	2002	2003
Leucaena leucocephala 2 years	1.98	0.26	2.36
Leucaena leucocephala 4 años	1.97	0.14	2.08
Mucuna pruriens 2 years	1.83	0.33	1.52
Mucuna pruriens 4 years	1.91	0.17	1.67
Spontaneous weeds 2 years	1.85	0.22	1.80
Spontaneous weeds 4 years	1.95	0.18	2.15
Continuous cropping (maize)	1.84	0.14	2.06

Table 6. Biomass quantity yielded by treatments after fallow. INIFAP 2003.

Treatments	Biomass (g/0.25 m^2)
Leucaena leucocephala 2 years	142.1
Leucaena leucocephala 4 años	126.7
Mucuna pruriens 2 years	253.1
Mucuna pruriens 4 years	205.4
Spontaneous weeds 2 years	180.6
Spontaneous weeds 4 years	163.4
Continuous cropping (maiz)	194.2

leucocephala seems to reduce biomass in both treatments, but the size of leaves and a fast decomposition is given lees biomass compared to other treatments.

Fertilizer treatments applied to maize are shown in table 7. No significant differences were found in 1996, 1997 and 2001 years for grain yield, however in 1998 to 2003 years significant differences shows that the best treatment was 40-100-0 of nitrogen, phosphorus and potassium respectively. For rain fed conditions distribution of rainfall is more important than quantity due to critical stages such as blooming and grain filling. In figure 1, rainfall is about 500 to 800 mm as an average in eighth years data. More than 800 mm occurred only in two years (1999 and 2001) except hurricane year. Yield variations among years depend on the quantity and proper distribution of the rainfall.

Conclusions

Organic matter content, phosphorus, potassium, calcium, and the pH increases with burn compared to no burn.

Mucuna pruriens had a slightly depress effect on spontaneous weeds compared to *Leucaena leucocephala*.

Table 7. Grain yield of maize under fertilizer treatments. INIFAP 2003.

	Years/ t/ha								
Fertilizer treatments	**1996***	**1997***	**1998**	**1999**	**2000**	**2001***	**2002**	**2003**	**Average**
0-0-0	0.83	2.47	2.17b	2.08b	1.75b	1.89	0.11	1.22c	1.80
20-50-0	0.94	2.72	2.47b	2.89a	2.05a	1.75	0.17	2.32b	2.16
40-100-0	1.26	3.28	2.91a	2.84a	2.30a	1.87	0.15	2.63a	2.44
L.S.D	-	-	0..330	0.304	0.266	-	-	0.231	

Any two means having a common letter are not significantly different at 5 % of level of significance. LSD Test
* No significant

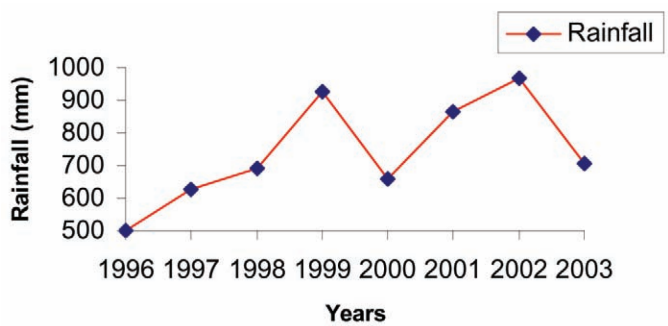

Figure 1. Annual rainfall from sowing to harvest grain maize. INIFAP (2003).

There are no clear contribution to yield of maize from legumes, but *Leucaena leucocephala* shows a tendency.

Mucuna pruriens biomass contribution was better than *Leucaena leucocephala* and spontaneous weeds.

Fertilizer response started at third year of continuous cropping with maize achieving high yield of grain with the treatment 40-100-0 of nitrogen, phosphorus, and potassium respectively.

Is possible to return to same area in short periods using at least two years also produce maize continuously in this soils for more than three years.

Conservation of natural resources can be enhanced using legumes to extend periods of crop and preserving forestry and flora for another purposes

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Historic Hydroclimatic Variability in Northern Mexico

José Villanueva-Diaz, dendrochronologist, INIFAP CENID – RASPA; Km 6.5 Margen Derecha del Canal Sacramento, Gómez Palacio, Durango, Mexico
J. Cerano-Paredes, D.W. Stahle, B. H. Luckman, M.D. Therrell, M.K. Cleaveland, and G. Gutierrez-Garcia

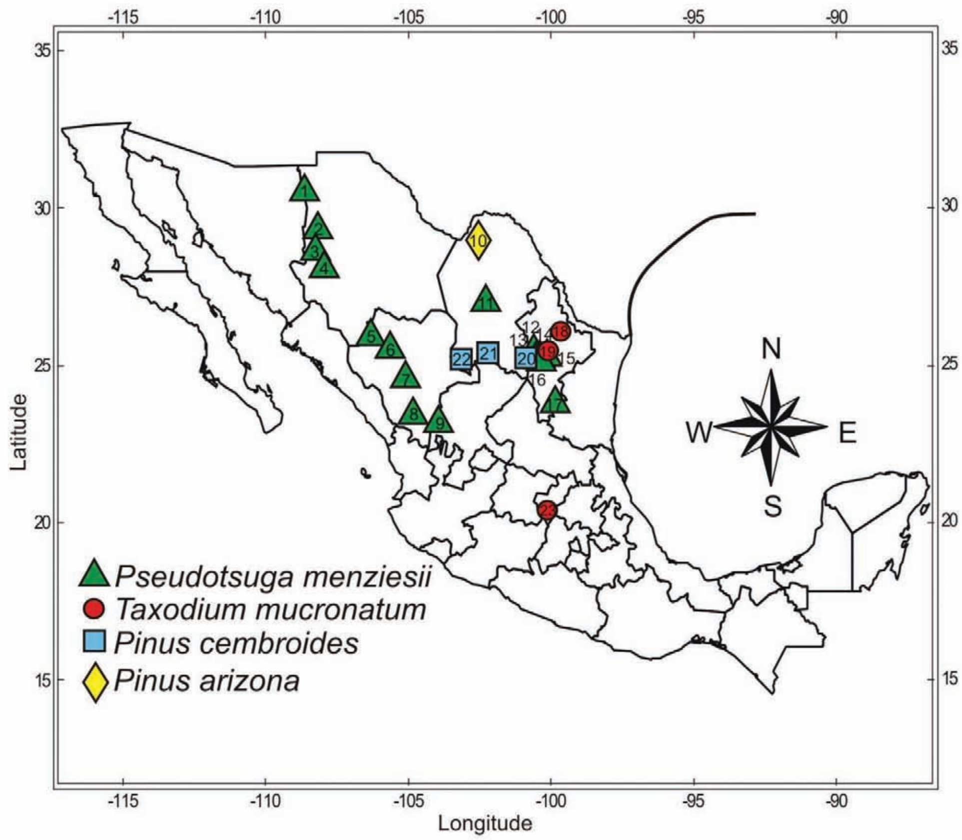
Abstract—*The understanding of historic hydroclimatic variability is basic to plan for a proper management of limited water resources in northern Mexico. The objective of this study was to develop a network of tree-ring chronologies for climate reconstruction and to analyze the influence of circulatory patterns, such as ENSO. Climatic sensitive tree-ring chronologies were developed in mountain ranges of the Sierras Madre Oriental and Occidental. A grid of new Douglas-fir chronologies were developed and winter-spring precipitation reconstructions were produced for northwest Chihuahua, northwestern Durango, southern Nuevo Leon, and southeastern Coahuila. The seasonal winter-spring precipitation reconstructions extended 530 years (1472–2002) for Chihuahua, 228 year (1765–1993) for Durango, 602 years (1400–2002) for Nuevo Leon, and 342 years (1659–2001) for Coahuila. Some of the low frequency events were specific for each reconstruction, but low frequency events (decadal resolution) were present in most of the reconstructions; specific cases are the droughts of the 1810s, 1860s, 1870s, and 1950s, and the wet periods of the 1820s, 1830s, and 1890s.Trends in dry or wet periods were disrupted by above or below normal precipitation affected by the ENSO phenomena, especially in the winter–spring period when this circulatory pattern produced in times abundant rains in northern Mexico. However, the ENSO influence on Winter-Spring precipitation varied with time. Convective rains and precipitation from cyclones formed in the Gulf of Mexico may explain some of the hydrological variability detected in the southern Nuevo Leon and the southwestern Coahuila precipitation reconstructions. However, these preliminary results indicates that winter-spring hydroclimate variability in northern Mexico is influenced by a range of circulatory patterns, and a greater grid of tree-ring chronologies should be developed to explain in detail the involved climatic factors as well as to reconstruct Summer precipitation, that makes up more than 70 percent of the total annual precipitation.*

Introduction

The study of historical variability of atmospheric circulatory patterns is basic to understand the current and future climatic changes and their effect on social and economical stability. The climate of northern Mexico is characterized by a seasonal precipitation regime and a strong monsoon component (Pyke 1972; Douglas and others 1993; Higgins and others 1999) with a pronounced maximum (> 70 percent) of annual rainfall in the warm season (May–October), and less than 30 percent on the rest of the year (Mosiño and Garcia 1974).

Precipitation along northern Mexico varies on time scales ranging from seasonal to decades (Magaña and others 1999). Water supply is a major constraint on development and future land use practices in northern Mexico. However, the lack of available data about long-term trends and variability of water yields is a significant limitation to planning the appropriate and future use of these resources. Water resource planning can greatly benefit from data on the range and variability of precipitation and streamflow that paleoclimatic studies can potentially provide. Therefore, the objective of this study was to examine the long-term hydroclimatic behavior over several hundred years by using tree-rings as a proxy data in developing precipitation reconstructions and analyzing the influence of circulatory patterns for northern Mexico. These data would allow the detection of low frequency periodicities that could be beneficial for the proper management of the limited water resources in this region.

In this study long-term Winter-Spring precipitations reconstructions for the states of Chihuahua, Durango, Coahuila, and Nuevo Leon were developed from the early wood chronologies of Douglas-fir tree rings collected at several locations in the Sierras Madre Occidental and



Site name	Chronology	Elev. (m)	Site name	Chronology	Elev. (m)
1. Mesa de las Guacamayas	1636-2002	2665	13. Pilares	1855-2000	3150
2. Madera	1774-2001	2820	14. La Viga	1659-2001	3400
3. Bisaloachi	1537-2002	2744	15. Coahuilón	1700-2001	3200
4. Cebadillas de Ocampo	1588-2002	2781	16. El Morro	1872-2000	3500
5. El Cocono	1450-2002	1950	17. Mesa de los Gatos	1400-2002	3200
6. Ciénega de la Vaca	1763-2002	2800	18. Cerralvo	1741-2003	1280
7. Cerro Bandera	1675-2001	3170	19. Río San Juan	1887-2003	1240
8. Las Bayas	1681-2001	2980	20. Sierra Zapalinamé	In process	
9. Jiménez de Teúl	1758-2001	2758	21. Sierra de Parras	In process	
10. Maderas del Carmen	1761-2002	1700	22. Sierra de Jimulco	In process	
11. Sierra Cuatro Ciénegas	1719-2003	2180	23. Barranca de Amealco	In process	
12. El Tarillal	1775-2000	3200			

Figure 1. Geographical distribution of new tree-ring chronologies recently developed in northern Mexico.

Oriental. These reconstructions are then analyzed and linked to large scale climatic forcing. The presence of dry and wet episodes on the reconstructions is validated with historical documents (when available) as a way to showing human responses to climatic extremes. It would be important to capitalize this information for a proper management of water resources on this extent dry region.

Methodology

Tree Ring Chronologies

In an attempt to extend existing short hydrological records tree-ring chronologies were developed from increment cores and cross sections taken mostly from Douglas-fir trees (*Pseudotsuga menziesii*) growing in mixed conifer stands along the Sierras Madre Occidental and Oriental in the states of Chihuahua, Durango, Coahuila, and Nuevo Leon. The sampled trees were selected from relatively undisturbed stands in sites classified as with low productivity to maximize the climatic signal. The cores were mounted, sanded and crossdated using standard procedures (Stokes and Smiley 1968) and tree-ring series were measured with a VELMEX "TA" stage micrometer at 0.001 mm resolution. Crossdating and measurement quality were verified with COFECHA, (Holmes 1983, Grissino-Mayer 2001). New tree-ring chronologies of earlywood (EW), latewood (LW) and total ring width (RW) were developed for new Douglas-fir sites and combined with recent chronologies from the region (fig. 1).

Ring-width measurements were standardized with ARSTAN (Cook 1987). All series were initially detrended either with a negative exponential curve or a straight line with a negative slope and secondly with a smoothing spline of 50 percent wavelength (Cook and Peters 1981). Principal Component Analysis (PCA) was performed on the grid of available chronologies to identify orthogonal modes of tree growth (Fritts 1976).

The relationships between climate and tree-growth were investigated by correlation and response-function analysis. A decadal smoothing spline was fitted to the reconstructed series to emphasize the decadal variance (Cook and Peters 1981). When possible, reconstructed drought periods were validated with historical documentation.

Climate Records

Meteorological information was obtained from the climatic data base ERIC II (IMTA 1977); the National Climatic Data Center's Global Historical Climatology Network (GHNC), and from individual meteorological stations of the Comision Nacional del Agua (2002). Missing data were estimated by Paulhus and Kohler's method (1952), and double-mass analysis (Kohler 1949) was used to test homogeneity between stations.

Precipitation Reconstructions

Historical cool season precipitation reconstructions were developed for the states of Chihuahua, Durango, Coahuila, and Nuevo Leon. Climatic information from the 4532 grid (GHCN) was related to the EW Douglas-fir chronologies from Chihuahua. Likewise, the Guanaceví meteorological station was associated to the first principal component values of a network of early wood chronologies for Durango (EW PC1). Douglas-fir chronologies from southern Nuevo Leon were associated to the mean climatic conditions from several meteorological stations located in the states of Nuevo Leon and Tamaulipas, and the meteorological station Saltillo was associated to the network of early wood chronologies from the Sierra de Arteaga, Coahuila.

Results and Discussion

Precipitation Reconstruction for Northeastern Chihuahua

It was found a significant correlation between the EW chronology from Bisaloachi, Chihuahua and the seasonal precipitation (October–May) for the 4532 climatic grid (fig. 2). The regression estimates were tested against independent climatic data with a variety of statistical measures (Fritts 1991). The climatic data was most reliable for the period 1950 to 1990. Therefore, the tree-ring data was regressed from the 1950 to 1990, 1950 to 1969, and 1970 to 1990 periods against the corresponding climatic data. Because statistical tests validated the two subperiods and the regression coefficients did not differ significantly (results not shown), the 1950–1990 regression relationship was used to reconstruct winter-spring precipitation. In general terms, the earlywood width explained more than 50 percent of the precipitation variance.

Figure 2. Location of the climatic grid 4532, developed by the National Climatic Data Center´s Global Historical Climatology Network (GHCN).

The model used for reconstruction was:

$\tilde{Y}t = -111.7637 + 290.693Xt$

Where $\tilde{Y}t$ is the estimated total October–May precipitation (mm) and Xt is the Bisaloachi EW chronology indices.

The Winter–Spring (October–May) precipitation reconstruction, period 1472 to 2002 shows the presence of frequent droughts affecting northwestern Chihuahua along 530 years of the reconstruction (fig. 3).

The worst 20th century drought occurred in the 1950s and 1960s. Similar drought episodes were detected in climatic reconstructions for Durango by Cleaveland and others (2003), Gonzalez-Elizondo (2003), and partially coinciding with a severe drought in Texas (Griffith and Ainsworth, 1981). A more intense drought was observed in the XVIII century, period 1767 to 1778, also detected in a precipitation reconstruction for northern Sonora (Villanueva and McPherson 1999). The drought of the 1550 to 1570 has been reported as one of the most severe for northern Mexico in the last 600 years (Cleaveland and others 2003), although this drought was of lower length and intense on this reconstruction. One shorter severe drought was observed between 1488 and 1496, apparently affecting other areas of the Sierra Madre Occidental (Cleaveland and others 2003). This seasonal

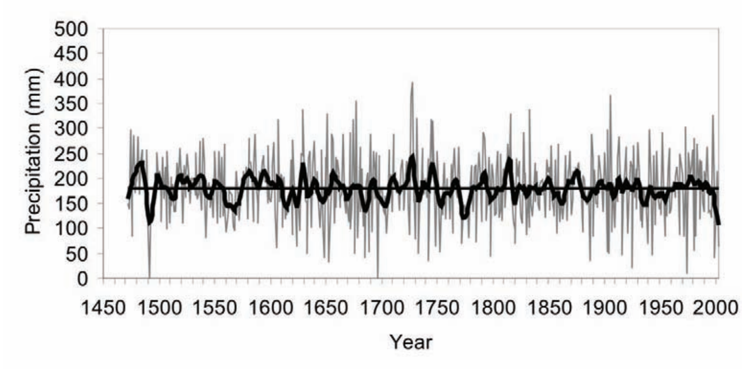


Figure 3. Seasonal Winter-Spring precipitation reconstruction (October–May), period 1472 to 2002, for western Chihuahua and eastern Sonora (climatic grid 4532). The mean precipitation for the reconstructed period was 143.2 mm (solid line) with a standard deviation of 52.4 mm. A smoothing spline has been fitted to the reconstruction to emphasize long-term droughts for the periods 1488-1496, 1552-1573, 1611-1626, 1767-1778, 1882-1887, 1945-1960, 1993-2002. Wet episodes were observed in the periods 1477-1486, 1590-1598, 1649-1661, 1736-1750, 1820-1824, 1873-1878, 1940-1944, and 1972-1979.

precipitation reconstruction provides a good estimation of the hydroclimatic variability of northwestern Chihuahua and eastern Sonora where the climatic quadrant 4532 is located, and verifies a shorter seasonal precipitation reconstruction (1647 to 1992) previously developed for the state of Chihuahua (Diaz-Castro and others 2002).

Precipitation Reconstruction for the Upper Nazas Watershed, Durango

Tree-ring chronologies were developed in the Nazas watershed and compared to climatological stations scattered on this basin (fig. 4).

The regression analysis between the first principal component of 9 Douglas-fir chronologies and the Winter–Spring precipitation (November–May) for Guanacevi climatic station calibrated 73 percent and 57 percent in the two subperiods (1941 to 1966, 1967 to 1993, respectively) and 63.7 percent over the full period (1941 to 1993). The reconstruction models pass all the statistical tests of accuracy.

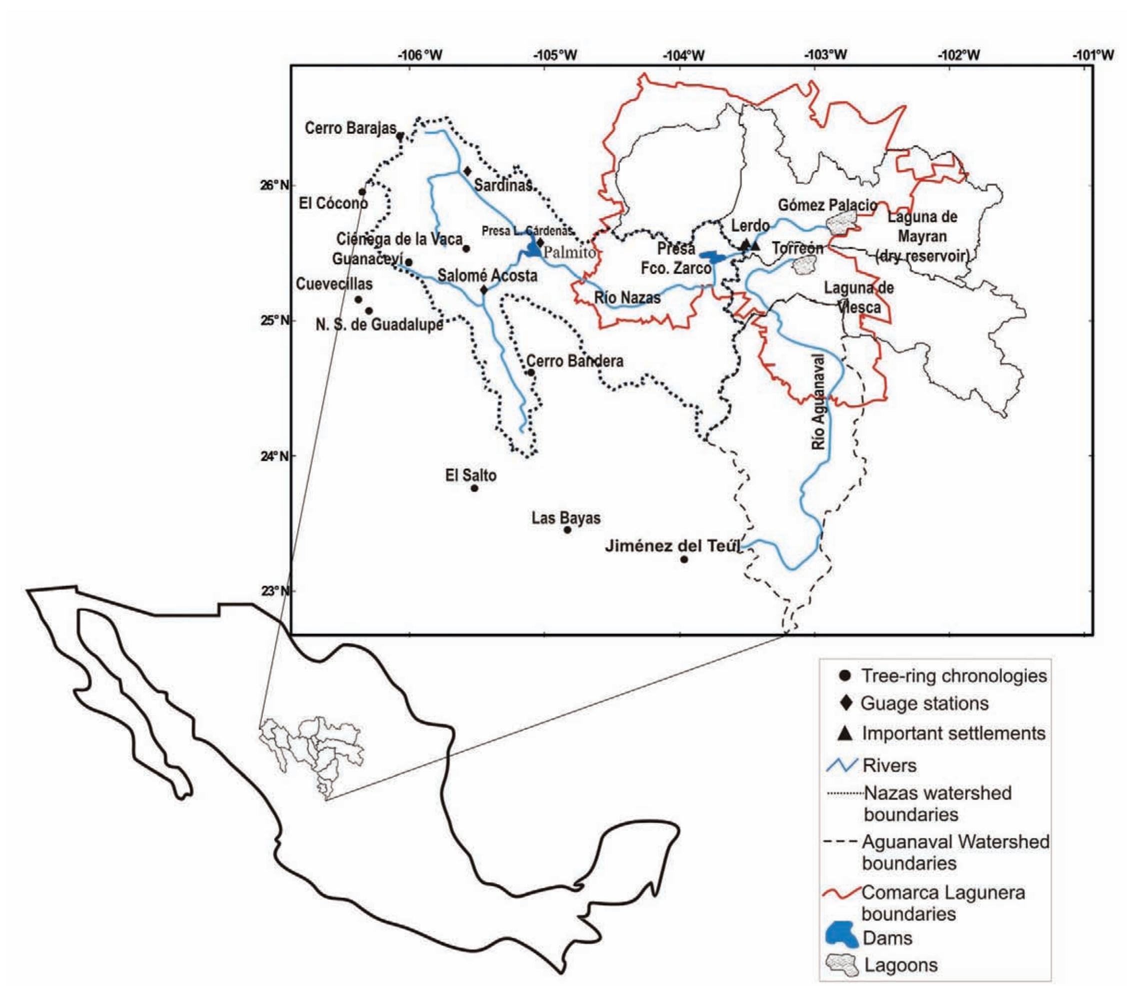


Figure 4. Distribution of tree-ring chronologies, climatic stations, and important settlements in the Nazas watershed, Durango, Mexico.

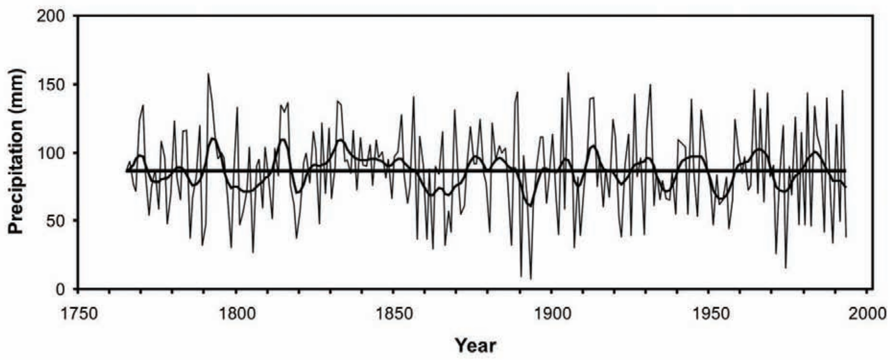


Figure 5. Reconstructed Winter–Spring precipitation (November–May) from 1765 to 1993 for the upper Nazas watershed, Durango, Mexico. A decadal smoothing spline fitted to the annual data emphasizes low frequency variance in the reconstruction.

The precipitation reconstruction covers the period from 1765 to 1993, the common period of all chronologies. The reconstruction is conservative and underestimates precipitation in isolated years of high precipitation, but provides the high and some medium frequency precipitation variability and is a good indication of past dry periods at decadal scales (fig. 5).

Similar to the Chihuahua reconstruction, this reconstruction shows a drought in the 20th century occurred between 1950 and 1957 with a mean winter-spring precipitation of 65.1 mm, 25 percent below the average of the reconstruction (86.5 mm). The 1950s drought has been identified by Cleaveland and others (2003) for Durango and in several regions across Mexico (Therrell and others 2002) and the southwestern United States (Cook and others 1999). Florescano (1980) identified the 1950, 1951, and 1956 years as some of the most extreme droughts for northern Mexico. Based on the precipitation reconstruction there are several drought episodes of similar or greater intensity to those in the 20th century. In the drought of the 1890's (1880 to 1896) and 1900's (1907 to 1910) precipitation was, respectively, 15 and 35 percent lower than the mean. Although the 1890's drought was not as severe as some of the 20th century droughts, it lasted almost two decades and was followed by a short intense drought. Documentary records suggest it led to a drastic reduction in grain production in northern Mexico (Garcia-Acosta 1993), reduced the water volume for irrigation on the Comarca Lagunera (Teran-Lira 2000) and may have contributed to the unrest that triggered "The Mexican Revolution" that started in 1910 (Escobar-Ohmstede 1997). The reconstructed record suggests that 1857 to 1872 was one of the longest droughts with an average of 71.2 mm (18 percent below the reconstructed mean value). Notwithstanding the length of this drought, few historical documents talk about this difficult period when food shortages and famine were common in the region, although Garcia-Acosta (1993) inferred a severe drought in Durango in 1867 based on food prices. An additional drought episode was reconstructed from 1797 to1811. The linkage between this and previous droughts, shortage of food, famine, and presence of pests produced social discontent that fuelled the movement for independence known as "The Independence War of Mexico" (Garcia-Acosta 1993).

Several of the wetter intervals in this reconstruction have also been identified in adjacent regions and extended across much of the western USA (Fye and others 2003).

Precipitation Reconstruction for Saltillo, Coahuila

A seasonal Winter–Spring (January–June) precipitation reconstruction was developed for Saltillo, Coahuila (fig. 6). In producing this reconstruction, five Douglas-fir earlywood chronologies developed from mixed-conifer stands along the Sierra de Artega, Coahuila were involved (e.g. La Viga, El Coahuilon, Los Pilares, El Tarillal, and El Morro). The average chronology from La Viga, El Coahuilon, and Los Pilares resulted to be more significantly correlated with the total seasonal precipitation January–June for the meteorological station Saltillo. Therefore, a bivariate regression model explaining more than 60 percent of the precipitation variance was built to reconstruct a seasonal precipitation for this region (fig. 7). The reconstruction of 342 years (1659–2001) extends 123 years back in time a previous precipitation reconstruction based exclusively in one site chronology produced by Pohl and others (2003) for this region.

Similar to the previous reconstructions, droughts were common along the 20th century, especially for the 1950s and 1960s. In the 19th century some of the severe droughts detected on this reconstruction took place in the 1890s, 1860s, and 1810s. Additional droughts were detected for the period 1720 to 1740, 1690s, and 1670s. Many of this droughts produced agricultural crisis and limited food availability, especially the ones observed at the end of the XVIII and XIX centuries (Cuellar-Valdéz 1979; García-Hernández 1997). The economical and social effects of droughts are increasing in intensity, extension, and duration for this region due in part to

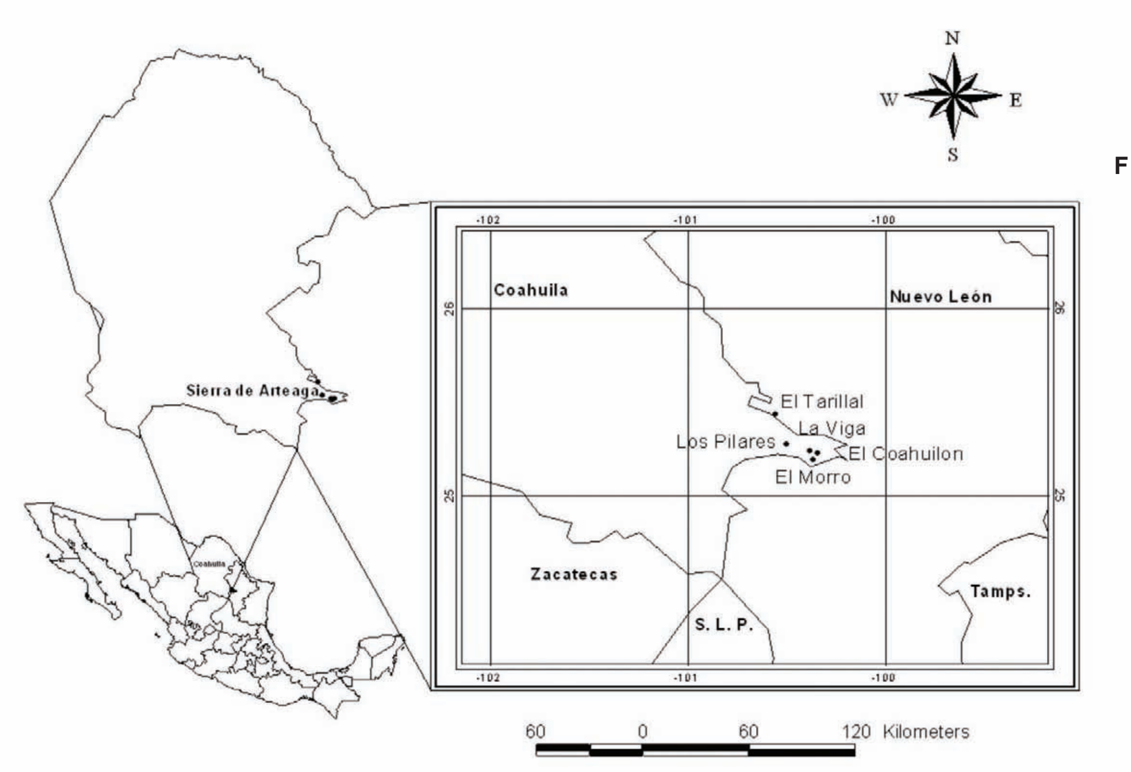


Figure 6. Geographical distribution of the earlywood Douglas-fir chronologies developed from collections located in the Sierra de Arteaga, Coahuila. Some of these tree-ring chronologies were used to develop a cool season precipitation reconstruction for the region.

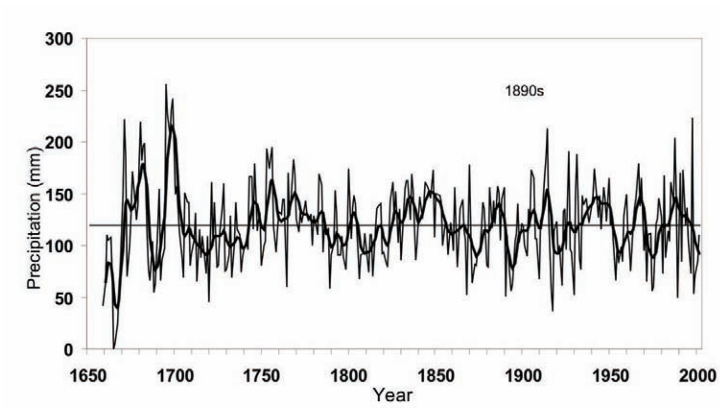


Figure 7. Seasonal Winter-Spring precipitation reconstruction (January – June), period 1659 – 200 for Saltillo, Coahuila. A smoothing spline has been fitted to the reconstruction to emphasize long-term droughts like the ones in the 1950s, 1870s, 1790s, 1690s, and 1670s.

the higher water demand for industrial, agricultural, and different human uses. The establishment of human settlements in places prone to droughts is exacerbating the effect of natural climate variability not only on this region but all over Mexico.

Precipitation Reconstruction for Central and Southern Nuevo Leon

One of the longest precipitation reconstructions for northeastern Mexico is the one derived from an earlywood Douglas-fir chronology located in the site Peña Nevada, Nuevo Leon. This chronology of 602 years length was significantly correlated with the seasonal Winter–Spring (December–April) precipitation for a grid of climatic stations located in central, southern and western Tamaulipas covering the period 1964 to 1997 (fig. 8). The calibration and verification procedures were statistically significant. A bivariate linear equation considering the total length of instrumental data indicated that the tree-ring chronology is explaining close to 50 percent of the seasonal variability of precipitation for this area.

The seasonal precipitation reconstruction (December–April) shows the presence of recurrent droughts affecting this region along the period of 1402 to 2002 (602 years) (fig. 9). On the 20th century the most significant drought episodes took place in the periods 1968 to 1975 and 1952 to 1956. Additional low ware availability was also detected on the periods 1857 to 1868, 1785 to 1790, 1738 to 1743, 1559 to 1590, 1526 to 1536, and a severe drought between 1459 and 1467. Some of the droughts observed in this reconstruction have been documented by Florescano (1980), especially the ones occurred in the 1950s and 1860s, similarly present in other precipitation reconstructions for northern Mexico. The lack of historical documents for this region has prevented a proper verification of the reconstructed data before the 1850s. However, is amazing how droughts affecting other regions of Mexico were also observed in this reconstruction. A specific case is the severe drought of the 1450s and

Figure 8. Geographical distribution of climatic stations (1. Allende, 2. Iturbide, 3. Casillas, 4. Ciénega del Toro, 5. Cerralvo, and 6. UValles) involved in a precipitation reconstruction for Nuevo Leon and Tamaulipas.

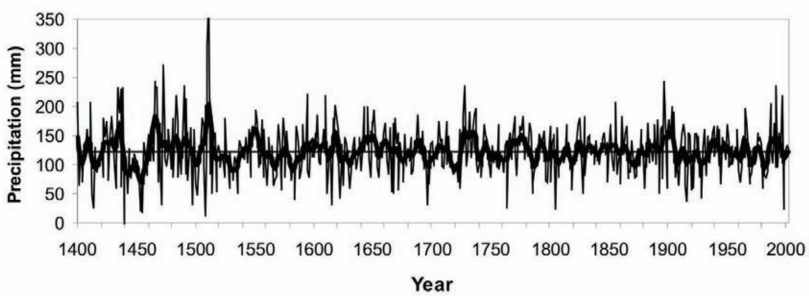


Figure 9. Seasonal Winter–Spring (December–April) precipitation reconstruction, period 1400–2002 for southern Nuevo Leon and eastern Tamaulipas. The smoothing spline emphasizes low frequency events. Drought episodes were observed in the periods 1439 to 1455, 1526 to 1536, 1559 to 1590, 1738 to 1743, 1857 to 1868, 1915 to 1922, and 1968 to 1975.

1460s in the Valley of Mexico that produced shortage of food and drinking water for the Aztec civilization.

A more detailed historical analysis would be important to support hydroclimatic studies in this region that has a great potential in socio-economical terms for Mexico.

ENSO Teleconnection to the Northern Mexico Precipitation Reconstructions

The cool season precipitation in northern Mexico and southwestern United States is strongly linked with the Southern Oscilation Indices (Ropelewski and Harper 1989; Stahle and others 1998, Magaña and others 1999). This relationship is clearly recorded in the tree rings of Douglas-fir growing in the Sierras Madre Oriental and Occidental.

The ENSO extra-tropical teleconnection in northern Mexico is quite strong, but the strength and spatial extent varies over time (Cleaveland and others 2003). The lack of stability is illustrated with the variability of correlation with the Tropical Rainfall Index (TRI) an estimate of the ENSO variability using rainfall anomalies in the central Pacific (Wright 1979). This statement is validated when comparing the TRI and the precipitation reconstruction for Chihuahua for the 1896 to 1995 period. Correlations in successive 20-year periods varied in a range of 0.2 to 0.69. Similar correlations values were found for the Durango reconstruction (Cleaveland and others 2003).

The relationship between the TRI and the Saltillo reconstruction was highly variable and the correlations ranged from 0.24 to 0.65. The highest correlation value of 0.65 was found before 1915 and the lowest (r = 0.24) after this subperiod (fig. 10).

A changing relationship was found between the TRI and the Nuevo Leon precipitation reconstruction. The correlation values were higher before 1900 and decreased along the 20th century.

The response of the northern Mexico precipitation to ENSO forcing appears to be strongest during warm ENSO events (El Niño), based on the correlation analysis with the TRI (Cleaveland and others 2003). On the other hand, the extended and similar drought episodes recorded in most of the precipitation reconstructions apparently were influenced by cold ENSO events (La Niña). However, other atmospheric circulatory patterns may have influenced the observed precipitation variability, especially for those reconstructions located in northeastern Mexico (Saltillo, Nuevo Leon), where cyclones, tropical storms, and other atmospheric patterns may influence much of the winter and summer precipitation which source of water is mostly the Gulf of Mexico (Magaña and others 1999).

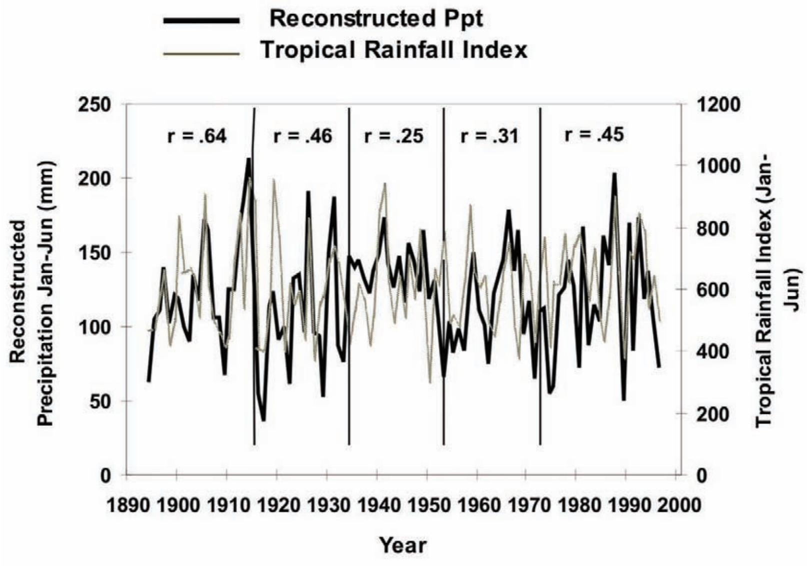


Figure 10. Correlation (r) of the Winter–Spring (January–June) Tropical Rainfall Index with reconstructed Saltillo January–June precipitation in 20-year periods, a demonstration of the long-term instability of the Pacific equatorial teleconnection with northeastern Mexico climate.

Historical Climatic Low Frequency Trends Detected on the Precipitation Reconstructions

The presence of low frequency events were significantly correlated (p <0.05) for the common period of the reconstructions (1782 to 1992), especially on those reconstructions developed for a specific mountain range. Precipitations reconstructions along the Sierra Madre Occidental indicated high and significant correlations (r = 0.08, p< 0.01). Likewise, lower correlation coefficients (p> 0.05) were found when precipitation reconstructions were compared between mountain ranges (table 1). This finding has significant implications to analyze the influence of climatic systems in a particular mountain range and indicates that the hydroclimate variability in northern Mexico is probably being influenced by different circulatory patterns or similar atmospheric phenomena but modulated by changing physiographic conditions that characterizes the Sierras Madre Occidental and Oriental, located along the western and eastern sides of northern Mexico, respectively.

Notwithstanding the influence of well defined atmospheric circulatory patterns affecting a particular mountain range is surprising the presence of generalized dry or wet episodes that affected extensive areas of Mexico. The droughts of the 1810s, 1860s, 1870s, and 1950s were detected in all of the reconstructions (fig. 11). These droughts produced shortages of food, fires, and epidemic outbreaks (Fulé and Covington 1999; Acuña-Soto and others 2002). The presence of these general events indicates that atmospheric circulatory patterns of greater extent such as ENSO and the Southwestern Monsoon System may be causing this climatic behavior. Therefore, they should be considered and analyzed in a greater detail for a better understanding of climate in the Republic of Mexico.

Conclusions

The cool season precipitation reconstructions developed for several places of northern Mexico indicated droughts of greater intensity and extent than those witnessed along the 20th century. These reconstructions

Table 1. Correlation coefficient values for several winter-spring precipitation reconstructions for a common period (1782 to 1992). All correlation values were significant (p< 0.001) but the highest values were obtained when comparing reconstructions developed for a particular mountain range, which is an indication of the influence of different atmospheric circulatory patterns in tree growth.

Winter –Spring precipitation reconstructions in norhtern Mexico	Ppt Oct-May Bisaloachi, Chihuahua[1]	Ppt Nov – April, Chihuahua (Diaz and others 2002)[1]	Ppt Nov - March Durango, (Cleaveland and others 2003)[1]	Ppt Jan – June Saltillo, (Pohl and others 2003)[2]	Ppt Dec – April Peña Nevada, N.L.[2]
Ppt Oct–May, Bisaloachi, Chihuahua[1]	1.0				
Ppt Nov–April, Chihuahua (Diaz and others 2002)[1]	0.79	1.0			
Ppt Nov–March, Durango, (Cleaveland and others 2003)[1]	0.65	0.78	1.0		
Ppt Jan–June, Saltillo, (Pohl and others 2003)[2]	0.38	0.43	0.56	1.0	
Ppt Dec–April, Peña Nevada, N.L[2]	0.33	0.37	0.51	0.49	1.0

[1] Precipitation reconstructions for the Sierra Madre Occidental.
[2] Precipitation reconstructions for the Sierra Madre Oriental.

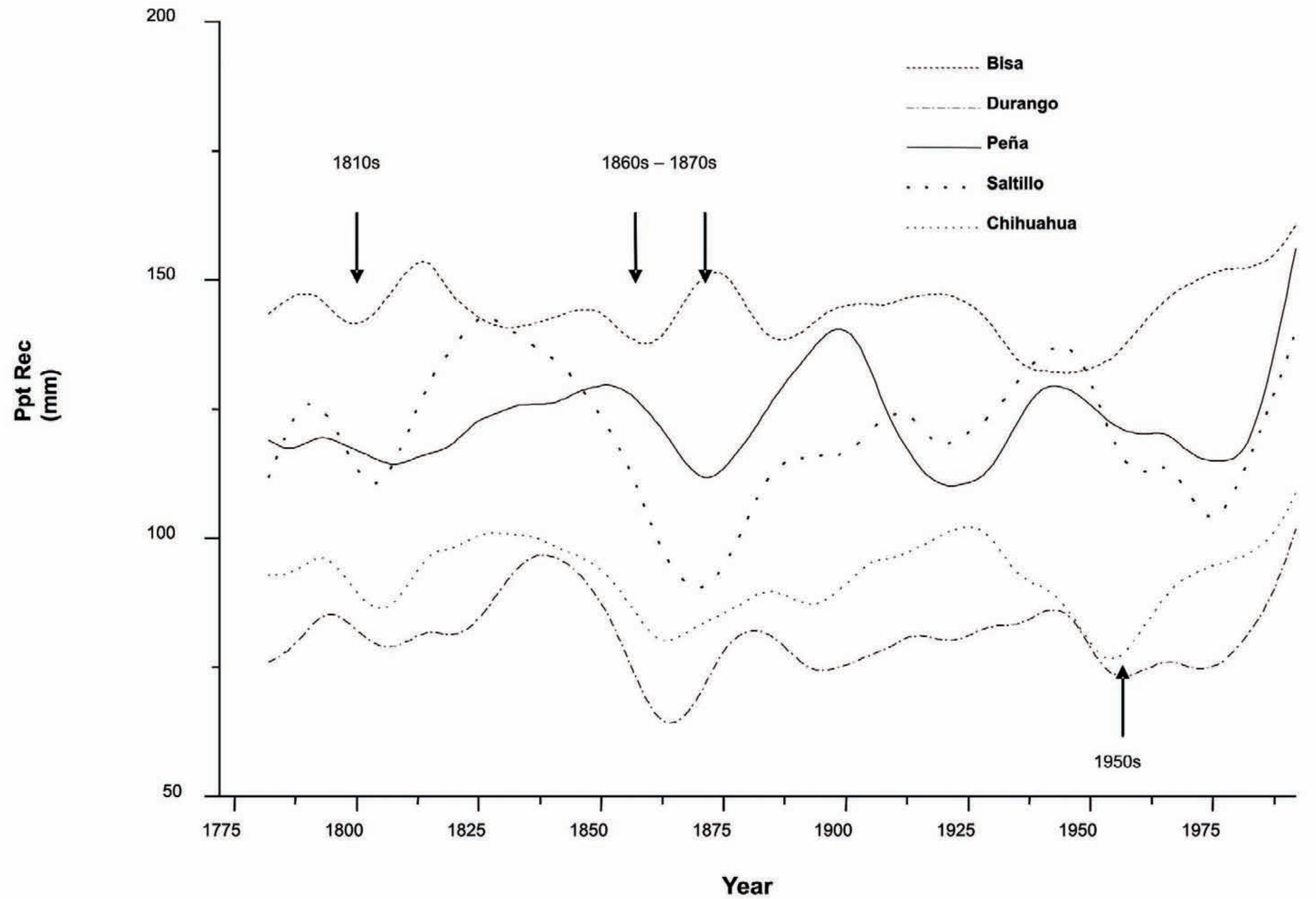


Figure 11. Low frequency events common to all precipitation reconstructions for northern Mexico. The arrows show dry periods present in most of the reconstructions such as the 1810s, 1860s, 1870s, and 1950s. Generalized low frequency events are attributed to the influence of atmospheric circulatory patterns (e.g. ENSO, SMS).

are well correlated with the ENSO indices and offer an excellent opportunity to further explore the history and variability of the Southern Oscillation. All reconstructions showed strong and variable in times seasonal correlations to the Tropical Rainfall Index indicating the necessity to explore in detail the ENSO circulatory pattern that explains much of the great scale cool season hydroclimatic variability in central and northern Mexico.

The expanding network of tree-ring chronologies now available for several regions of Mexico and composed by different species will play in a short future an important role in reconstructing Mexico`s late Holocene paleoclimate variability.

Additional sensitive baldcypress (*Taxodium mucronatum*) chronologies over a thousand years have been developed in the last few months for the central region and some shorter for northern Mexico. These chronologies have the potential to provide seasonal rainfall reconstructions and may help to explain the warm season precipitation variability that accounts for more than 70 percent of the annual total precipitation for central and northern Mexico, and that has been linked to the Southwestern Monsoon System. Summer rainfall is of main importance for agriculture, grassland productivity, ground water recharge, etc, and understanding its historic variability may help to plan for a proper management of this limiting resource in Mexico.

The lack of suitable proxy climatic records in the past has limited proper hydroclimatic analysis for water management and climate forecasting purposes. The new network of tree-ring chronologies in expanding process linked to historical socioeconomical data will help to explore relationships that may contribute to plan in advance the better management of limited water resources in central and northern Mexico.

Acknowledgments

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A Carbon Inventory for Mexico

L. Wood, Senior Associate and Remote Sensing Specialist, and D. A. Hughell, Associate and GIS Specialist, ARD, Inc., Burlington VT
H. G. Lund, Forest Inventory Specialist, Forest Information Services, Gainesville, VA
V. E. Torres, Remote Sensing Specialist, Prextec, Nicolas San Juan 360, Col. de Valle, México
Mario Pérez-Chavéz, Biologist and President, GEOSFERA, Adolfo Ruiz Cortinez, 209, Aguascalientes, México

Abstract—*Treaties such as the United Nations Framework Convention on Climate Change (UNFCCC) recognize the link between changes in vegetation cover and impacts on the global climate. The UNFCCC specifies guidelines for monitoring land use changes and for including such changes in the "equation" for evaluating a nation's compliance with efforts to reduce carbon dioxide (CO^2) releases into the atmosphere. With an estimated 20 percent of CO^2 emissions coming from land use changes, such monitoring must measure the carbon content of various vegetation types. ARD, Inc. developed such means through a United States Agency for International Development (USAID) project entitled Technical Assistance for Developing a Carbon Index for Mexico. The purpose of the project was to strengthen Mexico's ability to estimate the amount of biomass CO^2 lost or gained over time based on a consistent methodology. The ARD team developed a methodology for deriving national carbon estimates from, and in coordination with, well-established Mexican government programs. The team focused on the following land use change and forestry (LUCF) reporting categories: changes in forest and other woody biomass stocks, forest and grassland conversion, and abandonment of managed lands. For each category, the team developed technical guidelines that use data collection efforts already in existence or that would soon be underway—that is, long-term government programs funded each year that would be relatively consistent over time. The team felt that such commitment was necessary to support change estimates that occur on a time scale of decades. The team field-tested the methodology and had the results peer reviewed. The ARD procedures have application throughout the western hemisphere and indeed the rest of the world.*

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) requires participating nations to develop and communicate a national inventory of anthropogenic emissions and removals of greenhouse gases (GHGs), including carbon dioxide (CO^2) (Articles 4.1 and 12). The Intergovernmental Panel on Climate Change (IPCC), established in 1988, assesses scientific, technical, and socio-economic information relevant to understanding the scientific basis of risks of human-induced climate change. The IPCC also prepares reports and technical papers that provide independent scientific information and advice in support of the UNFCCC. The IPCC provides:

- Guidelines for assembling, documenting, and transmitting complete and consistent national inventory data, regardless of the methods used to produce the estimates.
- Instructions for calculating emissions of CO^2 and methane (CO^4), as well as other trace gases, from six major emission source categories (or "sectors").
- A compendium of information on methods for estimating emissions for a broader range of GHGs and a complete list of source types for each.

One of the six major emission source sectors is the land use change and forestry (LUCF) sector. LUCF consists of five categories, called "modules." With an estimated 20 percent of CO^2 emissions coming from land use changes (Watson and others 2000), monitoring the national inventory requires a means to measure the carbon content of various vegetation types. The UNFCCC specifies minimum requirements for measuring, monitoring, and reporting CO^2 emissions and removals due to land use changes, and for evaluating a nation's compliance with international efforts to reduce CO^2 releases into the atmosphere. To date, Mexico has filed two national inventory reports to the UNFCCC (1997 and 2001). A third report is required in 2009.

This paper describes a methodology to strengthen Mexico's ability to estimate the amount of biomass CO^2 lost or gained over time from land use changes that is consistent with IPCC guidelines and uses existing Mexican government data resources. ARD, Inc. carried out the work through a United States Agency for International Development (USAID) project entitled Technical Assistance for Developing a Carbon Index for Mexico (SEMARNAT 2003). At the time of this study, the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Houghton and others 1997) were still in use.

Mexican Government Data Resources

Two primary sources of data are required for the ARD methodology. The first is the national land use/land cover (LU/LC) maps of the Instituto Nacional de Estadística Geografía e Informática (INEGI, National Institute of Statistics, Geography and Informatics), the agency responsible for integrating Mexico's statistical information systems. These maps show 66 different land use and vegetation types. INEGIs methodology is fully documented, has remained consistent for decades, and includes ground truth. The polygons of the INEGI LU/LC maps can be used to estimate areas associated with all land use and vegetation classes of interest, for the entire country.

The second data source is the tree volume data of the National Forest Inventory. At the time of our study, the Government of Mexico had embarked on a national forest inventory – the Inventario Nacional Forestal (INF). The Ley Forestal (Forest Law) of 1992 and 2003 mandated this inventory and provided guidelines both in the law and in its accompanying rules and regulations. The Instituto Nacional de Investigaciones Forestales (INIFAP) carried out the inventory with oversight by Comisión Nacional Forestal (CONAFOR) with funding from CONAFOR's parent agency, Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT). CONAFOR provides detailed guidelines for the collection of inventory field data. These field data will provide wood volume estimates, which can be used to "characterize" some of the INEGI LU/LC classes in terms of their carbon content. Since the early 1980s, the INF has been the only government-approved source of wood volume data in Mexico.

Our methodology associates the INF sample points with the "forest" classes mapped by INEGI. Both data sets are essential to estimate the biomass carbon content in the LUCF sector in Mexico. The two data resources are described in more detail below.

INEGI LU/LC Maps

In Mexico, the successive INEGI LU/LC map series can be used to estimate area changes at the national level. As a country ranked among the world's top five in terms of plant species diversity, INEGI's land classification system is necessarily complex. At the scale of 1:250,000, INEGI uses three-tier, hierarchical classification criteria made up of plant community association, presence or absence of species indicating a secondary stage in the plant community, and soil erosion. At the top tier, this classification scheme is easily referenced to both forest classes and IPCC ecosystems. As part of this work, we developed a lookup table to link INEGIs 66 vegetation types to the IPCC's 17 LUCF ecosystems.

At the time of this study, the most recent complete cartographic set of LU/LC maps available for the entire country were the INEGI Series II maps derived from 1993 Landsat satellite image interpretation and supplemented with field data collected over the period 1994 to 1996. INEGI was in the process of producing the Series III maps using 2002 to 2004 satellite and field data, with expected completion of the vegetation and agriculture layers in November 2004. Together, the completed Series II and III maps are designed to measure change. The 1993 INEGI Series II establishes a baseline to estimate LU/LC change, while the ongoing Series III mapping effort defines the period over which changes can be assessed. INEGI had completed about ten digital sheets in draft form for Series III at the time of this study.

INF Forest Inventory

In Mexico, SEMARNAT is responsible for the design and supervision of the national forest inventory. The new INF follows closely the design of the USDA Forest Service and the Canadian Forest Service inventories (Lund 2003). Thus, the new survey will generate data for Mexico that are comparable to the rest of North America. The implementation of the forest inventory survey is underway, with modest progress in the watersheds of the rivers Lerma-Santiago in Central Mexico and Pánuco in the State of Veracruz. Limited progress is also being made in areas of the States of Hidalgo and Jalisco.

By overlaying a sampling grid on the INEGI LU/LC maps, the INF will produce sample wood volume data for all areas mapped as "forest" by INEGIs Map Series

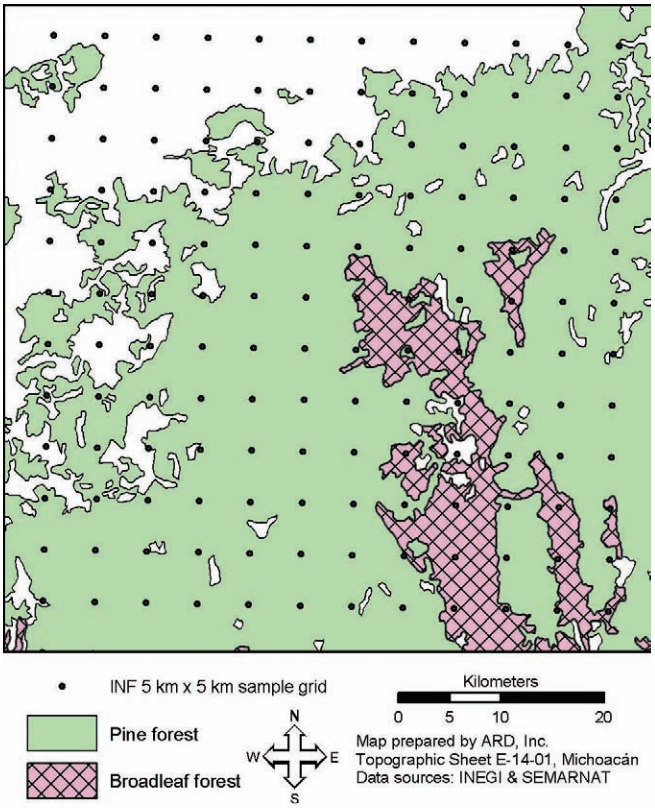

Figure 1. INF Sampling Grid Overlaid on INEGI LU/LC Map.

III. The grid spacing is 5 km x 5 km for tropical and temperate forest (fig. 1), 10 km x 10 km for scrub land, and 20 km x 20 km for arid zones. The INEGI maps restrict to "forest" classes the areas where INF field data are collected. That is, the INF sampling grid "filters" points that fall in "forest" classes, excluding points that fall into other classes such as agriculture, urban areas, and water bodies.

The field data collected for the INF includes tree species, height, diameter, total basal area, and density of herbaceous vegetation. Appropriate "expansion equations" are used to convert timber volume data to estimates of tree biomass. The INF does not currently collect data on litter biomass, but the substantial component of above ground forest biomass in Mexico is usually contained in trunks, branches, and foliage. Thus, a good approximation to the carbon content of the LUCF sector in Mexico can be derived from the samples of the INF.

Although the primary focus of the INF is to estimate the commercial potential of forest lands, the survey also collects data and information on scrub land and arid zone vegetation – categories that fit within the context of the UNFCCC agreement. When the INF is complete, Mexico will have the data necessary to provide good estimates of above-ground carbon for forest lands. The sampling intensity ensures that the inventory will obtain enough samples for each INF class to provide biomass estimates at a pre-specified level of confidence.

Definitions of "Forest"

The Marrakesh Accords (UNFCCC 2001) provide the definitions, modalities, rules and guidelines relating to land use, land use change, and forestry activities under the Kyoto Protocol of the UNFCCC. However, the definition of "forest" and "degraded forest" provided by the Ley Forestal, INEGI, and the Marrakesh Accords differ in significant ways.

The Marrakesh Accords define "forest" as:

> "a minimum area of land of 0.05 to 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 to 30 per cent with trees with the potential to reach a minimum height of 2 to 5 meters at maturity in situ. A forest may consist either of closed forest formations, where trees of various stories and undergrowth cover a high proportion of the ground, or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10 to 30 per cent or tree height of 2 to 5 meters are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest" (UNFCCC 2001)."

For national GHG reporting, nations are free to choose any threshold for defining forest land within the ranges given in the Marrakesh Accords.

Based upon the Ley Forestal, the INF defines "forest" as any naturally occurring area covered by trees, scrub, or arid zone vegetation.

INEGI distinguishes between forests and forests with secondary vegetation. INEGI defines "forest" as naturally occurring tree-covered areas larger than 25 hectares with more than 60 percent tree crown cover. Forests with secondary vegetation are defined as those having 10 percent to 60 percent crown cover with the presence of secondary species—specifically, the presence of key indicator species. INEGI does not include forest plantations, orchards, or urban parks in its definition of "forest." Forest plantations and orchards are mapped as perennial crops; urban parks are not separated from the "urban" class. Thus, the INEGI definition may omit a large amount of area that the Marrakesh Accords would consider forested.

What constitutes a "degraded forest" is yet another issue. In Mexico, a forest with secondary vegetation is often regarded as degraded forest. Such areas might remain as forests or be converted to different land use types. IPCC defines degradation of forest as "a direct human-induced long-term loss (persisting for X years or more) of at least Y percent of forest carbon stocks [and forest values] since time T and not qualifying as deforestation or an elected activity under Article 3.4 of the Kyoto Protocol. (Penman 2003a). It remains to specify an area threshold if desired, as well as time and carbon loss thresholds in order to "operationalize" such a definition.

The IPCC focuses on human-induced causes and, in this case, on degradation of the structure and function of the forest. The time scale for "degradation" is long term—to distinguish it from "carbon stock reductions" which are short-term changes (for example, timber harvesting as part of sustainable forest management). The term is intended to capture overuse or poor management of forests leading to long-term reduction in carbon stocks (in other words, biomass density). A forest with secondary vegetation may or may not result in a long-term reduction in carbon stocks or in reduced capacity of the forest to produce goods and services, so the Mexican definition encompasses a much broader set of parameters than the "degraded" forest defined by the IPCC. However, these lands certainly represent areas of active change in biomass.

In addition to forest lands, there are other categories of lands designated by the UNFCCC on which countries are to monitor and report. These include croplands, grasslands, wetlands, and settlements. Scrub and arid zone vegetation would be reported as "grasslands" according to IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (Penman 2003b). These areas, however, are classified as forest according to the Ley Forestal (and therefore the INF).

Methodology

When its third report to the UNFCCC is due in 2009, and before the INF is completed, the Government of Mexico will require information for estimating net emissions and removals of CO^2 in the LUCF sector. Our methodology is designed to accommodate the incomplete INF forest inventory data. Our methodology collects field data on a subset of INF samples large enough to provide carbon estimates to a pre-determined level of confidence or sampling error (Lund, Thomas 1989). This approach does not deviate from the systematic INF sampling grid, but rather selects points from the grid to satisfy the immediate needs for carbon reporting in lieu of a completed, nationwide INF.

We stratify INEGIs LU/LC cartographic series according to vegetation types, then use the INF sampling grid to determine areas where data can be collected to estimate carbon stocks. Such a subset must include stable areas as well as those undergoing change in each of the IPCCs LUCF reporting categories. For this subset, data collection should follow the INF standard procedures, but need not include the full set of parameters. Only data for those parameters essential for estimating biomass carbon need be collected.

Since there are no carbon measurements from the reference date, the Government of Mexico will need to assume that the carbon content of a given LU/LC class measured in 2002/2004 can be applied to the same class defined in 1993. The extrapolation of 2002/2004 carbon measurements to an earlier date must be substantiated by the calculated variance of the carbon content in the samples collected within the classes of interest. For example, if the carbon content of mature pine forest turns out to be relatively homogeneous in the INF survey of 2003 (in other words, the computed variance is small), one could extrapolate these measurements back to 1993 with greater confidence. On the other hand, if the coefficient of variance (the ratio of the sample standard deviation and sample mean) of the carbon content of a given forest type is as much as 40 percent, then this procedure may not generate reliable estimates. Thus, an analysis of within-stratum variance must be carried out before undertaking the collection of a sub sample of INF data.

The INEGI LU/LC maps do not contain enough information on biomass variance to be useful for allocating sample size. In our study, we found that for some INEGI categories (such as forest with secondary vegetation) carbon stock estimates may vary as much as an order of magnitude. Such a wide range of carbon values, coupled with the extent of forest with secondary vegetation in the country, could represent one of the greatest uncertainties for estimating carbon stock and carbon stock changes from the LUCF sector in Mexico. Thus, the INF sample collection must begin with a survey designed to yield the variance information required to define the number of samples necessary to provide estimates at a given confidence level. Once the parameters of the LU/LC classes are determined, the value and variance of the IPCC categories that are aggregates of those classes can then be established.

The following steps outline our procedure for establishing a forest biomass baseline ("phase 1"), estimating changes in forest biomass using INEGI maps and INF plots ("phase 2"), and computing the change ("phase 3").

Phase I. Estimating Current Biomass (Baseline)

1. Establish inventory unit boundaries.

2. Overlay INF grid.
3. Establish INF plots.
4. Record field-observed INEGI class and IPCC category (needed to estimate area sampling errors).
5. Measure trees (needed for volumes).
6. Superimpose latest INEGI maps.
7. Record latest INEGI map class for each plot.
8. Stratify plots according to INEGI map classification.
9. Compute average volume of wood per hectare by stratum.
10. Estimate volume of wood per hectare, variance, and so forth using tree data.
11. Estimate the area of each stratum. (There is a choice of using the plot expansion factor or the sum of the INEGI strata by class in the inventory unit. While the former may be "proper," the latter may be more useful when mapping change.).
12. Estimate total volume per stratum by multiplying area by average volume per hectare.
13. Expand to inventory unit by summing strata totals.
14. Estimate and report sampling errors.

Phase II. Estimating Past Biomass

15. Estimate INEGI forest type areas from old maps within same inventory unit.
16. Superimpose old INEGI maps over new; note areas of change.
17. Subtract or add areas of change to information derived from phase II, step 15.
18. Use strata average volume/hectare derived from phase I, step 9 and multiply by old INEGI stratum area to get volume per strata for the time the old maps were made.
19. Sum strata totals to get old inventory unit volumes.
20. Compare results from Phase II and I.

Phase III. Computing Change

21. Stratify according to the IPCC change category and insert data into appropriate IPCC category as to whether change was:
    - (Forest > degraded) = Closed forest to forest with secondary vegetation = Degradation or disturbance. (IPCC "Changes in Forest and Other Woody Biomass")
    - (Forest > non-forest) = Land conversion (IPCC "Forest and Grassland Conversion")
    - (Non-forest > forest) = Land conversion (IPCC "Abandonment of Managed Lands")
    - (Forest > improved forest) = Open forest to closed forest = Forest improvement ("Changes in Forest and Other Woody Biomass")
22. Estimate and report sampling errors for each IPCC category

Application of Methodology to the IPCCs LUCF Categories

Although establishing a "carbon baseline" is desirable, the essential information required for reporting to the UNFCCC are the net changes ("emissions by sources and removals by sinks") of CO^2 due to human-induced ("anthropogenic") causes. Specifically, for the LUCF sector, the reporting categories are (a) changes in forest and other woody biomass stocks; (b) forest and grassland conversion; (c) abandonment of managed lands; (d) CO^2 emissions and removals from soil; and (e) other. The first step, then, is to identify changes in areas relevant to the IPCC. Our methodology addresses categories (a) through (c) and, incidentally, (e), but not (d).

Changes in Forest and Other Woody Biomass

The IPCC category "changes in forest and other woody biomass" accounts for "the emissions or removals of carbon (and CO^2) due to changes in forest and other woody biomass stocks affected by human activity" (Houghton and others 1997). Specifically, "emissions" encompass commercial harvest, fuel wood consumption, and "other" wood removed. These are partially offset by "removals" calculated as the product of the area of forest biomass stock and annual growth rate. The computations required for estimating the CO^2 emissions and removals for this category are shown graphically in figure 2.

Changes in woody biomass can occur in areas that do not necessarily undergo a change in land use but which do change in their above-ground forest biomass density. (Hence, these areas remain in the same class assignment and are still classified as "forest"). This gradual process often begins with an undisturbed mature forest and in some cases ends with a change of land use (deforestation), commonly cropland, or pasture. In this case, the change would be accounted for under IPCC guidelines as a "conversion." Alternatively, if it can be demonstrated that these areas are undergoing a long-term reduction in their capacity to produce goods and services, they would be reported under "Other."

INEGI classifies forest with secondary vegetation by the presence of secondary species with a concurrent reduction of crown cover. Mexico has large areas of forest with secondary vegetation, especially in temperate forests. If changes in woody biomass do not translate into changes in crown cover or result in the introduction of indicator species, a comparison of INEGI map series will not detect the changes. (For example, a forest with 100 percent crown cover and 350 tC/ha of biomass in t0 could

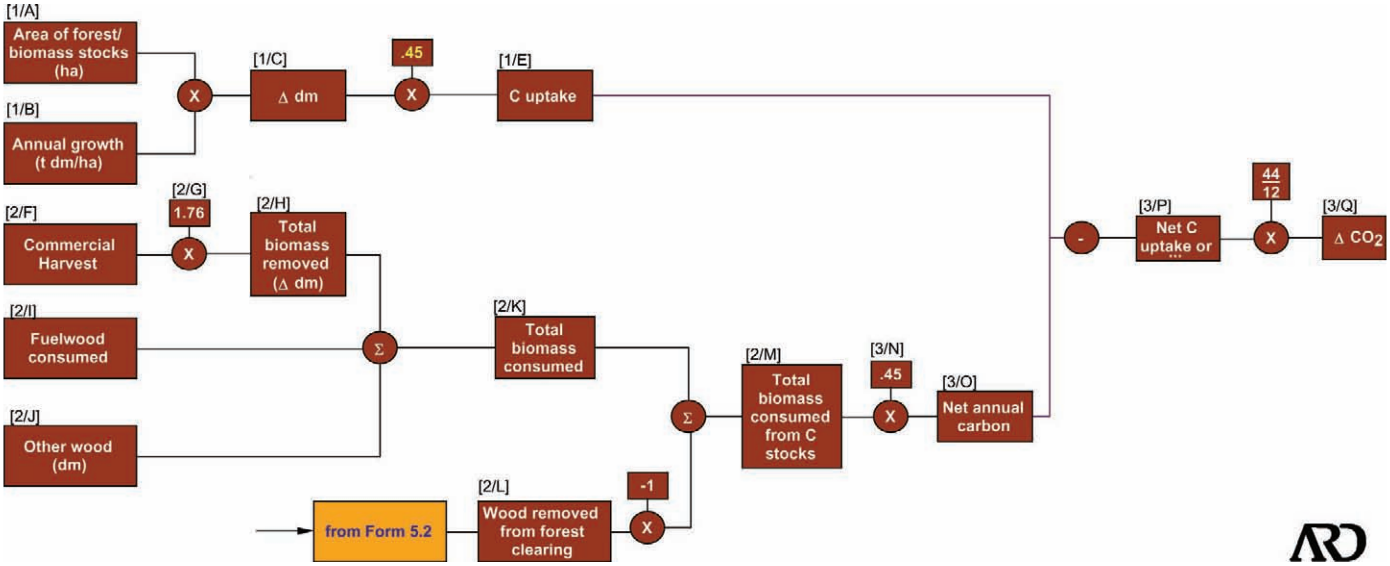

Figure 2. Changes in Forest and Other Woody Biomass.

be degraded to a 60 percent crown cover and 280 tC/ha in ti and still retain the same INEGI LU/LC type.)

Forest and Grassland Conversion

The IPCC category "forest and grassland conversion" is primarily intended to account for the effects of slash and burn agriculture. Procedures for computing the net CO^2 emissions and removals from this category (fig. 3) account for the activities of cutting undergrowth and felling trees, followed by burning the biomass on site or as fuelwood (off site), with some of the biomass remaining behind to decay slowly.

In Mexico, land conversion is recorded as "deforestation" when it takes place in temperate or tropical forests and "clearing" when it takes place in scrubland. Clear cutting is common in tropical forests in southern Mexico, where forest is replaced by rangeland. Elsewhere, changes are more gradual. Progressive fragmentation of temperate forest (Herrera 2004) nevertheless eventually leads to establishment of agricultural lands.

The INEGI maps are particularly relevant for establishing where forest and grassland conversion has taken place, since other national mapping programs have not used consistent classification schemes or incorporated ground truth, without which measuring change is difficult if not impossible. Additional detail is also provided which is useful for understanding the causes of the changes. For areas identified with secondary vegetation, INEGI

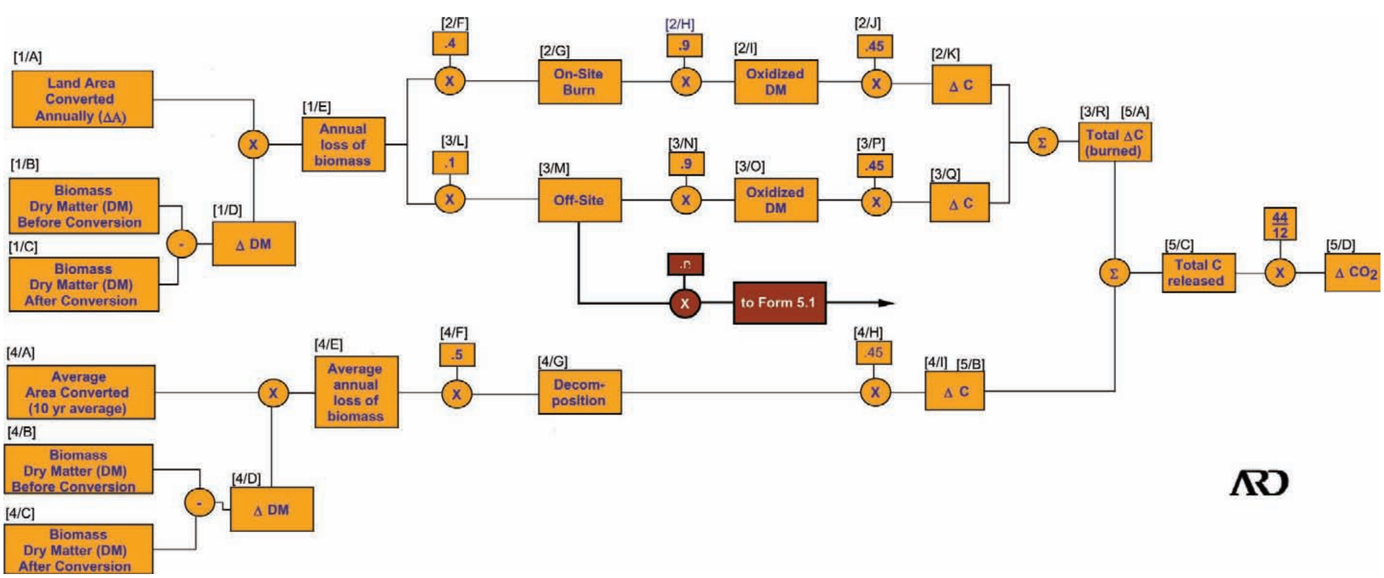

Figure 3. Forest and Grassland Conversion.

includes field verification of dominant species, while areas of mixed vegetation with shifting agriculture are shown by a specific hatching pattern. The major drawback of the INEGI map series is that they are only generated every 10 years.

Abandonment of Managed Lands

The IPCC category "abandonment of managed lands" deals with "net CO^2 removals in biomass accumulation resulting from the abandonment of managed lands," where "managed lands" include cultivated lands and pasture (Houghton and others 1997). Because carbon accumulation on abandoned lands is sensitive to ecosystem type, re-growth rates are further subdivided into land abandoned during the 20 years prior to the inventory, and land abandoned between 20 and 100 years ago. The computations required for estimating the CO^2 emissions and removals for this category are indicated graphically in figure 4.

The largest areas in Mexico of formerly managed, now abandoned lands are in Central Mexico (Herrera 2004). These areas were mostly marginal agricultural lands that had been abandoned due to unfavorable market conditions. They include many areas formerly registered in the Ministry of Agriculture's farm subsidy program Apoyos y Servicos a la Comercialización Agropecuaria (ASERCA).

Testing and Peer Review

Throughout the study we conducted a multiple-stage peer review, both technical and operational, of the evolving methodology. Peer reviewers included nationally and internationally recognized experts in the fields of forest inventory, mapping, and remote sensing, as well as a representative from the IPCC Task Force on National Greenhouse Gas Inventories. This peer review provided valuable guidance for directing our effort, and ensured compatibility not only with the IPCC but also with the North American Forestry Commission.

We tested the methodology in the Mexican state of Michoacán using Series II and III map sheets made available to us by INEGI. We engaged the services of a private contractor familiar with the INF procedures to collect data on a sample of INF points within INEGI quadrangle E-14-01. Of the 92 INF grid points that fall within this quadrangle, 64 are located in temperate forests, nine in tropical forests, and 19 in non-forested areas. We randomly selected 21 points from the INF grid which were classified as temperate forest in the INEGI Series II map. (We did not include tropical forests or other land cover types since the number of grid points in both cases would have been too small to be useful.) Procedures employed for collecting data from sample plots were nearly identical to the INF procedures, with the exception that data were not collected on species diversity, tree growth rings, minor vegetation, and soil organic matter. These data are not considered necessary for estimating above-ground biomass to the accuracy necessary for national carbon reporting.

During July 2003, the contractor collected field data on 19 of the 21 plots. (Land owners denied access to two plots.) We processed these data to calculate the volume of the stems and limbs for each plot (table 1). The results indicate rather high standard deviations, indicating a high "within stratum" variability.

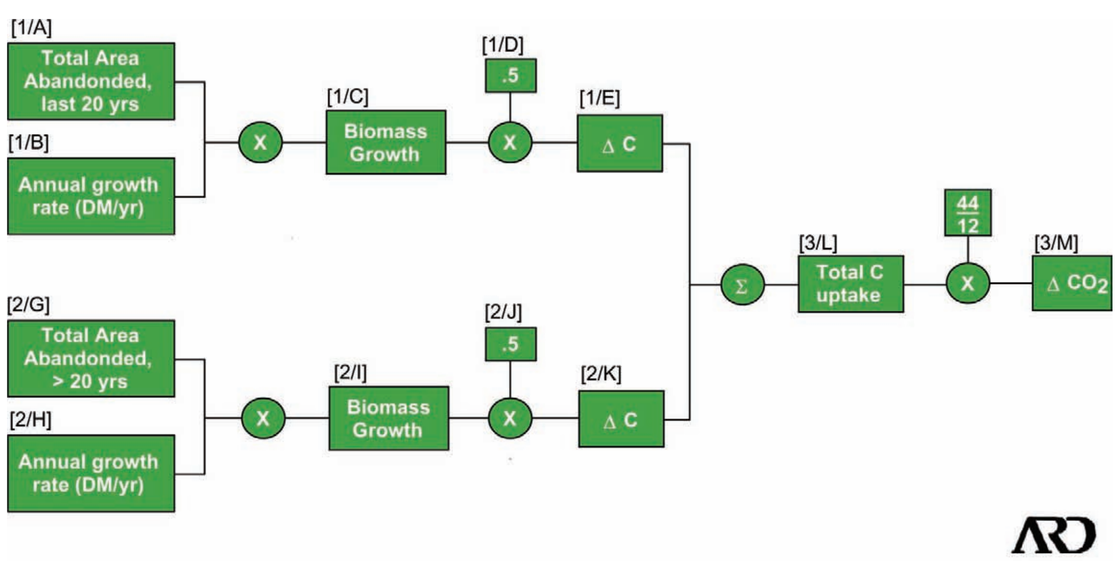

Figure 4. Abandonment of Managed Lands.

Table 1. Data from the 19 INF data points summarized by INEGI forest type.

			Volume (m^3/ha)	
INEGI Vegetation Type	**IPCC Category**	**Count**	**Mean**	**Std.dev.**
Pine-oak forest	Coniferous forest	6	120.4	83.7
Pine-oak forest/VSa	Coniferous forest	8	135.1	128.8
Oak forest/Vsa	Broadleaf forest	3	83.9	74.0
Oak-pine forest/VSa	Broadleaf forest	2	46.3	71.1
All vegetation types		19	127.6	100.0

It is useful to estimate the optimal sample size required to ensure a sample large enough to obtain the desired precision, while not sampling more points than needed. Using a "t" value of 1.96 and the average standard deviation from the data collected (100.0 m3/ha), the sample sizes corresponding to errors of 10, 20, and 30 m3/ha are 305, 76, and 34, respectively.

The preliminary results of our field test suggest that the methodology outlined in this paper would provide a mechanism for Mexico to make use of the INEGI LU/LC map series and INF for the purposes of national GHG inventory reporting to the UNFCCC in the LUCF sector.

Conclusions

The Government of Mexico should consider our methodology as a mechanism to improve its estimates of emissions and removals of GHGs, especially CO^2, from the LUCF sector in Mexico. Because the data upon which the methodology depends is the product of long-term, mandated government programs, it should yield consistent, reliable results now and in the future.

The specific Government programs that would allow the estimate of CO^2 are the 1:250,000 scale LU/LC map series of the Instituto Nacional de Estadística Geografía e Informática (INEGI) and the Inventario Nacional Forestal (INF, National Forest Inventory). The INEGI maps provide vegetation base maps (Victoria 2004), while the INF data provide information needed to characterize the mapped vegetation in terms of carbon content. However, unlike the well-established INEGI LU/LC map series, the INF program is advancing piece-meal, though there is a general strategy and plan of action to survey the entire country (Sandoval 2004).

Until the INF is complete, the sampling frame procedures used are fully defined and can be used immediately to gather data specifically for the purpose fulfilling Mexico's international reporting commitments to the UNFCCC.

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Society and Nature Interactions

Human and Nature Interactions: A Dynamic Land Base of Many Goods and Services

Ralph J. Alig, Team Leader and Research Forester, USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR

Abstract—*Availability of land is fundamental for sustainable forestry, providing the basis for the production of a wide array of goods and services (for example, biodiversity, forest carbon sequestration). This paper summarizes types of land-related data contained in major U.S. data bases, and gives examples of how such data were used in projecting changes in forest area for use in regional and national studies of forest sustainability. Forest land values are discussed, considering a variety of geographic, biological, regulatory, economic, and social situations. Forest land values provide informational signals on what amounts and types of forest land are likely and prospects for the provision of mixes of land-based goods and services. Urbanization is related to population growth and affects timberland values, forest fragmentation, forest parcelization, and ownership changes. Advances in data management and processing (for example, GIS) have allowed for advances in forest land analyses. Emerging issues include impacts of any developing markets for forest-based goods and services, such as forest carbon.*

Introduction

History contains many stories of the high regard with which man has viewed land in past times. For millennia, most wars were fought for the possession of land, and most people lived in close association with the soil, fields, and forests that sustained them. The United States has a wealth of land, with 747 million acres of forestland or more than 2.5 acres per citizen (fig. 1). With changes in society, such as growth in population and increases in consumption, human pressures on that land base are likely to increase. Monitoring such changes will be important, as will defining key policy-relevant questions that can lead to effective land use and land cover monitoring.

An example of monitoring and analysis that will be used in this paper centers on periodic U.S. natural resource assessments mandated by the national Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, to support USDA Forest Service (2001) strategic planning and policy analyses. The RPA act requires that decadal national assessments, with mid-decade updates, include an analysis of present and anticipated uses; demand for and supply of the renewable resources of forest, range, and other associated lands; and an emphasis on pertinent supply, demand, and price relationship trends. The 2000 RPA assessment provides a broad array of information about the Nation's forests and rangelands, including the current situation and prospective area changes over the next 50 years (Alig and others 2003, 2004). Related data illustrate the dynamics of our Nation's land base, and how adjustments are likely to continue in the future. Projections of land use and forest cover changes provide inputs into a larger system of models that project timber resource conditions and harvests, wildlife habitat, and other natural resource conditions (USDA Forest Service 2001).

The 2000 RPA assessment is the most recent one and the context has broadened over time (USDA Forest Service 2001). Interest in sustainable management of the world's forest resources was heightened by the United Nations Conference on Environment and Development in 1992. Since that time, various countries have joined together to discuss and attempt to reach consensus on ways to evaluate progress toward the management of their forest resources. The United States participates in the Montreal Process, designed to use a set of criteria and indicators for the conservation and sustainable management of temperate and boreal forests. The criteria provide a common framework for describing, assessing, and evaluating a country's progress toward forest sustainability at the national level. Information from the periodic RPA Assessments can shed light on whether we can sustain both increasing consumption of forest products and forest resource conditions (Alig and Haynes 2002). Current debates about sustainability involve both physical notions of sustainability and competing socioeconomic goals for public and private land management. Land-base changes also indicate the importance of viewing "sustainability" across the entire

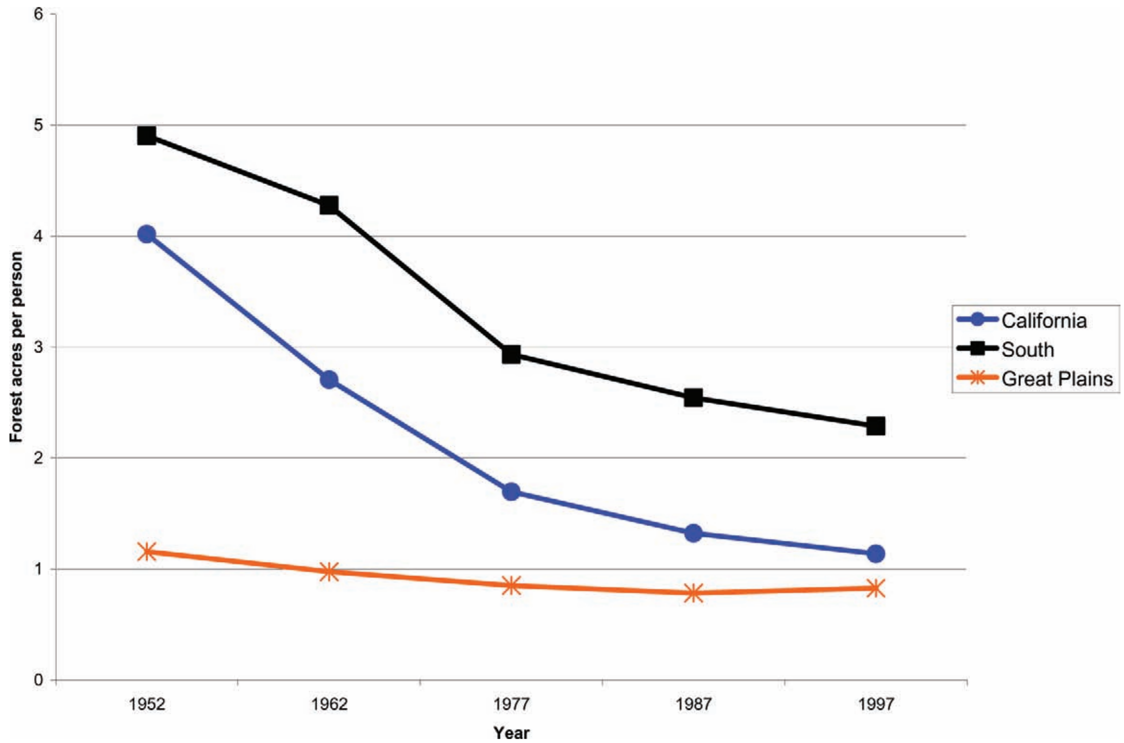

Figure 1. Change in per capita amount of forest area per resident, by selected region, 1952-1997 (acres) (Smith and others 2001).

land base and across sectors, in contrast to the current typical sector approach, as in examining "sustainable forest management" (Alig and Haynes 2002).

This synthesis paper has four parts. The first part discusses data bases used in analyzing changes in macro land use and land cover, and the methods used to project changes. The second component of the paper illustrates the utility of land value information when considering sustainability across sectors. The third part focuses on the issue of deforestation brought about by conversion to developed uses and what recent projections indicate. The fourth section of this synthesis paper discusses emerging issues regarding environmental services, such as forest carbon sequestration.

Land Use and Land Cover Changes

Over the past 25 years, renewable resource assessments have addressed demand, supply, and inventory of various renewable resources in increasingly sophisticated fashion, including simulation and optimization analyses of area changes in land uses (for example, urbanization) and land covers (for example, plantations vs. naturally regenerated forests). More than two decades ago, area projection modeling systems replaced expert opinion approaches in the national RPA assessments, as part of state of the art approaches for regional and national resources assessments. Such models reflect that key land base changes such as afforestation and deforestation are driven by quite different socio-economic factors. Projections of area changes are important for a wide range of natural resource analyses, including those for wildlife habitat, timber supply, global climate change, water, recreation, open space, and for other ecosystem services.

Land use data are collected by various agencies for a variety of purposes. Land use surveys generally differ in terms of statistical data-collection methods, scope, and a variety of other characteristics. No one land use database provides universal coverage over space and time for use in addressing all relevant land use and land cover policy questions. I next describe three primary data sources: the Forest Inventory and Analysis (FIA) data assembled to support the 2000 RPA assessment by the USDA Forest Service (Smith and others 2001); the National Resource Inventory (NRI) by the USDA National Resource Conservation Service (USDA NRCS 2001), and the Major Land Use Time Series (MLUS) by the USDA Economic Research Service (ERS) (Vesterby and Krupa 2001).

Forest Inventory and Analysis

The FIA surveys conducted by the USDA Forest Service are designed to provide objective and scientifically credible information on key forest attributes, such as forest stocks, growth, harvest, and mortality. Related data are collected by region, forest ownership category (for example, forest industry vs. nonindustrial private forests), and cover type (for example, oak-hickory), by using a sample of more than 70,000 permanent plots. The FIA inventories provide consistent forest inventory data for the Nation, back to 1952 (Smith and others 2001). Different sampling grids for the NRI and FIA surveys make the estimates from the two inventory systems statistically independent.

The FIA inventory data are gathered by using photointerpretation and ground truthing on a systematic sample of plots defined as pinpoints on the ground. These data include land use and ownership characteristics of sample plots, among other data. The land use data were used in the Kline and Alig (2001) study of land use in the west side of the Pacific Northwest.

National Resources Inventory

The NRI conducted by the USDA NRCS is designed to assess land use conditions on nonfederal lands and collects data on soil characteristics, land use, land cover, wind erosion, water erosion, and conservation practices (USDA NRCS 2001). In addition to collecting data on about 300,000 area segments and about 800,000 points within those segments, a geographic information system is used to control for total surface area, water area, and federal land. The NRI is conducted by the USDA's NRCS (2001) in cooperation with Iowa State University's Statistical Laboratory.

As a result of its statistical design, the NRI allows land use transition matrices to be developed since 1982. Land use shifts occur in both directions, a dynamic that is captured in the so-called land use transition matrices. For example, between 1982 and 1997, more than 17 million acres of nonfederal land moved out of the pasture and range category and into the forest category, while during the same period more than six million acres moved from forest to pasture and range use (USDA NRCS 2001).

Major Land Use Series

The MLUS is an inventory of land developed from a variety of land use surveys and public administrative records of land use. This long term series was developed by the USDA ERS (Vesterby and Krupa 2001). One of the most widely watched statistics by land use experts is the number of acres converted from undeveloped uses to developed, or urban, uses on an annual basis. The MLUS uses the official U.S. Census definition of urban (USDC Census Bureau 2001) and the NRI data use a definition unique to that data system, namely developed land. No technical definition of urban sprawl exists, but most definitions have elements of low-density development, geographic separation of essential places, and dependence on automobiles for travel. In response to the concerns about the growth in the use of rural land for rural residences, the USDA has added a new category to the MLUS for recent years. The FIA surveys do not provide a national estimate of urban or developed land areas.

The MLUS classifies some forested land as "special-uses" land, separate from a "forest-use" category. In particular, "special-uses" can contain forested land in federal and state parks, wilderness areas, wildlife refuges, and similar special-purpose uses. Hence, the area of MLUS "forest-use" land is lower than the FIA\RPA area of forest land (Alig and others 2003). The gap between forest land and "forest-use" land has grown over the past 60 years, with the growth of wilderness areas and other forested special-use land.

In addition, many additional sources of data exist on land use and land cover that are not used in the MLUS because they are not the most suitable for the purpose of comprehensively inventorying U.S. land. For example, the U.S. Geological Survey of the U.S. Department of the Interior maintains satellite imagery of land cover at various points in time. Many of these data sources are better suited for other specialized purposes.

Methods to Project Area Changes

Methods to project area changes for forest land and timberland differ by region of the United States. Methods vary depending on the likelihood of area changes affecting forests, the likely policy relevance of forest area changes, and the availability of time series of land use data with which to develop models of land use change. A method used increasingly in RPA Assessments and which involves use of FIA data is econometric modeling, based on statistical methods that are used to quantify relationships between land uses and hypothesized determinants. Landowners' profit maximization typically is the theoretical basis for these models, where landowners are assumed to allocate land parcels to that use generating the highest land rent or present value of future profits. Models are estimated with data describing land use decisions and profits derived from alternative land uses. Additional variables may be included to control for land-use regulations and other factors that influence land use decisions. For example, land-use policies often are used to mitigate potential negative impacts of urbanization. Econometric land use models typically are estimated with sample plot data comprised of a random sample of parcels or aggregate data such as county-level observations of land use (Ahn and others 2002, Alig 1986, Kline and Alig 1999, Kline and Alig 2001).

With the advent of satellite imagery and geographical information systems (GIS), econometric land-use models have been estimated using spatially-referenced plot or parcel-level data (Wear and Bolstad 1998, Kline and others 2001). Examples of explanatory variables in such models are rents (or proxies) for forestry, agriculture, and urban/developed uses.

An example of land use models developed using FIA data is described by Ahn and others (2002) for the South Central region. The model describes the relationship between the areas of land in different uses—private timberland, agricultural land, and urban and other land—and determinants of land use. The models were estimated by using OLS regression with pooled time series and cross-sectional data. The panel data set included 558 cross-sectional units (counties) and seven time points. Observations for the 558 counties in the South Central region were from FIA inventories conducted since the 1960s. The agricultural share of land was defined as that in cropland and pasture, and county-level observations were gathered from the Census of Agriculture for between 1964 and 1992. The share of land in urban and other uses was defined as a residual category containing uses other than forestry and agriculture (for example, suburban). The fitted models were used to project future land use in the South Central region, given assumptions about future population and net returns to land enterprises such as forestry.

Forest Land Values

Forest land values can vary by a variety of geographic, biological, regulatory, economic, and social situations. Human ties to land and the natural environment are one reason that we care about the forest land value. Forest land values help us understand the importance of forests, and to marshal land resources so that they might be used effectively and efficiently to help provide people with higher levels of living. Forest land values help us plan for better land use, to take steps for the more orderly and effective use of our land resources, and to intervene where necessary with land use zoning ordinances and other public measures to control and direct land use practices in the public interest. Forest use valuation is increasingly becoming more complicated, as is our economy, by overlays of land use zoning, environmental laws, forest practices regulation, site-specific environmental considerations, and recognition of forest resource values other than timber.

Much discussion in forest policy circles today is about forest sustainability, which seems to be part of a larger societal concern about the long-term capability of land to provide goods and services that we as a society demand. In addition to the question about the land's capability is that of land owners' responses to incentives to provide different mixes of goods and services. People vary in the values that they place on different environmental, economic, and social aspects of forests, and this affects the social valuation; this is in contrast to the private cost of providing goods and services that others may value from private forestland. An example to illustrate this is that many forestlands and open spaces (Kline and others 2004) comprise social values—ecological, scenic, recreation, and resource protection values, which are typically not reflected in market prices for land. When these social values are present, more forestland will be developed than is good for society. For open space policy, one needs to understand social values in the context of forestland market values and the economic rationale and impetus for public and private efforts to protect forestland as open space. Forest land values can reveal what it may cost to pursue different sustainability options, if land easements, purchases, or rentals are desirable. The land values reveal what people are actually willing to pay for a bundle of rights necessary to gain access to land that can provide goods and services for a certain time period.

Land prices embody information on relative valuations by different sectors of the economy. For example, valuation of land currently in forest uses in some areas is strongly influenced by trends in developed areas (Wear and Newman 2004). Land values for developed uses typically exceed those for rural uses by a substantial amount (Alig and Plantinga 2004). Agricultural values are usually second to developed uses in potential value, and they are often influenced by development potential. With rural land uses subject to increasing conversion pressure, open space concerns have heightened. The earliest significant open space preservation efforts in the U.S. involved preserving and restoring publicly owned forests and parks at national and state levels. These efforts were inspired by public concern for rapid loss of forests to agriculture and logging in the later 19th century, and the desire to protect timber and water resources, and lands of extraordinary beauty and uniqueness. Since then, public concern for land use change has evolved to recognize the contribution of open space to our day-to-day quality of life—its recreation, aesthetic, ecological, and resource protection benefits.

Changing perceptions about forestland mirror those in farmland preservation. National interest in preserving farmland arose in the 1970s from concerns about rapid loss of farmland to development, and the supposed threat to food security and agricultural viability. These concerns led to the gradual nearly nationwide implementation of local, state, and federal farmland preservation programs. More recently, recognition has grown for the environmental amenities and the social values of farmland and the role they play in motivating public support for preserving farmland. Research over the past two decades has sought to identify these land-based values and incorporate them into farmland protection policies and programs, to ensure that the public is getting what it desires from preserved farmland. Similar efforts may now be needed in forestry, to ensure that public and private open space protection efforts are tailored to provide the social values desired from forestlands.

Development of Forestland

Conversion of rural lands to urban and other built-up uses affects the mix of commodities and services produced from the global land base. In the United States, there was a 34percent increase in the amount of land devoted to urban and built-up uses between 1982 and 1997. During 1982-1997, U.S. developed area increased about 2 percent per year on average, according to the NRI (Alig and others 2004). The annual rate of conversion during the last five years of this period was more than 50percent higher than that of the previous five years. Forests, in particular, have been the largest source of land converted to developed uses in recent decades, with resulting impacts on forest cover and other ecological attributes.

The largest increases in U.S. developed area between 1982 and 1997 were in the South, a key timber supply region (USDA NRCS 2001). The South had one-third of its developed area added during those 15 years. Between 1982 and 1997, the South had seven of the ten states with the largest average annual additions of developed area according to the NRI. The top three--Texas, Florida, and North Carolina--each added more developed area than the country's most populous state, California. The increase in developed area for the South was close to 20 percent, almost four times as large as for the Great Plains, the region with both the smallest changes in developed area and population.

Several factors contribute to expansion of developed area in the South: 1) above average population growth due in part to climatic factors and attractiveness to immigrants (Glaeser and Shapiro 2001); 2) above average marginal consumption rates of land per additional resident; and 3) income growth. Expansion of developed area and urban sprawl in the South has been described as a major issue for future natural resource management, especially for the region's forests (Seelye 2001, Wear and Greis 2002).

The Great Plains region has the most developed area per resident (fig. 2) across all four NRI surveys, more than one acre in 1997. However, the region varies from the rest of the country in having lost population between

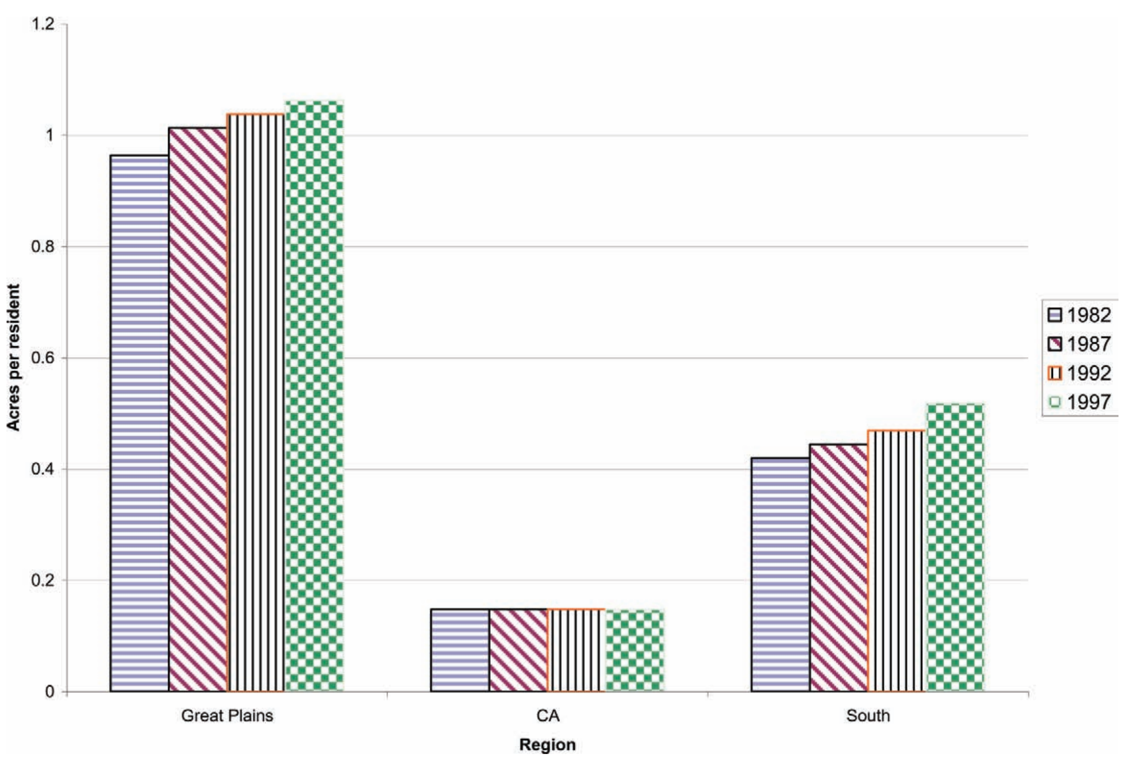

Figure 2. Total developed area per person, by U.S. selected region, 1982, 1987, 1992, and 1997 (USDA Natural Resources Conservation Service 2001).

the 1982 and 1987 NRIs, resulting in a loss in developed area. The South also has a relatively high marginal rate of land consumption, and also has had relatively large increases in population compared to the Great Plains. California, with the nation's largest population, has the lowest level of developed area per person, less than 0.2 acres per person.

Urbanization does not just result in direct conversion of forestland but can also involve forest fragmentation, forest parcelization, and ownership changes. Development pressures can also add to uncertainty about how forestland will be managed, if owners anticipate higher financial returns in an alternative use. Because forest land prices capture information regarding current as well as anticipated uses of land, land prices anticipate future development of forestland near urbanizing areas, casting a speculative shadow over timberland values (Wear and Newman 2004). With anticipated population and income growth, such dynamics could hold important implications for conditions of forestland and what environmental benefits may be sustainable.

Projections

Projections suggest continued urban expansion over the next 25 years, with the magnitude of increase varying by region (Alig and others 2004). U.S. developed area is projected to increase by 79 percent, raising the proportion of the total land base that is developed from 5.2 percent to 9.2 percent. Because much of the growth is expected in areas relatively stressed with respect to human-environment interactions, such as some coastal counties, implications for landscape and urban planning include potential impacts on sensitive watersheds, riparian areas, wildlife habitat, and water supplies. While providing additional living space and infrastructure, added development may also diminish agricultural output due to farmland loss and change ecological conditions due to conversion and fragmentation of forests and other natural landscapes. The projected developed and built-up area of about 175 million acres in 2025 represents an area equal to 38 percent of the current U.S. cropland base, or 23 percent of the current U.S. forestland base.

In line with recent historical trends, the South is projected to continue to have the most developed area through 2025 (Alig and others 2004). In the South land is often suitable for multiple land uses, given relatively gentle topography and ease of access. When examining land use dynamics, the many different pathways by which land use can change warrant examining both net and gross area changes for major land uses. For example, the flow between forestland and urban and developed uses is primarily a one-way flow toward urban and developed uses, although some land classified as urban and developed (for example, corridors for electrical lines) may infrequently shift into forest or agriculture. Movement of land between forestry and agriculture in the last two decades resulted in net gains to forestry that have offset forest conversion to urban and developed uses in area terms. However, the conditions of forested acres entering and exiting the forestland base can be quite different; entering acres may be bare ground or have young trees, while exiting acres often contain large trees before conversion to developed uses.

Concern about the attributes of exiting or entering forested acres was heightened in the 1990s when the rate of development increased, with about one million acres of forests converted to developed uses per year (USDA NRCS 2001). The total or gross area shifts involving U.S. forests are relatively large compared to net estimates. Gross area changes involving U.S. forests totaled about 50 million acres between 1982 and 1997, an order of magnitude greater than the net change of 4 million acres.

Environmental Services

The linkage between land use and the environment affects many goods and services. The example of environmental services provided by the land base that I will discuss is forest carbon sequestration. Emerging issues include possible impacts of any new non-traditional markets for forest-based goods and environmental services, such as forest carbon. In discussing environmental services, I will focus on forest carbon here, while recognizing that many goods and services are potentially impacted by land base changes. Forest carbon storage has become important in international negotiations on the management of greenhouse gas emissions, because increased carbon storage can be useful in offsetting emissions of carbon from fossil fuel burning and other sources. The amount of carbon stored in forests can change through land base changes, adoption of forest management practices that allow the incorporation of more plant materials into forest soils, and changes in age structure. Carbon can also be stored in wood products.

The amount of carbon stored in trees in the East increased by 80 percent from 1950 to 1992 (Birdsey and Heath 1995). Contributing factors were tree growth on farmlands allowed to revert to forests. maturing of forests, and more fast growing plantations in the South. In the West, the addition of new forest carbon through forest growth was offset by timber harvest, resulting in little change in the overall amount stored. However, carbon storage on federal timberlands in the West may increase notably, if fires and other natural disturbances (for example, insects and disease) don't significantly reduce timber inventories.

Data sources for the forest carbon estimates are FIA field estimates of the size of trees of various species, along with statistical models of the relationships between tree stem volume and the other components of carbon storage. Carbon contained in branches, leaves, the forest floor, and soil are estimated from such surveys. Estimates by Birdsey and Heath (1995) did not include national parks and wilderness areas or slower-growing forests in non-timberland forestland, although expansion into those areas is planned.

Land use changes can be an important part of changes in forest carbon storage, but data on soil carbon are relatively scarce. Further, the influences of land management activities on soil carbon are still poorly known. Measurement protocols for forest floor litter and soil carbon were planned at the time of the Birdsey and Heath (1995) study and were to be implemented as funds became available. Given that gross land use changes are typically an order of magnitude higher than for net changes (Alig and others 2003), influences of land use shifts on soil carbon are potentially quite important. Changes in the area of any of the major land use classes relate to demographic, economic, biophysical, and policy factors (Alig 1986), so that the suite of such factors need to be considered in global climate change assessments. Projections of forest-land and timberland areas are based on projections of relevant demographic and economic factors, which are more likely to change in the future than biophysical factors. Current policies can be frozen in place in an initial conditions run or baseline, so that we can examine where the current policy trajectory (for example, no U.S. action or implementation of policy for mitigating climate change) would lead, and then examine sensitivity of projections to certain policy-related assumptions.

Risk and uncertainty considerations include changes in technology. Impacts from global warming in some cases may be partially offset by technological changes, such as genetic stock improvements to boost forest carbon sequestration efforts. Other technological changes may also allow more output from input of land, especially in regional climates favorably affected regarding crop or forest production. The net outcome can't be easily forecast. Some scenarios may arise where forest use might be better able to compete with other major rural land uses, such as agriculture (Alig and others 2002).

Future Directions

Issues for land use and land cover monitoring include consistent coverage across the entire land base. Analogous to the snapshot of land-use information by USDA's NRI, land cover modeling would benefit from periodic nationwide estimates of changes in forest cover. One source will be mapping by the National Land Cover Data mapping project (an output of the Multi-Resolution Land Characteristics Consortium), with plans for an updated version of the National Land Cover map for the year 2002. Field-based observations are also needed, to provide complementary data such as land ownership and site quality. For FIA, one challenge is to link forest resource data to socio-economic data, such as characteristics of who owns the forest land. The challenge is growing because of diverse data needed to address policy questions that arise with increased attention to ecosystem services and sustainability and activities associated with the environment, economy, and societal institutions.

Changes in ownership of forests should also be monitored, in that sales and acquisitions of forest lands continue to be active as market forces, globalization, and consolidation impact the forest sector. Forest industry is increasingly viewing its forests as strategic financial assets. Fragmentation of ownerships into several smaller ownerships is referred to as parcelization. This phenomenon can also have profound impacts on the economics of farming or forestry, even when land is not physically altered in any major way. Trends in fragmentation and parcelization warrant further study, along with monitoring of changes in population density for different classes of rural and urban land (Alig 2000). More people on the landscape include those in rural areas with attractive recreational land and aesthetic amenities, often involving forests, and related to concerns about changes in quality of life. Such demographic changes increase the size of the wildland-urban interface, whose expansion has exacerbated wildfire threats to structures and people. Overall, the U.S. had about 80 people per square mile of land in 1999 (USDC Census Bureau 2001). This compares to about 5 people per square mile in 1790, and to a world average of more than 100 persons per square mile in 1999 (United Nations 2002).

One complication in past FIA survey planning, RPA assessments, and global climate change assessments has been the lack of a unified view of future land conditions constructed at a scale that serves all of these assessment areas adequately. Attaining the ideal unification is a substantial undertaking, and this could be aided upfront by an assessment of common information needs. A modeling system that can generate land base condition projections could provide for forest ecosystems a thorough and unified description of anticipated change in the extent, structure, and condition of the nation's forests at useful regional and subregional scales. At the same time, such a system could augment economic measures, useful when investigating changes in land markets and analyzing trends in land values. Human-environment impacts can also vary across space and time, including physical fragmentation of forest cover from land-use changes that can affect natural resources in a variety of ways. For example, urbanization may cause fragmentation of wildlife habitat. A privately-owned optimal landscape can depart from a socially optimal landscape, the latter which reflects society's preferences for public goods associated with interior forest parcels. Future policy-related research can examine land use shifts for parcels in a way that is optimal from reducing forest fragmentation. However, spatial configuration considerations make this complex, in that benefits of converting (or retaining) a parcel will depend on the land uses on the neighboring parcels as well as on other parcels affected by the policy.

Future advances in land use analyses will likely also rest in part on continued improvement of spatial databases, including spatial socio-economic data, as well as improvements in spatial econometric methods to support empirical data analyses. Trade-offs must be considered when assessing the costs and benefits associated with spatial detail. Along with improved data bases, monitoring of developed area trends, associated investment in infrastructure (for example, transportation networks and nodes), and related socio-economic factors will be important in facilitating updated projections of U.S. developed area.

Given the expected U.S. population increase and changes in economic activity, a key question is how society can make positive progress toward sustainability in the face of needing more developed land to serve more people in the future. Progress toward such goals may rest on progress in a search for a more integrated approach for describing the complex interplay between human activity and the environment. To help evaluate progress, we need a useful definition of sustainability along with measurable indicators that fundamentally reflect the long-term ecological, economic, and social well being as it relates to alternative uses of land. Human demands for forests will increase with growing populations and increasing personal incomes, challenging land managers to provide for a diverse array of societal needs, including ecological, economic, and social ones. Wood use has increased by 40 percent since 1960 and is expected to rise by about 30 percent in the next four decades (USDA Forest Service 2001). In addition to substantial demand for environmental services, this may also occur alongside growing interest in spiritual values associated with forests, their sustainable use, and restoration after certain disturbances.

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The Resource Buffer Theory: Connecting the Dots from Conservation to Sustainability

Peter E. Black, Professor, Water and Related Land Resources, Emeritus, SUNY College of Environmental Science and Forestry, Syracuse, NY

Abstract—*Review of conservation history and scientific developments helps us understand relationships between humans, environment, and sustainability. Applying "conservation" to natural resources and practical resource management occurred early in the Twentieth Century; practical economic definitions of conservation and natural resource followed. Resource surpluses underpin the luxury of conservation in which we currently bask. We are not paying attention to the fact that accumulated natural science discoveries about wide-ranging resource distribution – so specialized that many scientists are unaware of each others' works – are remarkably alike. The pattern – the Resource Buffer Theory – demands recognition, understanding, and emulation to ensure humankind's survival. Buffers are vast amounts of resources that are as essential to species survival as are the few units of the resource utilized by individuals; despite their vastness, they often display delicate limits. The terrestrial resource buffers to which we have access and on which we depend are Hardin's global commons. Maintaining a large biodiversity buffer is paramount. The distribution of carbon – the stuff of life and a critical linkage between the hydro- and biospheres – contradicts the pattern, indicative of Planet Earth's overpopulation. Consequent global change events are signaling us that humankind's oblivious violation of the ubiquitous environmental pattern provides an unparalleled challenge to our survival. Faced with the imperative of sustainability, we need to connect the dots, to control the Earth's human population and activities including resource use and waste, and to under-stand and thereby proactively emulate the Resource Buffer Theory in our natural re-sources management policies and practices.*

A Century of Conservation

It has taken a century following the Industrial Revolution to define and refine what we call conservation. Three individuals among many scientists, activists, and writers played particularly significant roles and serve as examples. Gifford Pinchot first applied the term "conservation" to natural resources in the early 1900s. Hugh Hammond Bennett applied conservation concepts to soil productivity management and urged the creation of the Soil Conservation Service (now Natural Resources Conservation Service) in the mid 1930s. At mid-century, S. V. Ciriacy-Wantrup defined conservation as "shifting rates of resource use toward the future" (Wantrup 1951). Resources, he said, are things that have utility and scar-city and are simply classified: renewable or flow resources are characterized by having different amounts become available in different time periods; nonrenewable or stock resources are limited in total quantity. Wantrup's linkage of resource utility (value) and scarcity (in time or space) provide background for understanding the range of resource management: exploitation is all use and no time, whereas preservation is all time and no use. There have been many battles over resources conservation, with champions of exploitation and preservation squaring off over legislation-defining public policy, and creating innumerable non-government organizations, government agencies, and regulations. Recognition that conservation is a social-political-economic meeting (or battle) ground suggests that a good definition of the word "conservation" is a mix of exploitive and preservationist policies and practices that varies over time as dictated by the resource-using public. Simultaneously, shortages in developing countries that do not even have "conservation" in their lexicon preclude that luxury when scarce resources are needed for day-to-day food, clothing, and shelter, often for a rapidly-expanding population.

These Twentieth Century thoughts and milestones—and later air, water, and environmental quality, and endangered species protection laws—characterized changing attitudes toward environmental management by an always changing mix of exploitation and preservation.

Fundamental philosophical and site-specific issues persist, hopefully in light of better scientific understanding of our natural resources.

The Atomic-to-Cosmic Blueprint

Reviewing the wide range and long history of basic and applied research illuminates a ubiquitous pattern to the distribution of our terrestrial and extraterrestrial resources. Thus, energy, space, and matter (and time?) are distributed so that (1) only a very small proportion of the total quantity of the resource is directly "used" by humans and, (2) the vast remaining—seemingly "unused" proportion—is an essential buffer. Buffers absorb environmental excesses that establish and maintain those conditions under which a species survives. For example, the oceans absorb biological wastes, gasses, eroded elements and compounds from the land masses, and energy from the sun and atmosphere. Covering two thirds of the planet, they also shield us from catastrophic impacts of comets and meteorites that do get past our Solar System's outer planets' gravitational pull. The theory complements Lovelock's (1988) assertion that Earth's combined physical, chemical, and biological systems—Gaia—exhibit homeostasis, that life favorably modifies a species' environment, thus promoting sustainability; if it doesn't, the species dies.

The pattern suggests a generalization, the Resource Buffer Theory: "For every resource where a small proportion is essential to life processes of individuals, the greater proportion maintains environmental conditions necessary to the survival of the species" (Black 1995). The significance of the pattern is in the lopsided distribution of vital resources, the wonders and aesthetic patterns of which describe order in the universe as aesthetically articulated in Music of the Spheres (Murchie 1967). The concept is, indeed, just a theory; it may not demand or even be capable of identification as a law or principle. Nevertheless, it is.

Research provides some of the more dramatic examples of the resources so distributed, including:

- Only 1 to 4 percent of the "dark matter" of the universe is "known" to us (Trefil 1993, Rowan and Coontz 2003), and recently-articulated "dark energy" is similarly distributed.
- Closer to home, the Sun contains 99.9 percent of our Solar System's mass, while 71 percent of the Solar System's planetary mass is in one planet, Jupiter (a very disproportionate 99.6 percent is in the outer three planets).
- The Earth intercepts approximately one billionth (9.1x10-8 percent) of the sun's energy available at the surface of a sphere at a distance of 93 million miles.
- Summarizing the distribution of Earth's life-giving water: 97 percent is salty; 2 percent is ice (or was prior to what currently appears to be accelerated global warming); three fourths of the remaining one percent is in deep and shallow ground water, and one-fifth of the rest is in lakes. The remaining approximately 0.006 percent of Earth's circulating fresh water is the renewable resource on which we directly depend.
- The lopsided pattern was probably first observed in biology where reproduction exhibits its excesses and seeming waste of vast numbers of unused resources of sperm, eggs, seeds, and seedlings, and where for agriculture and forestry it is managed as in thinning dense plantations.
- The most complex of the essential resources that exhibit this pattern is carbon, the very stuff of life. A mere 0.004 percent of the total carbon on the planet is organic; only 0.12 percent of that is in animals, the rest in plants. And, of this tiny percentage of all animal carbon, 4.0 percent is currently in one species, human beings. Actually, it is more than that. Since to my knowledge, no humans live in the oceans and the animal carbon is nearly equally distributed between oceanic and terrestrial environments, 8.0 percent of all the terrestrial animal carbon is in the 6.3 billion human beings that inhabit the Earth.

The Population Dimension and Global Change

The carbon data do not mimic the universal pattern; not for a species that is at the top of the food web. The numbers constitute evidence that humans overpopulate the Earth: according to the Resource Buffer Theory, one would expect "higher" life forms to have sequentially lower percentages of carbon. And, were the population to double by 2050 (the high growth rate estimate), 16 percent of the terrestrial animal carbon would be in one species: us. That number is probably not sustainable. Even the present 8.0 percent is probably not sustainable, primarily because it is at the expense of biodiversity and partially underlies accelerated global change. Perhaps of greater importance is the observation that in addition to the actual amount of carbon in human beings, there is the impact that human activities have on the carbon cycle and, therefore, the vital carbon buffer, a major portion of which makes up the biodiversity buffer.

The distribution of humans is equally serious. At present, one half of the world's population lives in cities of more than one million; 400 urban areas have populations of one million or more. Sustainable? Questionable. The financial resources to provide closely packed urban and sparse suburban and rural communities with water, food, sanitary facilities, and energy at western rates of excess resource consumption are not sustainable without energy subsidization (Odum 1989): and maintaining an affable climate in an atmosphere overloaded with anthropogenic-increased carbon dioxide and methane is unlikely. Even—maybe especially—in the resource-wealthy United States the fast-growing, uniform landscapes of the Sunbelt areas are particularly vulnerable to fire, drought, flood, climatic change, and, perhaps, disease. These harbingers of pre-glacial-period warming are already exerting relentless impacts to budgets currently challenging governments at all levels. They will get worse. The familiar situation in developing countries is critical, as evidenced by the well-publicized death rates due to inadequate and/or contaminated water, drought, famine, and disease.

Further, when stressed, delicate ecosystems—the biodiversity buffer—display amplified fragility. There is little doubt that humankind's industrialization has stressed ecosystems in a variety of ways. Re-source exploitation, population growth, urban sprawl, and reliance on the personal automobile are principal contributors to this stress. Widespread deforestation and agricultural- and tree-farm-induced mono-culture that support this life style characteristic of western civilization have replaced the natural ecology of the Earth's surface on a significant scale (Marsh 1874). Currently, extensive pavement and regulated storm water runoff management schemes to decrease local flooding also decrease ground water recharge that consequently diminishes on-site water for cooler climate, water supplies, and environmental variability. Increased impervious area results in subsidence as well as more downstream flooding such as in central Europe in 2002.

On a broader scale, wetlands, rainforests, and coral reefs are disappearing dramatically. This is a global problem and must not be considered independent of the Resource Buffer Theory. The classic understatement by Karl and Trenberth (2003) is "We're entering into the unknown with climate, and its associated impacts could be quite disruptive." Watson (2004) presents a stronger case:

> Human-induced climate change is one of the most important environmental issues facing society worldwide. The overwhelming majority of scientific experts and governments acknowledge that there is strong scientific evidence demonstrating that human activities are changing the Earth's climate and that further human-induced climate change is inevitable.

Clearly, ramifications of excess unsustainable human activity are already here. Local and global climate change includes greater extremes of precipitation and temperature associated with and/or caused by El Niño and La Niña, glacial retreat, rising ocean levels, more and greater droughts, and floods, and increased wildfires in Australia, Indonesia, and the United States. Biodiversity has decreased coincident with new diseases and reoccurrences of old pathogens. Southward movement of the winter storm track has brought record low winter temperatures and snow to the northwest and southern states, tornados in October of 2003, snow to the Middle East and Las Vegas, and the first-ever hurricane in the South Atlantic Ocean as I write. We can expect—and in all likelihood cannot prevent—ocean current reversals that are associated with alternating glacial and interglacial periods (Taylor, and others 1999). The North Atlantic Ocean Current did in fact reverse in the summer of 2003, apparently due to the reduction in the thickness of the arctic ice and subsequent movement of cold water through the formerly blocked Northwest Passage, with a probable assist from the Coriolis force. There were fifteen million square miles of cool waters pooled in the North Atlantic Ocean. The Nova Scotia lobster industry crashed and in Paris hundreds of deaths caused by unprecedented heat were recorded.

Connecting the Dots

The repetitive pattern of our resource distribution inspires the opportunity for action, but not without potential confusion. Modern sciences are quite specialized and research results are not often read by individuals in other disciplines. And, without statistics and "sound science" behind them, few authors scream "the sky is falling." Disagreement among reputable scientists, experts, and politicians with vested interests leaves us confused and adrift in a sea of often conflicting opinions that befuddle the public. Linkage between global change patterns and many of the above-listed afflictions of and affronts to human civilization are probably not provable by any standards of sound science, nor is sound science sufficient for governance of the commons (Dietz and others, 2004). We are too close to some of the changes to see them; others are not fully understood, and there may be unexpected and unpredictable outcomes. On the other hand, logic is speaking to all of us. Scan the current journals: articles on these changes are rampant. It may already be too late to stop the drastic changes anyway; but we are going to have to live with—or die by—these changes. It is time to put things together, to consider the evidence and logic that is before us.

The need to connect the dots begins with recognition of the fundamental, universal ecological pattern rooted in the theory and function of the resource buffers: they are essential for the maintenance of conditions that will ensure—or at least make more likely—the continued survival of the species. For example, the cause of the excess build-up of carbon dioxide and near lethal low values of oxygen in the Arizona research facility Biosphere 2 (Severinghaus and others 1994) was probably the failure to provide an adequate inorganic buffer that properly mimicked Biosphere 1, Planet Earth. Earth's buffer of inorganic carbon contains 99.978 percent of the planet's carbon in the sediments. Our current direct alteration of the fragile level of atmospheric carbon dioxide (along with methane and ozone) similarly endangers the conditions that could ensure our survival. For three hundred years climate was relatively stable and affable demanding only small, acceptable, and challenging fluctuations in human activity, ready to explode as it recognized the value of its natural resources and exploited them to support the Industrial Revolution. The interactions between climatic change and stability, subtle shifts of storm tracks, and the development of an agricultural base associated with growing population and industrialization are often complex as well as unpredictable (Fagan 2000). There is little doubt that humans are dramatically changing the conditions under which we live.

In fact, the buffers that sustain us—and myriads of other species—include the global commons referred to by Hardin (1968). To ignore them is to invite disaster. It is therefore quite appropriate that it is the commons from which we infer a focal pattern and to which we may address an innovative environmental management scheme. Surely, the most threatening change over which we have some control is the reduction in biodiversity, a critical buffer. Caused by the shift of carbon to human beings and human activities, biodiversity is in need of definition in theory, and evaluation in terms of quality and quantity so as to be fully understood in its commons role and thus capable of being nurtured in this light. In addition to direct inroads on the diversity of life on the planet, human—and to some degree geologic time changes—are severely impacting this all-important buffer. We are not only observing the onset of major climate change, but there is a resurgence of diseases (Levins and others 1994) that may be associated with the widespread uniformity of agricultural and forestry practices including West Nile Virus, avian flu, mad cow disease, Ebola virus, cryptosporidium, and giardia, to mention a few. Perhaps even AIDS and SARS are reactions of natural systems to overpopulation and biodiversity reduction. There remains the question of the source of the increased carbon for greater human numbers: if from the vast inorganic buffer in the sediments, the resultant increase in release of carbon dioxide to the atmosphere from increased human activities will promote temporary global warming and long-term climate change, ultimately a new glacial period. If from the organic pool of wetlands, rain forests or coral reefs the biodiversity buffer is directly diminished at our peril.

The luxury of conservation extends from the end of the Industrial Revolution, when segments of humanity were large enough to significantly affect global conditions, to the recent past where frequent and major consequences of our actions are beginning to strike back. And, as more and more comforts of civilization are developed, technology is called upon to protect against or reimburse losses from environmental disasters that wreak unprecedented personal, societal, and financial damage (Tenner 1997). The imperative of sustainability demands attention. Humankind faces serious threats to its otherwise promising current civilization because of our own growth, actions, and excessive demands on natural resources: resources on which we depend and that exhibit the lopsided distribution patterns characteristic of natural buffers. The "good life" that is the fruit of the Industrial Revolution and western civilization's excessive and often mindless exploitation of natural resources is, in the long run, not "good."

The bottom line: we're in trouble. Vitousek and others (1997) state unequivocally "humanity's dominance of Earth means that we cannot escape responsibility for managing the planet. Our activities are causing rapid, novel, and substantial changes to Earth's ecosystems." Assuming that we wish to resolve the problem and be the masters of our future on Earth, there is much to do research, education, and effective implementation of policies and practices to achieve population control. The challenge will be a critical and timely test of the awesome potential of globalization.

A Time for Action

First, an international and truly interdisciplinary team must be convened to formulate and evaluate fundamental questions about environmental assimilative capacities. Then, joined by social scientists, effective policy and management solutions with high success potential must be created. This is not a situation in which to pursue and achieve pet goals: this is a matter of survival of the human race, not of any one individual, community, hemisphere, or nation. This cooperative world-wide agenda may not even be feasible: Fagan (2004) points out that "if we've become a supertanker among human societies, it's an oddly inattentive one. Only a tiny fraction of the people on board is engaged with tending the engines. …." Yes, ironically, the Resource Buffer Theory applies to us, too. Those that know, however, need to show the way. Western civilization's excess resource users must reduce excess use and waste of natural resources, especially excessive pollution of the vital resource buffers. It is time—and hopefully not too late—to make timely and informed choices. To whatever extent we put off action by unproductive pondering of the enormity of the task and procrastinate on any action, we invite increasing potential disaster.

Second, the information from this assemblage—assuming it succeeds in its mission—must be disseminated in an unprecedented global education program. A challenging part of this effort will be convincing all—especially those in developing countries—to listen and understand so as to play meaningful and effective roles in the decision-making process to secure the future of humans on the planet; and those that know and understand the severity and enormity of the problem are equally challenged to effectively convey the message. The challenge to the resource-guzzling western civilization will be most difficult: how to limit resource use while allowing others to increase theirs, with an overall net reduction in technological development and resource use. Nothing short of this will work, although it is possible that partial steps might buy time, which might simultaneously delude us into thinking that we are safe. An unlikely alternative may be to entrust solutions to that "tiny fraction of the people … engaged with tending the engines." And, interim conditions, whoever implements them and for whatever reason, may not be any more pleasant than non-human-controlled solutions. A first order of business will be to convince all that failure would have disastrous consequences—soon, and sooner than we care to think about.

Third, we must design, adopt, and implement workable and acceptable strategies that will provide a schedule to enhance our ability to deal with the fundamental problem: unsustainable human activity. At the current rate of agricultural land degradation, and with current technology, "in just 42 years there will be sufficient arable land for a population of only 2 billion" say Pimental and others (1999), who have revised an earlier estimate of the Earth's carrying capacity down from 2.5 billion to 2.0 billion, less than one third the present number. Such an unprecedented challenge must be accomplished humanely to protect our humanity; it cannot be achieved by an elite leadership. And it won't win popularity contests in any case. However, if we wish to have control over the future, we must be proactive. Whatever is done must be achieved by global communication, cooperation, and action. An international Earth Summit on Environmental Sustainability might succeed, but not if its focus is the oxymoronic "sustainable development" as in the past: development is the historic cause of the challenge that now confronts us. It is thus important that we are aware of lurking pitfalls: efforts to bring resource use and waste under control are threatened by long- and widely-held religious beliefs along with ignorance, stupidity, waste, and greed. If the latter is a natural characteristic of humans (of life?), success might be discouragingly be-yond our grasp. We may not obtain the necessary understanding anyway, much less support from those who spread terror, reflecting their legitimate but derogatory view of how western civilization wastes its resources and disproportionately pollutes its buffers.

In view of widespread terrorism driven in part by unequal utilization of resources (as well as persecution, poverty, lack of feelings of personal worth or sense of community, and lack of hope) there is an ironically disturbing thought: we are already applying the Resource Buffer Theory in western civilization. But we're doing it in ways that may ensure western civilization's collapse: through disproportionate abuse of resources and environmental buffers. Developing countries will not be convinced of any urgency of action without substantive sacrifice by those that have an abundance of resources. The best way to convince the world's underprivileged of the seriousness of our mission—the importance of workable sustainability measures—is to acknowledge and act to reduce waste of resources and associated pollution of environmental buffers. Were we to make serious changes in those habits, we might gain essential support in the all-important sustainability agenda. One approach with high-success potential is Brown's (2003) suggestions of tax- and subsidy-shifts that in-corporate the "honest" cost of environmental degradation into supply costs of human needs. It provides alternatives that may be adapted to meet local and national needs, resources, populations, and times; and numerous nations have already applied the shift-based approach as a strategy with high degrees of success. For example, Iceland has converted from a carbon based energy economy to a hydrogen base; Japan has invested heavily in solar energy, and Ontario is "phasing out coal." Tax shifts and setting reasonable prices on water and energy are the only sure way in which to reduce consumption. This approach may be the best way to reduce or eliminate the inexcusable and wasteful use of fossil fuels for high-consumption personal transport and for vehicles such as racing cars, SUVs, and ATVs. The immediacy of the challenge is well expressed by McMichael and others (2004):

> Addressing sustainability is more than an academic exercise. It is a vital response to a rapidly evolving crisis and should be at the top of our research agenda. The forces that opposed social change for sustainability, whether from indifference, incomprehension, or self-interest, are powerful, and neither individual scientists nor isolated scientific disciplines will suffice to change understanding policy. Science itself needs to be fully engaged in this challenge.

And by Brown (2003), who points out that "we must be quick. Our demands on the earth exceed its regenerative capacity by a wider margin each day."

Finally, assuming that all agree about the significance of the pervasive pattern in the universe, humans must find ways to incorporate the environmental patterns that sustain us. Proper homage to Sir Francis Bacon implies that it would be a good idea to base our resources management practices on a strategy he elucidated in 1620: "Nature to be commanded must be obeyed." Finding ways to obey the fundamental pattern that we observe throughout the Universe in our everyday and long range resource management plans is a challenge to which all can find creative responses. It represents a major paradigm shift of the greatest importance. By adopting shift-based strategies to the natural environment and other innovative measures, we might really attain human sustainability. It certainly is worth a try.

Conclusions

There are three conclusions. First, the Resource Buffer Theory emerges from reflective consideration and observation of the characteristics of the abundant resources that surround us. Second, among the many resource buffers (global commons) available to us, biodiversity—represented by the out-of-line large percentage of organic carbon in humans that simultaneously marks our runaway numbers—is perhaps the most critical. Finally, to assure continued existence of humanoids on Earth, we must adopt a paradigm shift from resource and buffer abuse to one that attends to the fundamental and universal environmental pattern.

In sum, we need to recognize, embrace, and celebrate the Resource Buffer Theory that protects and sustains us by making it the focal point of our resource management policies and practices. A red flag demanding attention ought to appear whenever humans impact a resource buffer. Noting the limits of existing resources and the need to maintain buffers that protect the conditions that enable our species to survive should be the new goal of conservation. Conservation must address the question: How might we emulate the universal environmental pattern in our management strategies and practices? Based on sound science, conservation is the cornerstone to sustainability, to survivability. In this fundamental context the future of resource-using humans on planet Earth must be considered. We must pay attention; and act.

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What's Law Got to Do with It? The Relationship of Law to Environmental Systems Management and Sustainability Research

N. Theresa Hoagland, Attorney and an Environmental Protection Specialist, U. S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH

Abstract—*Legal concepts cannot be described as the area under the curve or in terms of equilibrium equations; however, law is one of several dimensions of a complex system that must be included in an interdisciplinary study of sustainability. It is one of the initial conditions to be considered in projecting the systems trajectory and it is also a constraint on implementation of research findings and recommendations for sustainable actions to be taken. Two methods for incorporating law into sustainability research are described. One is theoretical and is illustrated by how property rights affect foodweb and societal decision-making models. The second is more practical and is illustrated by how law affects the implementation phase of a study on stormwater runoff volume reduction.*

Introduction

Sustainability can be thought of as effectively managing environmental systems, including ourselves. The concept is illustrated in figure 1, which depicts a complex system composed of four dimensions through time: economic, technological, ecological, and legal-social. (Cabezas and others 2003) The system that results from the interaction of these dimensions is shown here as a trajectory through state space. The goal of sustainability is to keep the system trajectory within a "tunnel" that represents desirable conditions through time. The goal of sustainability research is to understand what the tunnel boundaries are and how the dimensions interact to create the system trajectory. The initial questions to be answered include: what are the variables in each dimension; how can they be measured or otherwise accounted for; and how do the variables in one dimension relate to variables in the other dimensions?

Three of the four dimensions are human-based (only the ecological dimension could exist without humans), but variables in the economic, technological, ecological, and (to some degree) social dimensions are similar in that they can be quantified and analyzed using scientific methods and mathematical formulas. When dealing with the legal aspect of the social dimension, however, science and math seem to play no part. How, then can law be integrated into a scientific study or mathematical model for analysis?

Comparing the dimensions in the context of the disciplines they represent yields the following perspective. Economics is the study of how people make choices, while social science is the study of what those choices are and why people make them. Science and technology represent what choices are available--what is physically possible given the basic laws of nature. Law is about what choices people (as a society) allow themselves to make. Thus, law is more malleable and one could question why we include it at all, since we can change it at will to serve our purpose.

There are several reasons for including law in our sustainability research. Existing law is one of the initial

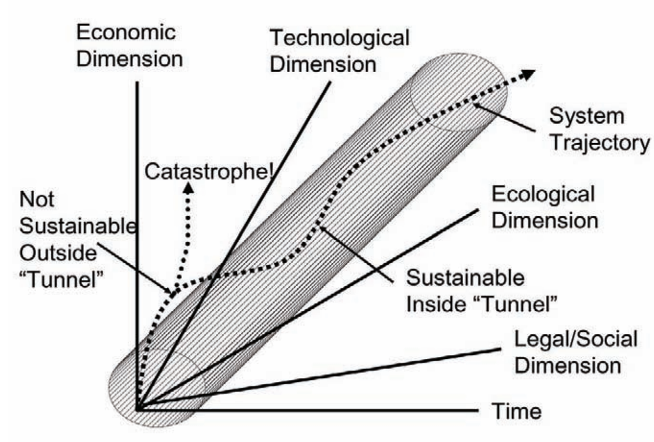

Figure 1. Multidimensional Concept of Sustainability.

conditions that must be considered in any attempt to project the system's future trajectory. There is a practical aspect, as well—the constraints of current law must be taken into account to avoid a solution that is theoretically satisfying, but has little hope of being implemented. Finally, law is itself a complex system and one hypothesis is that we are following systems rules in creating our laws without realizing it (perhaps law is not so malleable, after all).

This paper addresses the first two reasons. The next section describes how we include law in a foodweb model. Following that is a section on the more practical aspects of current law as a constraint in the analysis of options for reducing stormwater runoff volume. The conclusion proposes the next steps to be taken in incorporating law into sustainability research for effective environmental systems management.

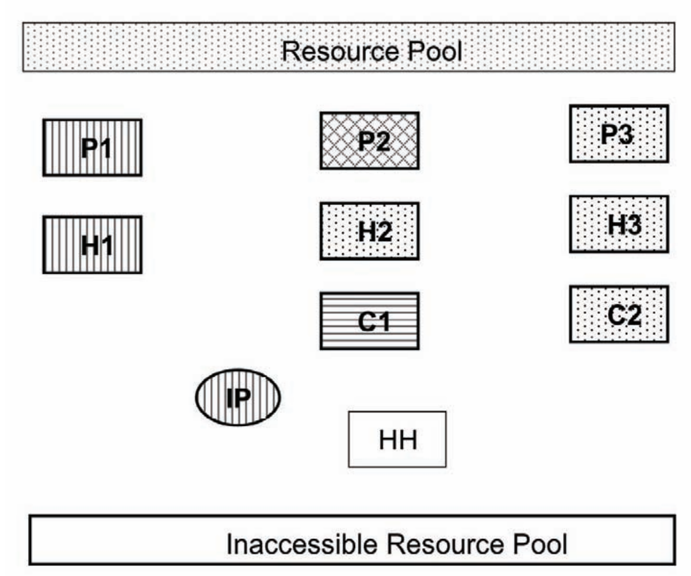

Figure 3. Legal Foodweb.

Foodweb Model

Figure 2 represents a basic foodweb with several trophic levels. (Cabezas and others 2004) The system is open to energy, but closed to mass and the arrows indicate transfers of mass within the closed system. This represents the ecological dimension (fig. 1) and the variable is mass. (We have added an Industrial Process [IP] to the model to account for the mass that is appropriated by humans for its vast infrastructure and non-food products).

Figure 3 represents the same foodweb from a legal perspective. Here, the variable is not mass, but rights attached to the mass (property rights). The conservation of mass still applies, but there is no corresponding conservation of rights (in fact, the transfer of mass is immaterial). It is common to have multiple rights attached to the same mass. For example, one person (the lessor) may have the ownership rights to a parcel of land, while another (the lessee) holds the right of possession, and a third (the heir) has a right to own the parcel at some time in the future. We therefore identify the compartments in terms of the type or property they represent. H1, H2, and IP are private property and are shown in boxes with vertical lines, P2 is government property (shown with cross-hatched lines), and H2, P3, H3, and C2 are "commons" (shown with a dotted background) to which no rights yet attach—they are free for the taking. C1 (shown with horizontal lines) represents a special category. It is wild in that no one owns it, but it is valued by society and so is protected by the government. (At this point, the resource pool is considered commons, but in reality, it, too, is an amalgamation of private, public, and commons property).

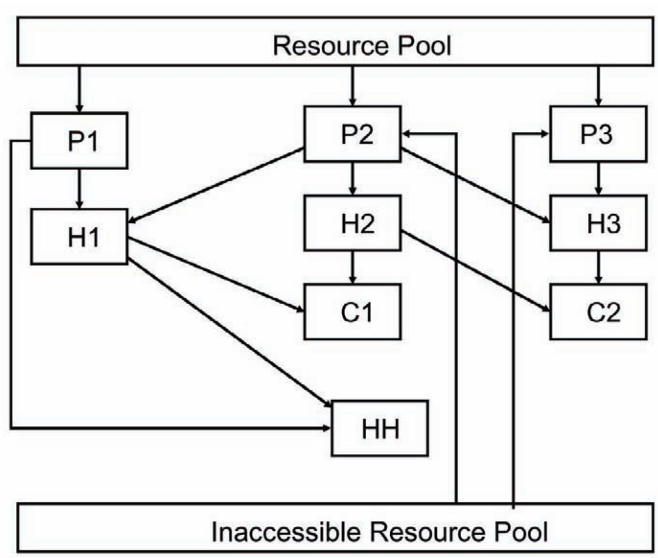

Figure 2. Ecological Foodweb.

Once property rights attach to the mass, a basis exists for an economic system that determines the value associated with the mass and its transfer. It also becomes evident that the foodweb can be divided into domesticated and non-domesticated species because the rules for the transfers of mass will be very different for each. Transfers of mass associated with the domestic species can be modeled according to economic principles (although unlike traditional economic models, since this system is closed to mass, there can be no assumption of infinite resources or substitutability). Transfers of mass between non-domesticated species are governed more by biological rules and sometimes by policy decisions.

Thus, with the addition of the legal perspective, the foodweb represents a more realistic picture of current conditions. We can now use it to test various ecological, economic, and/or policy scenarios and observe the effect on the overall system trajectory.

As an example of how this might translate into a model of societal decision-making, consider figure 4. In this model, the ecological and technological dimensions are considered first. If a desired transfer of mass is not physically or technologically possible, the story ends there. If, however, it is possible, then society considers the economic ramifications. If the transfer of mass is profitable or will otherwise have positive social value, either the private sector or the government may cause it to occur. If, however, society decides against the transfer, how it goes about stopping or modifying it depends on the type of property involved. (How society makes that decision is a function of the political process, not addressed here). In the U. S., the options are greatest if no one owns or controls the property. It takes a more effort to affect government property, but it is most difficult to stop or modify transfers of mass to which private property rights attach. Society (through its government) must buy the property or pay to use it, or it must impose limits on those rights. Limiting rights involves Constitutional issues and is rarely a popular approach. The next section on our stormwater volume reduction research project illustrates this point.

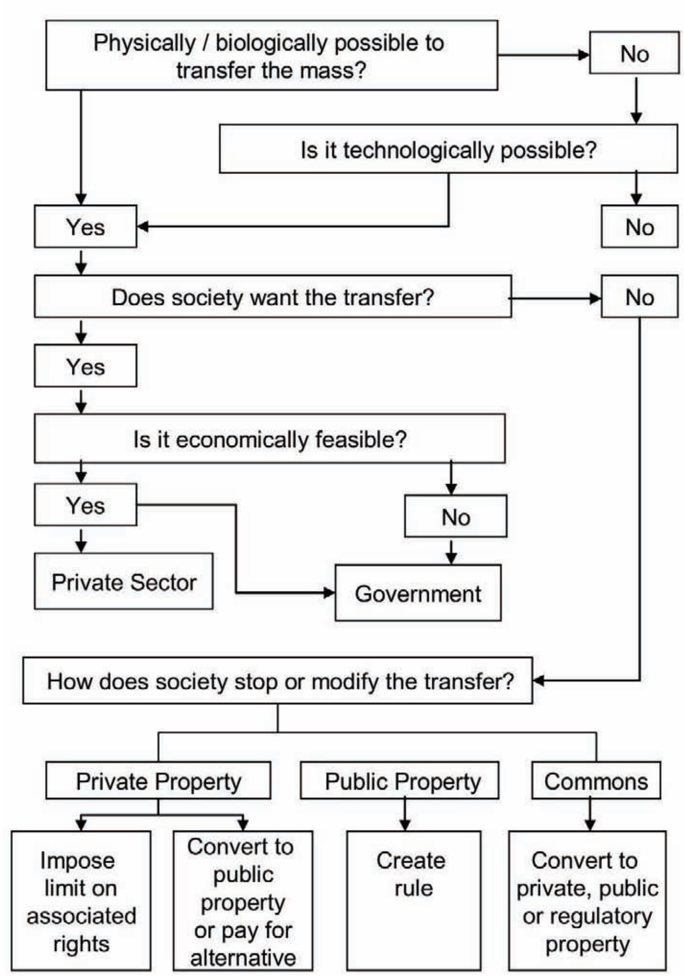

Figure 4. Societal Decision-Making Model.

Stormwater Volume Reduction

The stormwater volume reduction project is testing the hypothesis that small best management practices or "BMPs" (such as rain gardens) distributed throughout a watershed would be ecologically and economically superior to centralized stormwater conveyance and storage systems. (Thurston and others 2003). To explore the likelihood of success, our interdisciplinary team of hydrologists, engineers, ecologists, and attorneys identified four implementation scenarios for using economic incentives to encourage landowners to install the BMPs on their property. The options are: (1) use the existing stormwater fee and credit system in place in many communities; (2) institute a new charge that would be high enough to influence behavior; (3) place a mandatory limit on stormwater runoff volume, such that a cap and trade system could be used; and (4) pay property owners to reduce stormwater runoff volume, using an auction system to determine the participants. (Parikh and others 2004a) Table 1 ranks these scenarios according to the preference of the team members (1 being most preferable). A detailed discussion of each scenario is beyond the scope of this paper; however, Scenario 3 will be used to illustrate how current law functions as a constraint to be factored into the analysis.

Table 1. Ranking of Implementation Scenarios.

Scenario	Economic	Ecological	Legal
Use Existing Fee/Credit System	4	4	1
Create a New Charge	2	2	4
Impose Limit for Cap and Trade	1	1	3
Pay Landowners/Voluntary Auction	3	3	2

For a legal analysis, we start with a basic premise of U.S. law that rights are inherent in or given to the people and powers are given by the people to the government to protect those rights. (A very real conundrum is that the government must sometimes limit the rights of some to protect the rights of all). Applying this to Scenario 3, the questions can be stated as: does the property owner have a right to allow stormwater to run off his/her property (in other words, can the mass be transferred to others who may not want it)? If so, does the government have the power to limit that right?

Much to the frustration of the scientist or engineer, the answer to the first question is that it depends. Stormwater is from a naturally occurring phenomenon and rules governing its drainage onto another's property are considered part of state water law. States can vary significantly in their laws and state drainage law is a good example of this diversity.

Assuming the property owner does have a right to allow the stormwater runoff to occur, the powers side of the analysis focuses on whether the government can limit that right? In the United States, private property rights are very important and receive Constitutional protection, so the government must go through several "hoops" to limit them. Questions to be answered include: Is the power specifically delegated to the Federal Government (such that a Federal law like the Clean Water Act could be used)? If not, is it specifically prohibited to the States? If not, does the State Constitution allow it? Even if it does, would the limit violate the due process or equal protection guarantees of the U. S. Constitution? If the new limit can pass all these hurdles, it may be legal, but landowners may still challenge it as the government's taking private property for public use without paying for it.

The point is not to discuss the legal issues, (Parikh and others 2004b) but to illustrate that such issues exist and must be taken into account when evaluating the potential benefit of pursuing one research agenda over another. In this case, our research team chose to devote its limited resources to Scenario 4, because it offered a more straightforward path to actual implementation. As indicated in table 1, Scenarios 2 or 3 may promise superior economic or ecological results on paper, but if they are unlikely to be implemented in the real world, those results will never be realized. By the same token, the scenario that is most likely to be implemented from a legal standpoint (Scenario 1) is less likely to meet the economic or ecological objectives. Thus, by concentrating our efforts on the best compromise, we can maximize our research efficiency and hopefully influence sustainability in a very real sense.

Conclusion

"Interdisciplinary research" usually means that more than one type of scientist or engineer is involved, but in sustainability research, all of the dimensions (economic, technological, ecological, and legal-social) are equally important and must be represented. Law is typically applied, if at all, after the fact by those charged with interpretation and implementation of research findings and conclusions. Since sustainability is as much about the future as the present or past, it is well to remember that to a large degree, the future, like law, is made and not found. Our sustainability research attempts to integrate all of the dimensions within the existing rules of science and the existing rules of law.

Future plans include a refinement of the foodweb and application of measures, such as Fisher Information to various what-if scenarios. (Fath and others 2003). In the stormwater volume reduction project, a test case is being conducted in a local watershed in which landowners will be paid to install BMPs on their property. As time permits, a third project will begin to explore the idea of law as a complex system—do our rules of law follow the natural rules of systems and order to which even inanimate systems adhere and if so, what are the ramifications for sustainability?

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Establishing Empirical Bases for Sustainability Objectives

Lawrence Martin, Biologist, US EPA Office of Research and Development in the Office of Science Policy, Washington, DC

Abstract—*The argument is made that sustainability should be construed as measurable environmental conditions, and that sustainable development strategies should be considered in terms of how well they contribute to the sustainable condition target. A case study of the Chesapeake Bay is presented to illustrate how use of Material Flow Analysis (MFA) as a basic component in the proposed sustainability methodology serves to coordinate and harmonize information. Observations are presented on the MFA-Sustainability methodology pertaining to its harmonious accord with existing regulatory structures and the risk assessment paradigm.*

Introduction

As a general goal, sustainable development is a big tent under which all people of good will can discuss and debate options for advancing the human enterprise without excessive concern over definitions or metrics. In contrast, any effort to organize information to advance sustainability objectives is immediately weighed down with niggling details and debates over scale, scope, and system boundaries. Any notion of "sustainability"- if there is to be any difference between environmental protection as usual and conditions that can be arguably defended as sustainable over time - has to be built upon empirical limits and definitions of scale and place.

By its nature a "holistic" and multidisciplinary ideal, sustainability is a multivariate tangle of scale and issue complexity. An effort to establish empirical foundations and to assign metrics necessarily entails system boundaries and some measure of reductionism, introducing what might appear to be a cross-purpose between the holistic ends and reductionist means. This constitutes a challenge in devising a methodology to address sustainability as a quantifiable outcome while preserving the complex and multifarious qualities represented.

For clarity in discussing sustainability objectives, sustainability can be thought of as the goal for which we are attempting to fix a quantifiable condition or characteristics, and sustainable development is the process of achieving it through policy, law, technology, and strategic objectives (Clift 2000). Sustainability needs to be first characterized as conditions for which some defendable criteria are established, and sustainable development is then the process whereby some subset of the human enterprise is managed to enable the attainment of the sustainable conditions. If sustainability is to represent an improvement over environmental protection as we know it, we need to know what conditions are desirable to sustain. Otherwise, in the absence of an identified endpoint, any improvement can be represented as success. While this may be all to the good, it does not necessarily represent progress toward sustainability, and functionally robs the concept of sustainability of its essential distinction.

Definitions of sustainability traditionally subdivide the overall goal into environmental, social, and economic dimensions, each with metrics suitable to their respective objectives (NRC 1999). Social and economic objectives are subject to widely differing value judgments with the result being a broad range of desired conditions – some conflicting. In contrast, acceptable environmental conditions are more easily characterized, as they are set essentially by physical and natural laws relating to conditions that support life, that can with diligence be reasonably ascertained. Environmental condition is as a result, better suited to empirical debate and definition, and is a logical choice to model an empirical methodology. Social and economic conditions of sustainability, while equally essential, are most effectively introduced as criteria for selecting sustainable development strategies to meet prescribed ecological conditions.

Discussion

Recognizing that many different approaches have been taken to evaluating sustainability strategies, and that in some instances methods have been thought to be competitive or mutually exclusive, efforts to examine how these approaches relate to one another have been undertaken. Robert offers a 5 level framework for planning in complex systems that is helpful for organizing one's thinking so that comparisons of method and strategy can be more systematic (Robert 2000). His framework distinguishes between actual conditions in the biosphere, goals for biosphere conditions, processes for establishing target conditions, actions, and tools.

Robert's framework is simplified for purposes here to distinguish simply between sustainable conditions giving rise to the idea of empirical endpoints; and the means to those ends – programs, technologies, strategies and the like, that can only be regarded as more or less contributing to that sustainable condition. With an empirical understanding of a sustainable endpoint, methods can be inferred to characterize and measure steps necessary for achieving the desired condition/s. The methods to achieve it can be quantified as to their effectiveness by the measurable extent to which they contribute to the sustainable condition.

Sustainability endpoints share an overarching purpose to quantify conditions suited to preserving life; however, context dictates that endpoints vary wildly across scale, geography, culture, time and economy. This presents a difficulty in assessing the adequacy of, or feasibility of sustainable development recommendations using any kind of rigid analysis. Though process engineers are making considerable progress nailing down the particulars of assessment metrics for "sustainable" technologies where mass and energy outcomes are quantifiable and thus comparable, sustainability questions run to far more complexity (Sikdar 2003). The distinction highlights the difference between identifying sustainable development strategies leading to sustainable conditions, and optimizing between competing technologies or strategies. In the first instance, one determines minimum necessary conditions to sustain life based on identified criteria. In the second instance, one is optimizing an outcome by comparing strategies or technologies using identified criteria that may or may not be sufficient to maintain a sustainable condition. Linking the outcome of the second to the criteria of the first establishes a logical sequence for modeling sustainable development practices and sustainable conditions.

It is tempting to conclude that addressing sustainability across the physical, cultural, and economic geography can only be dealt with by keeping analysis scaled locally or regionally to reduce complexity. While this is appropriate for a large range of sustainability questions, such as "how much water can we consume from this source" or "can we develop a sub-division in this aquifer recharge area?" it does not work for many other questions. Issues such as "is hydrogen a suitable fuel for transportation, such that it makes sense to build a national infrastructure to support it?" or "Shall we legislate federal guarantees for insurance on buildings build on barrier islands?" can not be addressed on a local scale. The whole range of questions relating to the use of materials (particularly persistent, bioaccumulative and toxic (PBTs) in a global economy, and nationally legislated (dis)incentives can only be addressed on the most comprehensive and national/global scale.

These are more thorny problems of nesting sustainable development strategies (including sustainable technologies) so the piece-meal decisions that necessarily constitute the human enterprise can be evaluated in light of how well they serve ecological, social and economic endpoints (How does this technology serve sustainability objectives?). The systems level sustainable condition target is necessary for guiding decisions about any undertaking entailing significant resources to move the human enterprise toward sustainability. We appreciate that decisions leading to the large commitment of resources can result in tremendous shifts of material and energy with significant implications for sustainability of national and global ecosystems. Failure to shape such decisions with an eye to serving sustainable endpoints, while recognizing their planet-wide implication is a feature of the last millennium and one we can no longer afford to indulge. How to motivate this sort of analysis and behavior is elusive.

It is desirable that an assessment methodology for sustainability be available that allows an analysis to peer into the future of an enterprise, and to envision the affects to target systems based on reasonable projections. The methodology would need to be flexible so that it could be tailored to individual applications, but could provide comparable information between options. Most importantly it would need to be designed around the availability of information, and not be so information intensive as to be overly burdensome or expensive to use.

Brunner and Starkl offer a pragmatic overview of "off-the-shelf" decision support methods with an approach that holds economic, social, and ecological criteria equal, so that a qualitative social criterion such as broad democratic participation in the decision making is considered along-side rigorous biogeochemical criteria pertaining to ecosystem health (Brunner and Starkl 2004). While useful in its own right, it illuminates by contrast the value in formulating a methodology that first identifies sustainable conditions in the environment, and then evaluates social and economic strategies to meet them. This conforms to the model advanced above of first identifying sustainable conditions, and then applying social and economic criteria to optimize technology and strategies to attain the target conditions.

The challenge is in developing a methodology that meets the following criteria:

1. Is empirical (transparent process and reproducible) and follows a logical and generally agreed-to framework.
2. Allows flexibility among various applications and different scales (multidisciplinary).
3. Permits connectivity/integration between multiple models and methods, as well as comparison between strategies to effect sustainable practices.
4. Captures data useful for characterizing the health of the environment, as well as social and economic conditions, while minimizing need for new information collection.
5. Easily adopted by existing social and business institutions.

Proposal

Many strategies to characterize, quantify, and measure sustainability have been published, and numerous means to organize them proposed. The Material Flow Analysis (MFA) is one strategy among many, however, it offers an important feature key to characterizing sustainability as conceived above. MFA is a quantifiable analytical tool, and it describes conditions of material flowing through the environment and by extension, the economy – and society. Examples include important resource flows for national economies, feed stocks for manufacturing and production, and naturally, elements/compounds in circulation or sinks in natural systems. A MFA yields a picture, dynamic through time, capable of characterizing any condition or source of stress to the environment, economy or society (as construed through demographic data) when relationships are properly understood. In a model, MFA data can be used to test proposed changes to material flows based on various sustainable development strategies under consideration (NRC 2003). The MFA is well suited as a foundation, or center-piece to support an empirical methodology for sustainability, as it meets elements of all five criteria identified above.

It is proposed that the MFA serve as both an anchor for an empirical sustainability methodology as well as an organizing point of origin around which to assemble various analytical tools for various sustainability investigations. To describe this process, I begin with several assumptions already discussed. First, the environmental conditions desirable to sustain are already characterized using ecological indicators that can be expressed in terms of material flows.

Secondly, sustainable development strategies are identified to meet sustainable conditions. Environmental criteria (linked to material flows) are identified. Social and economic assessment criteria are also introduced at this juncture to fully optimize sustainable development options.

Thirdly, a set of analytical and decision support tools are selected by decision makers and their technical support teams. There will be substantive variation among sustainability inquires leading to a wide variety of tools suitable to various investigations. The utility of the MFA is once again apparent as a common foundation across different assemblages of analytical tools providing a unifying link among different investigations. The extent to which formal guidance can be provided by an authoritative body to improve scientific rigor and comparability of results across all sustainability investigations is a subject for further study, but is predicated on the idea that within this approach they will follow in some logical way from use of a MFA.

The Chesapeake Bay, centered primarily in Maryland, is offered as a case study for application of the MFA approach; its indicators of condition being dissolved oxygen, water clarity, and chlorophyll a.

A Case Study

The Chesapeake Bay is the largest estuary in the United States. It is roughly 200 miles long stretching from Havre de Grace MD, to Norfolk, VA, with over 11,600 miles of shoreline (greater than the entire shoreline of the West Coast). The watershed is approximately 64,000 square miles, and includes all of the District of Columbia and parts of six states (Maryland, Virginia, West Virginia, Delaware, Pennsylvania, and New York).

As with all bodies of water in the United States, the goal for the Chesapeake Bay, as provided for in the Clean Water Act, is to "restore, and maintain the chemical, physical, and biological integrity" (US Code). The US Environmental Protection Agency (EPA) provides guidance to the States and Tribes for the determination of designated uses and assessment criteria, and provides oversight to ensure that the States and Tribes designated uses and criteria are consistent with the Clean Water Act (CWA).

As the Nation's waters have been increasingly protected from toxic point sources of pollution, the annual reporting by EPA and the States (CWA 305-b & 303-d) rank excess nutrients and siltation as the two leading causes of impairment to water quality. This is true as well for the Chesapeake Bay.

In 2000, EPA began publishing CWA section 304(a) water quality criteria to assist States and Tribes with addressing problems associated with excess nutrients. EPA has recommended that states used its guidance as a starting point for developing refined regional and site-specific criteria for the protection and attainment of designated uses. To assist states in the Chesapeake Bay watershed as they work to address nutrient pollution as well as sediment pollution, EPA Region III issued guidance in 2003 (CWA 304-a) with a refined set of criteria for the Chesapeake Bay (US EPA 2003a). These criteria were developed to protect five designated uses which EPA identified and described based on the types of habitat that exist in the Bay. The five habitats – shallow water, open water, deep water, deep channel, and migratory and spawning areas – allow the water quality standards to be matched with the plants and animals that are adapted to life in those different areas, rather than on a single bay-wide standard (Chesapeake Bay Program 2001). The water quality criteria selected for characterizing and monitoring the Chesapeake Bay are dissolved oxygen, water clarity and chlorophyll a. The criteria collectively provide the best and most direct measures of the effect of excess nutrients and sediment pollution on the Bay's living creatures, thus allowing for the direct measure of environmental endpoints.

Placing this information in the context of the proposed MFA methodology, we have established that the Chesapeake Bay has been characterized using ecological indicators that reflect material flows of nutrients and sediment, per the first assumption identified in the proposal above. These criteria can then be directly linked to necessary reductions in the flow of air, land and water based loadings of nitrogen, phosphorus and sediments through the application of air shed, watershed and tidal-water quality Bay models and long-term water quality monitoring data records. Essentially, the conditions necessary for attaining the three sets of water quality criteria established for the Chesapeake Bay can be directly related to limits on nutrient and sediment loadings. In turn, these loadings can be allocated to sources and specific locations with the watershed.

Thus, we see how a stated goal, the protection of living creatures within the Chesapeake Bay, can be characterized such that specific materials – nitrogen, phosphorus, and sediment, can be examined as material flows into and through this ecosystem affecting the goal of protecting the organisms within the system. The MFAs necessary for managing the ecosystem were determined through studies linking causes of ecosystem distress to the excess of specific materials in the system.

Assumption two dictates that the criteria established for sustaining the conditions of the ecosystem (or systems) in question are used to vet strategies for attainment of the sustainable conditions. Now, in turn, the MFA becomes the foundation for shaping subsequent analysis of strategies to limit the flows and thus achieve a sustainable condition for the ecosystem.

It is important to appreciate that the methods employed in determining sustainable conditions are qualitatively different from those appropriate for optimizing sustainable development strategies. Whereas a sustainable condition is fixed (although may be represented as a range based on uncertainty), comparing sustainable development strategies may employ the many proposed sustainability metrics that rely on indices where a "score" can be derived. Sustainability metrics include measures of material used, waste created, toxicity, water, and energy consumed, and cost, as well as those identified for Chesapeake Bay water quality (Sikdar 2003). Scoring options with a set of metrics describes moving along a linear path toward sustainability. Creating the largest positive score and minimizing negatives allows one to score a sustainability index that can be comparatively evaluated. This is useful for comparisons, but unless a sustainable condition has been identified, lacks a context for determining adequacy. Without an empirical sustainable condition target, sustainable development metrics are unable to answer the question: "Is this a sustainable strategy/technology/product?"

Increasingly, ecologists and managers have at their command models, tables, reference data, and other empirical information that enables estimates, with known levels of uncertainty, to be made for the effect of various strategies to control the delivery of pollutants to specific ecosystems. As the literature grows the information is ever more transferable through models and other expert systems to provide decision support to the management of any ecosystem of concern. While the models and their transferability are far from infallible, ecosystem research is making steady gains and developing a comprehensive literature to describe ecological condition (Heinz Center 2002).

In the Chesapeake Bay watershed two models are used primarily to evaluate different options for the management of the ecosystem and control of nutrients and sediment. The Watershed Model is designed to simulate nutrient and sediment loads delivered to the Bay under various management scenarios and features a simulation of overall mass balance of nitrogen and phosphorus in the drainage basin. Input nutrients are simulated to be transported to any of three end-points: incorporation into plant material, incorporation into the soil, or loading to the Bay through river runoff (Donigan and others 1994). The Chesapeake Bay Water Quality Model features a 3-dimensional equation of the water column simulating the movement (and barriers to movement) of the three criteria for Bay water quality: dissolved oxygen, water clarity, and chlorophyll a (Wang and Johnson 2000). Together, the models are used to characterize the movement of nutrients and sediment into the Bay and their effect on the environmental criteria used to assess the sustainability of the water quality and living creatures in the five different designated uses (or habitats). Managers and decision makers equipped with this information are able to consider options to reduce the level of pollutants flowing into the Bay using various decision assistance tools. Checks against field monitoring data show deviation in the models from actual conditions, and consequently they are being refined. The targets for sediment and nutrient runoff into the Bay, newly established to meet the condition targets are 4.5 M tons/year for sediment, 87,500 tons for nitrogen, and 6400 tons for phosphorus (Chesapeake Bay Program 2003). States are using these goals to further develop and hone strategies for reducing sediment and nutrients into waterways.

Germane to assumption three, EPA's methodology built around the MFA characterizes other tools that can usefully be employed to use the MFA data in subsequent analysis to inform the sustainability goal/question. EPA Region III and the National Center for Environmental Economics identified additional analytical tools to round out the assessment of different pollution management scenarios on Bay water quality employing socioeconomic criteria (US EPA 2003b). Using data and assumptions established in the literature, EPA provides estimates of the annual cost of achieving controls based on the water quality criteria using best management practices. EPA then populated a socioeconomic model to determine the effects of various management scenarios, such as economic growth and revenues, employment, income, and investment. Selection of these tools was based on commonly held expertise informed by empirical information describing the effect of different management scenarios on the material flows of nutrients and sediment in the watershed.

A presentation of data resulting from the assemblage of models and other analytical tools is not possible within the space limitations of this paper; however, it should be known that as public information they receive rigorous scrutiny from advocacy groups and affected parties of all stripe. The constructive engagement of the public with expert information is a critical dimension of any sustainability initiative. Means to organize public values and recommendations into the decision making process is acknowledged to be an essential element of a sustainable development.

Observations

Sustainability Objectives Can Be Empirical

If you don't know where you are going any path will take you there - to paraphrase one of Carroll's creatures in his tale "Alice in Wonderland." While developing metrics to compare various sustainable development strategies for general conservation and toxicity purposes is necessary, it is not sufficient. The identification of a sustainable condition as a target is necessary to determine sufficiency of a sustainable development strategy. Using the MFA approach requires first parsing the scale issue to determine if the methodology is oriented toward a discrete place, such as with the Chesapeake Bay example above, or if it must extend to an unbounded (or global) geographic assessment, such as would be the case when considering persistent, bioaccumulative toxic substances. Following a determination of suitable scale to address the sustainability question, an investigation or set of inquiries is structured to yield identification of a suitable MFA that will characterize a flow/s relevant to characterizing the conditions of sustainability in the system under question. This phase of the methodology development will yield an empirical sustainability target condition. The next phase of the methodology development will be to characterize and assemble the decision support tools that will enable an assessment of sustainable development strategies for attaining the target condition.

The US Environmental Protection Agency's Science Advisory Board, an independent scientific review board for EPA, proposed a process very much like that described here in their 2000 publication "Toward Integrated Environmental Decision Making." Asked by EPA to update their groundbreaking report "Reducing Risk"(US EPA 1990) the SAB formed a committee with over fifty additional Ph.D.s to address the general question of how to update and extend the thinking about how science can best inform the decision making process (USEPA 2000). The integrated environmental decision making (IED) framework proposed by the SAB relies heavily on establishment of goals, use of the risk assessment paradigm (NRC 1983) and comparison of possible management scenarios by analyzing decision criteria. Key in making the assertion that the SABs IED is comparable to the sustainability methodology proposed here is the phrase repeated throughout their publication: "analysis of the economic and societal consequences of various options is an important aspect of options analysis." SAB makes the leap from environmental decision making to sustainability through asserting the necessity of including social and economic dimensions in the analysis of management options. In addition, I propose only that the MFA plays a key and critical role in organizing information essential to determining ecological condition.

The similarity to SAB's IED is important because the IED was viewed by the SAB scholars as "the next step" in improving environmental decision making. SAB's first of ten recommendations was "EPA should continue development of integrated, outcomes-based environmental protection, while maintaining the safeguards afforded by the current system." To this I add that the established regulatory process for environmental protection is a foundation upon which empirical sustainability can be built. Laws may need to be amended, and public process greatly enhanced with requirements for broader social assessments, but the basic building blocks of fact finding, scientific research, regulation setting, and voluntary compliance are sound footings on which to build sustainability.

An Empirical Approach to Setting Sustainability Objectives is a Seamless Extension of The Existing Regulatory Process and Approach to Environmental Management

As was illustrated with the example of the Chesapeake Bay, existing statutory approaches to protecting the Bay environment (ecosystems) have been employed to establish an empirical understanding of the conditions necessary to protect the habitat of organisms considered to be indicators of the sustainability of the Bay's health. This approach arises directly from the law governing US water quality and the flexibility afforded the EPA in working with the States to tailor the law to localized conditions. Another example is implementation of the Total Maximum Daily Load (TMDL) provision of the Clean Water Act which permits the EPA to look at total limits to a receiving waters capacity for absorbing pollutants in setting facility effluent permits, and thus enabling a ratcheting down of permitted pollution below effluent standards otherwise allowed. These examples illustrate that the use of existing mandates and regulatory stratagems enable the determination of empirical sustainability objectives. Only the means for compulsory attainment are not in place, however they represent nothing more than stricter standards.

The Risk Assessment Paradigm Offers a Constructive Platform from Which to Establish an Empirical Foundation for Sustainability

US EPA's policy on the use of human health and ecological risk assessment reflects growing reliance in this paradigm for ensuring a sound scientific foundation for environmental protection and regulation. The development of uniform guidelines for risk assessment, as formulated over the past 20 years, has yielded rigorous techniques for analyzing threats to human and ecological health that can be harnessed for examining how to also optimize them. The use of risk assessment, pioneered for health applications at EPA, has been adapted for use in determining risk to various features in ecosystems and choosing the best actions to protect them. Ecological risk assessment is a process to collect, organize, analyze and present scientific information for use in making decisions about environmental protection priorities. This is performed by evaluating the likelihood that adverse affects are occurring (or may occur). Risk assessment techniques provide a basis for comparing, ranking, and prioritizing risks, and estimating ecological effects as a function of exposure to stress in the environment – important functions embraced by SAB's EID. The function of a risk assessment in the MFA-based sustainability methodology is to ensure that the materials selected are in fact critical to understanding the function and health of the target system. In the Chesapeake Bay, selection of chlorophyll a, water clarity (or turbidity) and dissolved oxygen was based on substantial research showing correlation to nutrient and sediments loads to the Bay. Under circumstances less well substantiated, risk assessment tools provide a means to conduct a sensitivity analysis of materials being used to target sustainable conditions in a system, and to ensure that they will accurately reflect system health. A risk assessment to identify significant anthropogenic stressor/s in the Waquoit Bay demonstrated the utility of this approach (Serveiss and others 2004).

EPA supported the application of risk assessments to five pilot watersheds to ascertain the value of the risk paradigm to watershed management. In a report analyzing the use of ecological risk assessment methods for watershed protection it was found that watershed management benefits from the use of the formal, scientifically defensible methods of risk assessment by providing a process to help people examine their assumptions and conclusions, and to document their findings. The risk assessment framework is particularly valuable when addressing problems caused by multiple and non-chemical stressors (Eastern Research Group 1998).

Risk assessment principles can, be applied to provide insights on monitoring data collection, how to organize data, or formulate a problem. The application of this process for identifying sustainable conditions and evaluating sustainable development strategies for meeting them is straight forward, consistent with the use of MFAs, and further illustrates how existing means for environmental protection can be employed to effect the identification of sustainable condition objectives.

The Quality of Information, and Its Intensity, is Subject to Challenge

Information quality in any enterprise with claims to an empirical foundation is fair game for challenge. This is especially true in characterizing the health of ecosystems where each place is unique, variables are virtually infinite, and the science is far from unanimous. Until the present, government efforts to discern the weight of evidence followed the often messy path of scientific discovery relying on expert judgment – with that subject to the imprimatur of prestigious associations. This is a less certain environment today with the promulgation of data quality rules by the Office of Management and Budget (Weiss 2004). Scientific certainty is not a luxury often associated with advanced ecological research. Although the legal record on implementation of the Data Quality Law is still inchoate, it could undermine the use of MFA and related analytical tools to define sustainability objectives as a result of too great an uncertainty associated with the data. A consideration of the data intensity associated with bringing a measure of empirical rigor to setting sustainability objectives is also a reasonable concern. Recognizing that even perfect information may not carry the day in decision making, and that political (including popular democracy) and economic considerations may overshadow scientific information, it is fair to ask what level of resources is practical to derive empirical sustainability objectives. These questions should help inform future explorations of this proposal.

Summary

Sustainability is a desired endpoint requiring a degree of planning to achieve, and thus, societal coordination of the type afforded by government is unavoidable. The MFA-Sustainability methodology is not proposed as a shortcut to understanding sustainability; rather, it is an organizing methodology useful for coordinating empirical information to define sustainability and compare options in the contexts of place and identified risk. There is a need to make sustainability an empirical condition respecting of the biogeochemical conditions of a suitably scaled region. Any other approach to characterizing sustainability is subject to changing definitions and is difficult to defend empirically. The power that comes with designing empirical bases for determination of sustainable conditions and sustainability strategies is necessary to optimize the clarity and persuasive power of sustainability recommendations, and to ensure that policy is systematic and transparent. Because of the qualities inherent in the MFA it is presented as a core investigative tool for refining an empirical sustainability methodology oriented toward identifying and prioritizing actions to meet sustainability goals.

There is still a prodigious amount of study necessary to refine an approach to developing a MFA-based methodology for characterizing sustainability as a measurable condition (or outcome). Important considerations include the cost-effectiveness of the methodology, data quality constraints, and available means to build or access material flow data-bases. The NRC study recommends a national body to collect and organize the data.

Perhaps most important is to recognize that existing strategies employed by governments to protect environmental quality, such as regulation and the risk assessments that underlie them, can be harnessed to serve the purposes of defining sustainable conditions and to assessing the relative merit of sustainable development strategies for attaining them. Consideration of where existing environmental law enables pushing the envelope toward sustainability provides fertile ground for further exploring the feasibility of this approach.

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Ecologic, Economic, and Social Considerations for Rangeland Sustainability: An Integrated Conceptual Framework

Daniel W. McCollum, economist, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO
H. Theodore Heintz, Jr., economist, US Dept of the Interior and Council on Environmental Quality, Washington, DC
Aaron J. Harp, self-employed sociologist, Ann Arbor, MI
John A. Tanaka, economist, Eastern Oregon Agricultural Research Center, Union, OR
Gary R. Evans, College of Natural Resources, Virginia Polytechnic Institute & State University, Northern Virginia Center, Alexandria, VA
David Radloff, Sustainable Development, State & Private Forestry, USDA Forest Service, Washington, DC
Louis E. Swanson, Chair, Dept. of Sociology, Colorado State University, Fort Collins, CO
William E. Fox, III, rangeland ecologist, Texas Water Resources Institute, Texas A&M University, College Station, TX
Michael G. "Sherm" Karl, Inventory and Monitoring Specialist with the Bureau of Land Management, Colorado State Office, Lakewood, CO
John E. Mitchell, rangeland scientist, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO

Abstract—*Use and sustainability of rangelands are inherently linked to the health and sustainability of the land. They are also inherently linked to the social and economic infrastructures that complement and support those rangelands and rangeland uses. Ecological systems and processes provide the biological interactions underlying ecosystem health and viability. Social and economic infrastructures and processes provide the framework or context in which rangeland use occurs and continues. All these systems and processes interact and feedback on each other over time and space. To look at rangeland sustainability exclusive of any of the three basic components, ecologic, economic, and social, is to look at an incomplete picture. Such an incomplete picture misinforms and misguides decision makers as they seek sustainable management. This paper proposes a conceptual framework providing for interactions between ecologic, economic, and social aspects of rangeland use and sustainability. While the specific example relates to rangelands, the framework is generalizable to any natural resource.*

Introduction

Ecological systems and processes provide the biological interactions underlying ecosystem health and viability. Social and economic infrastructures and processes provide the framework or context in which rangeland use and management occurs and rangeland health increases or deteriorates. All these systems and processes interact and feedback on each other over time and space. To focus only on ecological aspects of rangeland use, management, and sustainability is to look at an incomplete picture. Likewise, the picture would be incomplete if one looked only at economic aspects of use, management, and sustainability. The latter has been recognized in recent years (McCollum and others [1993] summarize the arguments and propose one solution). In order to adequately assess and monitor rangeland sustainability, an integration of ecologic, economic, and social perspectives is needed.

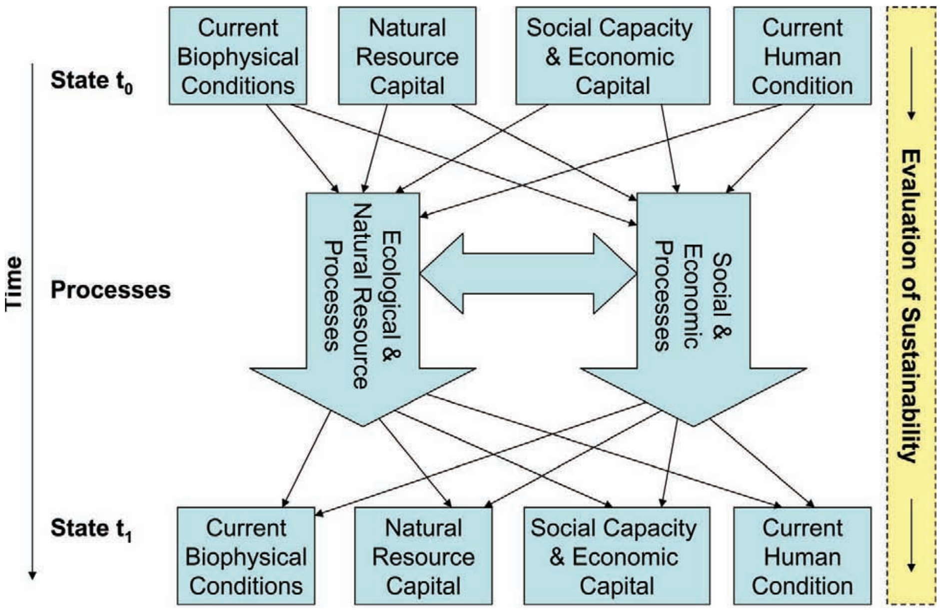

Figure 1. Tier 1 Rangeland Sustainability Evaluation Framework.

An Overview of the Framework

This framework links ecological factors and social/economic factors related to rangelands. In Tier 1 (fig. 1), the world is categorized into: (1) Current Biophysical Conditions (of air, water, soils, plants/animals, minerals), (2) Natural Resource Capital (the stocks of total biomass—including both plants and animals), (3) Social Capacity & Economic Capital (consisting of economic assets & liabilities and social opportunities & constraints), and (4) Current Human Condition (values and norms, income, health, security, etc.). The four boxes are acted upon by processes, represented by the large downward arrows. There are ecological and natural resource processes. These consist of reproduction, growth, death, decomposition; and include water cycles, nutrient cycles, carbon cycles, succession, migration, adaptation, etc. On the other side are social and economic processes. These consist of demand, investment, depreciation, management, social regulation, production, consumption, social interaction, institutional processes, etc. The processes change the conditions and capitals existing at time t0 and result in a new set of conditions and capitals at time t1.

Integration of ecological factors and social/economic factors is introduced into the framework as the horizontal arrow linking "ecological & natural resource processes" and "social & economic processes." This represents an explicit recognition that ecological and natural resource processes affect and are affected by social and economic capitals/capacities and conditions, and by social and economic processes. Likewise, social and economic processes affect and are affected by biophysical conditions and natural resource capital, and by ecological and natural resource processes.

A Tier 2 framework (fig. 2) details those interactions, focusing on three primary points of contact: (1) extraction, (2) waste discharge, and (3) ecosystem services. Humans extract natural resources. Extracted resources are used by humans and affect biophysical conditions and natural resource stocks. In the process of extraction, processing, and use of those resources, wastes are generated and discharged. Ecosystem goods and services are generated that are used by humans (whether they are aware of the ecosystem goods and services they use or not). One set of such ecosystem services involves detoxifying and decomposing waste discharges. Other ecosystem services include climate regulation, soil formation, biodiversity, among many others.

A Tier 3 framework proposes indicators with which to assess and evaluate rangeland condition and sustainability over time. Those indicators are represented in both the Tier 1 and Tier 2 frameworks (figs. 1 and 2) by the box labeled "Evaluation of Sustainability," on the right side of the diagrams. Indicators provide measurements of key variables that inform as to the condition and functioning of relevant stocks and flows.

Further Details on the Framework

Natural Resource Capital

The intent is to capture the stock of resources existing in the biophysical environment. Included in Natural

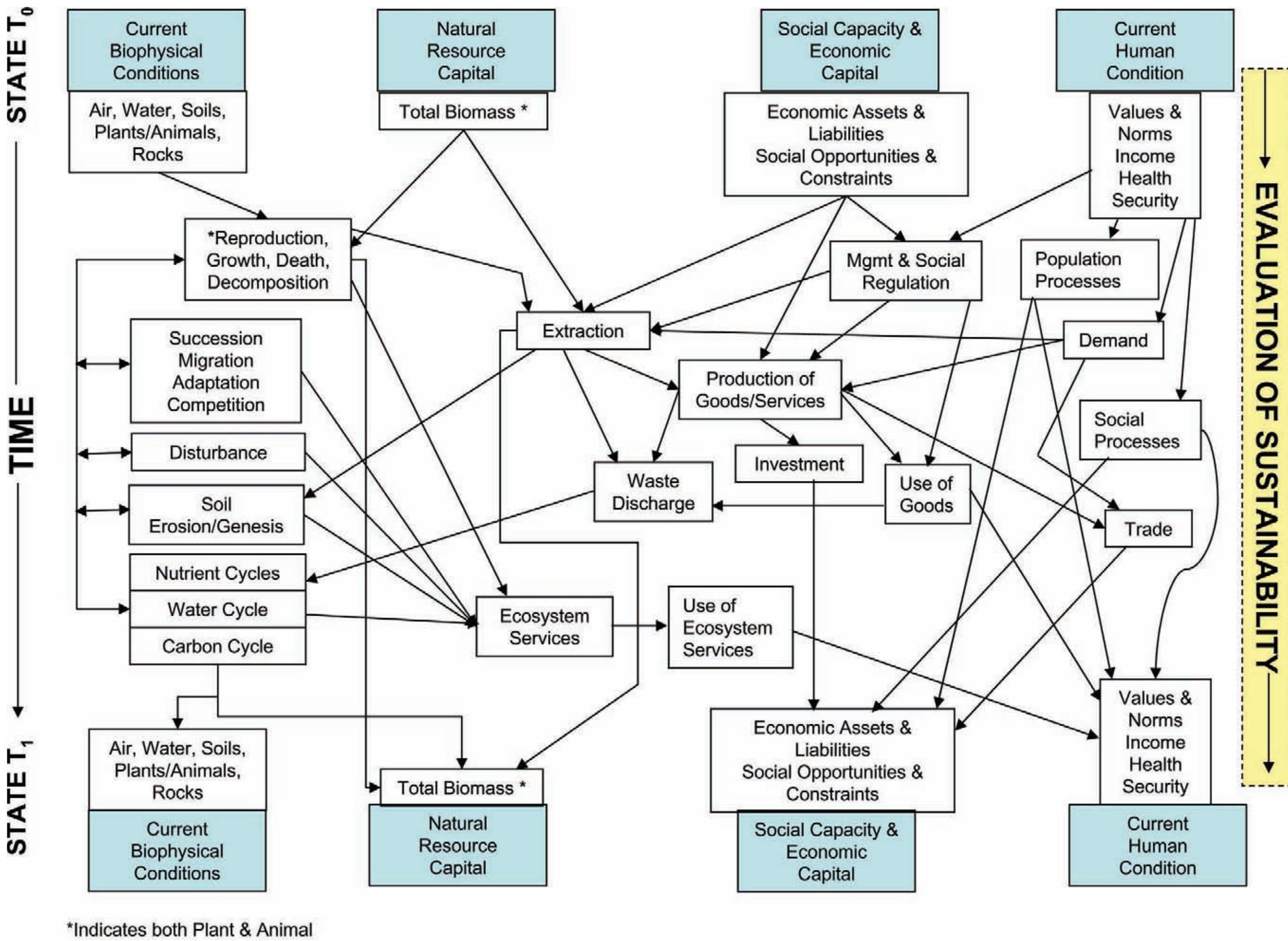

Figure 2. Tier 2 Framework – Rangeland Example.

Resource Capital is the total biomass present in the ecosystem—both plants and animals.

Current Biophysical Conditions

This includes the state and status of all the biota comprising rangelands, as well as the environmental conditions that influence and are influenced by the biota—in other words, the rangeland ecosystem. This includes all the biotic and abiotic entities that are specifically identified as comprising natural resource capital—plus others. Into this category would go things like air and water pollution, holes in the ozone layer, etc., along with the level of biodiversity of the rangeland ecosystem, conditions of the soils, etc.

Social Capacity and Economic Capital

This category includes the traditional economic notion of capital—all the assets and liabilities present in the economy, from buildings and machinery to inventories of raw materials to the productive capacity of the economy. The category is broadened to include the idea of social capital or social capacity. This represents the opportunities and constraints afforded by the existing organization of society. Included in this category are people's or community social and support networks, and the institutional structures of society—the legal system, the education system, etc. It also includes human populations. This is intended to represent a social and economic stock or capacity present in the society.

Current Human Condition

This box represents the state and status, or condition of people and society—human well-being. It includes values and norms present in the society. It includes economic conditions—employment and unemployment, income distribution within society, and growth rate of the economy, etc. It also includes broader social conditions—poverty, educational status, health status, security, etc. Another aspect of human well-being in this category would be conditions of society in terms of social interactions, community cohesiveness, social integration and stratification.

The Ecological Processes

This series of boxes represents all the processes that produce biomass, either by primary production such as photosynthesis, or by consumption and conversion of other biomass. It also includes the variety of processes that continuously cycle the finite elements that are entrained in the biologically active layer of the earth. They include the carbon cycle, water cycle, and nutrient cycles. The processes are performed or mediated by the rangeland biota, and they in turn set the conditions for the functioning of the biotic world. This cycling of matter results in some of the natural resource stocks present in the next period in time.

Other processes in this series of boxes include dynamics like succession, migration, adaptation, and competition; they include soil erosion and genesis. Disturbances like flood, drought, fire, etc. are envisioned as one of the series of ecological processes. As indicated by the double-headed arrows on the diagram, the ecological processes interact and feedback on each other. The processes are driven and controlled by current biophysical conditions, and the outcomes become the "new" current biophysical conditions in the succeeding time period.

The ecological processes are influenced and modified by various intentional human activities such as extraction of products like range forage and other biomass and water; and investment in management practices. They are also influenced by unintended consequences of human actions such as the release of waste products into the environment or by careless behaviors, etc.

The Social and Economic Processes

Economic processes include production of goods and services, demand, investment, consumption or use of goods and services, trade, etc. Production of goods and services is broadly conceived, so it includes "household production" as well as manufacturing processes. For example, people use natural resources and access to natural resources to produce a variety of recreation and leisure goods that then affect human condition. Also included are management and social regulation. These are envisioned to include social policy and management of natural resources, among other things. Just as there are population processes on the ecological side of the framework, so too are there population processes on the social/economic side of the framework. These processes include birth, death, migration, aging, morbidity, etc. Finally, there are social processes, which include social integration, stratification, extra-local ties, social differentiation, governance, etc. These are the processes that form the organization of society. Taken together, all these processes result in "Social Capacity & Economic Capital" and "Current Human Condition" at the next point in time.

The Interactions between Ecologic, Economic, and Social Factors

A shortcoming of many previous efforts to address natural resource sustainability has been the failure to adequately consider social and economic factors at all; and when they have been considered there has been no integration of social and economic considerations with ecological considerations. A typical effort to assess rangeland sustainability might include an analysis of relevant ecological factors. Toward the end of the effort there might be recognition that there should be some discussion of social and economic factors so a (separate) social/economic analysis is tacked on at the end. No real thought is given to the dynamic two-way interaction between ecological factors related to use and sustainability and social/economic factors. That is not to say that this effort and this conceptual framework solve all those problems. Rather, the Sustainable Rangelands Roundtable (SRR) and the efforts represented by this conceptual framework are a beginning. From its beginning, the SRR recognized the importance of thoroughly integrating ecological factors, social factors, and economic factors. All three are important to a well-informed assessment of rangelands and rangeland sustainability; and one cannot stand without the other two. Because it represents only a beginning, this conceptual framework and the thinking behind it are still evolving. By no means is this paper the final word on the subject.

We envision three primary points of interaction: extraction, waste discharge, and ecosystem services.

Extraction

In the case of rangelands the traditional extraction occurring is the removal of forage by livestock and wildlife. But, these are not the only extractions going on. Various plants are extracted from rangeland ecosystems for a variety of purposes. There are herbal and medicinal uses of some rangeland plants, there are landscaping uses, among others. Water is extracted from rangeland ecosystems for a variety of uses such as irrigation and human consumption. Animals are extracted by hunters and others. Such extracted products are demanded by people and enter into the production of goods and services. From there, they are used, consumed or traded and contribute to Social Capacity and Economic Capital or to the Current Human Condition. Also, as part of the extraction process, biomass is removed affecting the stock of Natural Resource Capital. Byproducts of extraction and the extraction process factor into the Biophysical Condition through such mechanisms as soil erosion, succession of species, etc.

Beyond those relatively straightforward extractions from rangeland ecosystems, there are extractions of habitat and rangeland itself. Such extractions are a primary way in which humans directly impact rangeland ecosystems. Some extractions are positive or neutral as far as their effect on the environment; others have negative effects. Increasing and migrating human populations encroach on rangeland. Use changes from grazing and open space to residential development and subdivision. Results include fragmentation of habitat, basic changes in the composition of species as development occurs and landscaping replaces many of the native plants, exotic and invasive species might be introduced and spread, and native wildlife species might become pests and nuisances leading to their removal from parts of the ecosystem, among other effects.

Another form of extraction is related to recreation and "spiritual" or "aesthetic" services. Natural environments produce services that are extracted not as commodities but as perceptions or opportunities. Such extracted services affect the human condition in ways such as experiences of wonder and majesty, scenic beauty, or as a backdrop to life activities. They can also enter into a household production process and contribute to leisure and recreation activities. This overlaps with "ecosystem services," which are discussed below.

Waste Discharge

Wastes are discharged into the ecosystem at several points and from several processes. Such wastes can have both positive and negative effects. We have already alluded to the byproducts of extraction. Grazing animals discharge wastes as they digest forage. Extraction of plants might leave "slash piles," such as one might expect at the interface between rangeland and forest ecosystems. In some cases, those wastes support microorganisms and other life cycles. In other cases, they lead to water pollution and adverse effects on human and non-human species, or they increase the likelihood of disturbances like fire. Waste discharge can contribute to the spread of invasive species, among other effects.

Perhaps the greater effects of waste discharge, though, result from humans and human use of goods and services. In this vein would be discharges from productive and manufacturing processes, wastes created by consumption and use of goods and services such as discarded packaging and other byproducts of human society. Some of those wastes get recycled back into productive processes while others get released into the ecosystem in a variety of ways and forms. Those wastes are acted upon by (or interrupt and otherwise alter) natural processes, and result in changed conditions of Natural Resource Stock and Biophysical Condition.

A more subtle effect of human society that might be included in a broad conception of waste discharges is human behavior or byproducts of human behavior that adversely affect the environment. Included in this vein would be behaviors such as burning fossil fuels, introduction and spread of exotic and invasive species, among others. Also included might be careless or malicious behaviors that result in environmental or ecosystem damage. While it could be argued that these are not truly "waste discharges," they are byproducts of society that affect ecosystems.

Ecosystem Services and Use of Ecosystem Services

Broadly defined, ecosystem services refer to a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life. These services maintain biological diversity and the production of ecosystem goods, such as seafood, wild game, forage, timber, biomass fuels, natural fibers, and many pharmaceuticals, industrial products, and their precursors. In addition to the production of goods, ecosystems support life through such things as: purification of air and water, mitigation of droughts and floods, generation and preservation of soils and renewal of their fertility, detoxification and decomposition of wastes, pollination of crops and natural vegetation, control of many agricultural pests, protection from the sun's ultraviolet rays, partial stabilization of climate, opportunities for recreation and leisure activities, provision of aesthetic beauty and intellectual stimulation that lift the human spirit, among others (Daily and others n.d.). Many ecosystem goods enter into our framework through extraction and productive processes, as alluded to above. The primary focus of this "process/interaction box" is to capture those services not explicitly entering by way of extraction and productive processes—such as those listed above as contributing to life support. These ecosystem services are used by humans, whether they know it or not, and contribute to the Human Condition.

Obviously, ecosystem services also have feedback mechanisms to the ecological side of the framework.

We recognize those feedbacks, but include them in the ecological processes such as decomposition, soil genesis, nutrient cycles, water cycles, carbon cycles, etc.

Completing the Framework: Tier 3

The stated purpose of the SRR, and the context in which this conceptual framework was generated, is to develop and refine indicators of sustainability, based on social, economic, and ecological factors, to provide a framework for national assessments of rangelands and rangeland uses. Hence, completion of the framework requires Tier 3. Tier 3 is a set of indicators covering five criteria: (1) Conservation and Maintenance of Soil and Water Resources of Rangelands; (2) Conservation and Maintenance of Plant and Animal Resources of Rangelands; (3) Maintenance of Productive Capacity on Rangelands; (4) Maintenance and Enhancement of Multiple Economic and Social Benefits to Current and Future Generations; and (5) Legal, Institutional, and Economic Framework for Rangeland Conservation and Sustainable Management. These indicators are intended to provide measures of key variables that will inform and facilitate monitoring and periodic assessment of the condition and functioning of rangeland ecosystems over time.

The indicators associated with each of these criteria are shown in figure 3. Further information and descriptions of the indicators can be found in a special issue of *Rangeland Ecology and Management* (formerly the *Journal of Range Management*) forthcoming in 2005. That special issue is comprised of papers by Mitchell

Criterion 1: Conservation and Maintenance of Soil and Water Resources of Rangelands

Soil-based Indicators

1. Area and percent of rangeland soils with significantly diminished organic matter and/or high carbon:nitrogen (C:N) ratio.
2. Area and extent of rangelands with changes in soil aggregate stability.
3. Assessment of microbial activity in rangeland soils.
4. Area and percent of rangeland with significant change in extent of bare ground.
5. Area and percent of rangeland with accelerated soil erosion by water or wind.

Water-based Indicators

6. Percent of water bodies in rangeland areas with significant changes in natural biotic assemblage composition.
7. Percent of surface water on rangeland areas with significant deterioration of their chemical, physical, and biological properties from acceptable levels.
8. Changes in ground water systems.
9. Changes in the frequency and duration of surface no-flow periods in rangeland streams.
10. Percent of stream length in rangeland catchments in which stream channel geometry significantly deviates from the natural channel geometry.

Criterion 2: Conservation and Maintenance of Plant and Animal Resources on Rangelands

11. Extent of land area in rangeland.
12. Rangeland area by plant community.
13. Number and extent of wetlands.
14. Fragmentation of rangeland and rangeland plant communities.
15. Density of roads and human structures.
16. Integrity in natural fire regimes on rangeland.
17. Extent and condition of riparian systems.
18. Area of infestation and presence/absence of invasive and other nonnative plant species of concern.
19. Number and distribution of species and communities of concern.
20. Population status and geographic range of rangeland-dependent species.

Criterion 3: Maintenance of Productive Capacity on Rangelands

21. Rangeland aboveground biomass.
22. Rangeland annual productivity.
23. Percent of available rangeland grazed by livestock.
24. Number of domestic livestock on rangeland.
25. Presence and density of wildlife functional groups on rangeland.
26. Annual removal of native hay and non-forage plant materials, landscaping materials, edible and medicinal plants, and wood products.

Criterion 4: Maintenance and Enhancement of Multiple Economic and Social Benefits to Current and Future Generations

27. The value of forage harvested from rangeland by livestock.
28. Value of production of non-livestock products produced from rangeland.
29. Number of visitor days by activity and recreational land class.
30. Reported threats to quality of recreation experiences.
31. Value of investments in rangeland, rangeland improvements, and recreation/tourism infrastructure.
32. Rate of return on investment for range livestock enterprises.
33. Number of conservation easements purchased.
34. Expenditures (monetary and in-kind) to restoration activities.
35. The threat or pressure on the integrity of cultural and spiritual resource values.
36. Poverty rate (general).
37. Poverty rate (children).

Figure 3. SRR Criteria and Indicators for Sustainable Rangelands.

and others, Karl and others, Joyce and others, Evans and others, McCollum and others, and Hamilton and others. Further refinement and testing of those indicators will occur over time. Like this conceptual framework, work on the indicators is an evolving process.

Absent from Tiers 1 and 2 is any notion of scale, either spatial or temporal. Rangeland ecosystems can be considered at several spatial scales. One might think in terms of a particular river drainage. Alternatively, one could think of rangelands at the national scale; or anywhere in between the two. Life histories of the various biota are highly diverse, so that significant changes in natural resource capital occur with very different frequencies, from years to decades to centuries. Issues of scale become important in Tier 3 when one begins to develop and collect data on indicators.

Discussion and Conclusions

We have laid out a set of basic ecological processes that act upon and maintain or alter rangeland ecosystems. We have also laid out a set of basic social and economic processes that act upon and maintain or alter people and communities. On the surface, there are some interactions between the two—economic processes depend on rangeland ecosystems for some raw materials, some people depend on rangeland and rangeland products for their livelihood—but the two components are largely independent. If that's all we did, we would be like everyone else—nice frameworks, but tell us something we don't already know.

The contribution of this effort is in the integration of the ecologic component and the social and economic components. Three primary points of interaction were suggested—three points of integration between ecologic, economic, and social factors related to rangeland sustainability. Human impacts on the condition of the ecosystem are filtered through ecological processes. Ecosystem effects on human condition are filtered through economic processes and use of ecosystem services. Are these the "be all and end all" of a truly integrated framework? No, but they are a beginning.

Acknowledgments

This conceptual framework was developed in the context of the Sustainable Rangelands Roundtable (SRR). The SRR is an inter-disciplinary collaborative partnership involving federal and state resource management agencies, tribal governments, academia, environmental organizations, resource user groups, and professional societies working to develop and refine indicators of sustainability, based on social, economic, and ecological factors, to provide a framework for national assessments of rangelands and rangeland uses. Similar roundtable groups exist for Forests, Minerals, and Water. Development of this framework benefited from discussions and contributions by the "Integration and Synthesis Group," made up of representatives from all four of the Roundtables and from the H. John Heinz III Center for Science, Economics and the Environment which produced a report on sustainability and the state of the nation's ecosystems in 2002.

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A New Dimension in Evolution: Impacts of Human Consciousness on Sustainability—and Beyond

Charles M. McKenna, Jr.

"The whole future of the Earth…seems to me to depend on the awakening of our faith in the future."

Pierre Teilhard de Chardin (Letters to Mme Georges-Marie Haardt)
From de Chardin's The Future of Man – 1964

Abstract—*Starting with the concepts of the "noosphere" – the sphere of thought – and the evolution of consciousness developed by Pierre Teilhard de Chardin in the first half of the last century, we will introduce a hypothesis declaring the interdependence of the noosphere with global systems, and extrapolate to new perceptions that these concepts, and others which seem to flow from them, could contribute to transforming historic views into more hopeful visions of the future of human development and life on Earth. Just as mental outlook plays an important part in each person's life path, so also do the ideas and world-views – limiting or expanding – held by the global community affect the assumptions, boundaries, and decisions of the human family as we discover who we are in an ever-evolving existence of increasing knowledge and change. Approaching the issue of sustainability from an engineer's point of view, we quickly see, as stated in the U.S. Army Corps of Engineers' Implementation Plan for its newly promulgated Environmental Operating Principles, that it demands "…a new view of engineering that embraces the physical and biological sciences as well as those of the social and economic disciplines. …This shift in our understanding of engineering will be huge." The paper will discuss three additional hypotheses as part of the movement toward sustainability; "moving from passive-reactive to active-creative world views," "the breakdown of the false dualism between nature and human activity," and "human thought and breaking the glass barrier between historical world views and a new paradigm that opens the door to new opportunities," and will go on to discuss policy initiatives and technology development that would align with these new perspectives.*

Introduction

The Earth, an already complex system, has evolved a new dimension of complexity – the human mind. To the extent that human creativity has resulted in actions that are changing our planet, how do we transform our understanding of reality to meet the limiting challenge of this century – assuring sustainability of our integrated sociopolitical, economic, and environmental infrastructure? Mohamed ElBaradei, the Director-General of the International Atomic Energy Agency, stated in an essay published February 12, 2004 in The New York Times, "If the world does not change course, we risk self-destruction." Of course Dr. ElBaradei was referring to nuclear proliferation. But could his words not be taken to refer more generally to a broad range of human activity as it impacts our home in space?

Exponentially growing interaction between human thought and its products and Earth's life-sustaining systems have brought us to a critical juncture in history where we are forced to re-examine the lens through which we view our planet and our interactive role with it. Old world views provide an old lens – one constructed over the millennia – that has shaped our beliefs and the institutions formed around them. It may not be enough to simply 'do better,' or 'work harder,' at shaping our behavior through the old lens. We may, in fact, need a kind of transformation – to re-address the fundamentals of our existence and discover a socioeconomic, legal, and technological framework that places us in a holistic relationship with the planet and on a self-sustaining path toward adding value to our home in space.

Human consciousness presents an added dimension to the womb that gave it birth. Human consciousness is the new guy on the existential block and has evolved its ideologies and institutions during the transition out of a relatively unconscious condition. But that condition is changing. Even though, in geologic time, the evolution of human consciousness is relatively recent, the cumulative knowledge and activity created by that consciousness has produced a condition that is changing the game. And during this relatively rapid rise of reflective consciousness, some of the assumptions we imbedded in our ideologies and institutions no longer play well. We need to start thinking about what parts of our fundamental structure need to change so that we can successfully reverse the slide into unsustainable behavior.

As human thought results in activities that are now recognized as cumulatively impacting the planet, it seems logical that one approach to coming to grips with the problems resulting from thought's negative impacts is to scrutinize the institutions thought has evolved and the ideas that shape our worldviews, all of which provide a container for human thought and activity. The engineer in all of us wants things to work, and when we observe that they are not working, we need to go back to the drawing board and ask some fundamental questions. The health of the planet was not a consideration when most of our institutions were formed, and that introduces a potentially fatal flaw in those systems as they exist and are applied in today's world. How do we break out of the container formed by those flawed institutions so that we can rejuvenate them and bring them into line with a new reality while not diminishing their essential and lasting value?

Perhaps there is a connecting and supporting link between the respect humans have for one another and their respect for all life and the infrastructure that supports it. Is it possible that one could exist in its fullness without the other? I suspect not. In fact, it may be the mental separation of the two worlds that contributes to our seeming inability to view existence holistically.

Foundation Ideas Leading to New Views of Existence

In the 1970s and 1980s, James Lovelock described an interdependence between the various parts of Earth's living matter which he formulated as a hypothesis:

> *Journeys into space….. (have) provided a new insight into the interactions between the living and inorganic parts of the planet. From this has arisen the hypothesis, the model, in which the Earth's living matter, air, oceans, and land surface form a complex system which can be seen as a single organism and which has the capacity to keep our planet a fit place for life.* James Lovelock, <u>GAIA: A New Look a Life on Earth</u>, P. ix-x (1991)

And further,

> *Our (James Lovelock and Dian Hitchcock) results convinced us that the only feasible explanation of the Earth's highly improbable atmosphere was that it was being manipulated on a day-to-day basis from the surface, <u>and that the manipulator was life itself</u>.* James Lovelock, <u>GAIA: A New Look at Life on Earth</u>, P. 6 (1991)

Another perspective, focusing on the human dimension, was voiced during the first half of the 20th Century by Pierre Teilhard de Chardin in which he added concepts describing a new dimension in the life of planet Earth – human consciousness and the sphere of thought – the noosphere:

> *All around us, tangibly and materially, the thinking envelope of the Earth – the Noosphere – is adding to its internal fibres and tightening its network;* Pierre Teilhard de Chardin, <u>The Future of Man</u>, P. 137 (1962)

At the heart of global sustainability are two foundation concepts: the physiochemisphere-biosphere interdependence and organic wholeness suggested by Lovelock, and de Chardin's noosphere.

Combined, these two concepts form the ingredients of a physiochemisphere-biosphere-noosphere interdependence, one of four hypotheses presented here: that human consciousness has now advanced to the cutting edge of global evolution, and forms an organic whole with planet Earth. If the apex of human evolution is to be reached, we must choose to nurture the organic wholeness of inextricable interdependence between Earth systems and human consciousness. Just as Lovelock has pointed out the Earth's physical-chemical-biological interdependence, we now recognize a similar interdependence between these global systems and human consciousness, an evolving organic wholeness whose interwoven sinews become more complex and tightly woven as human choice and understanding move us beyond sustainability to new horizons.

Life's adventure has taken on a new dimension. Human consciousness is now at the cutting edge of planet Earth's evolution. Human consciousness has always depended on global systems. Starting now, a reciprocal dimension is added. The future of global systems, assuming the continued advance of value-adding human civilization, will depend on human consciousness. The evolutionary child must now assume a reciprocal role in the care of its evolutionary parent. Global interdependence has come full circle.

If we accept this hypothesis, two major developments are required:

- world views must evolve that are in harmony with our new reality, and

- institutions must evolve that are in harmony with our new world views.

Three additional concepts may help us negotiate this transition:

- moving from passive-reactive to active-creative world views
- moving beyond the false dualism separating nature and the humasphere – the sphere of human activity
- moving through a mental barrier between self-limiting historical assumptions and a new paradigm that opens the door to unlimited opportunity.

Moving From Passive-reactive to Active-creative World Views

Life is changing. A fundamental shift is occurring. And thus the hypothesis that human culture is moving from a passive-reactive state, to an active-creative state. From a physical-mechanical point of view, the active-creative state has been in evidence since humans first started making tools and changing the world around them. But from an intellectual-consciousness point of view, a cultural point of view, we are just entering the active-creative state.

We are beginning to recognize the quality and quantity of human impact, accumulated over time by geo-unconscious development; and are now realizing that we have entered a new paradigm – the active-creative state. So it's not a matter of creating a new paradigm, it's a matter of understanding the one we're in.

What is the active-creative state? It is the application of thought to creating the future, taking the actions necessary to produce desired outcomes. It includes recognition that human actions form a growing part of evolution, and that evolution has itself evolved. No longer can evolution be viewed as the apparently unconscious advance of complexification. It now includes a powerful new element – life's own product – human thought.

The complexification of matter which we have witnessed from the beginning of the universe, as we know it, to the present, is the outer view – the manifestation – of evolution. The complexification of matter manifests itself as the gradual movement of matter from seemingly simple forms to, over the eons, greater and greater complexification, leading eventually to life, then ever greater biological complexity until most recently, the evolution of the human mind – perhaps the most complex of all. But at the heart of biological evolution are so-called errors in cell reproduction. As every cell seeks to reproduce it goes through a series of checks, balances, and error corrections. But even with this incredible system of error avoidance, some errors get through. And thus, a cell is mutated. And from then on, the cell reproduces itself in its mutated form. This mutation then renders the owner a range of possibilities, with extremes ranging from disease and destruction to new capabilities not previously available. These mutations are then tested in the environment as to their enhanced ability to fit existing niches. And, as Darwin so intelligently theorized, those changes that rendered the owners more capable of adapting to existential niches around them, were better able to prosper and reproduce – thus extending the life of the mutation and tending to make it a permanent part of the chain of that species evolution.

Are there feedbacks from the surroundings to channel cell mutation? My understanding of science's opinion is that mutation of cells is entirely random – accidental. And if time and research continue to support that theory, it emphasizes an even greater change in evolution's course from unconscious and random-caused evolution to the consciousness-caused evolution that marks the active-creative state. For increasingly, as human activity changes the world around us, it creates new niches within which to live and explore, ever opening new doors to life and experience.

Thus we begin to see that human consciousness has introduced a new branch of evolution – one might call it Noospheric evolution – an evolution not based on cell mutation (although it may include cell mutation), but rather the mutation of ideas and reflective thought – ever opening windows of insight into, and deepening understandings of existence. And out of these mutated perceptions are created the adaptive tools needed by a changing planet.

As we conceptualize a new planet and create new niches, we are at the same time on an exponential path to learning how to engineer mutations in physics and biology that will allow us to do better in the world – and better fit the new niches – that we increasingly choose to design around us. So the full maturation of the new evolution in the active-creative state is to fully accept responsibility for our actions, understand that our destiny is to gain sufficient wisdom to increase its multi-dimensional profundity, and continually seek to add value to our integrated existential infrastructure.

The active-creative state opens the door to new responsibility, and to the vista of a holistic world that is at the same time hopeful, wonderful, exciting, boundless, liberating, choice-derived, and transforming. It is the <u>active</u> awareness that we are <u>creating</u> a new planet, and that this new planet will depend on the choices we make and the actions we take – together. It gives new meaning to the word 'freedom.' We can choose to seek a world that increasingly supports life, or we can choose to ignore the signals of the planet and live for short term gains based on an outmoded socioeconomic model. The choices we make today will exist as the foundation for future life. Is there a greater freedom? Is there a greater responsibility?

The difference between active-creative and passive-reactive states is like the difference between a contributing crew member and parasite passenger on Space Station Earth (Steve Young, EPA); crew members maintain – and even enhance – the enterprise; parasite passengers are simply along for the ride while collecting critical components from the Space Station which are vital to its health simply for their own personal gain. Conscious or not, the passive-reactive state maintains the condition for dismantling the enterprise.

For most of our time on this planet, from a consciousness point of view, we have behaved as souvenir-collecting passengers. We must now choose to become crew members of our home in space. And to prepare ourselves, we must change our views of existence and our role in it. And that brings us to the heart of the matter: changing our perspective – changing the way we think.

Let's first consider the absolutely revolutionary – and evolutionary – function of the human mind as it applies to the question of sustainability and our future. The evolution of the human mind has re-created the Earth as an open system. And that changes everything. In the past, the Earth has been viewed as a closed system. And, except for the energy and matter arriving from the sun and outer space, the physical resources of our planet are relatively fixed. But what about thought – creative intelligence – the human mind? Only one resource on the planet is relatively unlimited – creative intelligence and the human mind. And although this may be true for each individual mind, its potential can only be fully reached as many minds become connected in an open global network of shared information, dreams, ideas and creativity.

Overcoming a False Dualism – Achieving an Integrated View of Human-created and So-called 'Nature-created' Environments

One of the great obstacles to viewing our planet holistically is the false dualism we have created separating the world of 'nature' – the physio-chemisphere and biosphere – from the humasphere, the sphere of human activity and its human-constructed infrastructure. And thus the hypothesis that human activity and human-created infrastructure are part of nature and not separate from it. Viewed holistically, are the things built by humans any less 'natural' than the things built by 'nature'? Isn't human thought the product of nature's evolution? Haven't human activities and all the things resulting from them grown from the seed of human thought? And don't we consider the homes that animals build part of nature? Therefore, why shouldn't buildings, roads, ships, constructed wetlands, our scientific and engineering endeavors, our knowledge base, and all human constructions – the humasphere – be considered an intrinsic part of nature?

Perhaps we created this dualistic view because the things we produce don't look much like nature, nor, often, do they function well with it. And iteratively, they don't look like or function well with nature because, in the mind of the designer, they exist in separate worlds. As long as we hold the disjointed view we created, we can be assured of a continuing path away from sustainability. So until our dualistic view is abandoned, we will not be able to harmonize human activity with global systems. The mental partitioning of so called human-created and nature-created worlds produces a false dualism which limits and inhibits both our world view and the evolution of human thought and action.

One of the great proponents and leaders in the area of designing systems that recognize the interconnectedness between nature and what humans create is William McDonough, architect, artist, designer, innovator, and author. He is a strong proponent of the idea that we should do no harm, and that everything we build should be "food" for something else when its life has ended – thus the idea, and the title of his book, Cradle to Cradle: Remaking the Way We Make Things (2002).

One of the great myths of our world view is the false dualism we have created by separating ourselves and our tools from nature, thinking that all the things humans construct, the humasphere, are not part of nature, but separate from it. This outmoded view may be very understandable because we're so low on the existential learning curve and only now starting to develop technology and construct infrastructure that respects the environment on which it depends. One of the essential mental steps to creating a better world is to accept that everything we do is a part of the total system, that it is all part of "nature," and that all of it must be created to be integral with it. Everything must be developed to exist and function in harmony with the entire system. It is all one.

Breaking the Glass Barrier Between Historical World Views and a New Paradigm That Opens the Door to Unlimited New Frontiers

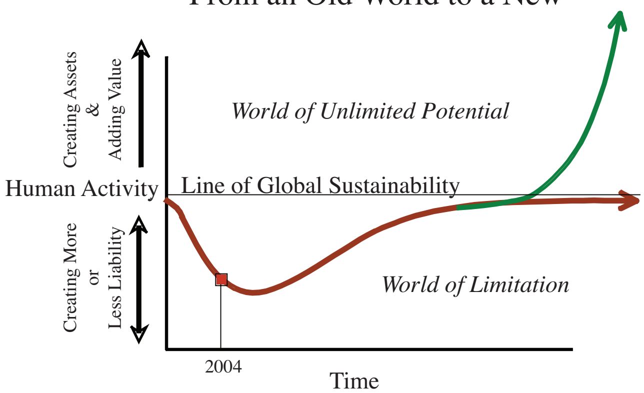
In the Figure below, titled In Thought and Action, From an Old World to a New, the area below the Line of Global Sustainability represents the box of current thinking. It represents the idea that we are ultimately limited in what we can do, and that the best we can do for the Earth is to limit the damage we cause. And within this box of limitation are three ideas, which are really three sides of the same limiting view. The first is the idea that we should minimize degradation of the global system in an attempt to approach sustainability, but that we can only approach it, never actually attain it. Although this view moves us in the right direction, it limits its goal to approaching sustainability, thinking, perhaps, that actually reaching it or moving beyond is not possible, and that true environmental sustainability can exist only in pristine wilderness.

The second is the idea that the Earth's system is so huge it doesn't matter what we do, the system will be capable of absorbing it. This second view has probably been human kind's prevalent view until recently, and may still dominate.

And the third is a belief that the whole enterprise will eventually wind down, so why worry about it. Just take what we want for today, and so what if we degrade the system to an ultimate state of inert uniformity, it's going to happen eventually anyway.

The Line of Global Sustainability is like the Glass Ceiling of Global Evolution, to be shattered by evolution's own product – creative thought. Breaking through the Line of Global Sustainability breaks us out of the mental box of limitation we have imposed on ourselves, and enables creation of an enhanced and unlimited system. The ability to do this forms the fourth hypothesis: that human consciousness, when it successfully integrates itself as an organic whole with global systems, is capable of evolving sufficiently to enable creation of an enhanced system with unknown limits. This hypothesis states that the noosphere, the interwoven sphere of human consciousness, recognizing itself as an organic part of global systems, will burst through the barrier of global sustainability created by our limited views, to evolve a world of unlimited potential – beyond sustainability. Movement toward this breakthrough initially manifests itself by efforts to limit the damage we do and to seek sustainability, but soon transforms to a paradigm in which we learn, not only to understand and maintain what has been created before us, but to build on the foundation of our inheritance by adding net value to the system and creating a new world of unknown limits.

In Thought and Action,
From an Old World to a New



A child may take many things apart, but can't put them back together again. As far as our relationship to our planet is concerned, and even our understanding of existence itself, we are still children – perhaps even embryonic. But as we begin to see the implications of our deconstruction of the environment, and see the threat our deconstructive actions impose on our life-support system, we will soon learn enough about the fundamentals of the system and our interactive role in it to, first, gradually stop the deconstruction and, second, begin to add value.

The key to changing human action is to change human thinking. The prevalent idea that some people are good and some evil – even, as held in some circles, that all people are born with so-called original sin – is one of the flawed conceptual views held in the box of limitation. This view must be replaced by a more hopeful vision – a view that good people can have bad ideas. Moving from one world to another is, first and foremost, a matter of changing our ideas, the way we think, and the way we view the world.

Essential drivers for moving from an old world to a new are love, trust, and hope – perhaps the most powerful, yet fragile, elements of our existence. In themselves, they may not be fragile. But our connection to them is. And it is our connection to them that gives embodiment to their existence, and in essence, to ours.

Policy Supporting a New World

Each person contributes something unique to the fabric of our planet. In a world in which human action is changing the planet, and realizing that human action results from human thought, it should be one of the great goals of our global community to create equality of opportunity through policies that strongly support sustainable technology research and development, and enhance educational, social and economic opportunity for all.

Economic Policy

For many, our economic system has been highly successful. However, it is an evolving system, and in its current state, severely flawed by its insensitivity to primary values in two major areas. The first, and perhaps most discussed today, is its insensitivity to some of the most valuable content on the planet – the underlying environmental infrastructure upon which our economic system – and everything else – depends. Some of our wiser policy makers have equated a healthy environment with a healthy economy. The trick is how to bring the value of services supplied by our environmental infrastructure into the economic equation. Right now, it's off the table. As Al Gore pointed out 12 years ago in his book, <u>Earth in the Balance: Ecology and the Human Spirit</u> (1992), our measure of economic value in the gross national product includes largely the things we trade and manufacture. It doesn't include the health of the biosphere and our "natural" resources. It doesn't bring eroded soil, stripped forests and lost species, lost wetlands, polluted atmosphere, or depleted water systems into the value equation. And as long as individual choices are based on wildly incomplete value information – both short and long term primary-value dynamics – then we are in serious jeopardy and operating unsustainably.

The second area in which our economic system is flawed is its relative disregard for the human condition. In a world with a view toward unlimited enhancement of life on the horizon, the incredible wealth imbedded in an integrated global human consciousness reaching toward its full potential is arguably the most valuable asset on the planet. Because we are concerned about the future of life on Earth and its relationship to the causative impacts of human activity, it is crucial that our utmost and most focused efforts go toward developing an ever-growing knowledge base, coupled with supportive economic and social environments, so that we can move beyond denial of the obvious and ignorance of the knowable to a condition of hope and creatively-constructive behavior. This will be necessary if we wish to create a sustainable world – and then move beyond it to the world of our potential.

Our economic system needs re-evaluation, and modifications or new systems explored. The current system is powerful in motivating activity where it increases the relatively one-dimensional bottom line and the lifestyles that money can buy. Unfortunately, it, along with all our other institutions, was evolved when the impact of human activity on the planetary system was not a consideration. The community of nations – all people – must come together to address this problem. This will only happen in democratic systems effectively enabled to overcome the narrow, short-term interests of current power structures. All systems are currently operating under disabling doctrines based on flawed assumptions, effectively denying the existence of their actions' short- and long-term impacts on the planet, and denying responsibility for the results.

There are many good things about the current system, especially as modified by progressive democratic societies with moderating policy for the common good. Therefore, attempts at changing current systems must assure that they substantially maintain current benefits and protections. However, change is needed. Recent regressive economic trends, in the U.S. and elsewhere, have led to expanding poverty, underemployment, and growing unevenness in the distribution of income and wealth, both locally and globally. Add to this the recent retreat from environmental protection, and we face an urgent need to address the question of modifying our economic system, either through fundamental change, or by policy which moderates the hard edges created by short-term, narrow, and irresponsible perspectives. Essential in this effort is the need to incorporate the value of the planet's life-support engine in our calculations of value, perhaps, as a goal, replacing gross national product with gross global value as the model for measuring progress and wealth. And since, under the hypothesis presented here, human consciousness is now a central part of the planet's life-support engine, it is critical that we now include all dimensions of human health and enhancement in the calculation of value.

To the extent possible, and certainly as a goal, we need to build an incentive system that will make enhancement of the environment, the creation of a holistic view of what we do, and adding value to our integrated social, economic and environmental infrastructure a natural response by all players. Daniel Janzen of the University of Pennsylvania, in his article, <u>Gardenification of Wildland Nature and the Human Footprint</u> (1998), has suggested that because the local and commercial forces are so intense, the best, and perhaps only, way to protect the biosphere is to involve the public and commercial interests by actively creating wildland nature as a global garden to be carefully used and increasingly loved by the local people. Dr. Janzen says it best. Here are his third and seventh through tenth paragraphs.

> *Why can't the wild tropical species be left "out in the wild" to fend for themselves? Because the wild is at humanity's mercy. Humanity now owns life on Earth. It plans the world, albeit with an unintended here and an uninformed there. Until the Pleistocene, not more than a few thousandths of one percent of the earth's surface was ours. Today it all is. If we place those species anywhere other than in a human safe zone, they will continue in their downward spiral as grist in the human mill, just as they have for the past ten thousand years.*
>
> *Shelter is much of the reason why the world's biodiversity is in deep trouble. Humanity and its domesticates - those ever-present extensions of the human genome - are genetically and culturally antagonistic to most wild biodiversity. It is part of the "enemy" and always will be. "Shelter" is largely shelter from the wild - be it monkeypox and rice borers, lions and wolves, or forest that shades pasture grasses and bean plants. I cannot imagine how to hide or integrate a hundred thousand species of wild organisms, and all the things that they do to and with each other, in someone's roof or in the Integrated Pest Control of an orange orchard. My goal is co-existence with wild nature, not its exclusion unto extinction.*
>
> *The acquisition of sustenance – feeding – appears to be the only hopeful refuge for wildland biodiversity. At first glance this seems an unlikely route. We are hunters and gatherers. We eat wild biodiversity, and we do all we can to help our chromosomal extensions eat that which we cannot eat. A bean plant is a green machine that grows directly out of our chromosomes, sitting where wild biodiversity once was, another mouth for sun and minerals.*
>
> *However, gardens are forever. Gardens are mushrooms on horse manure and cats under the kitchen table. Gardens are beehives and cows, and sixteen varieties of rice growing in one rainforest clearing. Gardens are hydroponic tomatoes and vats of whisky-spewing yeast. Kids do it, agroindustry does it, grandparents do it. Bushmen do it, astronauts do it, and Pleistocene Rhinelanders did it. And we will all still be doing it 10,000 years from now. The garden is a somewhat unruly extension of the human genome.*
>
> *So, how do we hide 235,000 species in the garden? By recognizing and relabeling wildland nature as a garden per se, having nearly all of the traits that we have long bestowed on a garden - care, planning, investment, zoning, insurance, fine-tuning, research, and premeditated harvest. And this leads to the question of absorption of humanity's omnipresent footprints.*

In some form or other, humans need to take charge of maintaining the biosphere, and all the services it provides, because, as Dr. Janzen points out, "…the wild is at humanity's mercy. Humanity now owns life on Earth."

Although individual internal motivation based on knowledge and understanding is most efficient, external motivation from policy and law is an important tool and must also be used – at least until the dimensions of our new existence become part of our genetic consciousness – in two different ways; one, creating incentives for positive behavior; and the other, consequences for negative behavior. Of these two policy paths, positive reinforcement is more efficient, because it also stimulates a change in thinking and opens the door to creative solutions. Perhaps it's a little like creating performance specifications for a product or service, as opposed to writing out how to do something in great detail. The latter takes away the potential for creative solutions and reduces the performer's responsibility for a successful result. But sometimes the more legalistic form is necessary – witness the laws against segregation which forced a different behavior, exposing many to a different experience and leading some to changed views.

Monitoring science and technology will play a key role in developing human understanding of the essential values in the biosphere we depend on. A very interesting article by Daniel Janzen, Now Is the Time (2004), describes a potent and intimate means of both monitoring and stimulating interest in the planet's biosphere, using existing technology to place a small bio-identifier cell-data phone in the hands of the public. To give you an idea of what he is talking about, here is the second paragraph of his paper:

> *Imagine a world where every child's backpack, every farmer's pocket, every doctor's office and every biologist's belt has a gadget the size of a cell phone. For free. Pop off a leg, pluck a tuft of hair, pinch a piece of leaf, swat a mosquito, and stick it in on a tuft of toilet tissue. One minute later the screen says Periplaneta americana, Canis familiaris, Quercus virginiana, or West Nile Virus in Culex pipiens. A chip the size of your thumbnail could carry 30 million species-specific gene sequences and brief collaterals. Push the collateral information button once, the screen offers basic natural history and images for that species – or species complex – for your point on the globe. Push it twice, and you are in dialogue with central for more complex queries. Or, the gadget, through your cell-phone uplink, says "this DNA sequence not previously recorded for your zone, do you wish to provide collateral information in return for 100 identification*

credits?" Imagine what maps of biodiversity would look like if they could be generated from the sequence identification requests from millions of users.

As Janzen's idea points out, monitoring science and technology must not simply focus on geographic views of the planet, although that will be one very valuable aspect. It is critical that in developing our monitoring science and technology, we develop it as part of a system that provides us the means to monitor and evaluate the relative health of all systems making up our life-support engine: the physiochemisphere, the biosphere, the noosphere, and the humasphere (the sphere of human activity) – along with all their connections and interactions – to create both static snapshots and dynamic models of the system.

The endeavor to reach sustainability, and eventually move beyond it, is the ultimate engineering enterprise – an Earth engineering enterprise. Human-caused planetary change is currently underway, but largely denied and un-acknowledging, especially by those who think their power and wealth would be threatened by the changes demanded by its recognition. Future life on this planet demands that these people and institutions now acknowledge human-driven climate and global change, take responsibility for it, and correct course. No greater betrayal of future life on this planet exists than the continued campaigns of denial and misinformation surrounding the subject of human-caused global change by those who see their narrow social, political, power, and profitability interests affected by a change in course.

Today, we are largely in denial of the planetary impacts of our actions. And as they relate to the enduring health of our planet, our activities are piecemeal and haphazard. Perhaps this is true, in part, because our ideologies and institutions have not given us the creative space to think in these terms. That must change. Humanity must accept responsibility for its actions, recognize the holistic nature of our system, and become planetary engineers.

Perhaps one way of doing that would be to develop the ability to construct a project assessment scheme which would give value to all the elements of a project's impacted area, and then evaluate the net value change with each project option. Conceptually, this would be similar to the National Environmental Policy Act (NEPA) process, but enhanced by including a value for the biosphere and the noosphere of the project-impacted area, as well as the interrelationship and influences over time of the immediately impacted area with its boundaries and the areas beyond. This would move us toward a global approach in value and impact assessment as our experience and understanding grows. It would also introduce the concept of evaluating the fundamental worth of the biosphere, the noosphere, and all their supporting systems as part of any analysis of asset allocation or reallocation.

My sense of it is that there is gold in here somewhere. Sometimes, when looking at existing problems and their potential solutions, they are seen from a status quo position wherein the change seems horrific, impossible, or unrealistic. However, if visualized from the other side of the problem, the problem may appear not only to have been resolved, but surprisingly, to have opened a whole treasure chest of opportunity not originally envisioned.

In that regard, the following concept is offered to illustrate a point, and is not assumed to be applicable without a great deal more consideration and analysis. This concept involves creating an integrated planetary value system to replace the current, much more narrowly focused, property valuation system. As an example, let's consider a house on a half acre of land valued under the current system at $100,000. Now, under a new integrated planetary value method, its value as a contributing part of the life-sustaining global system is added. Clearly, when viewed separately, the value of the planet's life-support engine dwarfs that of the humasphere, the products of human activity, i.e., everything counted in the assets of pre-existing global economic systems. Thus, using the integrated planetary value concept, a property's potential to add to the planet's life-support engine adds a value that dwarfs its previous evaluation under the current system. Let's say, for purposes of illustration, that the property is valued at 100 times its previous value, based on its condition relative to its potential contribution to the global system, and is now valued at 10 million dollars. And what does that do? Does it increase total taxes? Conceptually, no, because all property would go up in similar fashion, so the tax rate would go down to about $1/100^{th}$ of its previous value, and property taxes, on average, would remain about the same. However, to create a built-in incentive to increase the property's contribution to the planet's life-support engine, taxes would be based in part on an inverse relationship to the biospheric contribution of the property. If property condition was valued at 100 percent of its potential contribution to the planet's life-support system, the tax would be lowest, increasing as its valuation decreased.

Under the integrated planetary value system, property assets would rise dramatically, giving communities much greater financial strength. It would also tend to flatten the global distribution of wealth, so that countries currently considered poor would find themselves with much higher capital assets and proportionately better situated to maintain and develop their social and economic worlds. It would also seem to provide built-in motivations to protect planetary life-essential assets, both from its inverse tax relationship, as well as from its function in the marketplace. So the same tax and market forces that once tended to ignore and diminish our natural resources, would now be working to protect them. What would have changed in the serious consideration of such a concept are the perspective and the underlying assumptions of our value system, bringing them from an outdated and mythical belief system (that the environment is so huge it can't be significantly impacted by human activity) into alignment with the reality of today's world.

Now let's take this analysis several steps further by adding not just the value of the biosphere, but also the value of everything else, including the noosphere. How does each person on the planet relate to the total system in a constructive way? And how do we engineer a system that uses the continuing health of all systems as a motivating force in the dynamics of the one system increasingly impacting all others – the noosphere?

Social Policy

To enhance the noosphere it will be essential to dramatically alter our view of individual worth. If we were to consider each individual on the planet an irreplaceable facet in a global jewel, and if we then treated each person with the respect due their inalienable worth, we might find ourselves living in a different world. This would be engineering at its new core.

Approaching the issue of sustainability from an engineering perspective, we quickly see that a new view of engineering is demanded, one that embraces the physical and biological sciences as well as those of the social and economic disciplines. This shift in our understanding of engineering will be huge.

Because humans are part of our planet's life-support system, respect for it is directly connected to the respect we have for one another. This leads us to certain imperatives, including new initiatives in social equity that will raise opportunities enabling every person to experience a life of dignity and self-respect. These imperatives would include modifying our laws and policy to make it the right of every person to earn a living wage for themselves and their families. This effort is not only a matter of civil rights. It would also enhance the pool of human creativity, enabling everyone to participate, as Steve Young of the Environmental Protection Agency has said, as crew members instead of simply passengers on our home in space.

Population is often considered a major problem in reaching sustainability. Yet, although certainly a factor, it is a dependent variable – dependent on ideological, cultural, social, and economic factors. This makes it a very complex and divisive issue. Lester Brown and Mark Hertsgaard, in their excellent books Eco-Economy and Earth Odyssey, respectively, discuss the issue of population, but also point out that much of the environmental impact – perhaps most – due to human activity, comes from countries with the most controlled populations, i.e., the western developed world. And they and others point out that the United States, with about 5 percent of the world's population consumes about 25 percent of its resources. And it's that consumption – and perhaps the way it's consumed – that most powerfully relates to the levels of human impact on the global environment. So, although population is certainly a factor, the real concern is more related to human activity than simply population.

Wealthy nations, those with population control well in hand, often look at population control from their own perspective, viewing areas of the world with booming populations as somehow a threat to their share of the pie and a burden on global systems. Yet these motivations will not be sufficient to affect the changes they seek. Instead, it is the motivation within the populations at issue that will bring about meaningful change. The factors driving uncontrolled population growth, and the impact of those factors on those very populations, are at the heart of the matter and must be the focus of attention as choice-enhanced hope for the future unfolds. For if our future civilization depends on the maturation of the noosphere, not as driven by external imprimatur, but as internally motivated by the inspiration of each individual – interlaced in an increasingly radiant global jewel – then to the extent that the aspirations of these populations are thwarted by their own or other's world views, the path to maturation will be extended.

The path toward greater hope insists on respecting the lives of all populations, including our own, and assisting them in moving forward, in ways they choose, toward their full potential, all the while valuing individual identities and helping all build an increased sense of self-worth. Until the cultural and ideological barriers to action disappear, both within and outside all populations, the movement through cultural and ideological change cannot be successfully negotiated.

Underlying negatively impacting types of human activity are world views, ideologies, and institutions developed in the past when human impact on the global system was not a recognized consideration. Although local impacts were evident, the impacts were viewed as strictly local. And without the experience of a global view, these impacts seemed insignificant and the potential for their expansion under the power of human technology and development went unrecognized.

So, as mentioned previously, the solution lies in taking a multi-pronged approach – working on the long-term issues of changing world views and ideology through deepening our understanding of global systems, along with the more direct approach of providing legal and policy incentives to do the right thing to the extent we know them at the time.

Unfortunately, the forces of our narrowly focused economic system have created incentives that make widespread development and distribution of accurate information on the state of the planet very difficult. In a recent book by Ross Gelbspan, Boiling Point: How Politicians, Big Oil and Coal, Journalists, and Activists Have Fueled the Climate Crisis – and What We Can Do to Avert Disaster (2004), the first sentence of his Preface reads, "It is an excruciating experience to watch the planet fall apart piece by piece in the face of persistent and pathological denial." And in an August 15, 2004 New York Times Book Review article on Gelbspan's book, Al Gore writes the following in four contiguous paragraphs:

> *Gelbspan's first book, The Heat Is On (1997), remains the best, and virtually only, study of how the coal and oil industry has provided financing to a small group of contrarian scientists who began to make themselves available for mass media interviews as so-called skeptics on the subject of global warming. In fact, these scientists played a key role in Gelbspan's personal journey on this issue. When he got letters disputing the facts in his very first article, he was at first chastened – until he realized the letters were merely citing the industry-funded scientists. He accuses this group of "stealing our reality."*
>
> *In his new book, Gelbspan focuses his toughest language by far on the coal and oil industries. After documenting the largely successful efforts of companies like ExxonMobil to paralyze the policy process, confuse the American people and cynically "'reposition global warming as theory rather than fact,'" as one strategy paper put it, he concludes that "what began as a normal business response by the fossil fuel lobby – denial and delay – has now attained the status of a crime against humanity."*
>
> *I wouldn't have said it quite that way, but I'm glad he does, and his exposition of the facts certainly seems to support his charge.*
>
> *Gelbspan also criticizes the current administration, documenting its efforts to "demolish the diplomatic foundations" of the international agreement known as the Kyoto Protocol, and describing its approach to energy and environmental policy as "corruption disguised as conservatism." Again, he backs up his charge with impressive research. Moreover, his critique is far from partisan. He takes on environmental groups for doing way too little and for focusing on their own institutional agendas rather than the central challenges.*

If Gelbspan is correct, and the narrow interests of industry, governments, and a corporately-dependent media are intentionally, or even unconsciously, altering or withholding important information from the public, this is indeed a crime against humanity. And government's involvement in this activity, makes it especially culpable, since its single most important mission is to serve the common good, and not the narrow interests of the powerful and the "haves and have-mores," as our president labeled the wealthy while addressing those he calls his "base" in Michael Moore's documentary, Fahrenheit; 9/11.

We must seek to develop policies that will lead to better understanding of our planet's life-support engine, and develop the knowledge base that will allow us to make decisions based on their ability to add net value to the integrated global economic, social, and environmental infrastructure. No longer can truly democratic systems tolerate being effectively dominated by those who would deny or mislead, consciously or unconsciously, to serve their narrow self interests where these are in conflict with a higher purpose – the health of our planet and of civilization itself. On this we must insist. And the work required to attain the needed knowledge to satisfy this mission must be a first priority. The health of our planet's life-support engine is our most urgent global issue. The war on terror, although related and a clear manifestation of our dangerous and unhealthy state, is dwarfed by it.

Our world is precariously balanced – socially, economically, environmentally and technologically – between a creative and unlimited future, and disaster; and mostly because we have not yet truly grasped what is taking place around us. We must move toward a world where EVERY person counts, is respected, and has the opportunity to find their own special genius, not only because it's the right thing to do, but because it's essential. We must create a world of hope out of a vision that recognizes human creativity as having reached the cutting edge of evolution, thus making human consciousness the most essential resource and critical asset of a sustainable civilization. And if the goal is to reach beyond mere sustainability of our economic, social, and environmental infrastructure – not only reducing the damage we do, but also adding long-term net value to all life and the life-support engine of our home in space – then the true capital of the enterprise becomes an ever-expanding, ever-deepening, and ever-enriching of each individual's consciousness. Because we are all in this together, all people must be included. No one can be left behind.

A vision for moving toward a sustainable world includes the following, originally written by the author as part of the vision statement for the U.S. Army Corps of Engineers' Environmental Operating Principles' Implementation Plan:

- a realization that human activity is significantly changing our integrated economic, environmental and social infrastructure;
- that we can consciously choose to shape these changes so that they add net value;
- we define changes that add net value as changes that interact with the integrated system in such a way as to cause positive responses, not only at the time of the initial action, but also in a manner that catalyzes future positive actions;
- that the most fundamental value of the integrated infrastructure is its ability to sustain and enhance all life;
- that the enhancement of life, given the influence of human thought on the global system, will increasingly depend upon the evolution of human thought and understanding; and,
- that the nurturing and development of human thought requires a social and economic environment that enhances human dignity, opportunity, freedom, and equity for all people on this planet.

Education

Education is particularly important in shaping the noosphere. My vision for future education would be a system integrated more holistically into the life of the community. Regarded as a critical investment, it would stimulate the highest regard for those involved, and garner necessary resource allocation to allow it to function as a premier sector in society.

Today, especially in the United States, the issue of guns in school, children killed by other students, and an ever increasing prison population all point to system failure. Somehow, the energy that now goes into rehabilitation and attempting to pick up the pieces of broken lives must be moved to the early days of each individual's life experience, in the form of investments in a child's sense of self worth, leading to the development and release of their creative potential. At each moment in a child's development there must be available a selection of niches within which the child can test its experience and explore its potential. To accomplish this, an environment must be created that rewards the student not only for their own success, but also for encouraging others.

Making self-worth and social acceptance a high-priority goal of our education system may be accomplished most constructively by policy creating internal motivation within each child. Students relate socially with teachers and other professionals in the system, often quite importantly, especially for students from dysfunctional homes. However, their most intimate and important social contacts are with other students. Therefore, it is imperative that incentives be created encouraging each child to take responsibility, not only for their own development, but also for being a positive force in the development of other students within their circle of influence. In wildland, when a carnivore sees another animal injured or weak, it chooses it for its next meal. Unfortunately, our schools are often allowed to function as a wildland. Students often pick on other students seen to be weak, insecure, or a threat to another students influence, thereby tending to create further physical and psychological damage to an already damaged child. Experienced teachers and school administrators recognize the problem of child-to-child abuse, but are not able, and in some cases not willing, to use their time to correct this situation.

A student-motivated system should be created to efficiently deal with this important issue. To do this, perhaps an investment plan could be developed in which each student would be rewarded for his or her contribution to the psychological and social wellbeing of other students, especially those demonstrating particular need for social and self-image enhancement. This investment plan could be structured in two ways, one consisting of a range of monetary and non-monetary rewards to be given the student for near-real-time recognition of their efforts, and the other being a more long-term accumulation of assets or credits toward future programs or educational opportunities. This paper is not the place to work out the details of such a program, but creative teachers, parents, administrators and legislators could quickly work out a myriad of options for both these investment forms.

Funding for the Student Motivation Program could eventually come from the money currently invested in picking up the pieces of broken lives, i.e., prison costs, drug rehabilitation costs, and others that could be directly related to disabled starts in life. In the beginning, since it would not immediately affect the cost of currently broken lives, the funds would need to be considered an investment in the future. But in a generation, the reduced costs for prison and rehabilitation would pay for the investment. And not long thereafter, the added value of creative and capable people, who might otherwise have been a drain on community resources, would be adding far more value to the community than the cost of the Student Motivation Program.

In a more traditional vein, it would be beneficial to immediately initiate an internationally organized education effort targeting all ages and aimed at imparting an understanding of the interrelatedness of our global systems. This effort would present to students, as well as the general public, the most recent information on the dynamics of our global environmental infrastructure. It would be essential that, as for all education programs, it would be factually and scientifically driven, and not politically or ideologically. It would also be important that new information from the scientific community be integrated into the program quickly, relying heavily on the internet, with local teachers using subject matter from the internet in local classrooms and homes. This effort would include making broadband internet access globally available. Global broadband internet access would facilitate other communication and education efforts essential for other aspects of connecting a global community.

Sustainable Technology—Research and Development

Until now, we have lived in a condition where the almost-universally held worldview is that there is not enough to go around, if fairly and justly distributed. This produces both real and mental climates of scarcity in which humans resort to violence to solve their problems. It also produces a destructive dilemma in human thought. Where most of our cultures and ideologies, at least in part, teach us to treat others justly and fairly – even with love – our condition forces us into struggles for survival, whether legitimate or otherwise, that violate our inner sense of being, thus tending to force a distortion of our doctrines and ideologies in an attempt to justify our conflicting behaviors. Our economic system reflects our current reality and state of mind by pitting one group against another to see who will win – who will survive. Violence and distrust result from the struggle over limited resources between people, communities, cultures, corporations, nations, and coalitions. Clearly, it would be desirable to move beyond this state. To do so will require critical advances, not only in the way we think, but also in science and engineering.

Technology, at this juncture, is having both beneficial and negative consequences. Scientists and engineers, coupled with the entrepreneurial genius of modern commerce, have developed technologies liberating and giving hope to many. The advance of technology is here to stay. It is one of the expressions of the noosphere. At the same time, some of these technologies, and especially the way they've been applied, have severely impacted the life-support engine of our planet, as well as being used to limit the ability of many to improve their condition, especially where that advance was viewed as producing undesirable competition or a threat to controlling societies and their hold on power and resources. Again, it is clear that if reasonable alternatives were available, it would be desirable to behave in ways that enhance life for all on this planet.

If we yearn for a world where sharing and cooperation take precedence over hoarding and competition, then we need to begin to create that world. To reach that world, the place to begin is, first, in our minds, by tearing down the mental barriers that tell us it can't be done; and second, in our policy and investment decisions, placing high on the list research and development in technologies that could eventually lead to enhanced lives for all people and a healthy planet for future generations. Two technologies, information and energy, seem critically important for creating a significantly larger global "pie," large enough so that all humankind can share in it without leaving some people out, while at the same time adding value to the planet's integrated social, economic, and environmental infrastructure.

Information Technology and an Expanded Knowledge Base

The development of information technology seems intrinsic to development of an ever-deepening knowledge base critical for the transformation we are discussing. It is through accurate information emanating from an expanding knowledge base that we grow in understanding and are enabled to change the way we think. This differs from misinformation that, in the quest for narrow personal or organizational short-term gain, is propagated for purposes of misleading minds.

Information technology includes the total construct and condition within which information is born, communicated, used, and responded to. One of the greatest examples of information technology is the Internet, created by the Department of Defense as the Arpanet, and critically supported by Al Gore in legislation that enabled its transformation to the Internet.

Broadband high speed internet connectivity for all people could evolve a higher level of participatory democracy, greatly expanding the choice of options and opening up the flood gates of human creativity and participation in an evolving global community tied together with a common thirst for freedom, democracy, and the rule of law.

The ability to create, share, and access data and information and to connect minds in a global network is key to evolving the knowledge base needed for constructive social, economic, technological, and environmental evolution, and to realize true, informed, democracy.

A hopeful future depends on the evolution of human consciousness, and information technology is a key ingredient. Healthy development will only be fully realized in a decentralized, open, and interoperable information environment. Constructive social evolution depends on good information and the means to access and use it. The essence of democracy is that people freely choose their government representatives. That choice is only truly free when it is based on accurate information. Therefore, lies, disinformation, and character assassination are deep betrayals of the democratic principle and of all humanity. They are a betrayal of democracy and the people democracies represent. Intentional disinformation is a tragic dishonor in a world that is increasingly information dependent. The health of the noosphere and all global systems is dependent on our ability to make choices and decisions based on the best and most accurate information our knowledge base can produce.

The goal for democracy, for its health and even its existence, should be the enhancement of each individual's experience and awareness of reality. The ability to develop, access, express, and use accurate information is the ultimate freedom and the heart and power of democracy, and is essential to achieving sustainability and reaching beyond to the enhancement of an integrated global sociopolitical, economic, and environmental infrastructure. A healthy future is dependent on true democracy and the power of free people armed with accurate information.

The sum total of human activity on this planet – the humasphere – is now a significant player in the Earth's evolutionary process. To productively actualize this role, we need to think of ourselves and the planet holistically, not as separate entities. Nature and the things humans create are not separate. As discussed earlier, they may look different because we're in a transitional mode. But to mentally maintain them as separate entities seems to me to be a false dualism that will keep us locked in denial and unsustainable behavior.

Once we accept responsibility for our relatively new role in the evolution of our planetary system, we will be able to move forward to a positive future built on creative action and a sense of hope for future generations. But the transition it requires and which we are confronting now demands major changes in our thought processes. And these changes can only occur if there is open access to an expanding and interoperable knowledge base that is based on science, not ideology, and is designed to facilitate its evolution as an accurate depiction of existence.

It is critical that we understand as soon as possible both the impact of human thought and action on our integrated infrastructure and the time constants of global change. Humans are now at the cutting edge of our planet's evolution, and decisions based on good information are essential if we are to attain – and then move beyond – global social, economic, and environmental sustainability.

The process of raising people's consciousness of the long-term consequences of our actions is not an easy one. But things can happen when we least expect them, and enlightened leadership supporting good policy based on science, not ideology, can play a significant role.

Somehow we must bring the true costs of our actions as they impact the health of our planet's life-support engine into our decision-making process – whether it's purchasing a car, choosing mass transit over use of the automobile, or choosing which technologies to use and to invest in. And this will all take time – time to evolve new worldviews and supporting policy. Let us hope that we can accomplish this transition smoothly, maturely, and quickly.

We are all in this together. The biosphere has always been a shared global system. And now human consciousness is an increasingly shared and global phenomenon. Witness our connections through the internet; an increasingly open, interoperable, and inclusive information network; the global marketplace; and the ability to rapidly reach any location on the planet.

We are all tied together in an incredible enterprise. And until we liberate ourselves from the mental prisons of outmoded mythological and institutional belief systems that have grown up over the millennia, none of us will be truly free. And since none of us will ever have a complete grasp of reality, the process of liberating ourselves will be ongoing throughout human existence. However, there are crucial moments in that process, and we are in the midst of one now; a time when the impulse of rapid growth in human technology and development is beginning to make profound impacts on our environmental infrastructure; and when our current world views and belief systems, and the ideologies and institutions that have grown up around them over the millennia, are not sufficient to meet the challenge.

Energy

Sane development of energy technology is essential to a sustainable planet. Because of their insanely continuing lobby and propaganda campaign promoting use of carbon-based fuels and deceiving the public into thinking that human-induced global warming and the carbon dioxide-induced greenhouse effect is non-existent, or at best theory, the narrowly-focused coal and oil interests, backed by a big-oil influenced Administration, are leading the planet to a catastrophic edge. Human-induced global warming, a view supported by most of the respected scientists in the world who have studied the issue, is an extremely serious problem whose change of course will require an immediate and dedicated global response in the form of research on efficient solar energy production, efficient extraction of hydrogen from water, and the development of a distribution infrastructure for its use as fuel, most importantly in transportation. This includes research on solar cell efficiency, and development of desert-based solar-cell farms around the planet that could produce energy for direct use in electrical power grids and to extract hydrogen from water to be used as fuel for transportation systems and remotely-sited power plants. Also to be included are research on new forms of extracting solar energy through use of bio-organisms and other means, expanded use of wind power, expanded research to develop clean nuclear fusion, and continuing research on all forms of non-carbon-based renewable energy. Moving forward with any form of energy from biomass should be questioned closely because of its impact on soil, local and global agriculture needs, and the birth-to-death economics and environmental impacts of its use, including the fact that it is carbon-based and its use is likely to exacerbate the carbon-dioxide contribution to global warming.

Melting ice around the planet needs special attention. Ice is one of this planet's great climate stabilizers. It absorbs energy as it melts, and it gives off energy as it freezes. But because it undergoes a phase change from solid to liquid and liquid to solid, the energy stored or given off is large compared with the energy to change either ice or water one degree in temperature. Its loss, now on-going at an unprecedented rate, is not only a clear indication of global warming and a potential problem for those who will be affected by rising sea-levels in years ahead. Perhaps most critical regarding its loss is its potential impact on the planet's ability to maintain temperature stability within the temperature ranges needed for support of human civilization and the portions of the biosphere on which it depends. The fact that there is net melting of ice indicates that more energy is coming into and being generated within the global system than is radiating out. As long as there is significant ice mass still available to melt, thereby absorbing some of this excess energy, there will be a tendency to hold climate and temperature change to lower rates of increase than would otherwise be the case if there were no ice. This is not a reason to delay for one minute the effort to affect a solution to achieve a net energy balance for the planet, but rather, a reason to accelerate our efforts while the ice-cushion is still largely intact.

Although the ice and global warming issues are only part of the sustainability issue, they touch all of them. And for this reason they are clearly at the leading edge of concern, primarily because of their power over all life, and because reversing their direction is so intrinsically bound up with the inability of current institutions and ideologies, evolved in another world, to deal with them. The writing of Ross Gelbspan, discussed earlier, covers some of the key issues surrounding institutional resistance to meeting this challenge.

Moving Toward Sustainability: Seven Principles—A Guide for Individuals and Organizations

As a guide for individuals and organizations who wish to participate in the quest for a sustainable world, the seven Environmental Operating Principles, promulgated recently by the U.S. Army Corps of Engineers, form an excellent starting point. They are included here accompanied with the author's interpretive text broadened to include all parties. Unlike the Principles (in bold print) which reflect the Corps' official position, the text under each principle, as well as all other portions of this paper, express the views of this author and do not represent official Corps views.

The seven Principles were approved for public release in the spring of 2002 by the Corps' 50th Chief of Engineers and Commanding General, LTG Robert Flowers, whose leadership and vision made them possible. The author was pleased to have been included as a member of the team that drafted the Environmental Operating Principles, along with its Doctrine and Implementation Plan.

Principle 1: Strive to achieve Environmental Sustainability. An environment maintained in a healthy, diverse, and sustainable condition is necessary to support life.

Striving for Environmental Sustainability is striving for life itself. The environment is our source for life, the font of biological evolution and the womb of evolutionary sustainability. Striving for its sustainability is simply saying that we want life, and the process of evolution, to continue – to be sustained.

Environmental Sustainability is the dynamic condition under which the Earth's systems function together in a self-regulating and self-regenerating manner, maintaining a healthy interdependence while providing the essential ingredients for sustaining all life forms and serving as a platform for the evolution of human thought, for all time.

In this definition of Environmental Sustainability, we must place ourselves – both as individuals and as organizations. We are part of this planet's environment. And the strength of our participation in its evolution is growing exponentially. What we create becomes part of the environment. And thought – what we think and the thought processes that lead to human-borne change – is now becoming an ever more powerful evolutionary force for the entire system.

Therefore, to grapple with Environmental Sustainability requires moving to a new plane of understanding. It is not a matter of defining the limitations of our impact on an external environment. The environment is internal to us, and we are internal to it.

Thus, in achieving Environmental Sustainability, we must include the reflective and reflexive nature of human creativity, considering the processes of both its own evolution and its participation in the evolution of the entire system.

In doing this, we must recognize the importance of diversity of human creativity resulting from diversity in the world of thought, just as we recognize the importance of biological diversity as the necessary source of both healthy change and stability in our planetary life-support systems.

Next, we must recognize the power of vision as the flame front of human creative evolution. The future of human creativity will not be the result of a monolithic vision, but rather the multifaceted jewel of many visions. In this future, each vision will contribute a creative piece to the whole, providing and sharing a partial identity to and with the whole, while still maintaining its essential individual identity and strength. This diversity in thought and vision mirrors the biological diversity out of which thought has been born. Thus, maintaining two diversities – biological diversity and diversity of thought – is at the heart of Environmental Sustainability.

In this regard, the history of human culture has led us well. Through it, we have arrived at a place in time where both institutions and technology have evolved sufficiently to support individual freedom in thought and action while at the same time facilitating essential interconnectedness and cooperation. But we are still immature in this process: mature enough to recognize we have a problem, but not mature enough to have resolved it.

All of this applies very powerfully to us, both individually and corporately. We all design, produce, monitor, regulate, and operate systems that interact with and, to varying degrees, modify the physical, chemical, biological, cultural, and institutional world around us. Our future lies in first, understanding the importance of our role, second, beginning to limit the damage we do to the integrated global system, and ultimately, transforming our understanding and our actions so that we move beyond sustainability – completely ending our harmful activities and then actually adding net value to our planet's life-support engine.

Principle 2: Recognize the interdependence of life and the physical environment, and consider environmental consequences of Corps programs and activities in all appropriate circumstances.

Interdependence of life and the physical environment refers to the dynamic and mutually dependent relationship between all life forms, the Earth's life-support systems upon which they depend, and the products of human thought and activity. It refers to life and to all systems that have evolved life: before us, in our time, and for all time. And it introduces the idea that we humans are part of an evolutionary and life-supportive system, albeit a relative newcomer in the evolutionary process. It is a principle which raises the question, "What part will the human newcomer play in the future process of evolution; a participating and life enhancing role, or the role of a blind stranger?" And then it challenges us to answer by accepting the affirmative, life-enhancing role.

It is also a principle that introduces, qualitatively, the idea of the health of the entire life-support system, especially in relation to the consequences of human thought and activity. Human thought and activity have become an intrinsic part of the evolutionary process, although seldom seen as such. Recognition of the evolutionary impact that human thought plays today and will play in the future is a major challenge of our time. Recognizing this fact implies accepting responsibility for our actions. And our unwillingness to recognize this fact belies our unwillingness, or our fear, of accepting responsibility for the well being of future life, our future lives included. It is a principle that challenges us to choose affirmatively, accepting responsibility for our decisions, and helping to lead a nation, and a world, to an enhanced future.

Recognizing the existence of interdependence between life and the physical environment implies a certain level of understanding. To this end, the principle makes imperative the development of our knowledge base, integrating the study of the so-called "natural" environment with the engineered and constructed environment. The principle urges us to recognize the wholeness of life. It urges us to open our eyes to a new paradigm in which human thought and activity is not divorced from the font of life that bore it. It challenges us to give back to the planet's life-support system its due, not just for it, but for it and us, because together we are one.

Principle 3: Seek balance and synergy among human development activities and natural systems by designing economic and environmental solutions that support and reinforce one another.

To achieve environmental sustainability, the ultimate goal should be to create a milieu within which the understanding and subsequent behavioral patterns needed to create a balance among all systems will be evolved in such a way as to make these decisions and actions not only the right thing to do, but also the thing that we would do naturally. In other words, the ultimate balance should be achieved by structuring a system in which freedom of choice and action is enhanced while making balance and synergy part of the natural order.

Often we mistakenly label the things created by humans as 'unnatural' or 'constructed infrastructure,' as compared with everything else, which we label as 'natural.' This false dualism has been with us for millennia. It is time to change the way we think about ourselves in relation to the world around us. We must stop regarding human activity, and the things that result from that activity, as separate from nature. Human thought has evolved from nature, and so are the things that human thought produces. Other animals use tools, just not as extensively, nor with the comparable physical and intellectual capacity to seek existential understanding, accumulate knowledge, develop technology, reflect on the implications of change, and contemplate future scenarios.

We must remember that our journey of conscious evolution has just begun. It began several hundred thousand years ago. But in geologic time, we have just begun. So to look through this generation's window in time and make dire predictions or judgments is like looking at a baby and thinking that it will be a failure because it is too small, uncoordinated, and makes uncontrollable messes. Culture is in the baby stage, or earlier.

This principle urges us to grow up, to view the world holistically, and to take responsibility for our new role in it. No longer are we simply passengers on an "infinitely" large planet capable of absorbing our geo-unconscious activity. Rather, we are discovering that we must take the helm and, leaving behind the role of passenger, become crew of our home in space. We are the masters of our fate, and we must be actively creative in evolving our planet.

Re-engineering our socioeconomic control mechanisms can be done alone only on paper. Their full implementation requires system wide adoption. However, there may be opportunities for individuals, teams, and organizations to initiate change by experimenting with widely supported concept demonstrations in local or regional settings.

Principle 4: Continue to accept corporate responsibility and accountability under the law for activities and decisions under our control that impact human health and welfare and the continued viability of natural systems.

Corporate responsibility is critical to achieving Environmental Sustainability. And corporate responsibility cannot exist without individual empowerment.

Corporate responsibility implies mission sensibility and effectiveness extending beyond the bounds of current circumstance and institutional boundaries and reaching to the limits of our understanding of the need for enhancement of human dignity and the support of all life. Accountability under the law means that everything we do must be legal, and the law must be interpreted to assure that all activities comply with it. But accountability goes beyond bending to existing conditions. Behind the law is the public good. And the public good demands that, when deficiencies appear in current law, as made evident by changed circumstances, new information, or better understanding, accountability under the law and to the public requires good faith attempts to initiate legislative corrective action.

The sustainability enterprise is, by definition, a pioneering effort. New frontiers will abound. This is the stuff of innovation. Creative efforts to plot new courses will inevitably require the re-evaluation of existing law. And when that occurs, the principle of corporate responsibility insists that we follow through with our best efforts at providing advice and counsel to the institutional bodies responsible for making law and writing regulations.

Accepting corporate responsibility, because our situation is so dynamic, will mean continually deepening our understanding of what is needed to attain environmental sustainability, and then taking the necessary actions to make it happen, whether through legal, organizational, or engineering means. Extending our understanding of the need for enhancement of human dignity and the support of all life will present the greatest opportunity for a deepened sense of corporate responsibility.

The goal in developing corporate responsibility is to make it internally motivated and self-sustaining. Each individual within the corporate body must be regarded as an intrinsic part of the whole, must feel a necessary part of the enterprise, and be afforded the training needed to understand the sustainability issue at its depths. And to make corporate responsibility self-sustaining, and because our knowledge base is so dynamic, training must be ongoing throughout each individual's career.

Perhaps critical to corporate responsibility is assuring that its leadership is fully in tune with the concept of Environmental Sustainability. Each senior leader must be able and willing to lead the corporate body in attaining sustainability, and be willing to stand up to the rigors of cultural, institutional, and political pressures from all sides. Environmental Sustainability must become an organizing principle around which the corporate body forms.

Principle 5: Seek ways and means to assess and mitigate cumulative impacts to the environment; bring systems approaches to the full life cycle of our processes and work.

To mitigate cumulative impacts implies that there exist, either in design or in fact, cumulative impacts of planned, current, or previous efforts which, due to their undesirable aspects, need to be alleviated by changing their design or by some other means. Seeking ways and means to assess and mitigate implies seeking an understanding of the dynamics of new environments that are formed by the integration of new systems into their former environments.

The task that this principle sets out is immense. Yet it does not suggest that we attain the ways and means for assessment and mitigation all at once. Seeking only starts the process. However, it sets a direction. The paths will be determined as we experience the journey, because as we go along, one insight will lead to another, one understanding to another, one discovery to another and one success to another. And on and on until we, in cooperation with others, reach our goals of understanding the nature of cumulative impacts and their assessment and mitigation, and can finally find the ways and means to attain Environmental Sustainability.

The path toward Environmental Sustainability cannot be walked alone. So part of seeking the ways and means to assess and mitigate cumulative impacts implies that we look for whatever is necessary to attain our goal. And clearly, one of the necessary elements in attaining this goal is partnership and cooperation with others. Thus, connectedness will necessarily be developed between individuals, as well as between appropriate government, university, and private sector organizations. Ultimately, because Environmental Sustainability is a global issue, global connectedness must be achieved. However, as with all the means of achieving our goal, seeking does not mean that we are there yet. It means that we begin in earnest to walk the walk. And as with technology issues, bridging the gulf between cultures, institutions, and policies will take a long walk. But seeking is to begin, each day starting from a new position along the path.

Principle 6: Build and share an integrated scientific, economic, and social knowledge base that supports a greater understanding of the environment and the impacts of our work.

A comprehensive knowledge base will be the font from which our decisions regarding Environmental Sustainability will derive. No investment will be more critical. Our current level of understanding is far below that required for a comprehensive approach to achieving Environmental Sustainability. An important first step is to recognize the complexity of the issue, realizing that it has scientific, economic, and social components.

Our knowledge base is the dynamic and integrated source for our understanding of the world around us, and includes information, experience, theories, created extensions of known facts, and any information related to our ability to think, understand, and create. The closer our knowledge base comes to expressing the totality of reality, the more fundamental is its reach, and the more integrating its architecture. And as it becomes more comprehensive and integrating, the rate of learning is accelerated. For it becomes more facile in its adaptation and assimilation of new discoveries and new insights, ever more efficient in stimulating the process of knowledge formation.

The understanding we have of our world comes from our knowledge base. Our minds provide us a model of the world. We divide our world into separate compartments so that we can attempt to wrap our minds around them and gain some limited understanding of how they work. This compartmentalization of our world is a way for our minds to create simplified models so that we can function. And because the current state of mind-technology mix is relatively primitive, the modeling capability of our minds is similarly limited. And so we build external models to help us. But these models, too, are dependent on our understanding and the technology of the day. As our understanding advances, and the technology to investigate and display information moves forward, our models improve. And as our models improve, our minds become better informed, change their views, and form new levels of understanding.

And out of these new levels of understanding and subsequent change in world view, new expectations are formed. And that makes all the difference. Because out of these new expectations comes the creative tension to change a world that is perceived differently and no longer meets those expectations, into a world that does.

And this fact makes it absolutely essential that we make a permanent and unbending commitment to building and sharing an ever-deepening knowledge base.

Principle 7: Respect the views of individuals and groups interested in Corps activities; listen to them actively, and learn from their perspective in the search to find innovative win-win solutions to the Nation's problems that also protect and enhance the environment.

Respecting the views of individuals and groups is another key ingredient in achieving Environmental Sustainability. The founders of the United States established a great nation by demanding freedom and justice for all. Even as we are still working that out on the socioeconomic level, its truth rings loud and clear around the world. Never has it been more important that we be attuned to the eternal truth, so eloquently spoken by the late Dr. Martin Luther King, Jr., that "until all are free, none are free." These words, and the words of the U.S. Constitution and Bill of Rights, speak to all humankind. They say that each individual represents a diverse perspective, and that each individual's view reflects that person's creativity, and needs to be not only respected, but also nurtured. And they say that the lifeblood of any great endeavor is diversity of opinion and creativity, and that from a free and expressive people will come a great enterprise, whether a nation, or an organization, or a planet on the path toward transformation.

Conclusion

The health of the planet was not a consideration when most of our institutions and ideologies were formed, and that has introduced a fatal flaw in those systems as they exist and are applied in today's world. To break out of the container formed by those flawed ideas and institutions, four hypotheses have been proposed to assist us in reshaping our world view and, eventually our institutions and ideologies, so that we can meet the challenges of a new reality. The four hypotheses are as follows:

Human consciousness has now advanced to the cutting edge of global evolution, and forms an organic whole with planet Earth. This hypothesis states that the evolution of human consciousness has created a new dimension in the life of planet Earth, and that the Earth and its newly derived reflective capacity form an organic whole. It is a combination and extension of two previously developed ideas: Teilhard de Chardin's concept of the "noosphere" – the sphere of thought; and James Lovelock's GAIA – that the Earth's physical, chemical, and biological systems act as an organic whole.

Human culture is moving from a passive-reactive state, to an active-creative state. This hypothesis states that an over-arching world view of relative human powerlessness in the face of overwhelming global forces has formed a passive-reactive milieu, a limiting perspective of human capability, and has laid the foundation for many of our institutional and ideological beliefs. The recognition that we are, in fact, changing the planet, even though in a deconstructive way, brings us face to face with a cumulative power we previously did not think we had, and, if we are able to move beyond denial to grasp its reality, moves us inexorably to understand we can no longer remain in the passive-reactive state, but must evolve to an active-creative state in which we become actively involved in creating the future.

Human activity and human-created infrastructure are part of nature and not separate from it. This hypothesis states that we, and everything we do and make, are part of nature; and that separating human activity and constructions from nature creates a false dualism leading to self-fulfilling reinforcement of this dualistic view. Human constructions are intrinsically no less 'natural' than the things built by 'nature.' Human thought is the product of nature's evolution, and human activities and all the things resulting from them have grown from the seed of human thought. Often the things we produce don't look much like nature, nor, often, do they function well with it. And iteratively, they don't look like or function well with nature because, in the mind of the designer, they exist in separate worlds. As long as we hold the disjointed view we created, we can be assured of a continuing path away from sustainability. So until our dualistic view is abandoned, we will not be able to harmonize human activity with global systems. The mental partitioning of so called human-created and nature-created worlds produces a false dualism which limits and inhibits both our world view and the evolution of human thought and action.

Human consciousness, when it successfully integrates itself as an organic whole with global systems, is capable of evolving sufficiently to enable creation of an enhanced system with unknown limits. This hypothesis states that the noosphere, de Chardin's interwoven sphere of human consciousness, recognizing itself as an organic part of global systems, will burst through the barrier of global sustainability created by our limited views, to evolve a world of unknown limits and potential – beyond sustainability. The capacity to move through the previously self-imposed barrier of limitation will manifest itself by transforming our experience into a paradigm in which we learn, not only to understand and sustain what has been created before us, but to build on that foundation by adding net value and creating new worlds with unknown limits.

These hypotheses led to a discussion of new ways to look at both policy and technology as they might be developed to support a sustainable world. In the policy domain, economic, social, and educational concepts were discussed with ideas for change that might engender hope and enhanced creative capacity for developing a sustainable world. In the technology domain, both information and energy were discussed as critical to social, economic, and environmental sustainability.

And finally, the seven Environmental Operating Principles of the U.S. Army Corps of Engineers, promulgated in 2002, were offered as a starting point for both individuals and organizations to assist them in working toward integrated social, economic, and environmental sustainability. These were accompanied by the author's interpretive text, broadened to include all parties.

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Appendix 1.

A Thought Experiment

- In a peaceful and restful state, think of a world in which you feel hope for your life and the lives of your loved ones.
- Think of a world in which you have found a niche for your genius, in which you find satisfaction in your work, in your play, and in everything you do.
- Think of a world in which you are able to listen to and communicate with anyone instantly, clearly, and accurately.
- Think of a world in which you feel confident to successfully innovate and improvise to meet both your needs and those of others in dynamic situations with unknown outcomes.
- Think of a world in which there is magic in our interactions, and music in the results.
- And now, think of a living example (such as playing with a child, reading poetry, innovating a new process, thinking of those you love, or even of Love itself) of a kind of active-creative participation in an evolving future, each new moment being created seamlessly out of the old to create an integrated whole over time.
- Now think of a world of the not-too-distant future which has become a symphony, with all people linked interactively through a multi-dimensional information and communications network to form a global jewel.
- This is the world we will create, reaching sustainability – and beyond.

Relating Change Patterns to Anthropogenic Processes to Assess Sustainability: A Case Study in Amazonia

Libia Patricia Peralta Agudelo, GIS Senior Lecturer and Research Associate, CEFET-PR and the Institute of Sustainable Development, Paraná, Brazil

Abstract—*This work focuses on identifying deforestation patterns and relating these to social processes in an extractive reserve of Acre (western Amazonia). Using multi-temporal satellite imagery deforestation is observed as a series of distinctive patches against the background of forest cover. The study of patterns emphasizes the important relationships existing between spatial patterns and social and spatially explicit processes. Since human processes are scale-dependant, a series of indexes were used to assess the structure, function, and change of the spatial distribution of patches at two different scale levels: global and regional. The global level analysis is concerned with the identification of patterns of land-use change in the entire reserve. The regional level analysis uncovers patterns by observing that local populations are organized in individual family groups occupying specific land areas here described as landscape units. Conclusions show that certain areas are being more deforested than others due to the synergic combination of different factors. This is leading to an unbalanced shift from an economy based solely on rubber extraction to other types of economy. This study can assist in determining development strategies for the reserves that take into account the different social and spatial patterns observed.*

Introduction

The extractive reserves of Acre in the west of Brazilian Amazonia were conceived as part of a strategy for sustainable development, based on the extraction of renewable natural resources such as natural rubber, brazil nuts, oils, resins and fruits (Allegretti 1990, Almeida 1992). Such a strategy is considered necessary to act as a counter-balance to pressures for deforestation and cattle raising activities which have proved to be unsustainable. The study area selected for this study is the Sao Luis do Remanso Seringal (SLRS) located inside the Chico Mendes extractive reserve in the state of Acre. Compared to other areas of the reserve, the SLRS offers a "worst case" scenario in the study of land cover change and deforestation. The present study aims to analyse the dynamics of change operating in these remote areas over a certain time, namely between 1975 and 1989, a period were it is believed that deforestation in Amazonia was particularly intense due to public policies that stimulated the development of 'new economic and agricultural' frontiers.

Multi-temporal satellite images, from the Landsat MSS and TM sensors, were combined with the analytical capabilities of GIS to develop a methodology to measure, assess and monitor changes in the reserve landscape. Deforestation was observed as a series of distinctive patches against the background of forest cover (fig. 1). The study of patterns described by patches emphasizes the important relationships existing between spatial patterns and spatially explicit processes, which in this particular case are of an anthropogenic nature. A

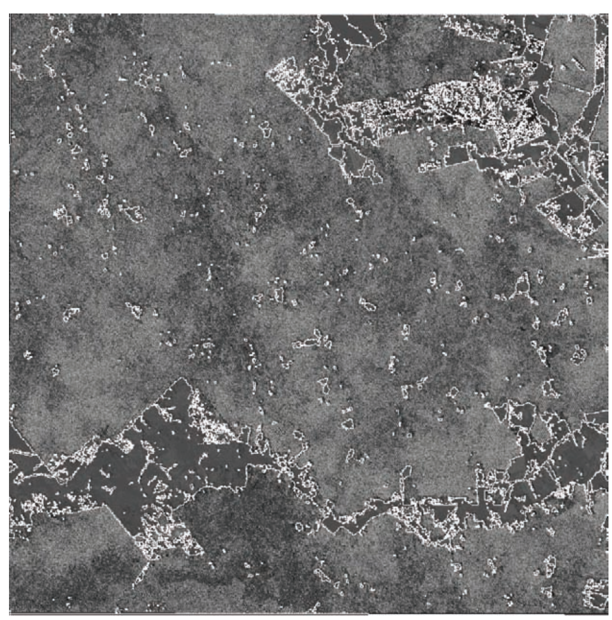

Figure 1. Landsat satellite image for 1989. Deforestation is seen as patches.

landscape ecology approach was adopted through the analysis of the relationships taking place between elements of the reserve's landscape and considering three main landscape characteristics: structure, function, and process. Human processes are scale-dependant. A series of indexes were used to assess the structure, function and processes of the spatial distribution of patches at three different scale levels: global, regional and local. For the purpose of this paper, only the global and regional levels are discussed.

The Global Level Analysis

The Global level analysis was carried out using the images available for the entire study area. The main objective of this analysis was to propose a series of indices to assess how the cleared patches identified were changing structurally over time, and to uncover patterns of spatial distribution of patches at different scales.

In that sense, three main indices were suggested:

- A Lacunarity index to assess patterns in the spatial distribution of patches at different scales and also to determine how gaps between cleared patches were changing over time.
- A Patchiness exponent to assess the distribution of patches according to their size.
- An Area-Perimeter Complicatedness exponent to assess drastic changes in patches' shape that might indicate changes in land use practices.

Lacunarity Index

The lacunarity indices were calculated for the raster data sets available for 1975, 1985, and 1989 In order to determine how the spatial distribution of clearings changed over time. This index is calculated by the use of a box size r that runs over the image, which previously converted into a binary map of forest and non-forest areas. The index calculates gaps between these two categories of cells. All binary maps had a grain size of 60 X 60 metres per cell. Lacunarity was calculated for r = 5 to 200 with an increment of box size of multiples of 5. Consequently, 40 lacunarity values were obtained for each map. Output was obtained as ASCII text files and imported into a spreadsheet where results were plotted on a log-log graph of lacunarity versus box size shown in figure 2.

Discussion and analysis of results

Higher lacunarity values denote heterogeneous and larger gap sizes, while bends in the lacunarity curves indicate more regularity in the spatial distribution and the range of gap sizes between patches. Lacunarity curves for the 1975, 1985, and 1989 data are straight, decreasing almost linearly until the lacunarity value of 1 is reached. Beyond this point, the curves bend slightly at r = ln 1.8 for the 1975 and at r = ln 1.65 for the 1985 and 1989 data sets (fig. 2) and the 1975 data presents the highest lacunarity values of all data analysed indicating larger gaps between patches for that period. However, at a box resolution of r = ln 1.5 , the 1989 lacunarity curve bends upwards exhibiting higher lacunarity values than the 1985 curve, indicating more heterogeneity between gaps for 1989 than for 1985.

At higher box resolutions the curves almost overlap and rapidly approach zero, indicating that while the number of cleared patches increases, the variance between gaps decreases.

Conclusions from Lacunarity Analysis

- The lacunarity index provided an insight as to how the cleared patches are spatially organised in the landscape. It was assumed that if gaps became more homogeneous at a given scale of observation, namely at 9 square km in average for all periods analysed, this reflected a specific pattern of spatial distribution due to social organization (family units) and land-use practices in the reserves. These results were, therefore, used

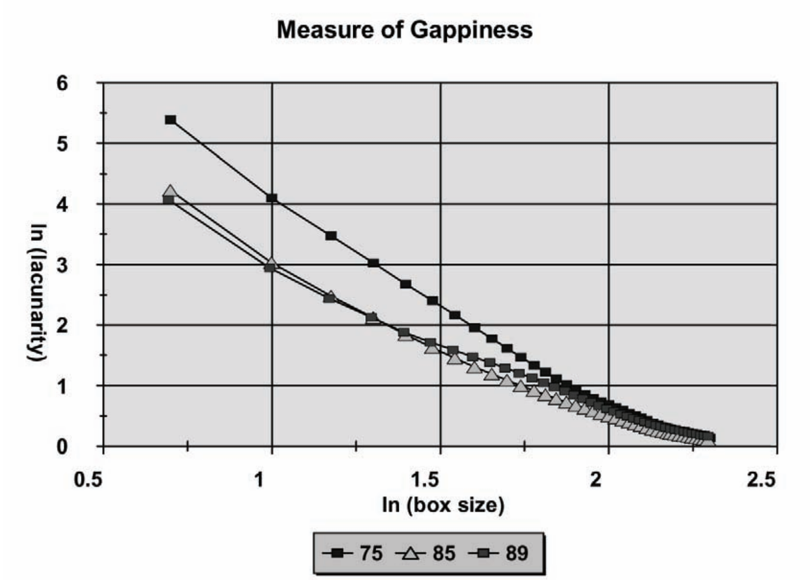

Figure 2. Lacunarity indices for 1975, 1985 and 1989 data.

to determine the extent at which to perform a more detailed analysis of the areas at a regional scale.

- Changes observed in the lacunarity indices of multi-temporal data provided a basis on which to assess changes in the spatial distribution of the cleared patches in the study area. The marked separation between the 1975 and the 1985 curves, suggests that between the mid 70s and mid 80s, the area was subjected to intense deforestation. The proximity of the 1985 and 1989 curves indicates that deforestation in the area of study during that period was not significant. However, higher lacunarity values for 1989 up from a scale extent of 6 square km (r = ln 1.5) suggest that even though deforestation was not intense during that period, gaps between patches in 1989 became more varied than in 1985 due to the increment in size of some of the existing patches.

These results were considered to provide an insight on the temporal and scale dynamics operating in the deforestation process of the extractive reserves.

The Area-Perimeter Fractal Dimension Index

The fractal dimension index D describes how the quantity Q varies with scale. Q could represent the dimension of an area, perimeter, line, mass, etc. Usually, the fractal index is mathematically described by the equation,

$$Q(L) = L D \quad (1)$$

where the exponent D represents the fractal dimension.

The use of the Area-Perimeter Fractal index in the global level analysis

In the context of the extractive reserves of Acre, patches with very complicated perimeters could be interpreted as representing a more or less "natural" habitat where rubber tappers are still involved in subsistence agriculture and depend largely on extractive activities for their survival. On the other hand, patches with regular edges (and usually greater in size) can be interpreted as being more significant in terms of agricultural practices and therefore, representing areas where there has been a shift from the traditional economic activities of extractivism to potentially more extensive clearings through agriculture and cattle ranching.

It is in that sense, the objectives of determining an Area-Perimeter Fractal index for the case study area are: to assess: drastic changes in patches' perimeter (and extent) to identify shifts from an extractive-based economy to an agricultural-based economy over time and to determine similarities in economic practices by comparing fractal indices for the multitemporal data available

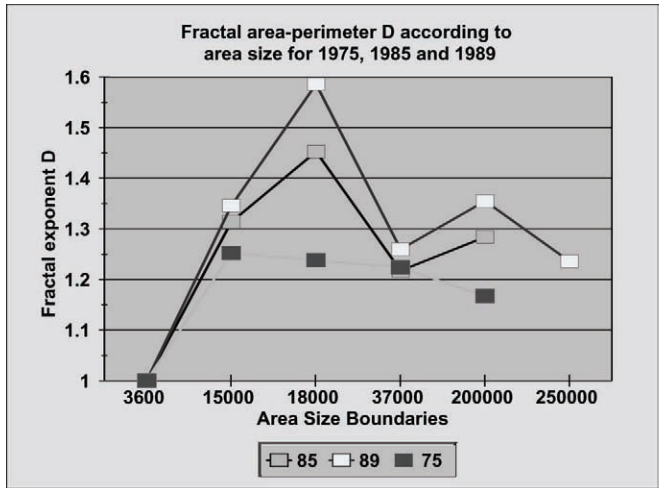

Figure 3. The Area-Perimeter Fractal index results for all periods.

Discussion of methodology and results

Data for this analysis was obtained by using a macro written in the Arc/Info programming language, AML, in order to export data on area size and perimeter length into ASCII text files for each period available. Calculation of the fractal indices was done in a QuattroPro spreadsheet by compiling data into groups of different area sizes, namely areas less or equal to 15,000, 18,000, 37,000, 200,000, and 250,000 square meters (fig.3). For the 1985 and the 1989 data, it was observed that patches with an area of less than 15,000 square meters (1.5 ha) presented low fractal indices, because these small areas tend to be composed of fewer pixels and present smooth edges. When area size increases from 15000 until 18000 square meters (1.8 ha), the fractal index increases considerably, suggesting complex patches' perimeters and therefore, economic activities that resemble natural phenomena. At area size values of lower than 37,000 square meters (3.7 ha) the dimension D falls dramatically suggesting the presence of more rectangular edges characteristic of large mechanised agricultural plots. At higher area sizes, it was observed that the fractal index D increases slightly, showing evidence of new clearings adjacent to the larger patches that define slightly more complex perimeters.

Main Conclusions from the Global Level Analysis

Dynamics observed in the study area show land use changed in the reserve, mainly from a rubber based to a more agricultural based economy. Main deforestation processes occurred between 1975 and 1985, a period that coincided with the Brazilian military regimes. The decrease of gaps between cleared patches observed in the 1989 period can suggest the collapse of a future economy based in rubber extraction (table 1).

Table 1. Main conclusions of the global level analysis.

Objective	1975	1985	1989	Index used
Characteristics of gaps between patches	large and heterogeneous gaps due to sparse small patches	smaller gaps thus larger patches than in 1975, intense clearings during decade	not many new clearings, just increment of existing ones	Lacunarity
Patch shape as indications of predominant economic activities	more complex shapes at areas ≤18000 sqm, economy based in traditional extractive methods, patches of greater sizes seem to refer to more systematic and agricultural plot clearings with smooth geometric shapes.			Area-perimeter fractal index

Regional Level Analysis

While the global level analysis was concerned with the identification of patterns of land use change taking as a basis the entire study area, namely the Sao Luis do Remanso Seringal, a more localized level of analysis is presented underneath. The idea of examining patterns of land use change at a regional level is based on the observation that population in the extractive reserves is organized in individual family groups to which a certain extent of forest is allocated. The extent of forest used and the group's impact on it seems to vary according to three main criteria, such as are:

- number of economically active family members, reflected in the size and number of cleared patches
- accessibility to main transport routes from which goods can be traded and acquired
- main economic activities undertaken by each group i.e. rubber extraction or agricultural plots

Discussion of Methodology and Results

In order to define regional units of study, raster data on the Sao Luis do Remanso Seringal was subdivided into smaller sub-areas, here referred to as regional landscape units. The null hypothesis formulated in this analysis is that structural changes within and between pre-defined regional units were random. However, if patterns were identified, it was believed that these might reflect specific interrelationships between cleared patches and social processes that might explain how the study area is developing and changing at a regional level. In that sense, a complementary goal of performing a regional analysis is to locate spatially the occurrence of specific processes that describe how each one of these regions is changing over time. Furthermore, by grouping units that presented similar changes over time, spatial and temporal patterns of regional land use change were identified. This analysis was carried out in four main stages by:

- Defining the extent of regional landscape units.
- Determining regional key descriptor attributes.
- Determining a series of metrics based on spatial distribution of clearings, access to main transport routes and main land use activities. In fact, these metrics define the structural characteristics of each unit considered (Forman and Godron 1986). Metrics are tested towards their contribution to the analysis by a correlation matrix, whereby metrics considered not to offer additional information were discarded. With the use of a Principal Components Analysis technique, metrics were grouped into orthogonal composite factors
- By identifying spatio-temporal patterns of change at the regional level, units are grouped according to their similarity using a Nonhierarchical Cluster classification technique. Here, units are classified according to the intrinsic combination of the structural metrics considered in the Principal Components analysis By categorising and mapping the classified clusters for all data periods available, the spatial location and "temporal evolution" of similar units was determined

Definition of the Extent of Regional Landscape Units

In the present case extent is considered as the size of the regional landscape unit on which to base the regional analysis. Due to the sparse nature of the spatial distribution of clearings observed in the study areas it was determined that each landscape unit should exceed the 1 km x 1 km extent recommended in the ITE Land Classification System for Great Britain (Haines-Young 1992).

One of the findings of the Lacunarity index used at the global level analysis was that cleared forest patches appeared less randomly distributed at a scale of 9 square kilometres for the 1975 data and at 12 square km for the 1989. This knowledge led to the formulation of the hypothesis that at that scale of observation, a specific pattern of social spatial organisation was observable in the region. To confirm these results, a complementary

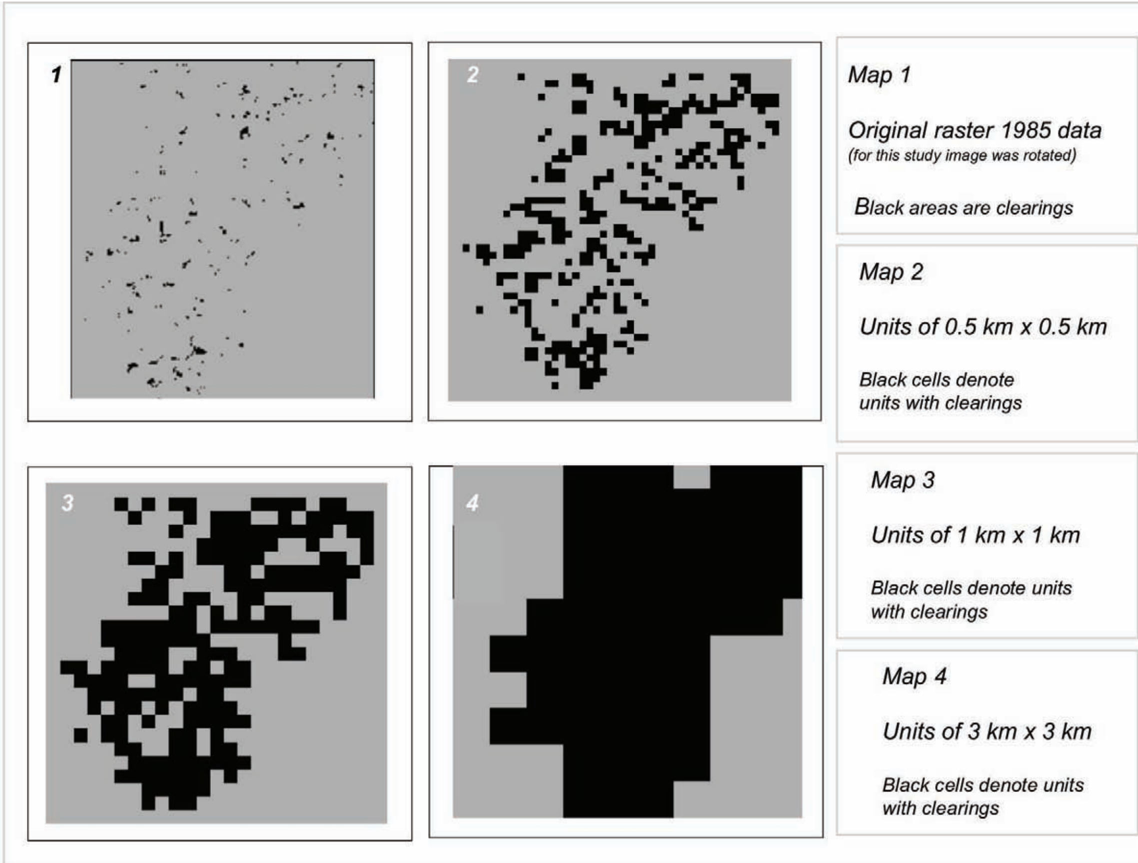

Figure 4. Tests to determine ideal size of landscape unit.

study to determine the extent of regional landscape units through the development of hierarchical binary maps was conducted using the analysis and programming capabilities of Arc/Info.

This process was only performed on one of the data sets, namely the 1985 data set, as a single unit extent would be applied to all the data sets available. The 1985 represented an intermediate period of data collection and, therefore, was believed to provide an average unit extent between all the data available. The analysis was conducted considering three scenarios, where the study areas were subdivided in units of approximately 3km x 3km, 1km x 1km and 0.5km x 0.5 km. In that sense, the final results were three raster maps with cells denoting the presence and absence of clearings at different analysis resolutions, presented in figure 4.

Determination of Key Descriptor Attributes of Regional Landscape Units

Key descriptor attributes were defined by considering the hypotheses drawn from the observation of the links operating at a regional level delineated in the conceptual model of the reserves. Descriptor attributes were defined in relation to four main characteristics: patch, patch distribution, patch accessibility, and patch shape. Within each key descriptor attribute related structural attributes were considered (fig.5).

In order to extract the relevant key descriptor attributes from each landscape unit and to obtain these in a compatible format to be further analysed, the study was conducted using the Arc/ Info programming language, AML, in three main stages.

1. The study area was subdivided into the desired landscape units, namely 9 square kilometres.
2. Complementary programmes (.amls) were written to extract all relevant metrics from the data sets and write results into an ASCII text file.
3. Results were analysed through a Principal Components statistical method.

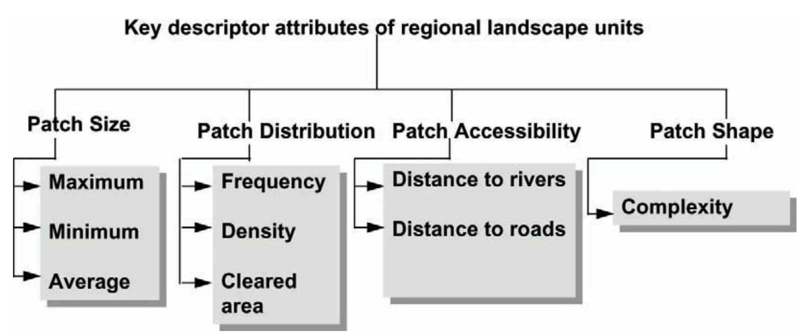

Figure 5. Structural Key Attributes considered at the Regional level analysis.

The Principal Components Analysis of the Variables Considered

Principal Components Analysis is a technique used for simplifying the information in a set of variables by identifying "principal components of variation" within the data. Results obtained from Principal Components analysis "re-describes" a given data set in terms of a smaller set of variables. So, components can be described as "composite variables" or "families" of relatively closely correlated variables. Thus, Principal Components Analysis identifies the similarities in spatial patterns or attributes of a data set, by "constructing new variables that are pair wise uncorrelated" (Mather 1976). Variables considered in PCA are assumed to be normally distributed where inter-correlated variables are grouped as new composite variables and are represented as orthogonal vectors in "theoretical space" where they are refereed to as "eigenvalues." Eigenvalues describe the percentage of variability within the total data set that can be "accounted for" or "described by" the component (Ebdon 1985, Johnston 1980). The first component is, therefore, the assemblage of variables that has the maximum variation when correlated to all other variables in the data set. The first principal component represents the most important axis of variation within the data set, but its strength depends on the particular variables included. Generally, most of the variation contained in the data set can be explained by the three first principal components.

The analysis provided NINE principal components, from which only the first three components presented eigenvalues greater that 1.0. The percentage variance explained by these three components was 87 percent for the 1975 data, 86 percent for the 1985 data and 83 percent for the 1989 data. Thus, Component I explained 36 percent of the variance for the 1975 data, 37 percent of the 1985 data, and 31 percent of the variance in the 1989 data. Components II explained around 28 percent and Components III and IV explained 13 percent and 10 percent respectively for all data sets. Even though some variables scored highly in more than one component, it was assumed that variables would be considered as mainly contributing to the component where they exhibit the highest loadings. In that sense, a categorisation of each component was made possible.

In order to make comparisons between the results of the PCA obtained for all periods of the Sao Luis do Remanso Seringal possible, a within-group categorisation of the PCA loadings was attempted (table 2). This was done by selecting the highest loadings of each variable and establishing to which component it was allocated. Table 1 illustrates the results of this categorisation by highlighting, loadings that have a value of 0.6 or greater in the same component for the three periods analysed. In that sense, it was concluded that the Component I was composed of variables related to the size and impact of the cleared patches, so it was categorised as an "Intensity of clearing" indicator. Component II included variables related to frequency and density of clearings per landscape unit, therefore, it was identified as referring to "Spatial Distribution of patches". Components III and IV related mainly to the shape of clearings through the fractal complicatedness index D, and to the location of the units in relationship to the main existing access routes. Therefore, Components III and IV were interpreted as reflecting categories of "Land use and accessibility." However, low loadings observed for the variable Distance to Roads at all instances considered suggest that the presence of the BR317 running outside the reserve's boundaries has not a really significant effect in the intensity, size and distribution of clearings. Nevertheless, it should be noted here that this observation refers only to clearings within the reserve's boundaries, as the satellite images available (fig.1) show intensive deforestation in areas adjacent to the highway.

Table 2. Loadings and Categorization of components I, II, III, and IV for all periods for the Sao Luis do Remanso Seringal.

	Component I			Component II			Component III			Component IV			
Variables	**75**	**85**	**89**	**75**	**85**	**89**	**75**	**85**	**89**	**75**	**85**	**89**	**C**
AvgSize	-0.8	0.68	0.91	-0.5	0.63	0.06	0.17	0.02	0.03	-0.0	0.27	-0.1	
MinSize	-0.7	-.02	0.25	-0.5	0.76	0.63	0.19	0.38	-0.5	-0.0	-0.3	-0.1	I
MaxSize	-0.9	0.85	0.75	-0.1	0.22	0.54	0.06	-0.1	-0.2	0.02	0.34	-0.1	
PerClear	-0.9	0.96	0.92	0.35	0.00	-0.2	0.00	-0.1	-0.1	0.11	0.15	0.0	
Freq	-0.4	0.73	0.35	0.88	-0.5	-0.9	-0.6	0.10	-0.1	0.09	-0.3	0.09	II
Density	-0.4	0.73	0.34	0.88	-0.5	-0.9	-0.1	0.10	-0.1	0.08	-0.3	0.06	
D_Compli	0.12	0.28	0.10	0.13	0.69	-0.0	0.83	0.39	0.54	-0.1	-0.3	-0.8	
DistRiv	0.23	0.06	0.31	-0.1	0.21	0.18	0.25	-0.7	0.69	0.9	-0.4	0.32	III/IV
DistRoa	0.22	0.02	-0.3	0.45	-0.5	-0.4	0.58	0.57	-0.3	-0.2	0.09	-0.5	

Main Conclusions from the PCA in Relationship to Spatial Dynamics in the SLRS

It is considered that the PCA offers an understanding of the main sources of variance between the structural characteristics of cleared patches within the units analysed. Conclusions from this study are that the regional landscape units defined for the Sao Luis do Remanso Seringal study present high variability (differences) when analysed in terms of the "intensity of clearings," followed closely by attributes related to the "spatial distribution of their cleared patches" and are less affected by categories reflecting "Land use and accessibility."

The multitemporal comparison of the components results serves as an exploratory tool to formulate hypothesis related to the processes involved in regional land use change within the units of study, suggesting for example that in 1985, the variation between the patches' size and shape was more affected by its accessibility i.e. greater patches were located near rivers, whilst for the 1975 and 1989 data, the patches' shape was more related to its accessibility and was independent from the patches numbers and spatial distribution.

Regional Landscape Change Patterns in the SLRS

In order to better relate the PCA results with landscape change patterns in the extractive reserves, these were grouped into clusters according to the similar combination of components scores. As a result, landscape units were mapped according to a cluster membership, determined by a value ranging from 1 until 5 (fig. 6). The description of the each cluster membership is described in table 3.

This mapping process uncovered spatial patterns formed by the distribution of similar regional units within the SLRS context. These patterns were not obvious from the observation of the raw image data and are considered relevant to define areas of critical sensitivity to deforestation and to provide understanding as to how similar areas are connected or isolated.

Results were interpreted following basic criteria, namely, by taking into consideration the number of units that were assigned to each cluster for each period of study. In that sense, it was determined that for 1975, units that presented small cleared patches and sparse distribution were dominant. By 1985, units that presented small clearings were still more common, however, a substantial increment in units presenting large cleared patches is observed. By 1989, the great majority of units presented large cleared patches sparsely distributed across each unit, indicating that clearings became widespread in the entire Sao Luis do Remanso Seringal context. When performing a spatial analysis of the clustered units with the GIS system, the following results were obtained for each year of study.

Conclusions

The general conclusion drawn from this study is that the reserve's landscape was dominated by small and numerous patches in 1975, which by 1989 had become dominated by large and sparsely distributed patches. This provided evidence of the disappearance of small clearings or the clumping of existing clearings between 1975 and 1989.

At a regional level, it was established that regions of the SLRS were being affected differently by deforestation and that this phenomena reflected social and economic processes taking place in the area. Two main processes responsible for the different regional deforestation patterns were identified and are described below:

1. <u>Two main poles of deforestation</u> located at the south and the north-west of the study area were determined.
   A cluster of regional units that suffered the greater deforestation was located towards the south-east of the study area in the proximity of the BR317 highway. A second area where considerable deforestation was observed, though not as extensive as the previous one, was identified in the north-west of the reserve, near the confluence of the Acre River and one of its main tributaries. This evidence shows a pattern of greater deforestation linked to the presence of main access routes, suggesting that these are the main regions from where populations are gaining access into the area.
2. The main <u>direction of deforestation</u> of the reserve was determined as originating from the main highway into the forest interior.
   By observing the spatial distribution of clusters for the three periods considered (fig. 7) it was observed that units seem to suffer a more dramatic deforestation in the direction away from the main highway into the reserve's interior, whilst units located inside the reserve seem not to change as dramatically through time. In that sense, the main deforestation direction was established to be from the south-east to the north-west of the SLRS. At the south-east of the study area runs the BR317 highway.

The main conclusion from this analysis is that the BR317 highway seems to encourage greater deforestation than the presence of main rivers in the area.

Table 3. Description of cluster categorisation for each period.

	Categorisation of clusters by year					
Clusters	**1975**	**tot**	**1985**	**tot**	**1989**	**tot**
1	Small patches, high density and sparsely distributed	29	Small patches, low density, tightly distributed	21	Dominated by very large patches, sparsely distributed.	9
2	Small patches, low density and sparsely distributed	19	Dominated by small patches with some large patches, high density and sparsely distributed	16	Large patches very sparsely distributed	20
3	Dominated by large patches, high density and sparsely distributed	2	Dominated by large patches, high density and sparsely distributed	14	Small and large patches, high density and sparsely distributed	5
4	Very large single patch	1	Very large patches sparsely distributed	8	Large patches, high density and sparsely distributed	22
5	Dominated by large patches, low density and tightly distributed	5	Very large single patch	1	Large patches, low density and tightly distributed	10
Total		**56**		**60**		**66**

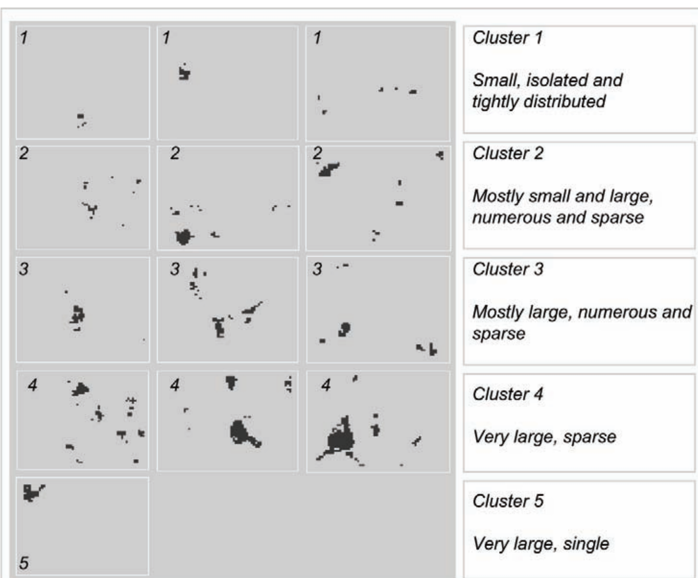

Figure 6. Sample of clusters categories for the 1985 period.

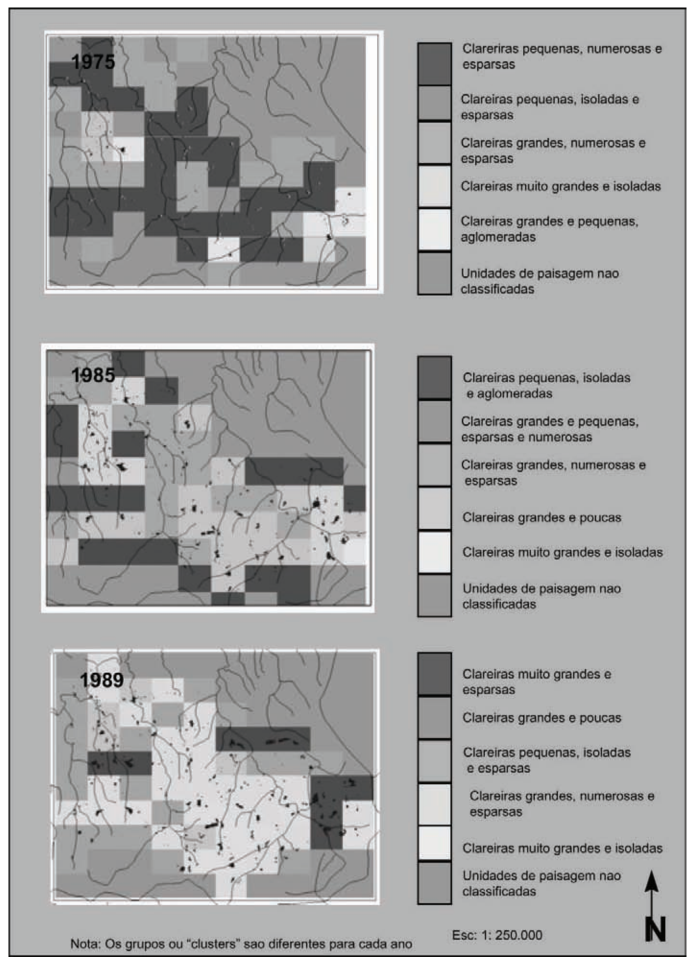

Figure 7. Spatial land use change patterns obtained for each period.

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Disembedded Ideologies, Embedded Alternatives: Agricultural Biotechnology, Legitimacy, and the WTO

Mark J. Philbrick, President, Terranet Consulting, Inc., San Francisco, CA

Abstract—*Notions of market embeddedness highlight the dependency of markets upon social, cultural, and political infrastructures for their operation and legitimation. In contrast, narrow interpretations of the World Trade Organization (WTO) agreements attempt to enshrine the primacy of free trade, institutionalizing the theoretical abstractions of neoclassical economics in a regime with substantial enforcement power. Though trade restrictions are permitted in order to protect the life and health of humans, plants, and animals, advocates of "free trade" insist that such measures be based on a risk assessment approach that manifests a constrained vision of science. The effort to articulate these disembedded economic and scientific ideologies in binding international law has catalyzed and inflamed public challenges to the legitimacy of WTO rules, processes, and foundational premises.*

The current transatlantic WTO dispute over regulations governing the deployment of genetically modified organisms (GMOs) illuminates the crisis of legitimacy at multiple levels. Publics, especially in the EU, are increasingly wary of technologies perceived as posing possible risks to human or environmental health, and of the regulatory and scientific institutions charged with managing these risks. The paper argues that narrow conceptions of risk assessment and management are inadequate to maintain or restore public trust in situations marked by profound uncertainty and a perceived "democratic deficit." Rather than promulgating the disembedded ideologies that it is seen as exemplifying, this case offers an opportunity for the WTO to embrace expanded and updated definitions of risk assessment and sound science. The threats that GMOs are perceived as posing to the human and natural environment have already engendered widespread protest. Failure to respond constructively would further erode the WTO's already tenuous legitimacy, highlighting the unsustainability of paradigms that ignore the larger contexts of economic and scientific activity.

Introduction

Theories of neoclassical economics, which have occupied a privileged position of influence over national and international policies since the Second World War, view economic activity as a world unto itself, seeing the social as distinct from 'pure' economic abstraction. In contrast, economic sociology views economic activity as intrinsically embedded within the social at the individual, group, national, and cultural levels. Drawing on Durkheim, Weber, and Schumpeter, among others, Swedberg and Granovetter propose three core tenets of 'new' economic sociology:

1. Economic action is a form of social action.
2. Economic action is socially situated.
3. Economic institutions are social constructions (1992, 6).

These precepts build on the work of Karl Polanyi, who argued, "the human economy, then, is embedded and enmeshed in institutions economic and noneconomic. The inclusion of the noneconomic is vital" (1992, 34). The noneconomic, which neoclassical thought relegates to "externality," is for Polanyi the more primordial, the ground upon which the economic stands, and contingently at that. Rather than existing as divorced abstractions, markets are multifaceted and dynamic forms of social organization that are in turn interlaced with individuals, nations, cultures and conceptions of personal and group identity at multiple levels.

Spillman suggests three foundational aspects of the social construction of markets. She claims that the objects of, parties to, and norms of market exchange all depend on historical and cultural contingencies. Her thesis suggests the possibility of variation over both nations and time, supported by the examples of the resistance to the commoditization of life in the development of the market for life insurance in the U.S., and the differential acceptance of child labor across societies (Spillman 1999). While the objects of exchange might seem self-evident in a primitive barter economy, modern trading depends upon the enforceable institutionalization of notions such as intellectual property rights, currency exchange, and binding contracts. Likewise, 21st century markets lean heavily on the legalization of corporate personhood, both private and NGO, as well as personal identity standards such as social security numbers to validate actors in market exchange.

Perhaps most critically, markets depend on some modicum of shared norms in order to function effectively. Building on Polanyi's suggestion that economic activity in both 'primitive' and post-industrial societies rests on a combination of reciprocity, redistribution, and exchange, only the last of which is addressed by neoclassical economics, DiMaggio argues that "a minimal commitment to norms of reciprocity and fair dealing is required for markets to operate at all" (1994, 37). While much of the work in economic sociology has focused on social networks and the intersubjective bases of market exchange (Granovetter 1985), social networks are themselves embroiled in, dependent upon, and in some cases contributors to specific political milieus and backdrops of cultural meaning and significance. At the microsocial level, trust and reciprocity play critical roles in the selection and maintenance of business relationships. DiMaggio asserts that shared cultural norms and values facilitate the development of such social capital: "without adding a cultural dimension to structural accounts of embeddedness, it is difficult to understand the negotiated, emergent quality of trust in many concrete settings, and the ability of entrepreneurs to construct networks out of diverse regions of their social worlds" (DiMaggio 1994, 39).

The "invisible hand" does not conjure shared cultural norms and institutions out of thin air. In her discussion of his work, Krippner elegantly summarizes Polanyi's account of the institutionalization of free market ideology in the 19th century, noting the tremendous political investment required to create the conditions for modern markets: "markets, even in ideal form, are not the expression of primal, timeless instincts; they are rather fully social institutions, reflecting a complex alchemy of politics, culture, and ideology" (Krippner 2001, 782). Alchemy is a notoriously variable process, liable to produce divergent results in different settings. Dacin, Ventresca, and Beal invoke cultural and political embeddedness in discussing the possibility of national variation in the legitimacy of market actors and institutions. Reviewing the literature, they find "distinctive institutional logics of action with consequences for the organization of industries and markets" among Europe, Asia, and the Americas, arguing, "Institutional features at the polity level drive patterns of economic activity" (1999, 322). The construction and operation of international trade institutions requires a delicate balancing act between disparate national economies and more importantly, the often-divergent cultural norms, values, and histories that underlie those economies.

The WTO inherits many of its principles from its predecessor, the General Agreement on Tariffs and Trade (GATT). Finalized in 1947 as part of the Bretton Woods family of institutions, GATT was formulated with a clear memory of the disastrous "beggar-thy-neighbor" protectionist policies of the interwar period. Ideologically grounded in Ricardo's belief that reducing trade restraints increases overall welfare, the GATT assigns "pride of place" (Ruggie 1982, 381) to free trade and market rationality. While it affirmed the desirability of tariff reductions, and established the principle of non-discrimination based on country of origin, GATT also included numerous safeguards and exemptions to allow nations to manage the impact of international liberalization on domestic constituencies. The U.S. resisted many of these exceptions, but acquiesced to the need to balance multilateralism and domestic stability, a compromise that Ruggie terms "embedded liberalism."

Robert Howse traces the postwar evolution of embedded liberalism into an "ideology of free trade" in the hands of an international economic elite. Insulated from the political considerations that underpinned the original bargain, the close-knit network of experts that effectively administered the GATT came to see implementation thereof in strictly economic terms, effectively dropping the "embedded" portion of the bargain (Howse 2002). Aided in the 1980's by conservative administrations in the U.S. and U.K that saw national regulations as vehicles for the payment of "rents" to special interests, momentum towards an agreement with stronger enforcement, expanded coverage, and strict limits on exemptions built among industrialized countries. The Uruguay Round of negotiations concluded in 1994 with the creation of the WTO, embodying a much purer commitment to free trade than did the GATT.

Although the WTO has 600 employees, a budget of just over $US 130M, and a headquarters in Geneva (WTO 2004), it is more accurately seen as a set of rules and processes serviced by an organization and undergirded by a philosophy of trade liberalization. In addition to the principle of non-discrimination among member states, themes of international harmonization and requirements that national measures minimize their "trade-restrictiveness" pervade the official texts (WTO 1994a). Even allowable trade restrictions are carefully constrained in these terms, e.g. in the preamble to the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS):

"Reaffirming that no Member should be prevented from adopting or enforcing measures necessary to protect human, animal or plant life or health, subject to the requirement that these measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between Members where the same conditions prevail or a disguised restriction on international trade" (WTO 1994b, italics original).

The WTO also incorporates new agreements on intellectual property, services, and non-tariff barriers to trade, as well as a binding dispute resolution process. The texts seek to establish the rules for international trade, enshrining a particular set of principles as the norm. To the degree that these principles reflect an excessive emphasis on the abstracted conception of markets as "purely" economic, they are disembedded, and their institutionalization is an attempt to embed disembeddedness as the governing principle of international economic interaction.

It may be instructive to recall that Ricardo developed his theory of comparative advantage, the gospel of free trade, in the context of the mercantilist economies of his day, in which capital was relatively immobile by 21st century standards. Further, he made no attempt to consider distributional effects: even if reduced tariffs increase aggregate wealth, specific individuals and groups may still suffer. The GATT sought to address these and other limitations of economic theory by embedding trade agreements in larger social, political, and cultural contexts. The decomposition of the GATT bargain into a narrow ideology of free trade is a step backwards; the attempt to entrench this idealized vision is not a necessary or desirable evolution but a strategic move in the struggle for control over the institutions upon which global markets depend.

The WTO is a nominally democratic organization: decisions are made by consensus, and each member nation has an equal vote. In practice, however, proposals are negotiated among key parties behind closed doors, and presented to the balance of the membership for an up/down choice. Though countries such as the U.S. have elected governments, trade delegations are appointed, and subject to capture by vested interests (McMichael 2000). Further, while the original treaty required ratification by national parliamentary bodies, such as the U.S. Senate, the WTO agreements were explicitly designed as an all-or-nothing 'single undertaking', precluding any possibility of domestic modification. In short, the gap between WTO rules and direct citizen participation is yawning. Combined with the increasing influence of WTO rulings on domestic agricultural, environmental, and consumer policies, accusations of a "democracy deficit" shock little (Verweij and Josling 2003; Woods and Narlikar 2001).

The problems of "regulation without representation" are exacerbated in Europe. In addition to the implicit tension between national and international measures, the EU struggles with a 'democracy deficit' of its own. Finding trade policy an especially acute manifestation of the perceived crisis of pan-European institutions, Meunier (2003) separates "process" and "outcome" legitimacy in analyzing the possibility of using the European experience as a model for international governance. Effective democracy, in her view, requires much more than free and fair elections. Rather, both the processes and effects of binding collective decisions have structural, social, and cultural components, and the perceived legitimacy of any given set of institutions or laws entails a complex interaction among all of these factors.

Nanz and Steffek traverse sympathetic ground in their criticism of WTO legitimacy. Suggesting that new conditions require new conceptions, they offer an expanded definition of democracy as "understood as a framework of social and institutional conditions that facilitate the expression of citizens' concerns and ensures the responsiveness of political power" (2004, 318). Although globalization is not a new phenomenon, the degree and speed of international interconnection and interdependence in the early 21st century exceed that of previous incarnations, presenting new governance challenges. As Dunning argues, the pace of creative destruction of social and relational capital may well lag behind that found within the financial and technological arenas (2000). The evolution of new forms of democratic control, though the process will likely be fitful and time-consuming, is no less important in the development of sustainable societies than more easily indexed indicators. Abstraction and simplification are of great value in multiple domains so long as they are acknowledged as such. Mistaking abstraction for reality, or more egregiously attempting to impose oversimplified abstraction as legislated reality can conflict combustively with social and cultural memories and identities. The transatlantic WTO dispute over agricultural biotechnology is both an explosive example in its own right, and a representative case of the governance struggles likely to characterize the coming decades as global human society attempts to come to grips with the consequences of its self-anointed successes.

Disembedded Complaints

The EU has been less accepting of genetically modified crops than much of the western hemisphere. As of 2002, Europe boasted less than 1 percent of the global hectarage of GM crops, the vast majority of which is in North America (James 2003). After approving a number of GMOs for either import or cultivation between 1994 and 1998, representatives of five member states announced their intention to suspend any new authorizations, pending the development of new rules specifying labeling and traceability standards for GMOs (Council of the EU 1999). This declaration is known as the de facto moratorium, and has been a focus of contention.

The EU moratorium has affected American corn farmers, as Monsanto's Bt Corn has not been approved for human consumption in Europe. In 1997, the U.S. exported roughly 1.6 million tons of corn to Europe, valued at just over $305M. In 1999, the figure was 12.7 thousand tons, worth $1.4M (Pew 2003; USDA 2003). Additionally, developing countries such as Zambia have rejected shipments of U.S. food aid partly for fear of contaminating their corn crops, restricting their ability to export to European markets, thus drawing U.S. government ire. After years of public squabbling, the U.S., Canada, and Argentina (the world's leading exporters of GM products) lodged formal complaints against the EU with the WTO in May of 2003. The three cases have been combined, and the parties made their first written submissions to the dispute panel in April and May of 2004.

The complainants allege that the moratorium violates the provisions of the SPS agreement, among others. In particular, they claim that both the moratorium and several specific national import or marketing bans contravene article 8 and Annex C by imposing an "undue delay" in approval procedures. Defining the moratorium as a "measure" covered by the treaty, they assert that it is not supported by scientific evidence, as required by article 2.2, nor based on a risk assessment as specified in article 5.1 and Annex A. Finally, they aver that the EU has applied "arbitrary or unjustifiable distinctions" that have resulted in a "disguised restriction on international trade", contrary to article 5.5 (Canada 2004; United States 2004).

In addition to the formal parties to the dispute, at least two groups have submitted amicus curiae briefs to the dispute settlement panel. The authors of the more academic of the two submissions (Winickoff 2004), renowned experts in risk analysis from both sides of the Atlantic, argue that the complainants' case fails to recognize the evolving nature of the science of risk assessment. Recent scholarship, they note, increasingly questions the assumptions of certainty, knowability, absolute objectivity, and exclusive expert judgment implicitly characterized by the complainants, developments that reflect directly on the appropriate interpretation of the standards of sufficient scientific evidence and risk assessment referenced in articles SPS 2.2, 5.1, and annex A. As the EU argues in its response, the "measures" in question should properly be considered under article 5.7, which allows for temporary measures in cases of scientific uncertainty; the complainants make no meaningful mention thereof (EC 2004).

The briefs further highlight the observation that understandings of risk, risk assessment, and sufficient scientific evidence vary across cultures and among situations. The dynamics of public confidence are also context-specific, underlining the need for differential national consultation styles and schedules. Canada's submission cites a previous Appellate body ruling establishing each (WTO) member's "prerogative" and "implicit obligation" to determine its own appropriate level of protection (Canada 2004, 89). In contrast to the Canadian and U.S. arguments, both amicus briefs recognize public participation in the risk analysis process as a necessary element of this determination. The second brief, presented by a diverse international coalition of NGOs, also notes the unique political environment of the EU in advocating against a finding of undue delay (Amicus Coalition 2004). Both briefs also display an understanding that the development of local legitimacy is a critical element of risk assessment, a comprehension sorely lacking in the complainants' documents. Perhaps most strangely, the EU lifted the de facto moratorium in May of 2004, issuing its first GMO approval since 1998, yet the U.S. and Canada persist in their case. Though other interpretations are possible, it is not difficult to conceive this dispute action as an attempt to establish binding precedent via an attack on interim procedures that were never designed to withstand WTO challenge, an opportunistic effort to embed disembeddedness.

Towards Embedded Alternatives

Disembeddedness, as discussed so far, might be summarized as the routinized operationalization of simplified abstractions without adequate regard for the complexities of empirical reality, a characterization that nicely captures the attitude toward scientific justification exemplified by the U.S. submission. Winickoff describes the U.S. understanding of risk assessment as "a factually grounded, objective, and value-free analytic exercise requiring (1) precise identification of possible harms to human health and the environment, and (2) use of formal, expert-based assessments of the likelihood of such harms" (2004, 4).

While perhaps sound by Popperian criteria, this approach utterly fails to account for both the inherent limitations of laboratory experimentation in identifying unknown hazards and the social context of risk assessments. The flaws of such an abstract conception of science parallel those of neoclassical economics; risk assessments, and the science thereof, are inextricably embedded in their surrounding societies. Attempts to enshrine simplified abstractions of issues of cultural importance as the basis for policy decisions are destined to engender political conflict; embedding disembeddedness is not a legitimacy enhancing activity.

Funtowicz and Ravetz's intuition that "the science involved in risk assessments is somehow radically different from that of classical lab practice" (1992, 252) catalyzed their efforts to develop a model for "post-normal" science. In response to what they saw as the glaring omission of considerations of both uncertainty and values in risk assessment, they offer an alternative to the classical definition of risk = hazard * exposure. Noting that assessments of hazard and exposure are subject to both significant scientific contention and variability of public perception in real-life situations, they propose alternative components of risk definition rather than hazard and exposure, their diagram "has as its axes systems uncertainties and decision stakes" (1992, 253, italics in original). Situations that score low on both axes fall within the jurisdiction of applied science; problems of moderate uncertainty and medium stakes are amenable to 'professional consultancy', which combines technical knowledge with strong practical experience. When "facts are uncertain, values in dispute, stakes high, and decisions urgent" (1992, 253-4), post-normal science reigns.

Extending Science

Funtowicz and Ravetz's identification of decision stakes as a critical factor grounds their model in everyday reality, and leads directly to the inclusion of non-scientists in risk assessment. Aware of the radicalism of their ideas, they explicitly call for a "new political epistemology of science," one that incorporates both "extended facts" and "extended peer groups" (1992, 252-4). As Wynne points out, the acknowledgement of uncertainty on the part of the scientists provides a critical bridge in facilitating the development of "the hybrid communities necessary for doing the intellectual and political work of building robust multidimensional policies" (Wynne 2001, 3). In discussing his research with hill sheep farmers near the Sellafield/Windscale nuclear complex in the aftermath of Chernobyl, he relates how the scientific culture of control and knowability both decreased the effectiveness of the scientists and degraded their legitimacy with the locals. By insisting on the accuracy of their preconceived radioactivity diffusion models (later proven to be based on improper soil types), and ignoring farmers' comments in designing feeding experiments (which were eventually abandoned for the reasons stipulated by the farmers), the scientists ignored vital data, and discredited themselves with the very constituency they ostensibly served (Wynne 1989, 1996).

Astutely, Wynne also draws more general conclusions. Arguing for extending scientific "peer groups" in consonance with Funtowicz and Ravetz, he observes how the farmers perceived the scientists' flagrant disregard of their hard-earned wisdom as a threat to their social identity. Carefully privileging neither the farmers nor the scientists, and recognizing the challenges inherent in communicating across divergent frames of reference, he strongly advocates extended peer participation in risk assessment. Wynne's beliefs find some WTO support. In EC-Hormones, the WTO's Appellate Body expressed concern about attempts to constrain the definition of the risk assessment required by the SPS agreement in a narrow scientific straitjacket. In overturning language suggesting that risk assessments must articulate a quantifiable probability of occurrence, the Body stated:

"However, to the extent that the Panel purports to exclude from the scope of a risk assessment in the sense of Article 5.1, all matters not susceptible of quantitative analysis by the empirical or experimental laboratory methods commonly associated with the physical sciences, we believe that the Panel is in error… It is essential to bear in mind that the risk that is to be evaluated in a risk assessment under Article 5.1 is not only risk ascertainable in a science laboratory operating under strictly controlled conditions, but also risk in human societies as they actually exist, in other words, the actual potential for adverse effects on human health in the real world where people live and work and die." (WTO 1998, §172, italics added).

Day-to-day practitioners have visceral, real world experiences often otherwise unavailable to laboratory scientists, and the combination of the two perspectives yields a much richer data set for risk analysis. Extended peer groups provide extended facts in support of an expanded political epistemology of science; 'embedded' risk assessment holds forth the possibility of improving empirical quality as well as public legitimacy.

More socially, cases of uncertainty and high stakes create a volatile and often controversial brew; public involvement is essential to capture the multivalent dimensions of risk in such settings. Lay populations tend to emphasize possible consequences in their evaluation, especially irreversible ones (Slovic 1992). More generally, publics across the globe tend to include a much broader set of parameters when contemplating risks than do experts (Renn 1992). Factors typically excluded from professional calculations include whether or not the risks are voluntary, whether those subjected to risks have reasonable access to information about the possible consequences of their actions, and the degree of culpability of those responsible for managing risky activities, should incidents occur (Marris 2002). Publics also view the trustworthiness of the operating institutions as an essential element of possible risk, rather than an external factor. Characterizing lay people as ignorant, Luddite, or irrational, because their attitudes and opinions fall outside the scope of narrowly conceived risk assessment exacerbates their perception of the threat posed by the relevant institution, further degrading its trustworthiness and legitimacy, and intensifying sensations of danger (Wynne 1992).

Differential Legitimacy

Winickoff emphasizes that risk framings, assessments, and legitimacy are all culturally contingent. Given the importance of the organizations operating and promulgating technologies in public evaluations, differing national perceptions of crucial actors comprise a salient element of risk assessments. In their examination of 1999 Eurobarometer data and 2000 American survey results, Priest, Bonfadelli, and Rusanen (2003) found a strong inverse correlation between the size of the "trust gap" between industry and environmental or consumer organizations and favorable attitudes toward agricultural biotechnology. When industry and environmental groups have similar credibility, as in the U.S., public attitudes tend to be encouraging of GM crops. In countries where environmental groups are seen as substantially more trustworthy than industry, e.g. France and Denmark, support for agbiotech is low. These findings are consonant with Spillman's (1999) focus on the cultural construction of the objects of and parties to market exchange. In the case of agricultural biotechnology, the legitimacy of the parties is at much at issue as the technologies themselves.

Grappling with trust issues, spawned in part by the Bovine Spongiform Encephalopathy (BSE) crisis and the Belgian dioxin scare, the EU has funded extensive research on public perceptions of science and regulation. One such study, titled "Public Perceptions of Agricultural Biotechnology in Europe (PABE)," employed multiple in-depth focus groups in five countries and several phases, seeking to identify "the underlying factors shaping viewpoints, rather than the viewpoints themselves" (Marris 2002). In contrast to the industry tenet that scientific ignorance drives public resistance, focus group participants based their concerns about GMOs on their experiences with the fallibility of human technological organizations and regulatory schemes, and their acceptance of irreducible uncertainty in risk assessment. Although BSE is often seen as a cause of opposition to GMOs, and participants did make frequent reference thereto, they saw the governmental failures (and initial denials of risk) as exemplary of normal operations, not as an aberration. Rather than expressing blanket opposition to genetic engineering, focus group members more commonly reacted negatively to the seemingly surreptitious introduction of GMOs into the food supply as common additives without advance notice. Participants also objected to the lack of labeling, the failure of proponents to acknowledge uncertainty regarding unintended consequences, and the mismatch between industry rhetoric about 'feeding the 21st century' and the products commercialized to date.

Again, these concerns relate less to the technologies themselves than to the equity of their deployment, and public trust in the deployers. Should the WTO rule against the EU, Europeans would likely perceive a violation of their sovereign ability to determine the legitimacy of participants in their markets as both parties and objects? Given the cultural centrality of food, many may also perceive an affront to their individual and social identities, further stiffening their resistance, and undermining WTO trustworthiness. The EU and its member governments are well aware of their publics' sentiments – officials have repeatedly cited the need to restore public trust as the rationale for developing new assessment and labeling regulations. Their submission to the WTO argues that the moratorium was necessary in order to allow adequate time to permit sufficient public participation in the formulation of new guidelines, as well as to complete longer-term studies such as the U.K.'s Farm-Scale Evaluations, which measured the impact of entire suites of GMO farming practices on local biodiversity (PMSU 2003). A ruling against the EU would be seen as valuing trade interests over both democratic processes and comprehensive science, further souring European opinion towards both agbiotech actors and the WTO.

Conclusion

The WTO is commonly seen as personifying the negative aspects of globalization. Its commitment to reducing barriers to trade is seen as leveling the playing field in favor of the powerful, and its removal from ordinary citizens has created a profound "democracy deficit" in public eyes. To the degree that a narrow conception of risk assessment continues to infuse its rulings, a disembedded scientific ideology joins the abstractions of neoclassical economics to create a driving philosophy increasingly at odds with market, social, and environmental realities. However, the current transatlantic dispute over biotechnology offers an opportunity for change.

The arguments of the two sides reflect two competing interpretations of the WTO agreements; the

European position manifests a more sustainable view of the appropriate relationships between trade, science, the environment, and society. A finding by the dispute settlement panel and the Appellate Body that the European moratorium falls properly under article 5.7 of the SPS agreement as a precautionary measure in the absence of sufficient scientific evidence would signal a dramatic shift. Though a legislative solution, perhaps a renegotiation of the SPS and related texts to embrace a comprehensive version of the precautionary principle, such as articulated in the Cartagena protocol, and to more explicitly recognize the right of members to establish their own rules of market legitimacy, would be more appropriate in the longer term, a ruling substantially in favor of the EU would constitute a very constructive step. The alternative would further degrade the legitimacy of the WTO, diminishing its effectiveness as citizens demand domestic policies increasingly at odds with a 'pure' ideology of free trade. Markets, and market institutions, are inextricably embedded in the social, cultural, and political; pursuing ideologies that advocate otherwise is a prescription for social collision, and ultimately unsustainable.

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Human Institutions and Processes

Using Biodiversity Indicators to Assess the Success of Forecasting Adaptive Ecosystem Management: The Newfoundland and Labrador Experience

C. Sean Dolter, Project Manager, Western Newfoundland Model Forest Inc., Corner Brook, NL

Abstract—_This paper reports on an initiative referred to as the Biodiversity Assessment Project (BAP). A suite of tools is being developed to assist forest managers in assessing the predicted future forest conditions of Newfoundland and Labrador's forests under a variety of management scenarios._

Since 1999, the Western Newfoundland Model Forest partnership has worked with the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) to develop a suite of strategic planning tools that assess the impact of various forest management scenarios on selected biodiversity indicators. This original approach began with Millar Western Forest Products Ltd. (MWFP) in Alberta, Canada, in cooperation with Peter Duinker, Lakehead University, and is now being modified to fit the Newfoundland and Labrador forest condition.

The preliminary results show that forest management actions can have significant impact on various biodiversity indicators, depending on the selected management scenario.

There are several components to BAP. The coarse filter layer examines the ecosystem diversity and landscape structure indices. The fine filter layer focuses on species-specific Habitat Suitability Models (HSMs). WNMF is also defining the natural disturbance regimes for western Newfoundland and comparing the selected biodiversity indicators between a natural forest condition and a managed forest. This future control forest will be used to set the natural range of variation on each biodiversity parameter being used for assessment.

The BAP tools will also be developed to assess central Newfoundland eco-regions so they can be used throughout the province and applied to specific situations, such as fire-dominated ecosystems. The BAP will begin to be incorporated in the provincial wood supply analysis starting in 2005 as a prototype assessment tool.

Introduction

Traditional Forest Management

What is now known as the province of Newfoundland and Labrador is two separate land masses. Newfoundland is often referred to as the island portion of the province and has a total land mass of 11.1 million hectares (ha). Labrador is located northwest of the province of Quebec and has a land mass of 29 million hectares.

Since the turn of the 15th century, the people of Newfoundland have been steadily evolving in the way they interact with the forest around them (Griffin 1979). Griffin used the following headings to define the history of forest management in Newfoundland and Labrador:

1. The period of destruction: 1497 to 1880
2. Exploitation and protection: 1880 to 1934
3. The foundation of an administrative framework: 1934 to 1949
4. The beginning of extensive forestry: 1942 to 1972

The forest of Labrador has seen limited development compared to the island of Newfoundland. Traditional use of the Labrador forest was primarily based on its utilization by Aboriginal peoples, Innu and Inuit, for subsistence living until the 20th century. Even today, sustainable forest management in Labrador is at a much smaller intensity with a harvest allocation of only 30 percent of the annual allowable cut (AAC). Forestry in Labrador is seen as a co-management challenge by the Innu Nation and the Government of Newfoundland and Labrador.

The island is a different story. Coastal regions of the island saw intensive development up until the late 1800s.

Trees were used for building homes and commercial structures, boats, fishing flakes, stages, and for fuelwood. Three miles in from the coastline was considered the "three mile limit" and allowed fisherman to cut the forest within this area (Nazir and Moores 2001) without restriction. Insular forest utilization before then was based on subsistence activities of the Beothuk Indians. European interests turned toward the forest in the mid to late1800s as the sawmill industry began to expand. In the early 1900s, the pulp and paper industry began to be the primary forest-based industry. Beginning on the west coast of the island, the pulp, and paper industry swept across the province, utilizing the most merchantable and accessible stands. For the past 100 years, forest management has evolved from forest protection to timber management to multiple use management, and today, sustainable forest management (SFM) (Newfoundland Forest Service 2003).

Evolution to Sustainable Forest Management

Nazir and Moores suggested that Griffin could add two additional categories to the evolution of forestry in Newfoundland and Labrador to include:

5. Integrated management: 1972 to 1990
6. Sustainable forest management: 1990 to present (Nazir and Moores 2001)

Integrated management required managers to take a larger view of their activities when involved in resource management. Having to integrate all parts of the resource equation to obtain a harmonious whole was the greatest challenge, causing conflicts with inter-governmental policies and responsibilities. After years of striving for accommodation and compromise, managers began to bring issues together and unite under common resource objectives (Mitchell 1986).

With the Canadian Council of Forest Ministers (CCFM) embracing the Criteria and Indicators definition of sustainable forest management (CCFM 1995), forest managers and decision-makers now had to think outside of anthropogenic causes and effects and begin understanding ecological processes outside their realms of expertise. The six criterion for SFM encompass every element of forests, not just the elements that are impacted directly by harvesting, road building, or silviculture. Talking about sustainable forest management is one thing - understanding the complexities of interactions is another. Agreeing to working within a local level indicators framework, an essential component of CCFM's SFM framework, also meant tracking temporal performance indicators and setting thresholds for variability in indicator performance. Newfoundlanders and Labradorians now had to examine the gaps in their resource knowledge base and begin being accountable for their resource management decisions.

The Challenge of the SFM Process

Industry, government, and community organizations had to become more unified to take on the new challenges of resource management. In 1992, the Western Newfoundland Model Forest (WNMF) was formed as part of the national model forest network. Its diverse range of partners set the stage for formulating approaches to SFM in light of limited resources, both financial and knowledge-based. A community-based stakeholder organization has the ability to cut through red tape and leverage resources from a number of agencies and programs. The number one priority of the WNMF has been to develop a framework to help evaluate the effects of long-term forest management activities on forest structure, ecosystem diversity and a select set of wildlife species. This unified approach to address the challenges of SFM has been called the Biodiversity Assessment Project (BAP) (Duinker and others 2000). BAP is the focus of this paper.

Process Inclusiveness

BAP provides an opportunity for those with an academic and management interest in forest connectivity and fragmentation, species utilization of habitat, and natural forest succession to come together as a community to assist managers in resolving the ecological challenges confronting them. Striving to achieve SFM requires forecasting and monitoring the effects of present day and future management activities on suites of indicators. The approach BAP adopted was to use local level indicators of biodiversity that could be both used in monitoring and in forecasting ecological impacts.

In defining SFM, Criteria and Indicators (CIs) are divided into two separate components. Ecological CIs are illustrated under the following titles:

1. Conservation of Biological Diversity
2. Maintenance and Enhancement of Forest Ecosystem Condition and Productivity
3. Conservation of Soil and Water
4. Forest Ecosystem Contributions to Global Ecological Cycles

Socio-economic CIs focus on the last two titles:

5. Multiple Benefits to Society;
6. Accepting Society's Responsibility for Sustainable Development (CCFM, 1995)

BAP concentrates on the first and second criterions of SFM. WNMF is working on integrating several other complementary approaches with BAP to address the remaining criteria.

The complex, multi-faceted nature of biodiversity brings about the need to better address our limited knowledge of resource processes and their associated bio-indicators. BAP must be flexible and adaptive in order to integrate what we do know about ecological processes with what we need to find out.

MWFP of Alberta, first approached a team of scientists to create a system that anticipates the complexities of forest systems at a landscape scale. BAP-Alberta was a multi-million dollar project with 29 specific habitat suitability models. According to Starfield and Bleloch (1986), models are tools which "help us to (1) define our problems, (2) organize our thoughts, (3) understand our data, (4) communicate and test that understanding, and (5) make predictions." Therefore, models are learning tools that can help determine the impacts of any external perturbation on the entire system (Higgelke 1994). WNMF partners liked the way MWFP approached the complexities of biodiversity assessment and brought that process to western Newfoundland but WNMF had a different perspective on the implementation of this project. The WNMF partnership includes a multitude of various agencies and organizations, existing resource databases, and facilities to broaden the ownership of such an initiative. In the long term, BAP will assist WNMF in integrating information on forest parameters under the ecological CIs, but with limited resources, WNMF project managers decided to start small with the implementation of BAP. WNMF partners applied adaptive ecosystem management principles in order to progress in the development of BAP.

"The adaptive process maximizes the manager's learning about the system, and is consequently a safe approach to initiating management in complex systems" (Baskerville 1985). In designing forest management goals and associated actions, the measurement of progress is carried out in a manner that allows the manager to learn about the complex system from his/her management of it. The BAP allows one to forecast management actions in a well-defined feedback loop, as illustrated in figure 1, and track the resulting effects for a variety of management actions. BAP users are forced to recognize errors in their proposed assumptions, thus allowing for continuous learning from system performance.

Ecologists, biologists, foresters, research scientist from numerous disciplines, and resource managers all have a role to play in integrating their knowledge and developing assumptions on ecosystem structure and function when knowledge gaps are confronted. The outputs of their efforts will be integrated into a common framework to assess impacts of forest management activities.

Partnerships

The WNMF partnership is comprised of federal, provincial, and municipal government agencies, industry organizations, economic development associations, environmental organizations, academic institutions, and a commercial trapping group. The partnership wanted the BAP to be a tool utilized by all sectors of resource management, not just industry. The partnership was the catalyst for transferring BAP to WNMF and put together a team of resource planners, managers, ecologists, biologists, and computer specialists from a multitude of different organizations. They formed the Biodiversity Assessment Project Working Group (BAPWG), which is directed by the following partners:

Industry

- Corner Brook Pulp and Paper Limited - Chair of BAPWG
- Abitibi Consolidated Company of Canada

Federal Government

- Natural Resources Canada, Canadian Forest Service
- Parks Canada, Gros Morne National Park

Provincial Government

- College of the North Atlantic, Geospatial Research Facility (GRF)
- Department of Environment and Conservation, Inland Fish and Wildlife Division (IFWD)
- Department of Environment and Conservation, Water Resources Division
- Department of Natural Resources, Forestry Services Branch (FRB)

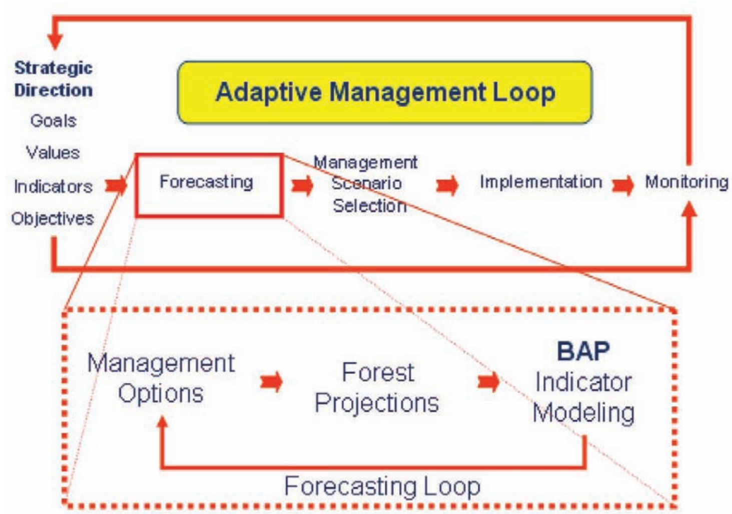

Figure 1. Adaptive Management Loop (Doyon 1999).

Community

- Western Newfoundland Model Forest

Working on behalf of the BAPWG is a technical subcommittee guided by the original researchers involved with MWFP. It is the objective of all partners to cooperatively transfer BAP-Alberta models to the WNMF. WNMF is developing and testing BAP tools in order to accurately predict our future forest conditions under both natural and human influences.

Public Participation

Accountability is the cornerstone of the WNMF partnership and the BAP. Public participation and input into forest management has two direct avenues. Public associations and individuals have direct access to WNMF resources and will be provided access to working groups unless they will not agree to the ground rules of consensus decision-making. BAPWG has an open chair policy for organizations wanting to participate in the development process of a specific initiative.

The second avenue addresses the implementation stage of the BAP. The Forestry Services Branch of the Provincial government's Department of Natural Resources manages the forests of this province. It is responsible for ensuring that forest management districts prepare management plans in consultation with public and community stakeholders. Local planning teams prepare strategic documents and five-year operating plans that incorporate both timber and non-timber forest values. One of the major areas of concern for these planning teams is the ability to forecast the impacts of their future management directives. Are they truly practicing SFM in their districts? What are the ramifications of different management scenarios on biodiversity? BAP will be their future tool to ensure some level of confidence in their decision-making abilities.

Capacity Building

The future application of BAP is dependent on the relationship established between the inventory agencies, research community, forest resource managers, and the planning teams. The desired outcome of forest management decisions has to be a result of trade-offs between user groups and the natural variability of biophysical indicators. BAP, when used in a negotiating process, will provide a number of scenarios to participants, thus building their capacity to assess the biodiversity outcomes of these virtual scenarios.

BAP Process Overview

BAPWG is presently running analyses on four different scenarios using the output of the wood supply projection models - Woodstock and Stanley (Remsoft) of the Forestry Services Branch. The four scenarios are:

1. Business as usual – if management was to stay as presently practiced with the current annual allowable cut.
2. Business as usual: Fragmented – if the average five year harvest block was to stay at 50 ha in size with a variability between 10 and 100 ha. A green-up delay of 5 years would be imposed for harvesting adjacent blocks.
3. Business as usual: Aggregated - if the average five year harvest block was to stay at 300 ha in size with a variability between 100 and 800 ha. There would be no green-up delay for harvesting adjacent blocks.
4. Marten Friendly – This scenario respects the landscape thresholds set by the Recovery Team for Newfoundland marten. There will be no mean block size but a minimum of 10 ha and no maximum limit. Tree height would have to be maintained at greater than 6.5m with no green-up delay.

Also being run concurrently is a landscape simulator that incorporates the natural disturbance regime of the WNMF study area, Forest Management District 15. Through a series of applied research projects on insect disturbed forest areas, Dr. Yves Jardon of the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) produced historical outbreak data that he used with LANDIS. LANDIS is a commercial landscape simulator model capable of producing a future forest scenario void of anthropogenic disturbances and based on projecting only natural forest succession processes. This natural disturbance regime scenario, when analyzed by the BAP tools, gauges the natural range of variability of the bio-physical indicators, setting minimum and maximum thresholds.

BAP has three levels at which these scenarios will be assessed:

1. ecosystem
2. landscape
3. species specific

Coarse-Filter Biodiversity Analyses

At a coarse level of bio-indicators, ecosystem diversity and landscape configuration are targeted (Doyon and MacLeod 2000). The following set of bio-indicators is thought to broadly consider the basic habitat requirements of forest-dwelling, vertebrate species (Rudy 2000).

Ecosystem diversity

Bio-indicators used in the analysis of ecosystem diversity are:

- Area-weighted Stand Age
- Tree Species Distribution
  - Species distribution by broad habitat type
  - Species presence
  - Species dominance
- Habitat Diversity

These three indicators enable BAP to track the changes in forest composition due to management practices being projected.

Landscape configuration

Bio-indicators used in the analysis of landscape configuration are chosen for their sensitivity for gauging the impact on connectivity. These bioindicators are:

- Average patch size and shape
- Average edge contrast/Edge length
- Patch core area
- Adjacency
- Nearest neighbour

Fine-Filter Biodiversity Analyses

At a fine-filter level of assessment, habitat supply models were developed for specific wildlife species. As of August 2004, the BAPWG has models for Newfoundland pine marten (Martes americana atrata), woodland caribou (Rangifer tarandus), and boreal owl (Aegolius funereus). All models follow the same format and utilize harvest projection inventory tables produced by each scenario.

Species specific

In a forest management context, some wildlife species, because of their individual characteristics, need to be analyzed separately (Doyon 1999) and cannot be generalized into core wildlife groups. A species status as an indicator or keystone species may determine their priority for modeling in BAP.

The BAP uses specific species to analyze the forest in terms of future habitat potential for that wildlife species. BAPWG has chosen an initial suite of species based primarily on data availability but also because of their diverse habitat requirements. In 2004 to 2005, the Inland Fish and Wildlife Division of the Provincial government's Department of Environment and Conservation, as the biological experts on the BAPWG, will choose a suite of future species by evaluating several forest species according to the criteria listed in table 1.

BAP Flow

The following process diagram (fig. 2) illustrates how BAP fits into interdisciplinary research and decision making in Newfoundland and Labrador. The BAPWG is responsible for the transfer and development of BAP tools. Once the prototype has been developed and accepted, the partners of the BAPWG will be responsible for further refinements and implementation. As figure 2 illustrates, BAP is dependent on many sources of input. Once the forest inventory specialists have provided the basis for the projections in the province's wood supply projection models, Woodstock and Stanley, and researchers have provided further information on other ecosystem components, BAP can generate a stand attributes table for assessment. The assessment is filtered through the coarse stream for ecosystem and landscape analyses once the habitat reclassification is done. Concurrently, the bio-indicators will be filtered through the fine stream where the habitat requirements to select which species will be assessed.

Decision Making

BAP is designed as a decision support system for both the public consultation process and the provincial wood

Table 1. Criteria for Selecting BAP Species (Doyon 1999).

Criterion	Description
Sensitivity to Disturbance	Expected to be sensitive to intensive forestry practices
Species status	Have been given rare, vulnerable, threatened, or endangered status
Monitoring	Easily monitored (relatively common with entire home range contained within the FMA area)
Habitat specificity	Have specific requirements for particular habitat types
Special habitat elements	Use special habitat elements such as snags, downed woody debris, and arboreal lichens
Functionally essential species	Have substantial influence on the ecosystem (top predators or large browsers)
Landscape configuration	Expected to be sensitive to landscape composition and structure (area- or edge-sensitive species)
Socio-economic value	Hunted, trapped, viewed, or photographed by local people
Available information	Have been studied extensively

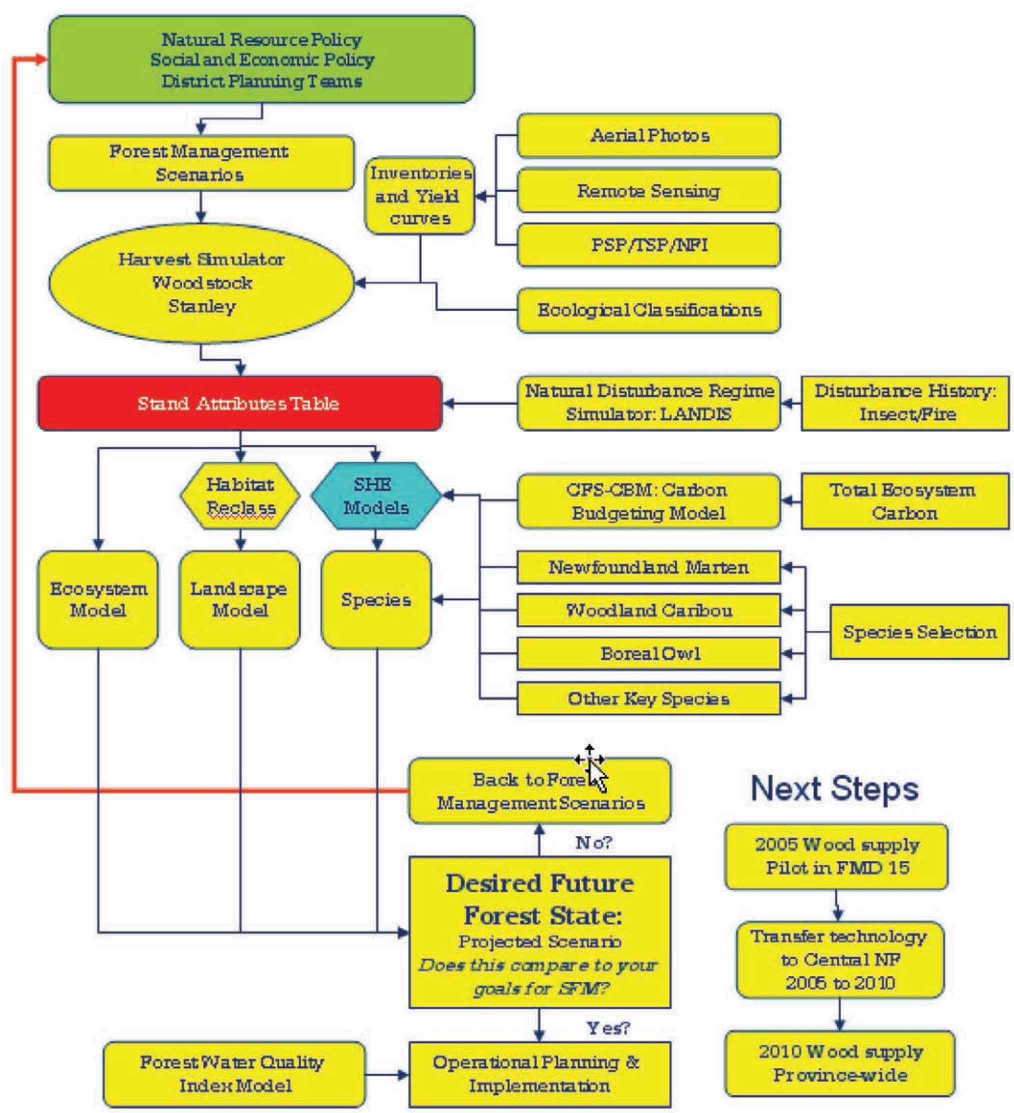

Figure 2. BAP Process.

supply analysis. Once integrated into the provincial forest management planning process, each district planning team will be responsible for setting the constraints for different management scenarios. After the bio-indicators for each management strategy are analyzed, compared, and evaluated, the planners and planning teams will receive an opportunity to decide if the outcome of the projection compares with their goals for SFM. If they do not, re-testing of management scenarios occurs until an acceptable management strategy is achieved (Newfoundland Forest Service 2003).

Conclusion

The Western Newfoundland Model Forest is committed to seeing the BAP process through to its adoption as a formal mechanism for protecting the biodiversity of Newfoundland and Labrador forests. As a partnership, we do have concerns over the balance of ecological integrity, economic sustainability, and social rights and freedoms when developing decision support systems for forest management. Process transparency, access to information, and providing the opportunity for community participation will ensure the success of the Biodiversity Assessment Project and its incorporation into the public consultation process for decisions on forest management planning in Newfoundland and Labrador.

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The Ontario Benthos Biomonitoring Network

Chris Jones, Benthic Biomonitoring Scientist, Ontario Ministry of Environment, Dorset Environmental Science Centre, Dorset, Ontario, Canada, P0A 1E0
Brian Craig, Network Science Advisor, Environment Canada, Ecological Monitoring and Assessment Network Coordinating Office, Burlington, Ontario, Canada, L7R 4A6
Nicole Dmytrow, intern, Ontario Ministry of Environment, Dorset Environmental Science Centre, Dorset, Ontario, Canada, P0A 1E0

Abstract—*Canada's Ontario Ministry of the Environment and Environment Canada (Ecological Monitoring and Assessment Network) are developing an aquatic macro-invertebrate biomonitoring network for Ontario's lakes, streams, and wetlands. We are building the program, called the Ontario Benthos Biomonitoring Network (OBBN), on the principles of partnership, free data sharing, and standardization. This paper discusses the importance of biomonitoring, describes why benthos are commonly used as indicators of aquatic ecosystem condition, explains the complementarity of biological and chemical assessments, details OBBN components, and lists some research needs. The paper is framed by several themes: inclusiveness, partnerships, capacity building, and creating effective links between monitoring and decision-making.*

Traditionally there has been an individualistic approach to Biomonitoring in Ontario, with little communication between practitioners. This lack of coordination has limited the application of biomonitoring in the past, chiefly because no mechanism for sharing and comparing data existed, and because there was no consistent training. Based on approaches used in the U.K., Australia, and the U.S.A., the OBBN will overcome these difficulties by specifying standard methods (with options for tailoring programs to match expertise and financial resources), enabling data sharing between partners, automating assessments, and providing training.

Biological criteria for evaluating aquatic ecosystem condition are generally not available. The OBBN uses a reference-condition approach (RCA) to define biocriteria: samples from minimally impacted (reference) sites define an expectation (for example, the normal range) for biological condition at a test site. Assessments evaluate whether a test site's biological condition is within the normal range. The OBBN's automated analytical tools and a protocol that balances flexibility with standardization will allow the citizen scientist and university academic to do bioassessments of similar calibre. New partnerships, and the ability to generate local information on aquatic ecosystem condition, will build capacity for adaptive water management and enhance the link between science and decision making.

Introduction

Ontario Canada's Ministry of the Environment (MOE) and Environment Canada's Ecological Monitoring and Assessment Network Coordinating Office (EMAN CO) co-founded the Ontario Benthos Biomonitoring Network (OBBN). Once fully implemented, the OBBN will allow partners to evaluate aquatic ecosystem condition using the reference-condition approach and shallow-water benthos as indicators of environmental quality.

The purpose of this paper is to explain our vision of the Ontario Benthos Biomonitoring Network within the context of a complex mosaic of Canadian initiatives that together result in substantial capacity for adaptive environmental management and informed local decision-making. The common thread through this mosaic is a commitment to the fundamentals (Jones and others 2002): building partnerships, and providing information on ecosystem condition and management performance to local decision makers. We begin by discussing the importance of biomonitoring, explaining why benthos are commonly used as indicators of aquatic ecosystem condition, and highlighting the complementarity of biological and chemical assessments. We then describe the components of the OBBN and justify each in relation to their role in adaptive, community-based ecosystem management. The paper concludes with a list of research needs related to implementation.

Importance of Aquatic Biomonitoring

Monitoring supports adaptive water management; it provides feedback on the status of aquatic resources and the performance of policies, programs, and legislation (Jones and others 2002). Biomonitoring—the process of sampling, evaluating, and reporting on ecosystem condition using biological indicators—is an important part of aquatic ecosystem management. This is because management end-points are often biological (for example, protection of aquatic biota and their habitats), and because laws and policies typically stress the protection of aquatic biota.

Ontario's legislative basis for biomonitoring includes the Ontario Water Resources Act (R.S.O. 1990, CHAPTER O.40), which has a clearly biological definition of impairment. It states that "the quality of water shall be deemed … impaired if … the material discharged … causes or may cause injury to any person, animal, bird or other living thing …." Similarly, Ontario's Environmental Protection Act (R.S.O. 1990, CHAPTER E.19) has clearly biological elements of its definition of adverse impact, including: (a) impairment of the quality of the natural environment for any use that can be made of it, (b) injury or damage to property or to plant or animal life, (d) an adverse effect on the health of any person;, and (f) rendering any property or plant or animal life unfit for human use. Canada's federal Fisheries Act (R.S. 1985, c. F-14) provides further impetus for biomonitoring by stating that no person shall carry on any work or undertaking that results in the harmful alteration, disruption, or destruction of fish habitat (for example, spawning grounds; nursery, rearing, and migration areas; and food supply).

Reflecting our legislation, Ontario's policies also suggest a need for biomonitoring. The document, "Water Management: Policies Guidelines Provincial Water Quality Objectives of the Ministry of Environment and Energy [sic]" (Ontario Ministry of Environment and Energy 1994) states, "With respect to surface water quality, the goal is to ensure that … water quality is satisfactory for aquatic life…" Similarly, Ontario's Provincial Policy Statement (PPS) (R.S.O. 1990, CHAPTER P.13), an extension of the Planning Act, states, "the quality and quantity of ground water and surface water and the function of sensitive ground water recharge/discharge areas, aquifers, and headwaters will be protected, or enhanced." The PPS further states that development and site alteration is only permitted in significant habitats if no negative impacts on the natural features or the ecological functions will result.

Although the above are Ontario examples, similar legislation- and policy-based justifications for biomonitoring can be made in many countries. An international example includes the EU Water Framework Directive, which requires both good ecological status (based on the reference condition approach, see below) and good chemical status of surface water (EU Commission 2003). In the U.S., the concept of biological integrity has been included in water legislation (for example, the Water Pollution Control Act) since 1972 and "is now an integral component of water resource programs at state and federal levels" (U.S. EPA 2002).

Benthos as Indicators

Benthos are large, bottom dwelling insects, crustaceans, worms, mollusks and related aquatic animals. They are good indicators of aquatic ecosystem health because they are sedentary, their life cycles range in length from months to years (compares well with typical 1-3 year business planning and budgeting horizons typically applied in environmental management), they are easy to collect and identify, they are responsive to changes in water and sediment quality, they are ubiquitous, and they are not typically seen as an economic or recreational resource themselves (Mackie 2001). Benthos have been used extensively to assess water quality in streams and lakes (Rosenberg and Resh 1993 and 1996).

Complementarity of Biological and Physical-Chemical Monitoring

Physical-chemical (stressor-based) and biological (effect-based) monitoring approaches are complementary (table 1). An example of a stressor-based index is a water chemistry analyte (in other words, a surrogate for the toxicity of water to fish). An example of an effect-based index is age class abundance of smallmouth bass (in other words, a surrogate for reproductive success and mortality of fish exposed to a chemical stressor).

A case study for the Pretty River, Collingwood, Ontario shows the complementarity of these two types of indicators. Table 2 shows benthos data between 1996 and 2001 for Pretty River while figures 1 and 2 show water quality for the same stream and time period. The majority of the distribution of data for phosphorus and zinc (stressor-based indicators) were well below

Table 1. Complementarity of stressor- and effect-based aquatic monitoring (adapted from Roux and others 1999).

	Stressor-based Approach	Effect-based Approach
Monitoring focus	Stressors causing environmental change, i.e., chemical and physical inputs	Effects (responses) of natural and/or anthropogenic disturbances, e.g., changes in the structure and function of biological communities
Management focus	Water quality regulation: controlling stressors through regulations	Aquatic ecosystem protection: managing ecological integrity
Primary indicators	Chemical and physical habitat variables, e.g., pH, dissolved oxygen, copper concentration	Structural and functional biological attributes (e.g., relative taxa abundances, frequency of deformities)
Assessment end points	Degree of compliance with a set criterion or discharge standard	Degree of deviation from a benchmark or desired biological condition

Table 2. Species abundances for each listed benthos taxon collected during a 5 minute kick and sweep sample for the Pretty River, Collingwood, Ontario.

Qualitative Sample	Kick 1 (~5 min)	Number	Kick 2 (~5 min)	Number
Molophilus	Hydropsyche	37	Hydropsyche	4
Caenis	Stenelmis	3	Optioservus	1
Stenonema femoratum	Optioservus	2	Stenonema (imm.)	1
Stenonema (imm.)	Antocha	12	Fossaria	1
Caecidotea	Hemerodromia	1	Paracapnia	4
Hydropsych	Stenonema (imm.)	13		
Stenelmis (l)	Orthocladiinae	1		
Hesperocorixa	Tanypodinae	1		
Agnetina	Chironomini	1		
Taenioteryx	Tanytarsini	6		
Paracapnia	Ephemerella	1		

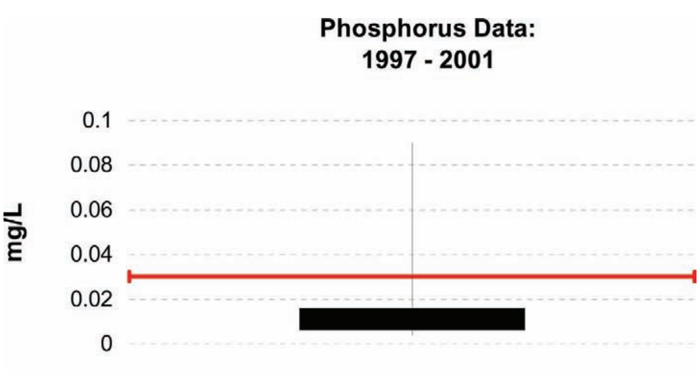

Figure 1. Phosphorus data from Pretty River, Collingwood, ON. The central 50 percent of the data is shown as the box, with vertical bars extending to the maximum and minimum observed values. Unpublished data.

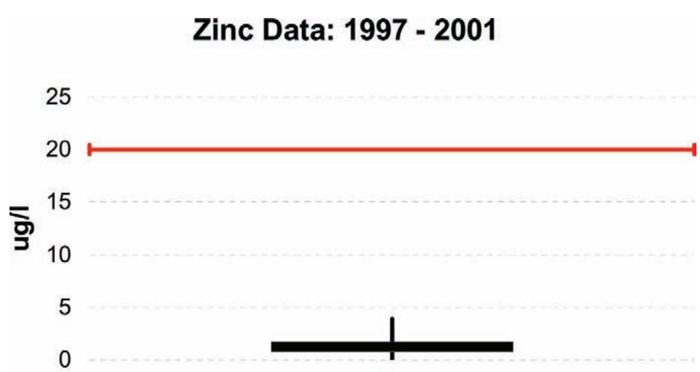

Figure 2. Zinc data from Pretty River, Collingwood, ON. The central 50 percent of the data is shown as the box, with vertical bars extending to the maximum and minimum observed values. Unpublished data.

Provincial Water Quality Objectives (MOEE 1994), suggesting good water quality conditions; however, in comparison to local minimally impacted stream communities, the very low overall abundance and the relative scarcity of sensitive benthos (effect-based indicator) suggested a strong effect of habitat degradation (which was consistent with the site's history as a man-made bedrock floodway channel). In this case, seemingly contradictory water chemistry and biological monitoring results can be combined to make a more complete assessment of aquatic ecosystem condition than either approach could on its own, in other words, to conclude that water quality is good but that biota are suppressed by habitat degradation.

Ontario Benthos Biomonitoring Network Vision

Herein we describe OBBN components and reinforce the connection of each component to adaptive community-based ecosystem management.

Background

Even though the need for benthos biomonitoring is well known, its application has not been widespread in Ontario for several reasons: although regulatory guidelines for water chemistry are available, no analogous biocriteria exist for biomonitoring; bioassessment is complex due to a number of confounding factors (for example, biota respond to factors other than water quality); no standard sampling protocol exists; benthos identification requires special expertise; experts disagree on interpretation; and traditional methods are costly.

A historical patchwork approach to biomonitoring in Ontario created three main barriers to wider application: no standard protocol, no mechanism for sharing data, and no consistent training. The OBBN will remove these barriers by specifying standard methods, enabling data sharing between partners, automating analysis using a reference-condition approach, and providing training. With the direction of a multi-partner Technical Advisory Committee, we are developing the network according to the principles of partnership, free data sharing, and standardization. EMAN sees the OBBN as a pilot project for a Canada-wide aquatic biomonitoring program that is accessible to volunteer "citizen scientists" and professional research scientists alike.

The Ontario Benthos Biomonitoring Network has four objectives:

1. To enable the assessment of lakes, streams, and wetlands using benthic macro-invertebrates as indicators of environmental quality.
2. To provide a biological performance measure related to management of aquatic ecosystems.
3. To provide a biological complement to Ontario's provincial surface water chemistry monitoring program.
4. To facilitate a reference condition approach to bioassessment in which minimally impacted sites are used to derive a community expectation for a test site.

We expect to fully implement the OBBN by 2005. Coordinating partners, MOE and EMAN CO, are providing scientific guidance and limited sampling equipment. Partners (federal, provincial, and local governments; conservation authorities [Ontario's watershed-based quasi-governmental water management agencies]; universities; non-governmental groups; and volunteers) are sampling lakes, streams, and wetlands, using and reporting information according to their own mandates, and participating in collaborative research to refine protocols and analytical methods.

Reference Condition Approach

We recommend a reference condition approach (RCA) to bioassessment (fig. 3), in which minimally impacted reference sites are used to define "normal" and set an expectation for community composition at test sites where water and habitat quality are in question (Wright and others 2000, Bailey and others 2004). Using the RCA, we consider test sites unusual if their communities fall outside of the normal range. Unusual sites warrant further study to determine if human activities are responsible for the deviant community composition.

The first step in the RCA is to sample reference sites. Because no objective, quantitative criteria for "minimally impacted" exist, we ask partners to sample sites that are not obviously exposed to any human impacts (such as point-source contamination, regulation of water level, water impoundment, deforestation, habitat alteration, development, agriculture, or acidification), and that represent best local conditions. Test site sampling will commence once a reasonable amount of reference site data is available.

OBBN Protocol

Providing standard operating procedures is vital to wide implementation of aquatic benthos biomonitoring in Ontario. Some degree of standardization is important in any monitoring program to ensure comparability of results over time and across jurisdictions, and this is particularly true when using a reference condition approach; however the OBBN protocol (Jones and others 2004) also recognizes that some degree of flexibility is equally vital in a program that is founded on partnerships. OBBN partners differ with respect to their financial resources and expertise, and standard methods must have options that can accommodate these differences. Table 3 summarizes OBBN protocol recommendations. Approximately 400 sites have been sampled to-date in Ontario using these protocols.

OBBN Database and Automated Analytical Tools

The OBBN includes an internet-accessible database for storing and sharing reference site and test site data. The database is being jointly developed by EMAN CO and the National Water Research Institute of Environment Canada and will be integrated with a proposed national

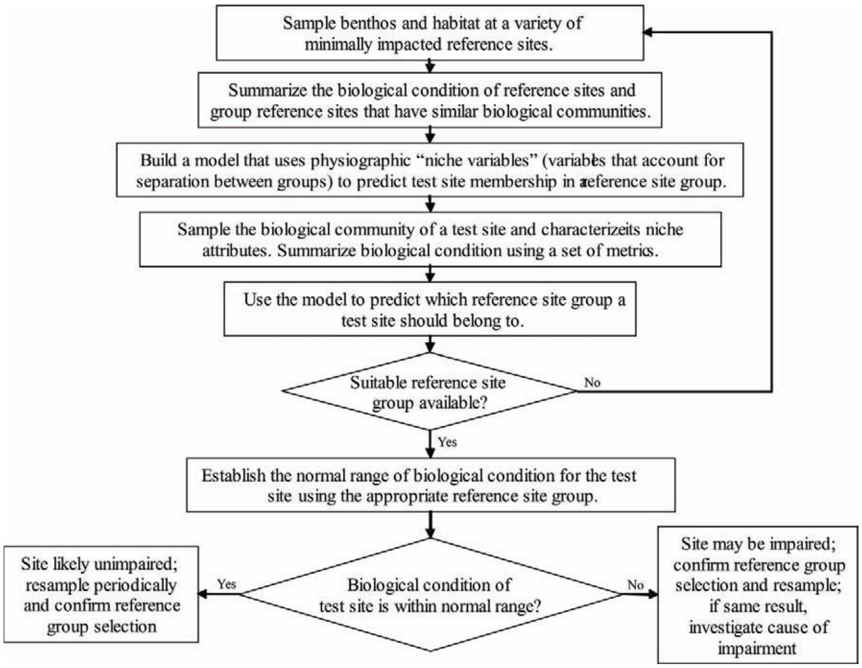

Figure 3. Steps in the reference condition approach to bioassessment.

biomonitoring program. Several automated analytical database modules are currently under development: a test site and reference site selection utility, a mapping utility, a summary metrics calculator, and a statistical module for hypothesis testing. These modules are critical to the success of the program because they mean that sophisticated bioassessments can be done equally by volunteer citizen scientists and professional research scientists alike; they will allow partners to generate readable, custom, nearly-instantaneous assessment reports that represent a considerable increase in available information for local community-based decision making in Ontario. These assessment tools are a substantial innovation in light of many other programs in which community volunteers merely collect, submit data to a central warehouse, and receive little or no feedback on what the data mean.

Generating a custom report with the automated analytical tools requires an OBBN partner to proceed through six steps:

1. Log-in to the database with a client password (passwords are coded to training certification level and effectively limit data entry fields and forms a user has access to based on training received).
2. Enter site location, benthos, and habitat data for test site (site photo optional).
3. Execute the reference site selection tool (runs a predictive model that predicts a test site's reference site group membership based on site- and catchment-scale physiographic information, and queries the database for records associated with reference sites in the predicted group).
4. Execute the Metrics Calculator (calculates a user-defined set of benthos community summary metrics for both the test site and reference sites).
5. Execute the hypothesis testing tool (automates the statistical calculations associated with a multivariate t-test, which determines if the test site is within or outside the normal range considering all summary metrics [and redundancies among metrics] simultaneously).
6. Execute the reporting tool (which compiles products from each of the above modules into a simple output).

Table 3. Summary of OBBN protocol recommendations.

Biomonitoring Component	Recommendation
Benthos Collection Method	Traveling kick and sweep (other optional methods are available for special studies or atypical habitats)
Mesh Size	500 µm
Time of Year	Any season; assessment comparisons are made using data from the same season
Picking	In lab (preferred) or in field (optional); preserved (preferred) or live (optional), microscope (preferred) or visually unaided (optional); random sub-sampling to provide a fixed count per sample
Taxonomic Level	Mix of 27 Phyla, Classes, Orders and Families (minimum detail); more detailed identifications are optional and are recommended for reference sites
Analysis	Reference condition approach: community composition summarized using a variety of user-defined indices and hypothesis testing based on generalized distance (Bowman and Somers 2004)

Training

Training is a critical component of the OBBN for two main reasons. First, it ensures that protocols are followed correctly so that partners have confidence in the quality of reference and test site data shared through the network. Second, it fosters interest in monitoring and better use of monitoring information in the environmental decision making process.

The large number of OBBN participants and relatively few full-time staff administering the network (one government scientist and one recent graduate intern) necessitated a train-the-trainer approach, which is still under development. To-date, training has been offered at a series of multi-day courses that cover all aspects of the program, with emphasis on the reference condition approach, sample collection and processing procedures, and benthos identification. So that deficiencies in OBBN methods can be corrected, the training workshops will be augmented with short protocol-audit workshops, in which exercises will determine if participants are applying techniques as written and if difficulties are arising.

To-date, several hundred partners have attended training courses and their feedback will enable refinements to the training program. A future training focus will be benthos identification. Rather than developing a unique taxonomic certification for Ontario, we plan to implement the North American Benthological Society taxonomic certification program, which is still under development (North American Benthological Society 2003).

Collaborative Research

The OBBN includes a collaborative research component that is aligned with program implementation, principally the refinement of methods. Collaborative research opportunities ensure efficiency, assist with the delivery of the resulting information, and allow partners to get more involved in monitoring science than they would otherwise be able to. Studies investigating high priority questions related to collection methods and timing of benthos sampling are underway. These studies will determine where optional methods can be applied, if sufficient numbers of animals are collected, and whether different collection methods yield similar relative abundance estimates for a site. A temporal stream study is investigating seasonal patterns of benthos community composition and may allow us to refine sampling windows specified in our protocol manual.

We list several OBBN research questions below. Studies to answer each question will be undertaken in priority sequence with results being reported using media appropriate to our audience, typically peer reviewed literature and government technical bulletins.

- Is the reference site mean plus/minus 2 standard deviations a reasonable definition of the normal range? Does this definition reflect what we consider to be an ecologically significant effect, in other words, the minimum effect size we wish to detect?
- How many groups of reference sites are there? How many sites are required to define a group? How minimally impacted must a site be to be considered a reference site? Does this threshold change depending on location in the province?
- How accurately can we predict a test site's reference group membership? What are the best attributes on which to build our predictive model?
- What is the ideal ratio of reference sites to number of metrics used in the analysis?
- Does the detail of benthos identification (for example. Order-level vs. Genus-level) affect the sensitivity of a bioassessment and the amount of diagnostic information provided? Does the selection of a sampling method affect sensitivity or diagnostic resolution? Can we use "response signatures" to identify certain types of impairment? Which indices contribute the most information to bioassessments in different parts of Ontario?
- How many samples are enough for whole lake, whole river, or whole wetland assessments?

Summary

Monitoring is important to adaptive environmental management because it provides feedback to managers on the status of resources and the performance of management activities. Biomonitoring is required to support legislative and policy direction in many jurisdictions, and provides effect-based results that are relevant in management schemes that aim to protect biota. Benthos, bottom dwelling invertebrates that live in most aquatic systems, have many traits that make them excellent indicators of aquatic ecosystem condition.

The Ontario Benthos Biomonitoring Network will enable partners ranging from volunteers to research scientists to reliably conduct benthos bioassessments on lakes, streams, and wetlands. The result will be a marked increase in the amount of locally available information on aquatic ecosystem condition for consideration in environmental management decisions. The OBBN has five components that have been built specifically to promote comprehensive bioassessment coverage of the province: a database that enables reference and test site data sharing, a standard protocol (which contains options so procedures can be tailored to partners' expertise and financial resources), training, automated analytical tools, and a research program. The network will be fully implemented by 2005 on the principles of partnership, free data sharing, and standardization and is part of a mosaic of Canadian programs that are delivering effective information to local environmental decision makers.

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Tri Community Watershed Initiative: Towns of Black Diamond, Turner Valley and Okotoks, Alberta, Canada Promoting Sustainable Behaviour in Watersheds and Communities

Maureen Lynch is the Coordinator of the Tri Community Watershed Initiative, Black Diamond, AB, T0L 0H0

Abstract—*For the past two years, three rural municipalities in the foothills of the Canadian Rockies have been working together to promote sustainability in their communities. The towns share the belief that water is an integral part of the community; they have formed a Tri Community Watershed Initiative to help manage their shared resource. Activities of the Initiative include changing municipal policies, writing municipal water, and river valley management plans, working with partners, hosting community events and engaging local media in community success stories. The towns are also assisting residents in outdoor water conservation efforts. To date, 100 percent of the households – more than 15,000 residents in approximately 6,000 households – have participated in community-wide water conservation campaigns that protect the local watershed.*

The Initiative has improved local policy and decision-making through a collaborative, multi-stakeholder approach that delivers ecological monitoring science in a manner that improves knowledge in the decision-making process. Involvement of town councilors in this ecological monitoring initiative has allowed local decision makers to gain awareness and knowledge that has led to action on community environmental watershed issues and increased community capacity.

Decisions made at local and landscape scales have a direct impact on sustainability. This Initiative has succeeded in ensuring that choices are informed and reflect the collective values of the community. By identifying values and defining sustainability, the communities have been empowered to monitor progress and feed into adaptive decision-making processes. The framework and best practices the towns have developed for engaging communities will be discussed as well as lessons learned.

Introduction

Since 2002, the Towns of Black Diamond, Turner Valley and Okotoks have been working together to engage residents of the Sheep River Valley in personal action toward the preservation and protection of their watershed. Through identification of common issues, the municipalities have developed a Tri Community Watershed Initiative to help promote more sustainable use of local water resources. Initiative elements include implementation of water conservation strategies, introduction of water practice policies, community engagement opportunities, working with partners and developing public information and education materials. Establishing normative behaviours that focus on voluntary adoption of best management practices through development of cooperative models and more informed decision-making, the initiative has proven to be effective in changing municipal water policies and influencing water use behaviour in the communities.

The Tri Community Watershed Initiative is helping the towns to engage the residents of the Sheep River Valley in personal action toward sustainability and greater ecological health. An important initiative component is the implementation of community-based social marketing (CBSM) campaigns, which have proven to be an effective method in influencing residential behaviour in the communities. Since 1999, the Town of Okotoks has successfully used CBSM as part of its water conservation initiative, resulting in a 20 percent reduction in residential water use during the summer months. The Towns of Black Diamond and Turner Valley recently adopted a CBSM approach to address water conservation issues and experienced overwhelming support from residents for the program.

Water as a Bridge Between Communities

The Towns of Black Diamond (population 1,900), Turner Valley (population 1,500) and Okotoks (population 12,000) face a variety of challenges as a result of influences of local growth, urban sprawl, forestry, oil and gas exploration, tourism and recreation, intensive livestock operations and traditional agricultural practices. Local town councils must respond to increasing demands for policy to balance social, economic, and environmental issues. Residents share concerns about their own awareness and knowledge, which they feel contribute to the success of their community. The towns are situated within a 20-km radius of one another and are located near Calgary, Alberta, Canada. Identified issues of common concern are linked to watershed management and the municipalities share the belief that water is an integral part of the community.

In March 2002, the towns supported a proposal to participate in the Canadian Community Monitoring Network (CCMN), a one-year pilot initiative of Environment Canada and the Canadian Nature Federation to link monitoring to decision-making. The project aimed to determine the best approaches for engaging communities in monitoring activities that contribute to local sustainability. Under the CCMN project, 12 coordinators in 31 widely differing communities across Canada were hired to test and refine different approaches to implementing Community Based Monitoring (CBM). Each coordinator used a range of personally tailored, context-specific approaches accompanied by a suite of tools. The four key phases of the CCMN model for CBM developed through the project include community mapping, participation assessment, capacity building, and information gathering and delivery (EMAN CO and CNF 2004).

The Towns of Black Diamond, Turner Valley and Okotoks, as participating communities in the CCMN project, learned that progress toward a common vision of sustainability can be measured by environmental monitoring when it is driven by local information needs and community values. In addition, they found that local monitoring information can be integrated into adaptive decision-making structures where verification, investigation of cause, research into mechanisms or development of options can be initiated in response to early indications of environmental change.

As three southern east slope communities located along the Sheep River in the foothills of the Canadian Rocky Mountains, the towns have a history of almost 100 years of living and working within their watershed. These communities share concerns about use and stewardship of their water resource and are acting together to reduce impacts. A common vision of engaging resident in the preservation and protection of the Sheep River has begun to emerge among local municipal councils. Local action is linked to community engagement and public information and education programs are helping to build community capacity on watershed issues.

The Sheep River is a natural free-flowing river, which has no in-stream or off-site water diversion facilities to store and protect municipal water supplies. Communities rely on natural flows and the wise and responsible use of water resources to provide for their needs. The towns believe in the importance of directing efforts towards the preservation and protection of their watershed and collectively seek to reduce their impacts on the water they use and return to the river. “We are all downstream water users” appropriately describes the relationship among these communities.

Currently the Sheep River is relatively healthy; however, threats from various urban uses have the potential to contribute to watershed deterioration. Water conservation and wise water use by all Sheep River watershed users is a significant issue. A 30 to 50 percent water saving can be achieved, for example, in households by using three low-flow devices (toilets, showerheads, tap aerators). Climatic conditions and lack of scientific data to determine healthy aquatic environments are ongoing water management concerns for the Towns of Black Diamond, Turner Valley and Okotoks. Members of these communities have expressed a need to “take action” towards urban water use and management issues and access additional expertise to provide opportunities to engage residents in stewardship programs.

Raising Awareness and Knowledge Through Community Action

Through the Tri Community Watershed Initiative, the Towns of Black Diamond, Turner Valley and Okotoks have built community linkages to support local citizen-led watershed efforts. To date, three annual tri-community river clean ups, involving more than 350 volunteers and 9 llamas, have gathered 7 tons of garbage—including everything from tractor tiers to kitchen sinks. Decision-maker involvement includes town councilors, mayors, staff, and residents.

Additional community engagement opportunities help to further build capacity. More than 100 students from local Foothills Composite and Oilfields High Schools have conducted water quality monitoring tests on the Sheep

River with RiverWatch, an award-winning not-for-profit organization that links water monitoring activities to the Alberta Learning Curriculum. Students have participated in pre- and post-field work, in-class discussions, and data collection to measure physical, chemical, and biological river parameters. Town councilors and local media also participated, providing links to local decision-making and community engagement. In addition, RiverWatch Summer Science Water Camp activities have provided an opportunity for 25 children to float down the Sheep River in inner-tubes and learn about natural history, aquatic health and river safety while conducting water quality monitoring activities.

The towns also hold focus groups with residents to discuss water conservation issues and identify barriers and constraints. Meetings with neighbouring communities provide opportunities to discuss water-related issues including the hosting of a national panel discussion on water conservation with regional partners, Environment Canada, Canadian Nature Federations, Canadian Community Monitoring Network regional coordinators, and mayor, council, staff and residents. In addition, the towns have held a Facilitation Skills Workshop to train 25 residents, staff and decision-makers in local sustainability issue management.

In addition, the towns are assisting residents in outdoor water conservation efforts. Using a Community-Based Social Marketing strategy, the towns have created a two-way dialogue by visiting resident door-to-door, discussing water conservation issues and identifying barriers and constraints to wise water use. To date, 100 per cent of residential households (5,400 households, 15,000 residents) have received incentives such as fact sheets, hose washers, tap timers, and wildflower seed packages. The towns have reinforced their wise water use messages through utility bill inserts, direct mailers, highway signage, and newsletter and newspaper articles. The communities also share a common Horticultural Hotline in which Town of Okotoks' Open Spaces Staff answer more than 1,000 telephone calls per year from area residents on water related issues.

The Tri Community Watershed Initiative has been recognized with two APEX Awards of Communications Excellence and has been named as a Finalist in the Alberta Emerald Award Foundation for Environmental Excellence.

As a result of their involvement in the Tri Community Watershed Initiative, the three town councils have improved water efficiency policies by passing low-flow fixture bylaws (for new homes, businesses and renovations), water conservation bylaws, joint resolutions to work together, right-to-know pesticide bylaws, and line item budget funding for residential water conservation programs. Participation of town councilors in grassroots ecological monitoring initiatives through such activities as River Clean-Up Day has allowed local decision makers to gain awareness and knowledge that has led to action on community environmental watershed issues and increased community capacity building.

Capacity Building—Remind, Reinforce and Reveal to Succeed

Through the joint efforts of the Towns of Black Diamond, Turner Valley and Okotoks, the Tri Community Watershed Initiative has:

1. Lead to action on local community river valley issues.
2. Engaged the communities in volunteer and residential watershed activities.
3. Encouraged active community participation in watershed policies.
4. Encouraged commitment of municipal councils to watershed management.
5. Enabled the communities to develop resources, expertise, and partnerships to raise community awareness, knowledge, and personal action.

The Tri Community Watershed Initiative has also generated substantial financial contributions to the three communities, including funding from EcoAction ($100,000), Environment Canada/Canadian Nature Federation – CCMN Project ($39,000), Community Animation Program ($9,000), Community Initiatives Program ($7,000), in-kind donations ($10,000) and line item budgeting from the Towns of Turner Valley, Black Diamond, and Okotoks ($32,000).

Public involvement within the Towns of Black Diamond, Turner Valley and Okotoks has been extensive, with more than 500 participants (3,000 volunteer hours) taking part in watershed activities. Demographics range from residents, students, councilors, town staff and environmental partners. Face-to-face meetings, presence, and visibility within the communities, and exchanging information have all been successful methods of sharing with our partners. Approximately 150 meetings have been held within the three communities to discuss water related issues, with more than 2,000 participants in attendance. Specifically, the Tri Community Watershed Initiative has provided the towns with:

- Personal contact with 5,400 households and 15,000 residents to discuss water conservation issues and identify barriers and constraints to wise water use, resulting in a 20 per cent reduction in summer residential water use in the Town of Okotoks along (the Towns of Black Diamond and Turner Valley are currently reviewing summer residential water use statistics to determine reduction rates).

- Community capacity building with local schools, resulting in 100 local high school students and 25 elementary-aged students conducting water-monitoring activities. Six local teachers have been trained in RiverWatch monitoring protocols.
- Improved aquatic health of the Sheep River through river clean up activities, resulting in 350 volunteers and 9 llamas collecting 7 tons of garbage and ongoing annual efforts.
- Tools to link community watershed activities to inclusive decision-making, resulting in five new water-related bylaws and three town council resolutions.
- Twenty-five community members trained in facilitation skills.
- Increased media profile of tri community efforts, resulting in 25 newspaper articles, 10 radio interviews, 5 magazine articles and 3 television interviews.

Maintaining a Healthy, Free Flowing Ecosystem

The Towns of Black Diamond, Turner Valley and Okotoks have demonstrated leadership, responsibility, and cooperation in the Tri Community Watershed Initiative. Their collective efforts have improved the quality of life in their communities by providing opportunities to address local level policy processes and engage in local watershed activities, which reflect the desires of community residents and the legacy they will leave for future generations. Through their involvement in the Tri Community Watershed Initiative, the Towns of Black Diamond, Turner Valley and Okotoks are connecting residents to environmental issues and demonstrating innovation and excellence through the development of knowledge, practices, and processes that suit the watershed needs of the three communities.

Influencing Watershed Behaviours

The Towns of Black Diamond, Turner Valley and Okotoks have created strategic linkages within their communities and strengthened partnerships with such groups as *Calgary Regional Partnership, RiverWatch, Earthwatch, Cows & Fish, Highwood Business Development Corporation, Headwaters Health Authority*, and *Canadian Cattlemen's Association*.

Most recently, the Tri Community Watershed Initiative formed a formal partnership with the Bow River Basin Council (BRBC) a non-profit, non-government, multi-stakeholder, charitable organization dedicated to conducting activities for the improvement and protection of the waters of the Bow River Basin. With a membership of more than 125 organizations, the BRBC maintains a forum for council members to share perspectives and exchange information, and encourages the implementation of cooperative water use management strategies through participation in activities that promote and demonstrate increased awareness of water use management issues.

The BRBC has identified support of the Tri Community Watershed Initiative as an important priority in its public information and education goals and objectives. The BRBC recognizes that by providing the opportunity for this initiative to more formally capture and share results among BRBC members, the council will enable a very powerful opportunity for other municipalities and groups to replicate similar successes. This multiplier effect will make a substantial contribution to the overall health and management of the Bow River Basin watershed, allowing more communities to learn from, and adapt and adopt, the innovative strategies and approaches developed through the Tri Community Watershed Initiative.

As partners, the Tri Community Watershed Initiative and BRBC have created a two-year project entitled Influencing Watershed Behaviours that aims to protect the Sheep River watershed by focusing on five main themes: integrated pest management, river valley management, water conservation, capacity building, and shared tools and resources. Specifically, the project will help:

- reduce residential water consumption by identifying constraints and enablers to indoor and outdoor water conservation practices
- reduce use, and create a better understanding, of residential pesticides by identifying constraints and enablers to improve residential integrated pest management (IPM) practices
- protect river valley lands by undertaking a river valley management planning process and hosting local watershed workshops, planning sessions, field trips and river clean-ups
- build capacity and share tools and resources among stakeholders in the BRBC and Calgary Regional Partnership by surveying members, identifying needs, producing generic resource materials and hosting information-sharing opportunities on water conservation and IPM issues.

The Influencing Watershed Behaviours project commenced April 2004 and to date a number of activities have been undertaken. This summer, the Town of Okotoks replaced approximately 200 residential water meters and provided free indoor water conservation kits as an incentive for residents to participate in wise water use, and an additional 500 homes received free outdoor water conservation kits. A Turner Valley neighbourhood hosted a xeriscape gardening information session, focus group and garden tour. The Okotoks Home Hardware store continues to provide in-store displays and discount coupons on water-efficient products. The Town of Okotoks was also recently chosen by the UN Year of Fresh Water for a Global television commercial on municipal water conservation to be aired over the next year. Local media coverage has assisted in promoting water conservation messages and the importance of protecting the aquatic health of the Sheep River. Future program components include a survey of BRBC members to identify common watershed concerns, a workshop to share project information, and development of generic Community Based Social Marketing resources materials on water conservation and integrated pest management, for use and replication among BRBC members.

Residents and stakeholders of the watershed are being made aware of the project through the use of door-to-door visits, focus group sessions, telephone surveys, fact sheets, posters, website information, demonstration sites, radio and television coverage, newspaper advertisements and articles, meetings and presentations. By increasing understanding, awareness, knowledge, and action towards a healthier Sheep River watershed, the project is establishing normative behaviours that focus on voluntary adoption of best management practices. The approach of the project is through a two-way dialogue between residents and municipal councils. Information sharing with external partners is also enabling residents and stakeholders to develop co-operative models for positive change and more informed decisions that collaborate on the strengths of those involved.

The environmental benefits will last long after the project is completed and will directly impact residents in the Towns of Black Diamond, Turner Valley and Okotoks as well as members of the Bow River Basin Council, Calgary Regional Partnership, and the Sheep River Water Users Group. Residents who are installing water-saving devices and adopting water conservation behaviours are contributing to a decrease in water consumption and better progress towards demand management of water while saving money. Residents who implement integrated pest management techniques will contribute to a decrease in pesticide use and possibly voluntary elimination of pesticides from their yards and gardens. Outcomes and impacts will lead to important changes in the lives of community residents, as the project helps the towns address common municipal issues of residential water and pesticide use by using shared resources and a collective, co-operative joint-community approach.

The Towns of Black Diamond, Turner Valley, and Okotoks have demonstrated leadership, responsibility and co-operation in their joint sustainable community development efforts over the past two years. This project will further support their collective efforts to improve the quality of life in their residents and connect to environmental/health benefits by providing opportunities to address local level policy and decision making processes which reflect the desires of community residents and the legacy they will leave for future generations. The project will reduce peak flow demands on infrastructure, stretch the use of available water, provide consumer savings (i.e. low-flow fixtures), protect the aquatic environment, contribute to the sustainability of the environment and water as a vital natural resource, and help meet increased demands of economic and population growth to proper management of the resource and ensure adequate water quantity and protect water quality.

Quotable Quotes

Here's what people are saying about the Tri-Community Watershed Initiative:

> "CCMN helps strengthen links between community-based environmental monitoring and decision making. We kind of have a corridor pilot project here in Alberta. It's a wonderful, unique opportunity. We're in close touch with each other so maybe we'll be able to do something that broadens the network of communities here (in southern Alberta). This is a national program so we have resources available to us that might not otherwise be available. Some of these opportunities would not exist without this program."

--Maureen Lynch, CCMN Project Coordinator for the towns of Black Diamond, Turner Valley and Okotoks on the formation of the Tri-Community Watershed Initiative (Source: Okotoks Western Wheel Newspaper – May 15, 2002)

> "The clean-up is an opportunity to show respect for the green areas of town. Picking up litter and garbage in our river valley means that litter and garbage isn't going to continue down the valley. If we keep litter out of the river valley it will continue to look like a natural area. The regional aspect of the clean up is very important. We have to monitor the quality of water and ensure

that the entire river valley is clean and tidy. If we clean all that up we will feel better about the environment we live in."

--Karen Brewka, Town of Okotoks Horticultural Specialist, on the importance of the First Ever Sheep River Clean Up Day (Source: Okotoks Western Wheel Newspaper - May 22, 2001)

"We finally get to go outside and do something instead of learning about it in a book. Everyone learns differently. Not everyone learns from books. The more you're able to use your hands in things like this the more you remember."

--Linnea Morris, Oilfields High School Biology 20 Student, participating in the CCMN/RiverWatch monitoring day on the Sheep River in Black Diamond, AB (Source: Okotoks Western Wheel Newspaper - May 29, 2002)

"The average Canadian adult spends six minutes a day outside…we really have sheltered ourselves. The students are here and they're learning data but being outside is teaching them to become better people in the world too."

--Jim Christie, Oilfields High School Biology Teacher, field trips like RiverWatch are an essential way for students to learn. (Source: Okotoks Western Wheel Newspaper – June 5, 2002)

"I think it's a great thing for everyone to be learning, especially when you live in the area. It's important for town council to support programs that involve our environment, youth, and everything that directly affects our drinking water."

--Kristie Tucker, Black Diamond Town Councillor, on her participation with local Oilfields High School students in the CCMM/RiverWatch monitoring day (Source: Okotoks Western Wheel Newspaper – June 5, 2002)

"The kids are out there and it's always the contact that make the biggest impression. That's the first thing. The second thing is actually collecting the data and the third thing is having fun. This has been a complete success."

--Stuart Peters, RiverWatch Project Coordinator, on the success of Oilfields High School Students' participation in the CCMN/RiverWatch monitoring day (Source: Association of National Park Rangers RANGER Journal – Fall 2002)

"They're (local residents) sophisticated in their understanding, and as politicians we need to listen. They've been very effective in directing water quality decisions. I feel pretty optimistic about the progress we can make as communities sharing the same watershed. We've come a long way. We're recognizing the impact we can have by working collectively."

--Jane Toews, Black Diamond Councillor re local residents' profound influence on environmental decision making (Source: Canadian Nature Federation NATURE CANADA Magazine – Spring 2003)

"The big success was the three towns worked together so well. Conversations and discussions overcome barriers. Each person and household will have their own unique circumstances."

--Maureen Lynch, Regional Coordinator of local CCMN project on the awareness and dedication generated over the past year (Source: Okotoks Western Wheel Newspaper – June 18, 2003)

"Well done! Keep up the excellent work in engaging your communities in the governance of the Sheep River watershed. The community-based social marketing approach is proving to be very successful. These innovative and creative approaches are a very worthwhile means of achieving the health watershed that all three communities are striving for. Outreach and sharing is very important both within and among the three communities and out to others."

--Teresa Chilkowich, Environment Canada EcoAction Coordinator (Source: Mountains as Water Towers Conference, November 2003)

"The towns (Black Diamond, Turner Valley & Okotoks) are committed to protecting and enhancing their shared watershed, and the proposed project will help the municipalities address common municipal issues of residential water use, using shared resources and a collective, co-operative joint-community approach."

--Wayne Meikle, Chair, Healthy Okotoks Coalition (Source: letter dated January 27, 2004)

"This exciting project will assist in better policy decisions and increase stakeholder and residential awareness, support and participation in watershed initiatives. The towns of Black Diamond, Turner Valley and Okotoks have demonstrated leadership, responsibility and cooperation in sustainable community development over the past two years in their Tri Community Watershed Initiative efforts."

--Mark Bennett, Executive Director, Bow River Basin Council (Source: letter dated February 1, 2004)

> "Your project represents how municipalities can focus awareness and action towards the preservation, protection, and enhancement of their watershed for the benefit of all."

--Jay Wieliczko, Senior Habitat Technician, Alberta Conservation Association(Source: letter dated February 1, 2004)

> "This clean water project clearly demonstrates your organization's commitment to protecting and preserving our environment, and I am pleased to have your organization help us in our efforts. You are to be commended for your initiative in taking action in support of a healthy environment."

--David Anderson, P.C., M.P., Environment Minister re approval of funding from EcoAction for "Influencing Watershed Behaviours" project (Source: letter dated April 26, 2004)

> "I am sure that your project will not only make a tangible contribution to the quality of the environment in your community, but also encourage others to do their part. Individual Canadians, and groups such as yours, can help shape our country's environmental future."

--A. Anne McLellan, P.C., M.P., Edmonton West re receiving funding from Environment Canada for project "Influencing Watershed Behaviours" (Source: letter dated May 10, 2004).

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The Role of Institutions of Higher Education in Sustainability: The Comprehensive, Public, Land-Grant University

Patrick J. Pellicane, Ph.D., Colorado State University, Fort Collins, CO

Abstract*—This paper introduces a background discussion of the importance of sustainability in the 21st century, the issues surrounding how we learn, the role of science, and the importance of interdisciplinarity with respect to ecological and socio-economic sustainability. Furthermore, background information is provided about the history and origins of the American public, land-grant university together with a discussion of a few of the opportunities and challenges that it faces with respect to its role as an engine to achieve sustainability.*

Introduction and Background

At the beginning of the 21st century, the word, sustainability, is becoming a buzz word in a variety of different arenas. Although the word is often preceded by an adjective (for example, economic, environmental, ecological, etc.), it is less common to see sustainability discussed in a more holistic way that extends beyond a certain limited frame of reference. To a growing number of people, the concept of sustainability is more complex than often assumed and recognizes the extremely complex interactions between interrelated environmental, ecological, social, political, economic, and other factors. In fact, a working definition of sustainability that appears to be gaining traction is: the process of decision-making which allows future generations at least as many natural resource options as is available to this generation, while at the same time, fostering the growth and vitality of the spectrum of human institutions that support social stability.

This approach to sustainability is arising in large part due to a variety of realizations that were all but absent for much of the late 20th century. In addition to the development of a set of scientific and technological developments that converged to bring about a new and evolving view of the relationship between the numerous facets of the natural environment and a myriad of social institutions, the moral and intellectual bankruptcy of past resource management philosophies has become evident. For many years, extreme views regarding the relationship between human and environmental interests, advocating either preservation of the environment at the expense of social development and economic progress, or economic and commercial development with indifference to ecosystem health, dominated the discussion. This debate has been marked by each sides lack of tolerance for the other opinion. Today, the confluence of technological capabilities to collect and analyze enormous amounts of spatial and temporal data, an increasing understanding of the complex interrelationships between the myriad of physical and biological environmental systems and social institutions, and the experiences of failed paradigms concerning how people interact with the natural environment is creating a growing interested in, and potential for, the concept of the simultaneous sustainability of the natural environment and human institutions.

The complex interrelationships that exist between seemingly disparate environmental and humanistic interests are beginning to be recognized. This is evident in the way in which people learn. Recent developments in psychology have revealed how human beings receive, retain, and synthesize information into knowledge and applications. When the brain receives information that is in an isolated form and disconnected from a larger context, its significance is analogous to that of a single piece of a jigsaw puzzle. Any one piece has very little meaning in and of itself. However, when each of the individual pieces of the puzzle is seen in the context of the adjacent pieces, a picture begins to form that is recognizable and has meaning. Traditional methods of management and problem solving in natural resources have involved presenting information as individual and isolated puzzle pieces. For example, silvicultural practices designed to optimize some component of forest growth may be indifferent to wildlife, air/water quality, local societal well-being, and other interconnected factors. As such, this decision may have negative consequences that could overwhelm any forest growth efficiency. This approach makes it difficult, if not impossible, for people to grasp the numerous components of a problem or form a solution that accounts for the integrated effects of the component variables that define the issue. Future approaches to large-scale problem solving will have to represent the salient issues in the context of other important issues and integrate them in a geospatial and temporal framework.

For virtually all of the 20th century, techniques used by state and federal agencies to make surveys and measurements of environmental parameters lacked the sensitivity to provide crucial information for local situations and often missed or placed too much emphasis on environmental anomalies. Traditional tools lacked either the precision and/or robustness to provide the information upon which optimal land-use and other decisions could be based. Furthermore, it was often the case that field measurements were used only once and lacked the interoperability that is becoming increasingly in demand. The increasingly-available geo-spatial tools (for example, GPS, GIS, remote sensing, spatial statistics, and others), especially those that deal with pixel-based methodologies, are ameliorating many of the problems that were associated with traditional measurement techniques. There is now a mechanism whereby people in the natural resource management fields, as well as a myriad of other areas, can obtain information about very small and specific geographic areas and use it in a variety of ways.

People throughout the world are realizing that in order to achieve both a healthy and vital environment for this and future generations and to create thriving and sustainable ecosystem resources-based economies and other social institutions a unified framework must be put in place that will give people of all backgrounds access to high-quality information and knowledge regarding a myriad of resources. This framework must be spatially- and temporally-explicit; at the necessary level of resolution; be sensitive to diverse needs; and have a high utility for sustainability planning and decision-making.

Unifying Information and Knowledge

If society is to be successful in accomplishing its sustainability goals, then the unification of information and knowledge across disciplines will have to occur on a scale much greater than we are experiencing presently. In addition, institutions of higher education will have to play a leadership role. This will mean that the ways in which we teach, do research, and perform service/outreach will have to reflect the desired future outcomes.

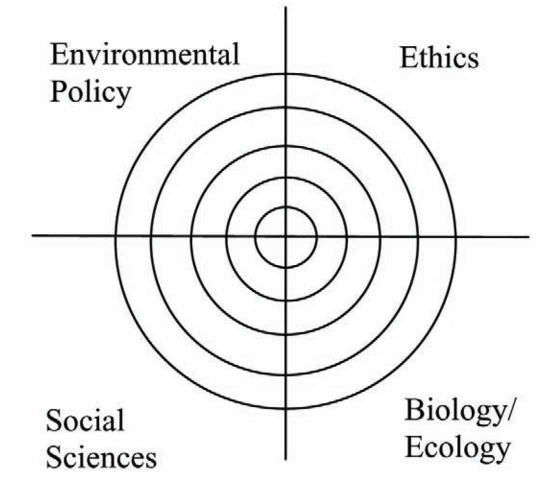

Figure 1. Conceptualization of the nature of problems and their interactions.

In the much the same way that contemporary science has become increasingly fragmented, researchers in the natural resources arena have worked in intellectual isolation that separates, rather than connects, them from other fields that are impacted by their work. Much of the environmentally-related, biological science performed in the 20th century was often marked by a lack of connection to any human values or interactions. This philosophic approach to science has drifted away from that of the 17th and 18th century enlightenment thinkers, who many believe were essentially correct in their thinking. Their basic premise was that the greatest enterprise of the mind has always been and always will be the attempted linkage of the sciences and humanities. It is believed by some that the fragmentation of science that has occurred in the 20th century has caused thinkers to focus more on the discipline in which they operate (for example, the particular animal, plant, forest stand, rangeland, etc.) than on the bigger question of what are the social and ethical impacts of their work. Figure 1 is a schematic that may be useful in grasping the relationship between components of a problem. Each of the four quadrants defines a part of the contemporary academic mind. Each has its own practitioners, language, modes of analysis, and standards of validation. As the concentric rings are viewed, it becomes clear that the further a scientist is from the center (at 451 angles to the axes), the more intellectual isolation occurs. However, the vast majority of the important sustainability problems occur near the center of the figure. Here, most of the work is needed, but relatively little has been done.

The American, Land-Grant, Public University Tradition

Prior to the 19th century, American colleges and universities were private with many being religion-based. With the founding of the institution that is today the University of Virginia by Thomas Jefferson, a new tradition in American higher education was initiated. In 1862, Abraham Lincoln, who was a serious student and admirer of Jefferson, signed the Morrill Act which created the national public, land-grant university system. The signing of this legislation during intense years of the Civil War was an act of optimism that reflected Lincoln's sense of a growing and dynamic future. The land-grant university was designed to provide education to the children of all citizens in the "mechanical arts" (in other words, agriculture, engineering, etc.) and prepare the next generation of citizens with a liberal education that would facilitate the growth of a vital, democratic society. Many believe that the establishment of the land-grant university systems is the single greatest accomplishment of American education. Today, the role of the land-grant university has expanded considerably to include virtually every area of societal need, while at the same time, maintaining its role to which it was originally intended. In addition, the Historically Black Land Grant Universities created by the 1890 legislation, designed to educate the descendants of slaves, and the sea- and space-grant universities were created to fulfill additional societal needs to provide greater societal inclusiveness and address non-land-based issues.

Colorado State University, like many similar universities, not only offers programs in traditional areas, such as liberal arts, engineering, natural sciences, but recognizes its obligations to a state-wide constituency by offering a wide range of programs in agriculture, veterinary medicine and biomedical sciences, natural resources, and a variety of social and other human subject areas.

Opportunities and Challenges Facing Public Higher Educational Institutions

If sustainability in its greater holistic sense is to become a reality, it will be imperative that a major effort be developed which brings together diverse people from across the spectrum of societal institutions and across geopolitical boundaries. For any category of social institution (e.g., education, government, industry, etc.) the interactions between segments of society that contribute to the sustainability issue will be at least as important as those within any particular institution. In the paragraphs below, the issues facing public land-grant universities will be viewed from an internal perspective.

Major public research universities are extremely complex institutions. Inherent in their structures are such things as decentralized administrative units, faculty autonomy, tenure system, disciplinary-based academic organization, affiliations with state and federal natural resource agencies, and entrepreneurial environments that represent both opportunities and challenges with respect to being position to address sustainability issues. Although universities and other institutions of higher education have the ability to shape the future and impact the sustainability of social and ecological resources in many ways, the following paragraphs will address a few key opportunities and challenges that exist. The paragraphs below discuss a few of the issues related to the role of land-grant, public universities in promoting sustainability.

Opportunities

When they are at their best, universities are repositories for the most intellectually-aggressive, socially-responsive, and technically-proficient individuals, who when focusing their energies and talents on important social issues, can play a significant role in ameliorating social maladies and other issues that confront society. Recent examples at Colorado State University include work on improving the lives of people with diseases such as cancer and tuberculosis, homeland security, genetically-modified mouse models, equine reproduction, social issues revolving around ethnicity, and many others. In addition, through discovery that occurs in laboratories, studios, and other intellectual campus venues, patentable products are developed capable of stimulating economic activity and advancing society. The development of health monitoring devices, synthetic human tissue, mathematical processes to facilitate secure wireless communications, and others are typical of those innovations that not only improve society, but stimulate economic activity. Finally, university faculty has the opportunity to work with students who will be the next generation of leaders. As such, they have the ability to instill certain core values in students and set them on a trajectory towards understanding the complex relationships between people and natural resources with an eye toward the responsible use and management of these resources. To impact sustainability of human and ecological resources, integrated efforts at university campuses will be necessary to infuse into society the knowledge, educated citizenry, and applications needed to address the challenges and opportunities.

Interdisciplinary programs and activity

To achieve sustainability in the 21st century, the integrated efforts of many people from diverse backgrounds, disciplines, and professional points of view will need to be assembled. To be successful people will have to understand the role of their profession and those of disparate, yet related, professions to achieve desired goals.

More progressive universities promote and encourage the initiation, growth, and vitality of programs that exploit the synergies associated with the collaboration of people from disparate, but complimentary disciplines. In the 21st century, it is becoming increasingly clear that people working at the center of traditional disciplines will not solve the most important societal problems. If the origin of the illustration in figure 1 depicts the intellectual neighborhood in which socially-meaningful solutions to sustainability and other vexing problems exist, it is very unlikely that any one person or group of disciplinarily similar individuals can have the breadth of knowledge to have a meaningful impact on such complex problems. Although no university can maintain a faculty of sufficient depth and breadth to address all socially important problems, when people working on the boundary of key disciplinary areas join forces, new intellectual areas can immerge that in time can evolve to provide new insights and perspectives. The talents of these people can be organized in a variety of ways to optimally exploit their capabilities and generate maximal synergy.

One way new fields can develop, grow, and gain recognition is by the creation of new programs that will ultimately become majors, and possibly, departments. From the work of intellectually-diverse individuals have arisen numerous new fields of endeavor. The past fifty years has been marked by the creation of many new fields that were derived from more established and traditional fields of study. Examples include: biochemistry evolving from biology and chemistry; mathematics, computer science, and electrical engineering forming computer engineering; geospatial sciences are derived from the combination of efforts from disciplines such as geography, computer science, information technology, and others; biomedical engineering developing from mechanical engineering and a variety of other biological and natural sciences; and many others. Today, these and other programs that were unheard of a generation or two ago are now ubiquitous on the national university landscape.

Although it is not difficult to find outstanding faculty, excellent facilities, and other indices of quality through the campus of many comprehensive, public, research universities; it is clear that the greatest growth will be in the areas where the institution can focus their existing strengths and exploit synergies to develop excellence in new and exciting areas. These strengths will usually be related to faculty expertise, infrastructure, local/regional industry, societal need, and a variety of other factors. By creating incentives and mobilizing talents, administrators can serve as catalysts to focus institutional resources in directions that will produce the greatest benefits to the university and society. The distinct advantages of mobilizing and organizing institutional resources to focus on key areas with social, scientific, technological, economic, and/or cultural relevance that have the ability to add value to society are becoming clear to many. One of the opportunities and responsibilities of senior university administrators is to be vigilant in identifying where future opportunities for long-term growth and vitality exist, and distinguish them from intellectual fads that have a short shelf-life. Once identified, an effective and efficient administrative structure needs to be developed that will marshal the human, physical, and financial infrastructure necessary to be successful. Finally, as important as knowing when the propitious time to create a center or institute has arrived, it is equally important to know when a concept has out-lived its usefulness and be willing to move resources to a more profitable areas.

At universities where interdisciplinary programs are promoted and sufficient intellectual diversity exists, the potential for combining the talents of experts in geospatial sciences, biology, economics, sociology, natural resources, and many other fields to address the sustainability issue exists. By creating centers, institutes, and other administrative entities that bring attention to specific institutional strengths, universities can attract public attention and support and the financial resources necessary to achieve their goals.

Triad mission of education, research, and outreach

One of the most basic aspects of public land-grant universities is the triad mission of education, research, and outreach/service. In these three components of the modern university exists the full range of activities that relate to the discovery of knowledge, the transmission of that knowledge to the next generation of practitioners, and finally, the application of that knowledge to opportunities and challenges that face society. Of particular relevance are the relationships that exist between these three activities. In operationally complex universities, it is difficult to draw distinct lines between the various mission components. The Venn diagram in figure 2 illustrates conceptually the overlap of the educational, research, and service/outreach missions of a public, land-grant university.

Although the numerous interrelationships between the various components of the university mission can

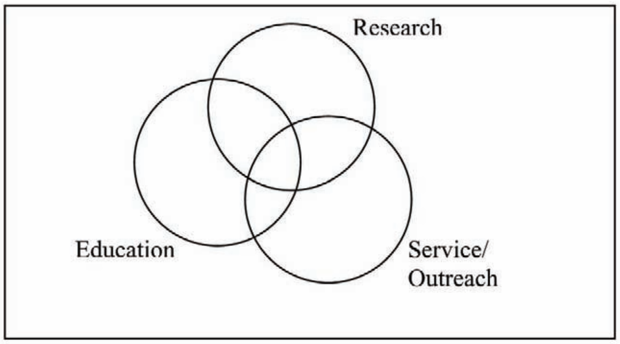

Figure 2. Venn diagram showing the interrelations between the components of the land-grant, public University's triad mission.

be variable between areas, a few examples can illustrate the concept. The research mission provides students with financial support and the opportunity to conduct basic and/or applied research under the guidance of an experienced mentor, and as such, supports the educational mission. Students provide labor, energy, a fresh point of view to enhance the research mission. Furthermore, their contributions to the undergraduate teaching activity free the time of faculty to pursue research activities and provide excellent training for the faculty of the future. There are a variety of natural connections between the outreach/service activities and the research and educational efforts of a public university. Student education is enhanced when they have the opportunity to apply their knowledge to real problems. Issues that arise in the service/ outreach enterprise for which an answer does not exist can often result in new concepts for research proposals. As such, a synergy exists between these efforts that can be applied to enhance the promotion of sustainability.

Connection to industry, government, and other stakeholders

It has become abundantly clear that a successful university takes the threads of undergraduate and graduate education, research, and service/outreach and weaves a complex fabric of programs that enriches the campus environment. At a major research university, a thriving and energetic contract and grant research enterprise will be a powerful engine to drive the growth and vitality of the entire institution. At CSU, annual contract and grant activity now exceeds $200 million. This amount places CSU among the top three public universities that are not affiliated with medical schools in sponsored research dollar volume. The CSU indirect cost distribution model is such that slightly more than half of the captured revenues are sent to general university accounts. Although not completely obvious to the general faculty, the educational and outreach missions are enhanced by an aggressive, successful, and growing research enterprise. The remaining indirect cost recovery is returned to the college and department of origin to support and stimulate growth of their research programs. This infusion of resources, as well as the ideas that promote the development of research proposals to address new and important issues, result from the connections that exist between universities and external stakeholders. External constituencies can take a variety of forms. However, typical types of external stakeholders include: industry (individual companies, trade associations, etc.), state and federal agencies, private foundations, NGO's, etc.

Challenges

Although public, land-grant universities are ripe with opportunities, there are also a number of challenges that they face with respect to being instruments to promote the concurrent sustainability of both socio-economic and ecological systems. In the paragraphs below, a few of these issues will be discussed.

Funding

As stated previously, universities rely on external sources of support to advance their research mission and support graduate education. For many reasons, support from external constituents is both desirable and necessary. However, it is not without some difficulties. As a receiver of support, university research priorities often reflect the funding priorities of external groups. As such, university research directions are often driven by the vicissitudes of markets, current political influences, and other idiosyncratic issues. Therefore, universities are sometimes forced to surrender their role as leaders, and accept positions of followers of societal interests.

Another funding issue relates to the cost of doing research. As science and technology are advancing at rapid rates, it is becoming increasingly difficult to develop and maintain the infrastructure necessary to perform modern research that will create the greatest social value. Issues related to buying arcane equipment needed for biological and other science/engineering research, together with creating an infrastructure conducive to storing and maintaining laboratory animals in a legally-sanctioned environment are becoming increasingly vexing.

Faculty autonomy

At American universities, faculty members are often protected by rules of tenure that have served them well over many decades. Tenure, as originally designed, was to ensure position security which would allow faculty to express opinions and forms of intellectual freedom in a way that would shelter them from academic reprisal. Today, under the blanket of tenure, faculty enjoys a great deal of freedom to act independently. With this in mind, it is more difficult to get faculty to work in areas that they do not find interesting or appealing. When appropriate incentives are in place, faculty could be encouraged to participate in programs that could provide a wealth of collateral benefits to students, faculty, the greater university, and a variety of external constituents.

Developing faculty cooperation to promote sustainability poses some unique issues that need consideration. Because sustainability of human and ecological systems demands the talents of people from virtually every college, who practice different modes of operation in their fields and even use different technical language, getting broad-based involvement is difficult. In addition, there are many individuals on university faculties that are reluctant to interact with people whose intellectual disciplines are very different than their own. As such, getting the interdisciplinary cooperation that needed to successfully promote sustainability will be problematic.

Administrative structure

Academic programs in American universities are most often organized in departments which are administratively placed in colleges. This structure has served the academic community well for many decades and is a fundamental part of the university landscape. For all of the value that this arrangement has added to the American educational system, it is not without shortcomings that represent obstacles to cooperation between diverse individuals who have contributions to make to interdisciplinary programs in general, and sustainability efforts in particular.

Departments within colleges are often composed of like-minded and disciplinarily homogeneous professionals. This creates a focused intellectual group that tends to see issues from a singular point of view. Although there are countless advantages to such an arrangement, it does not lend itself particularly well to creating the intellectual diversity that is needed to address many of the more complex and vexing problems associated with the sustainability of ecological and socio-economic resources. At more progressive and mature universities, administrative structures exist in which mechanisms are in place to allocate teaching credit, indirect cost recoveries, and other products of cooperation in a systematic and rational fashion. When these processes are in place, meaningful cooperation that crosses departmental and collegiate boundaries becomes relatively straight-forward, encouraged, and nurtured. For many universities which are more entrenched in traditional modes of operation, the lack of faculty incentives and other systemic obstacles create a reasonably impermeable barrier to cooperation. However, even in these environments, there exist many examples of excellent cooperative educational, research, and outreach activities. Most of these usually result from contributions of faculty time and effort beyond those expected of them in their normal work assignments. Unfortunately, when these efforts result from the generosity and professional interest of the faculty without administrative support, their probability of being successful over a long period of time decrease, and their intellectual vitality enjoy a short lifetime than might have been had with more proactive administrative assistance.

Conclusions

Universities have an enormous opportunity to develop, transmit, and apply the knowledge needed to advance the cause of sustainability in the 21st century. Their wealth of intellectual resources, contact with groups that identify issues and can utilize intellectual products, and ability to shape the minds of the next generation of professionals are only a few of the potential contributions that they can make. In addition, there are a variety of funding and structural issues that hamper universities in their efforts to be leaders in this area.

A Successful Experiment: The Boundary Spanner on the Bitterroot National Forest

Sharon Ritter, Research/Management Coordinator, Bitterroot National Forest, Hamilton, MT

Abstract—*The Bitterroot Ecosystem Management Research Project and the Bitterroot National Forest funded a boundary spanner to coordinate research activities taking place on the Forest, increase technology transfer and outreach, and foster increased dialogue among and between researchers and managers. Coordination involved use of a research special use permit and a GIS map to track research projects. This led to protection of researchers' study sites and forest resources, increased cooperation between and among the Forest and researchers, and safer working conditions. Technology transfer involved a mixture of methods, the most successful of which were events like field trips that provided opportunities for researchers, resource managers, and the public to interact. The boundary spanner helped increase dialogue among and between researchers and managers through personal interactions. A good boundary spanner should have a strong interest in research and learning in multiple discipline areas, minimal biases against researchers or land managers, willingness to understand the different cultures and organizational structures, good communication skills including listening skills, diplomacy, willingness to spend time working directly with people on both sides of the research/management boundary, good organizational skills, and willingness to network with a larger community of educators, other agencies, and the public.*

Introduction

In 2000, fires burned 307,000 acres of the Bitterroot National Forest (Forest), almost a fifth of the Forest's land area. Like bark beetles homing in on charred trees, researchers swarmed to the Bitterroot. While the Forest has long been a focus of research, we suddenly had 60 research projects going on at once. At the same time, we were designing a comprehensive post-fire recovery project, which involved a huge and controversial Burned Area Recovery Environmental Impact Statement. Taking on tracking and coordinating research projects with recovery work was a daunting task. We also wanted to use the best available science in preparing the Environmental Impact Statement, and encourage research into questions that plagued us, and would likely plague other Forests faced with managing their lands post-fire.

Previous to this, the Bitterroot Ecosystem Management Research Project (BEMRP) had discussed creating a boundary spanner position. A boundary spanner is a person who works at the interface of science and land management, acting as a bridge between the two cultures represented by research scientists and land managers. The fires of 2000 provided the impetus, and let's face it, the funding, to bring on that person—given the title of research/management coordinator. BEMRP and the Bitterroot National Forest jointly fund this position.

BEMRP is a unit of the Rocky Mountain Research Station that is run as a partnership involving the Rocky Mountain Research Station, Aldo Leopold Wilderness Research Institute, Bitterroot National Forest, Northern Region of the Forest Service, and University of Montana. Its mission is to "strengthen the scientific theory and practice of managing Rocky Mountain ecosystems at the landscape level in the context of social, economic, and ecological opportunities and constraints." BEMRP itself is a boundary spanning group, providing researchers and managers an opportunity to directly interact, share research ideas, and design studies of mutual interest.

BEMRP and the Bitterroot National Forest defined three primary tasks for the boundary spanner:

1. Coordinate research activities taking place on the Forest.
2. Increase technology transfer and outreach.
3. Foster increased dialogue among and between researchers and managers.

This paper describes our experiences with each of these, and discusses lessons learned.

Boundary Spanner Task #1: Coordination of Research Activities

In 2001, the Forest started using the special use permit system to keep track of researchers working within the Forest's boundaries. This requirement was unique in the Northern Region and rare elsewhere. Each researcher was required to apply for a permit and provide a study plan and map. The boundary spanner reviewed the study plan, checked for overlap with other research studies, and coordinated reviews by the botanist, heritage program manager, and wilderness program manager. Then the appropriate district ranger signed the permit, and the boundary spanner made copies of the permit and study plans available to the other districts. Depending on the completeness of the study plan and other materials, and the rangers' availability, permits took from a week to four weeks to get signed. We never denied a permit, although we did ask for modifications to protect resources.

Previous to the research permit system, the Forest had research projects going on within its boundaries that the district rangers didn't know about and hadn't approved. Often, we didn't even receive reports on research that took place on the Forest, sometimes not hearing about it until seeing a publication years afterwards. We created a list of research projects that we posted on our website including summaries of objectives. Having a person track the projects kept Forest employees informed and other researchers learned about existing projects that might overlap theirs. The public also learned about various projects this way.

We also created a GIS map showing all study site locations and provided a copy to each Forest district (fig. 1). This helped in two ways. First, when planning a project such as a timber sale or weed-spraying, they could check to see if there might be any conflicts with research sites. Second, when someone came across study site markers on the Forest, they could figure out whose study sites they were. Recently, the Forest started NEPA analysis on a prescribed burn. When we noticed that the burn would take place on a researcher's study area, we contacted him to find out whether this would prove to be a problem, and might have to be postponed. It turned out that this researcher needed to burn his plots after the first year of data collection anyway, which would have required NEPA analysis, so this particular project worked out perfectly for all of us.

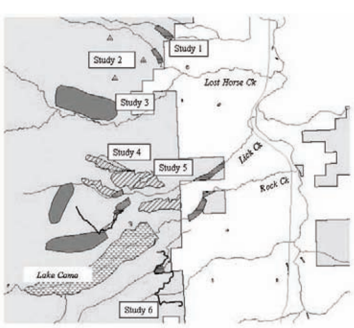

Figure 1. A portion of the Bitterroot National Forest research map showing locations of 6 study sites. This area also has active forest management and recreational use. For scale, Lake Como is 3 miles long. Illustration by Sharon Ritter.

Tracking research on the Forest provided direct benefits to the researchers. We let them know ahead of time about road and area closures, so they could arrange their work to avoid them. During the two years we were most actively involved in burned timber salvage operations, we knew which researchers were going to be where, and helped them contact the sale administrators when they needed to enter a timber sale area otherwise closed to the public. We provided safety training and notices, informed them of our closed gate policy, provided sensitive plant lists, and cloned radios for them (with some restrictions). We provided them with data, maps, GIS layers, and aerial photos to help plan field work and complete data analysis.

An especially important part of the boundary spanner's coordination work was letting researchers know of other research and management activities going on. This led to more communication among the researchers, so that they could benefit from each other and avoid duplication of effort and overlap of study sites. For example, we had two projects studying debris flows, and one of the researchers was excited to learn about the aerial photos taken by the other researchers. Fire history maps, burn severity maps, and other data compiled by some researchers saved others much time and effort. Without the boundary spanner being aware of all of the projects, these researchers might not have heard about the efforts of others for years afterwards.

Some researchers at first resented having to apply for a permit. Other researchers recognized the value of managers knowing what research was going on and where. One researcher eventually was saved from having control sites logged thanks to our research map showing study site locations. In another case, we had three research sites in areas the Forest planned to treat for noxious weeds. We arranged to delay treatments there for a few years until the research field work was completed.

Because researchers aren't always aware of the workings of a national forest, they occasionally expected the boundary spanner to have more control and knowledge of activities than a person in that position could have. Despite a few mishaps where a researcher's study site markers were removed, we've been generally successful at protecting researchers' plots. During the Burned Area Recovery project, we asked researchers to let us know if any of their plots in the burned areas needed to be protected and designed projects to avoid those sites.

Lesson Learned #1

Try to make researchers aware of the boundary spanner's duties and limitations, that they're in a working Forest not an experimental one, and that a district ranger has jurisdiction over what activities take place on the district. This conversation needs to be up front, perhaps relayed in a website or as part of the permit approval process. Also, as part of the permitting process, it would help to have the researchers describe how they will mark their plots. We had to send one researcher back out into a wilderness area to paint over the fluorescent orange paint used on trees to mark plots. If we had known ahead of time what he planned to do, we would have told him this type of marking wasn't appropriate in a wilderness area.

Lesson Learned #2

The Forest found that having someone track research projects was valuable and recommends that if you can swing it, with or without permits, do it. It's worth it for both sides, whether you have five or 50 studies. The research study site map was particularly useful for keeping track of projects.

Boundary Spanner Task #2: Increase Technology Transfer and Outreach

Forest Service resource managers rarely get funded to go to conferences, and when they do, they usually attend ones specific to their resource. But in their jobs, they must manage across disciplines, and the more they understand about those various disciplines and resources, the better they will be able to manage our public lands. In addition, they want to use the most up-to-date research available. Scientists in turn are interested in providing research that is meaningful and useful to land managers.

The boundary spanner helped increase the level of technology transfer and public outreach conducted by researchers working on the Forest. We had field trips involving researchers and resource managers, and others including members of the public. We had a full day of research presentations, and several smaller sessions with one to three researchers talking. We created posters and displays, posted the list of research projects on the Forest's website, added information about current research projects to our annual monitoring report, connected researchers with other community groups, and provided research story ideas to newspapers and television.

Field trips were very successful for managers, researchers, and the public. An example of one field trip was to a Research Natural Area where the Forest and researchers from the Rocky Mountain Research Station and University of Montana have been treating grasslands with herbicides and prescribed burning and adjacent low elevation ponderosa pine forest with thinning and prescribed burning (fig. 2). A ranch manager attended another field trip there a few years earlier, and encouraged by the results that were monitored by the researchers, subsequently treated more than 6,000 acres of a nearby ranch in a similar way (fig. 3). Our field trip included the ranch treatment areas, and comments back from both the public and land managers were all positive.

The one-on-one chance to interact on these trips, in the field, is extremely important. It fosters connections, and encourages conversations that lead to new research questions and increased use of existing research. It gives the researchers feedback on how research is being used, whether it's providing practical information, and a feeling of appreciation for what they are doing. For managers, the personal connection with the researchers increases their interest in the studies, and gives them a chance

Figure 2. Researchers monitored results of thinning, weed control, and an understory burn at the Sawmill Research Natural Area. Success of these treatments encouraged the neighboring Burnt Fork Ranch to apply similar treatments. Photo by Mick Harrington.

Figure 3. Private forester Craig Thomas reports on the Burnt Fork Ranch treatments to a group of resource managers and members of the public on a field tour. Photo by Janie Canton-Thompson.

to ask questions about past research such as how it applies to other situations, and to learn about preliminary observations from current work. When members of the public attended, they added another dimension to the discussions, showing researchers what the public's concerns and questions are, and helping them comprehend that there are other factors besides science behind land managers' decisions.

Lesson Learned #3

Don't shy away from field trips. They take time to set up and advertise, and have a limited "distribution" compared to, say, a research report. But the benefits are worth the effort on many levels. By getting media coverage, you can increase the dissemination of the information, and word-of-mouth from the attendees also serves to disseminate results.

The benefits of locally held seminars weren't as clear. The turnout wasn't as good as we had hoped, from either the public or the resource managers, although those who did attend were excited and appreciative afterwards. We expected more resource managers to jump on the chance to get a personalized presentation right in their own area. The most successful event we had was when we scheduled eight speakers in a day. This allowed for interdisciplinary learning, and the researchers enjoyed the interaction also. The full day of talks may also have been important enough to the managers to keep them out of the field for a day, whereas a noontime seminar may have cut into their day too much.

Lesson Learned #4

If your target audience is resource managers, hold the seminars during the day, and schedule multiple talks in one day.

An important part of the research special use permit was a requirement that researchers provide the Forest with copies of any reports resulting from the research on the Forest. As projects concluded, the coordinator checked researchers' websites and contacted them to be sure we received publications. We added these to the Forest's planning library, so that in the future, when we designed management projects, we had easy access to locally derived information. Often, in the past when we did receive reports, they went into the files of a few specialists on the Forest, rather than put in a library and indexed so they were available to everyone.

Some researchers were reluctant to participate in technology transfer activities because of the time involved. On the other hand, other researchers went out of their way to help disseminate results in ways most useful to the public and resource managers, which was interacting face-to-face. Researchers have different abilities to communicate results. Some are better with the public than others are, some are better at writing than public speaking. Similarly, managers and the public have different learning styles. Some prefer to read publications; others learn better listening to talks or being on a field trip.

Lesson Learned #5

Everyone is busy. Make the best use of each person's time to disseminate information in a way that works for both sides of the boundary.

The boundary spanner took on some additional tasks to help the Forest and the Rocky Mountain Research Station. When resource managers needed scientific information for management analyses, the boundary spanner helped find publications and directed the managers to researchers familiar with the particular issues. Currently, Forests throughout the west are putting together green fuel reduction projects that will involve thinning, prescribed burning, or a combination of the two. The Rocky Mountain Research Station and the Forest agreed to have the boundary spanner work on an annotated bibliography of Northern Rockies research studies looking at the effects of these types of treatments on various resources such as soils, wildlife, and water. The bibliography of approximately 250 papers is annotated because of the difficulty many forest resource managers have in obtaining copies of publications, especially people working in remote areas. This bibliography was a direct response to the needs expressed by the managers, and was starting to get used as soon as people heard it was underway.

Boundary Spanner Task #3: Fostering Increased Dialogue Among and Between Researchers and Managers

Researchers don't want to work in a vacuum. They want to be sure that their proposed research will be useful to managers, and that their completed research is getting out there and used. Managers are frustrated when research doesn't meet their needs. The boundary spanner's third task was to help build closer relationships that would result in improved communication. Researchers and land managers have visited both formally and informally through field trips, seminars, and special meetings that gave them a chance to share ideas and concerns, and to learn more about each other.

Understanding each other is an important part of communicating. In a 1997 report resulting from a workshop held at the Rensselaerville Institute in New York, *Integrating Science and Decisionmaking: Guidelines for Collaboration Among Managers and Researchers in the Forest Service*, the two cultures are described this way:

Culture of Research

- Time horizons are often long.
- Interest is in findings that can be generalized outside the study area.
- Rewards come from publication and peer recognition.
- Freedom of inquiry is expected.
- Validation often comes from outside the agency.
- Science is less a statement of truth than a running argument.
- Scientists accept that things will change.
- Science thrives on contention—the more questions, the better.
- Researchers expect explicit assumptions.
- Researchers express findings as probabilities.

Culture of Management

- Time frames are often tight.
- Closure of issues is desirable.
- Clients are often contentious.
- Operations are driven by specific objectives.
- Work is performed in a fishbowl.
- The public must be involved in decision-making.
- Decisions are based on many factors, one of which is science.
- Definition of acceptable risk is part of the job.

The boundary spanner's goal is to build a bridge between these two cultures so that they can understand, trust, and respect each other.

Thanks to the efforts of BEMRP and the boundary spanner, managers have helped direct research toward questions important for managing resources. Researchers appreciate that managers recognize their research efforts and sincerely want to make use of the results of their work. Some funding sources, such as the Joint Fire Sciences program, place a strong emphasis on coordination with a land management agency. Researchers that maintain close communication with the Bitterroot National Forest benefit from these relationships.

Lesson Learned #6

Spend time developing personal, one-on-one contact with the researchers, and foster interaction between the researchers and resource managers. While this may not be feasible in many areas, where the two groups are located near each other such as we are in the Bitterroot, this is valuable. It's easy to stick with your own kind, researchers hanging out with researchers and managers hanging out with managers. It takes an effort to cross that cultural boundary, but is important.

What Makes a Good Boundary Spanner?

Lesson Learned #7

Each person who might serve in a position as a boundary spanner will have weaknesses and strengths. Here are some qualities that a boundary spanner should have:

1. Strong interest in research and familiarity with the scientific method. A boundary spanner needs to know what scientists need to design and carry out a successful, scientifically sound research project.
2. Strong interest in learning in multiple discipline areas, and the capability to do so.
3. Minimal pre-existing biases against either researchers or land managers.
4. Willingness to spend time getting to know the organizational structures and cultures of the two sides of the boundary, and willingness to learn about constraints and reward systems of each. Feel free to hire an "outsider," someone who isn't so ingrained in either research or management that she or he can't step back and understand both sides.

5. Good communication skills, both in writing and in speaking. This includes someone who is a good listener and is able to effectively communicate by e-mail and phone.
6. Diplomatic skills--someone who people feel they can trust. The boundary spanner will received confidences from both sides of the boundary, and must be able to enhance understanding and resolve conflicts without betraying those confidences. The boundary spanner also needs to use tact when dealing with conflicts and various personalities.
7. Willingness to make the effort to get to know people on both sides of the boundary. This may require having a work space in both locations, so that they can interact with both groups in informal as well as formal ways. The boundary spanner needs to be able to empathize with both sides of the boundary, and this requires taking the time to get to know the individuals.
8. Good organizational skills for tasks like setting up meetings, field trips, and seminars, and tracking multiple research projects.
9. Willingness to be connected to the larger community served, whether it's the public, environmental educators, school teachers, nonprofits, regional office of the Forest Service, director's office of the research group, or other groups. This networking is very important for success in technology transfer and outreach.

Applicability Elsewhere

The Bitterroot National Forest is lucky to have so much local research taking place and access to such a fine cadre of researchers. This is thanks in part to being close to the University of Montana and Rocky Mountain Research Station. The Forest's mix of managed land and relatively unmanaged wilderness areas, its variety of habitat types, and several long-term data sets make it an ideal laboratory.

One question is how would our lessons learned apply to a more remote location, perhaps one so remote from research stations and universities that only a few studies take place and researchers visit infrequently? Having someone designated as a boundary spanner who can keep track of projects and help with technology transfer is important for every land management agency. How it works might vary based on the number of studies and accessibility to researchers. In some cases, a regional office might need to take on more of the boundary spanner technology transfer role. The individual management units, however, should track the projects and take advantage when any of the researchers show up. By the nature of their jobs, these scientists are up-to-date on literature and genuinely interested in sharing their results and learning about what kind of information resource managers need to effectively manage the lands under their care.

Partnerships in Community-based Approaches to Achieving Sustainability: The Atlantic Coastal Action Program

F. Rousseau, Research and Liaison Officer, Environment Canada - Atlantic Region, Community and Departmental Relations, Sustainable Communities and Ecosystems Division, Dartmouth, Nova Scotia, Canada, B2Y 2N6
Colleen McNeil, Coordinator, Atlantic Coastal Action Program, Environment Canada - Atlantic Region, Community and Departmental Relations, Sustainable Communities and Ecosystems Division, Dartmouth, Nova Scotia, Canada, B2Y 2N6
Larry Hildebrand, Manager, Atlantic Coastal Action Program, Environment Canada - Atlantic Region, Community and Departmental Relations, Sustainable Communities and Ecosystems Division, Dartmouth, Nova Scotia, Canada, B2Y 2N6

Abstract—*The Government of Canada believes that a healthy democracy requires the active engagement of its citizens in understanding the economic, social, and environmental issues faced by the nation. In the Atlantic Region, Environment Canada has been actively working, for more than a decade, on helping citizens achieve this integrated view and providing local communities with the means to develop their own visions of sustainability. In this regard, the Atlantic Coastal Action Program (ACAP) has been one of Environment Canada Atlantic Region's greatest success stories. ACAP is a community-based program that promotes local leadership and action. For more than 13 years, ACAP activities have involved thousands of community residents working as volunteers in local and regional initiatives. Their successes include solving complex problems related to sewage treatment, toxic contaminants and water quality, building local capacity and, educating their communities on issues such as pollution prevention, monitoring, climate change, assessment and household hazardous wastes to name a few. By working as a partner with local communities rather than imposing decisions, Environment Canada has helped a diversity of communities to responsibly address environmental issues of "local interest." When communities realize that they can solve some of their own problems, they are empowered and can directly (or indirectly) influence decision-makers and policy makers. All of the ACAP groups have experiences in collaborative ecosystem management that have influenced local and/or regional decision-making. This paper outlines a number of these experiences, describes ACAP and its process as well as ACAP's influence within Environment Canada and the rest of the Atlantic Region.*

Introduction

On November 4, 2002, the Canadian Government announced its financial commitment towards tri-level financing for the construction of a sewage treatment plant for St. John's Harbour in Newfoundland, Canada. This announcement was the result of many years of applied research, monitoring, educational campaigns, and numerous related efforts to influence decision-makers, conducted by a dedicated group, St. John's Harbour ACAP Inc. The St. John's group is a member of a community-based program, launched in 1991 by Environment Canada, known as the Atlantic Coastal Action Program (ACAP). (Environment Canada 2003).

St. John's Harbour ACAP Inc. is just one of 14 organizations in Atlantic Canada, with a 15th soon to be added in Labrador, nested under the ACAP umbrella. There are two ACAP sites in Newfoundland, two in Prince Edward Island and five each in the provinces of Nova Scotia and New Brunswick. Like the St. John's group, all of the ACAP sites are dedicated toward achieving sustainability in their communities and all have experienced successes in influencing local and/or regional policy and decision-makers. A few examples of these successes, including that of St. John's Harbour ACAP Inc., are outlined throughout this paper.

ACAP and the ACAP Communities

Environment Canada initiated the ACAP program in response to both the need to restore and sustain watersheds and adjacent coastal areas in the Atlantic Provinces and the growing public demand for involvement in decision-making related to their own environments. The main objective was to get communities involved with governments in developing restoration and maintenance plans and actions for harbours and estuaries in Atlantic Canada. The process, now in its third phase, has involved the development and implementation of comprehensive environmental management plans (CEMP) in each community, partnership building, local action and awareness projects, and the advancement of science. Originally focused on water quality issues, the program has evolved to focus on wider sustainability issues, including those of an economic and social nature.

The 14 coastal communities involved in ACAP were identified at the outset as "hot spots, or areas experiencing significant ecological degradation. The communities range in character from urban settings with heavy pollution of harbours, to areas with traditional industries associated with pollution and to areas with runoff from heavily fertilized and chemically treated farmland. In accordance with this range of character, ACAP community successes also range widely from solving complex problems related to sewage treatment, toxics and water quality, to building local capacity and educating their communities on pollution prevention, monitoring, assessment, and household hazardous wastes. ACAP accomplishments are, in fact, widely recognized and they continue to gain respect and credibility on the local, national, and international stages (Environment Canada 2003).

ACAP Phases I, II and III

In Phase I (1991to1996) of the program, Environment Canada (EC) provided 'core funding' to the independent, non-profit ACAP organizations, so each could hire an Executive Director, set up an office and complete their planning documents (the CEMP mentioned above) for their regions. The CEMP was the primary focus of this phase and involved a thorough investigation of the critical issues affecting local resources, an assessment of the remedial options available, and a choice of options which best served the environmental and socio-economic objectives of the community. The CEMPs, which remain central to the ACAP sites today, were intended to help guide the communities in the future management of their ecosystem, outlining expected time frames for implementation of plans and responsible stakeholders.

For the subsequent two phases of ACAP, Environment Canada has provided annual funding to the groups for the implementation of their CEMPs. The funds are provided for work in the following areas: knowledge generation, capacity building, direct action and the advancement of science. This support helps to build the local capacity and knowledge required for communities to make informed decisions and address complex issues related to the environment.

ACAP relies on local involvement and support. While Environment Canada contributes to project funding, community stakeholders contribute most of the resources through volunteer labour, in-kind contributions, and financial support effectively levered from other federal departments, provincial and municipal governments, academia, other ENGOs, industry and local businesses. ACAP projects thus result in a variety of partnerships and these consistently demonstrate the value of an inclusive community-based approach and produce results on an ecosystem-wide basis.

Science Linkages Program

In Phase II of ACAP, a Science Linkages Program was launched to enable ACAP organizations to conduct science in partnership with EC scientists. EC developed the program in answer to requests from both the ACAP sites and the EC scientists. The sites wanted to not only take responsibility for their part of the ecosystem but to possess the skills and the information required to carry out those responsibilities; the scientists wanted the benefit of having trained volunteers helping them to fill information gaps and to do quality science. Together, the partners develop proposals, conduct scientific work of mutual interest, and report results. Since its inception in 1997, over 60 EC scientists have transferred their knowledge of scientific methods and practices to the ACAP organizations, while the organizations in turn have helped the government scientists to gather missing data, to bring partners to the table who would not normally participate with government, provided volunteer hours and, provided valuable knowledge about local science needs and ecosystems (Environment Canada 2003)

Windows

Environment Canada is in partnership with the ACAP sites and, as with all good partnerships, effective communications are a must. To ensure that participants in the ACAP initiative are always linked, Environment Canada has come up with a unique way to maintain its connection to the individual ACAP communities. While the staff which administer the ACAP program is small, a formal link to and from each site is maintained via the "windows" approach. Windows are EC employees who sit on each community Board of Directors as ex-officio members. The windows provide a link between the groups and EC staff, as well as with other government departments. This has led to a high level of understanding and cooperative working relationships as most of the windows have been with their ACAP sites for fairly lengthy terms – some as long as 10 years. The windows provide a personal connection, which has established trust, credibility, and respect; all keys for a successful partnership (Environment Canada 2003).

ACAP's Impact and Influence

Economic Impact

A recent study (Gardner Pinfold 2002) conducted for Environment Canada showed that having communities deliver ACAP programs costs much less than if the programs were delivered in the traditional way; through government offices and employees. Environment Canada's total ACAP investment from 1997 to 2001 was about $6 M; based on the analysis conducted, it would have cost the federal government 12 times that amount to directly deliver a similar internally-run program. As well, hundreds of direct and spin-off jobs are created annually throughout Atlantic Canada through ACAP. In total, the economic impact (GDP) for this same period was about $22 M in direct and spin-off economic activity, which far exceeds EC's original $6M investment.

ACAP organizations are able to have such a significant impact because of their ability to secure funds from local partners, industry and other government departments. The money is invested in local communities, and benefits those same communities. A good example of the economic returns that ACAP groups can help to generate is the astounding $4.6 million per annum that has been generated by the creation of a 63 km interprovincial linear park managed by the Société d'aménagement de la rivière Madawaska et du lac Témiscouata inc. (SARMLT) in partnership with Québec (Gardner Pinfold 2003).

Impact on Environment Canada Business Lines

Although the ACAP sites are independent organizations and basically conduct their own business, Environment Canada is a partner in each of the initiatives and thus participates in setting direction, identifying issues, and selecting the appropriate responses. Since the Environment Canada windows act as a two-way channel from EC to the ACAP sites and vice versa, they help the administrative staff in keeping the sites well informed on EC priorities and targeted results. In most cases, EC's vision and goals for the environment align well with those of the ACAP organizations. As a result, over 1,000 community projects delivered by the ACAP organizations since the program's inception have been demonstrated to contribute directly or indirectly to the priorities, or 'business lines' of the department, as follows in table 1 (adapted from Trites-Tolson 2002).

All of the ACAP sites conduct or participate in multi-partner scientific projects that link directly or indirectly to EC priorities. Bluenose Coastal Action Foundation (BCAF)'s current project, summarized below, provides an example of the type of collaboration that is helping EC, the ACAP sites and others partners meet their own priorities and mandates.

The BCAF project concerns the provision of a prototype for the development, by Nova Scotian scientists from Dalhousie University, Environment Canada and the Department of Fisheries and Oceans Canada (DFO), of a new form of coastal monitoring and management system. Their goal is to use environmental observation systems and advanced numerical models to describe physical, chemical, and biological changes in the marine environment (BCAF 2004).

BCAF's role in the much larger project is to aid in the development and validation of bio-optical data products for use in coastal observation and prediction systems in Lunenburg Bay, Nova Scotia, as well as to develop an extensive education and outreach program for the Town of Lunenburg. BCAF personnel are responsible for an extensive water sampling program that includes the collection and analysis of water samples as well as sea-truthing samples. The collected samples will be processed by BCAF staff, and analyzed for chlorophyll and absorption by particulate and dissolved materials. Other sampling measures include water clarity and optical properties. These are core measurements for optical observation systems that will be used in the larger project, along with remote sensing of ocean color, to monitor the state of coastal ecosystems in coming decades (BCAF 2004).

Table 1. Estimated ACAP contribution to Environment Canada Business Lines.

Business line	Estimated percent contribution
Nature	44 percent
Clean Environment	33 percent
Management and Administration	12 percent
Weather and Environmental Prediction	11 percent

This long-term project will eventually offer local fishermen accurate real-time weather and water conditions, a sound scientific basis for detecting and describing weather and climate related influences on coastal ecosystems, and it will be extremely useful when determining the effects, both short and long term, of new sewage treatment measures implemented in the Town of Lunenburg in 2003. As for meeting EC's priorities; not only has a coastal monitoring and management system been a primary area of development within its Atmospheric Science Division but, the ultimate goal of developing a modeling system for monitoring change in coastal environments is one of prime importance to the division and fits well within EC's mandate of safety and security for the Canadian public. In addition, the project offers both EC and BCAF the chance to expand and create new partnerships within the scientific and international arena.

Influence on Policy and Decision-Makers

Within environment Canada

As already mentioned, the ACAP Science Linkages Initiative was launched to better link EC scientists with ACAP organizations. In her December 2003 report on the Initiative, the author noted that "Science Linkages fosters true partnerships between ACAP communities and EC scientists whose working relationships are built on mutual trust and respect" (Dech 2003). Understandably, this mutual trust and respect had to be earned over time and was not so apparent in the early days of the Initiative. For many of the EC scientists, especially when it came to monitoring activities, there were questions of quality control, reliability of data, duplicability of tests, etc. For the communities, there was some concern that the federal government was downloading its environmental responsibilities for clean up and remediation onto them.

Effective project results, the reconciliation of diverse interests and, recognition and praise from peers and other scientists have answered many of the questions raised for both the scientists and communities and today, ACAP's success has a great influence on how many of us do business within EC Atlantic.

One of the most influential aspects of the ACAP program on EC scientists is the windows approach discussed in the introduction. EC scientists involved as windows have invariably reported that the experience has broadened their perspectives and given them, insights into the issues of importance to communities, the acquisition of skills around better ways to articulate science to citizens, and a better recognition of the interrelationships between the environment and social and economic conditions (Hildebrand 2002). It has also provided them with partners they would not normally have worked with, and given them access to funding not normally available to governments.

As for community-based monitoring; it took a couple of years for both sides to see its benefits and potential, but it is now common for EC scientists to actively seek out the help of the ACAP organizations. Not only does volunteer monitoring supplement EC's efforts, in some cases it is the only data available for a given site. "Most EC scientists, says Hugh O'Neill of Environment Canada's Environmental Quality Laboratories in Moncton, N.B., "have a high regard for the ACAP process… but, in retrospect, many scientists did not realize the capacity that some communities had access to, ranging from university and industrial scientists and their labs and dollars, to local bird watchers." (O'Neill pers. comm. 2004).

All of the ACAP sites are involved in monitoring activities, some of them well established programs such as River Guardians, Swim Watch, and Air Watch. A number of the ACAP sites have also established their own labs to conduct fecal coliform bacterial analysis, etc. Although these labs have not been directly involved in regulatory-decision-making (in Canada, only data from "accredited" labs can be used in court cases and the cost of accreditation is just too high to be borne by most volunteer groups), EC and other organizations with enforcement mandates can and do launch their own investigation based on the sampling results obtained from the ACAP groups, as will be seen in the description of the St. John's Harbour ACAP Inc. project (page 14), which was noted in the introduction.

Environment Canada is involved in a number of ongoing monitoring programs to which the ACAP sites are regular and long-term contributors. The response from the lead EC scientists to ACAP's contributions have been invariably positive. Dr.Amar Menon, former head of EC's Shellfish Monitoring Program in the Atlantic Region, is a scientist with a high regard for ACAP and community-based monitoring. Dr. Menon has been involved with numerous ACAP volunteers (and others) in water quality monitoring where shellfish are harvested at various coastal locations in Atlantic Canada. EC's biologists provide the training and ACAP volunteers monitor and sample in local waters. Volunteers must follow very prescribed and detailed protocols and undergo regular audits (Menon pers.comm. 2004).

Environment Canada's other responsibilities under the Canadian Shellfish Sanitation Program (CSSP) include the promotion of pollution prevention and remediation of shellfish growing areas. On this front too, the ACAP sites are able allies to the scientists. Several of the ACAP communities have begun remediation and shellfish restoration activities. In Charlotte County along the Bay of

Fundy in New Brunswick, ACAP groups (working with the Premier's Clam Bed Action Committee) are active in pursuing the clean up of bacterial contamination in the area.

Remediation activities, throughout the Atlantic Provinces, have been successful in re-opening 2485 hectares of shellfish closures for commercial shellfish harvesting. This is of extreme importance for the area, where 2000 Km2 of coastal waters (representing 33 percent of the classified shellfish growing area) have been closed to the harvesting of shellfish due to fecal bacterial pollution since the 1960s. Reopening of these areas for commercial harvesting could not have been done without the help of community-based monitoring and remediation projects. (Environment Canada 2004)

ACAP monitoring and data gathering capabilities are also valued by EC's Environmental Emergencies Section (EES). EES has developed a geographic information system (GIS) for the Atlantic region to provide instant environmental data for decision-making responses to the thousands of spills involving oil or other hazardous substances that threaten the coastal zone resources of the region. The need to update and add to the mapping of more than 35,000 km of shoreline is a constant one and EC benefits greatly from the willingness of ACAP organizations to collaborate in collecting new information (Laflamme pers.comm. 2004).

The first such collaboration was between EC and the St. Croix Estuary Project, Inc. (SCEP). In 2001 to 2002, SCEP collaborated with EC, through a Science Linkages project, in collecting data from the Passamaquoddy Bay area which helped in the development of a local community contingency plan for oil spill response. SCEP is unique from other ACAP sites in that it is located on an international river and represents the interests of both Canadian and American residents of the St. Croix Valley.

A similar collaboration is currently being developed between Environment Canada and the Miramichi River Environmental Assessment Committee (MREAC). Other partners include the Department of Fisheries and Oceans Canada (DFO) and a variety of provincial and municipal government organizations whose cooperation will give MREAC and EC access to some of the local information that is often the hardest to obtain. Completed web-accessible map layers (of endangered species, nesting sites, spawning areas, valuable lobster and oyster habitats, coastal marshlands, beaches, municipal and other discharge zones etc. for the Miramichi coastal zone and estuary) will prove invaluable to the Environmental Emergencies Section, to local emergency response units and to MREAC which has become a centre where community stakeholders can access information for their own uses (MREAC 2004).

Local and regional

Community-led, multi stakeholder organizations like the ACAP sites are inclusive and strive to include people who represent a cross-section of their individual communities including, citizens, business, industry, academia, non-government organizations, and various levels of government. ACAP's biggest success is probably the use and acceptance of the multi-stakeholder and community-based processes, which have shown that even established adversaries can work together when common interests are evident. The program has produced a dynamic network of relationships, joint ventures and other strategic alliances, with ACAP organizations serving as effective facilitators and brokers. The story which follows, of the St. John's Harbour ACAP Inc.'s effort to get the issue of sewage treatment on the political agenda, illustrates the effectiveness of understanding the players, forming strategic alliances, and doing good science.

Long before the Government of Canada made the financial commitment announcement to the construction of a sewage treatment plant for St. John's Harbour; the ACAP organization gathered data on the need for municipal wastewater treatment, conducted related monitoring projects, sought public consensus and sought to convince the local municipalities, the provincial, and the federal government that treatment was essential.

By 1997, St. John's Harbour ACAP had acquired the support of three local municipalities for conducting an investigation into the best way to handle the sewage problems in the local harbours. However, they needed to convince municipal officials that it would take more than a pipe extension to tackle the problem. Results of community-led bacterial monitoring did the trick and by 1999, not only were the municipalities on-side, the provincial government also joined with St. John's Harbour ACAP and the communities in clamoring for treatment. The federal government, however, was still not convinced that treatment was necessary so ACAP St. John's increased its bacterial monitoring studies through a Science Linkages project.

They monitored various fish and shellfish from 2001to 2002, with the help of EC's Moncton lab and DFO, to determine if fish found in the Harbour proper were sufficiently contaminated to draw regulatory attention. This was followed by monitoring for chemical contamination of fish and shellfish (metals, mercury, pesticides, PAHs, PCBs, and dioxins were analyzed in lobster and flounder), some microbiological studies were also carried-out (at Memorial University) in the Harbour and nearby environment.

The monitoring results led to DFO closing shellfish and fish harvesting in the Bay (Baird pers.comm.

2004). This was a first in Canada – DFO had never before accepted community monitoring results as the basis for looking into harvesting closures. DFO's own monitoring confirmed the ACAP organization's results and they declared that sewage discharges were having an impact on human health. The federal government came "on board" and tri-level government funding was announced in November 2002. The contract for this project was awarded to Municipal Construction Limited in November 2003.

According to Diana Baird of St. John's Harbour ACAP "One of the problems with government doing the monitoring in these cases is that the data tends to get shelved", "government officials don't seem to want to approach the media with negative results whereas community groups do." So, according to Ms. Baird, community groups are better at getting information to the public and this leads to greater progress – "you can't expect communities to get involved (or to support something) or to change their ways, if they don't have the information." (Baird pers. comm. 2004).

The discharge of raw or partially treated municipal sewage into rivers, estuaries and harbours is one of the most frequently raised issues by the ACAP organizations (and many other Atlantic community groups) and the lessons learned by the St. John's group were of value to all and are, therefore, part of its success.

In recapping the more than eight years of struggle to get sewage treatment for the St. John Harbour area, Diana Baird had this to say about the ACAP process: "it is really the collaboration that has the value – getting all that knowledge and participation around the table was a new way of doing things…the first year was very much a feeling process, we had to establish trust… Thanks to Environment Canada, people from all sectors sat around the table to work things out…DFO has now become more open to us…And it has opened our links to local universities, to labs…we have credibility and value…We now get more and more calls from all over (EC, DFO, municipalities, etc.) for information about the Bay…scientist are coming to us." (Baird pers.comm. 2004).

Extending the Reach of ACAP

ACAP groups not only network individually but also increasingly join-together in multi-site partnerships that have regional and national impacts. For instance, when scientists from Environment Canada's National Water Research Institute (NWRI), Canada's largest freshwater research facility, proposed a national strategy for monitoring and assessment of aquatic biodiversity in Canadian inland waters, one of the goals was to develop a national, volunteer-based, invertebrate stream bio-monitoring network.

ACAP sites were the primary target for network participants in the Atlantic region. In fact, in 2002, out of 17 community sites involved in the Atlantic Network, 10 were ACAP sites. It was recognized that they were already well established, very successful and had a history of working well together. In a letter to the ACAP science Linkages co-ordinator, Dr. Trefor B. Reynoldson, then leading the Atlantic portion of the program, noted that "The Institute [NWRI] sees the Science Linkages program as an important step in developing a Canadian Aquatic Bio-monitoring Program (CABIN)" (Reynoldson 2002). Four of the ACAP sites originally involved in the Atlantic Network have now banded-together, under the leadership of NWRI scientists and Acadia University, to adapt and transfer some of the bio-monitoring techniques they have learned in inland waters to estuarine waters.

The ACAP organization is "building on success' in other ways. For instance, in addition to geographical expansion (into Labrador) and networking together to increase their collective strength, the ACAP sites are adopting and/or mentoring adjacent watersheds and neighbouring coastal areas. The ACAP approach is further evident in a number of larger Atlantic Region multi-stakeholder coalitions (some with three or four ACAP groups in the membership) organized around larger regional ecosystems (for example, the Gulf of Maine Council, the Bay of Fundy Ecosystem Partnership and, the Southern Gulf of St. Lawrence Coalition on Sustainability). ACAP's influence can even be felt in inter-departmental and inter-governmental collaborations (working towards improving government program service delivery to communities) such as the Nova Scotia Sustainable Communities Initiatives and the Collaborative Environmental Planning Initiative for the Bras d'Or Lake in Cape Breton, Nova Scotia. These and other organizations help to ensure that the ACAP pillars of sustainability, multi-stakeholder partnerships, and community empowerment will continue to support the environmental health of Atlantic Canadian communities for generations to come.

Conclusion

Although the ACAP sites may differ somewhat in character and priorities, there are commonalities inherent in the ACAP process itself, many of which have evolved over time, and come to be thought of as "best practices." These include the following:

- Recognizing that communities have their own vision of sustainability.
- Recognizing that governments are part of communities.

- Using a consensus model for decision-making rather than a confrontational approach.
- Seeking a balance between environmental, social, and economic considerations.
- Developing a detailed framework (the CEMP) for action based on community vision - this lets the communities identify education, monitoring, remediation and other needs through the identification of local priorities.
- Using knowledge generation activities to produce a common perspective and help inform decision-making.
- Annual funding for individual site offices and coordinator.
- “Core” funding for projects.
- ACAP community leveraging of funds and in kind resources.
- Building scientific capacity within communities through the provision of advice and technical support as well as training on proper sampling and research techniques.
- Reducing “red tape, and facilitating expertise and information exchange (for example, through “windows”).
- Measuring and demonstrating progress in research sustainability goals.
- Training and engaging local people (especially youth) to carry out monitoring and/or remediation.
- Hands on involvement among participants develops rapport, trust and new relationships.
- Using both local knowledge and traditional science.
- Sharing ownership of information to enhance confidence in its quality and increase its application, as well as to help in resolving disputes and avoiding conflicts.
- Feed back from decision-makers is essential.

In conclusion, one of the most important contributions of community-based environment management, such as that provided by the ACAP program, is the ability of the communities involved to bring to light potential and existing environmental, social and economic problems to decision-makers at all levels and in all sectors. That the participating community organizations can also be full partners in finding and helping to implement possible solutions that are scientifically defensible, economically advantageous, socially acceptable, and environmentally sound is evidenced by the ACAP experiences described in this paper.

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Engaging Industry in Community Decision Making for a Sustainable Future

Brent Tegler, Applied Ecologist & Partner, North-South Environmental Inc., Campbellville, ON, Canada L0P 1B0

Abstract—*Community based monitoring (CBM) is often directed at examining significant environmental impacts arising from the activities of industry. When industry is included as one of the active partners or stakeholders participating in CBM the results of monitoring are shared and there is a good opportunity to inform decision makers in ways that lead to positive outcomes. Too often, however, there is an antagonistic relationship between those undertaking environmental monitoring and those managing industry. CBM provides an alternative by utilizing an inclusive process that ensures communication with all stakeholders from the outset of monitoring initiatives. In this way the public, government and industry participate as a team sharing knowledge, resources and concerns to develop meaningful solutions to shared problems. The success of CBM engaging industry in community decision making will be discussed to show the ingredients of success based on current examples within Canada.*

Introduction

Whether consciously or unconsciously community members individually and collectively make trade-offs among the priorities of economic, social and environment well-being. Community members would agree, however, that the choices made should not compromise the provision of our most basic needs such as clean air and water for life support and food for sustenance. Nor do community members want to eliminate the earth's natural biodiversity and the habitat needed to sustain it. In other words there are ideals held by community members that suggest communities want to act sustainably. In order to know if a community is sustainable, information must be collected about the state of the ecosystem; social, economic, and environmental conditions. Monitoring the ecosystem is therefore a core activity, fundamental to a community that strives to function sustainably.

Across Canada a variety of monitoring projects have achieved positive results for communities working towards sustainability. Community Based Monitoring (CBM) has shown that it is capable of gathering relevant information in a timely fashion to Inform Community Decisions (ICD). Community Based Monitoring Informing Community Decisions (CBM-ICD) is defined as a process where concerned citizens, government agencies, industry, academia, community groups and local institutions engage in a collaborative community effort to monitor, track and respond to locally identified issues (EMAN CO and CNF 2003). CBM-ICD activities include partnership development, consultation and outreach, visioning, capacity building, monitoring of an environmental issue or concern, and linking gathered information to local decision-making that supports sustainability and adaptive management.

CBM-ICD Success

When community members take an active role in ecosystem monitoring multiple benefits are derived for the whole community. There is an increased awareness and understanding of human-environment interactions among those who participate in monitoring, such as school children, teachers, and citizen groups and to those who provide support such as researchers, corporations and government scientists. In addition, this knowledge is shared with a wider community when CBM practitioners effectively communicate the results of monitoring to others. The result is informed decision making and adaptive management leading to positive changes in the way we manage human activities in the environment.

Local data derived from CBM-ICD initiatives can also provide cost effective and meaningful data to assist in regional and national monitoring programs, thereby helping to establish baselines and provide early warning of larger trends that merit further investigation. In essence, CBM-ICD extends the geographic reach of existing monitoring programs and provides data gathering at a much finer scale. Our knowledge of the impact of human actions on the environment is greatly expanded because CMB-ICD provides monitoring data collected by citizens that look at creeks, ponds, bays, wetlands, parks, woodlots, fields and backyards in local and rural neighbourhoods.

CBM-ICD engages a community in sustainability programs that promote progress towards a common vision of sustainability by providing opportunities for dialogue between citizens, government, and industry. Collaboration, a key characteristic of CBM-ICD, increases communication among all stakeholders allowing people to more directly benefit from the knowledge and assistance of universities, governments, and industry. In return CBM-ICD provides an understanding of local issues and concerns about the ecosystem and communicates this information to others, including fellow citizens and decision makers in government and industry.

CBM-ICD Inclusiveness

Sustainability is a process that engages people through programs that make them aware of social, economic, and ecological interconnections and responsibilities. The sustainability process works best when individually and collectively people make decisions and take actions based on good information and clear choices. While science is an important contributor of good information to the sustainability process, the process also relies on communication mechanisms that ensure human values are considered, tradeoffs are discussed and future options kept open.

CBM-ICD initiatives can and should involve local industry. Industry forms an integral part of communities through direct and indirect employment, infrastructure development and through financial contributions to the local tax base and to non-government and/or non-profit organizations that work towards better communities. In addition to the latter social and economic effects, industry can also significantly affect the environment within a community. The predominant public view is industry affects the environment in negative ways. Industry can and does, however, affect the environment in positive ways by reducing or eliminating current negative effects or by restoring an environment impacted by past effects. While industry must ultimately have an impact on the environment, insufficient effort is made by local communities to monitor and understand these impacts in a way that could lead to more informed choices.

Unfortunately because the role of industry is often crucial to the social and economic well-being of a community, there is often reluctance by the community to work with industry due to a fear that exposure of industry's shortcomings may lead to the termination of benefits that are seen to sustain the livelihood of a community. In addition there is a culture of fear within industry when it comes to meaningful consultation with the public regarding performance. In most cases government is the go-between; establishing and enforcing guidelines, standards, and requirements that must be met by industry in the interest of the public good. Consequently the public direct their concerns to government, not industry, and industry works to comply with existing government regulations that may not reflect the concerns of the local community.

When industry works directly with the community in a CBM-ICD initiative new opportunities to act sustainably are created. Currently, however, there are too few examples of public-industry partnerships in monitoring. It is hoped that by examining the components of success that characterize CBM-ICD, monitoring can be seen as a mechanism to foster greater environmental responsibility among all members of a community including industry while providing a cost-effective mechanism to effect change in the stewardship and protection of the environment by government, industry and the general public.

CBM-ICD Partnerships and Networking

CBM-ICD is a collaborative initiative involving a wide variety of stakeholders in a variety of capacities. CBM-ICD creates forums that allow stakeholders to share a wide range of interests, abilities, knowledge, and concerns. Stakeholders in CBM-ICD include various levels of government; municipal, provincial, federal; education institutions including primary schools to universities and colleges; industry and corporations; non-government organizations; and individuals of the general public. Stakeholders can be involved in some or all of the following activities: the sharing of knowledge in the methods of data gathering, analysis and reporting; direct participation in data gathering; assistance in data analysis and reporting financial and in-kind support; the sharing of related data relevant to the community; and the bringing forward of issues of concern and local knowledge.

The activities of communities in monitoring and influencing local decision making will often involve new frontiers for all involved. In order to make the best use of the available information and the new information obtained, neighbouring communities will ultimately corroborate and/or compare approaches to monitoring, monitoring methods, funding sources, most importantly data, and the results of analyses. Networking is therefore an obvious tool that CBM groups use to facilitate shared learning and data comparison. One of the most valuable outcomes of networking is shared best practices. For example, while the public may have legitimate questions about the environment and wish to participate in environmental monitoring, there is often a lack of understanding of the methods to be used to collect meaningful data. A network can bring forward and share the experience that has been applied to similar questions elsewhere.

Capacity Building

CBM-ICD bridges the gap between society and the environment by engaging communities in processes that define what sustainability means locally and tracks progress through ecosystem monitoring to produce relevant, timely information that informs decision making. Citizen science does not demand that a person is an ecologist or environmental scientist. Individuals and groups may become knowledgeable of complex issues through a desire to know. Experience has shown that the needs of ecosystem monitoring can be accomplished with minimal training; relying more on commitment than specialized knowledge.

The key components of CBM-ICD required to successfully engage communities in programs that examine the relationship between human activities and the state of the environment can be summarized as follows (North South Environmental Inc. 2004):

Getting Started—organizing meetings, initiating partnerships, engaging stakeholders

Citizen-Science Monitoring Protocols—simple methods for scientific measurement

Funding—sources and application procedures, and long-term stability

Data Analysis and Management—analysis methods, quality control, and data storage

Communication—presenting results to educate communities and influence decision makers

Collaboration—sharing methods, results (data), and adaptive management responses

Capacity Building—training/technical assistance to achieve meaningful results.

Industry has significant abilities that can assist in the capacity building of CBM-ICD citizen science and citizens can have significant experience and local knowledge than can be volunteered to industry. Each should be stakeholders in the process. Community members may have concerns about what should be monitored and industry may assist in how to conduct monitoring. Direct funding for monitoring may come from industry and these may lead to matched funds from government or other stakeholders. Industry can participate in data analysis and management, which will assist in the communication of results to those within industry that can effect positive change. In all of the components of CBM-ICD, industry has the ability to provide the technical advice, training, and support needed as part of community capacity building.

Link to Decision Making

Sustainable ecosystem management is not an endpoint; it is a process that explores social, economic, and ecological interactions (in other words whole ecosystems) to know the implications of human actions. When society is well informed of the state of the ecosystem through monitoring, decision makers can recognize the tradeoffs required to balance ecosystem needs (social, economic, ecological). In essence, a sustainable society makes informed choices about the kind of environment in which they choose to live. Citizen science as conducted in CBM-ICD contributes to this process through citizen engagement, the acquisition of information on ecosystem condition, reporting to decision makers and adaptation through changes in policies and the implementation of actions that lead to an improved ecosystem condition.

Industry must be seen as a full participant in sustainable development, embracing an emerging vision of *whole ecosystem adaptive management* linking our knowledge of ecological trends and conditions to human economic and social activities. CBM-ICD embodies these principles through collaboration with all members of the community, including industry, in inter-disciplinary data gathering and analysis. The results of monitoring are communicated to key decision-makers so that they are better informed and can respond to local knowledge about the relationships between social, economic, and ecological issues and needs.

Conclusion

There are multiple benefits of CBM-ICD including: an improved ability to report on status and trends at local, regional and national scales; building a community that has the capacity to understand and use ecological information; the establishment of improved partnerships and networks among the community; an increase in knowledge about the environment that is in turn distributed among society; increased environmental awareness within a community leading to a change in the day-to-day behaviour of individuals leading to reduced impacts on the environment; increased environmental awareness and concern among citizens of a community leading to an increased voice informing policy decision makers; citizens gain a better understanding of the economic costs of environmental protection; citizens provide labour for environmental monitoring and for the completion of restoration projects that effect environmental change; citizens within the community that have excellent environmental knowledge and experience, transfer and apply their expertise at little or no cost; and citizens seek and raise funds for environmental programs.

Industry can be a full participant in CBM-ICD initiatives, contributing to an increased understanding of ecosystem condition, a more engaged and informed society and the creation of communities that are more likely to be sustainable.

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Science, Communities, and Decision Making: How Can We Learn to Dance with Many Partners?

Liette Vasseur, Associate Vice president – Research/Vice Rectrice Adjointe à la Recherche, Laurentian University/Université Laurentienne, Sudbury (Ontario) Canada P3E 2C6

Abstract—*Ecosystem management, also called integrated management can be defined as integrated careful and skilful use, development, and protection of ecosystems using ecological, economic, social and managerial principles to sustain ecosystem integrity and desired conditions, uses, products, values, and services over the long term. Although ecosystem or conservation management issues can have global, regional or trans-boundary impacts, most activities need to be focused at the sub-regional and community level to be effective. The basic concept is that the community is the most efficient unit for change in conservation management. The main challenge is to first understand these concepts and then acquire the knowledge to sustain, use, and protect natural ecosystems in order to reach a more integrated ecological, economic, and social development. In addition, community involvement can be limited because of their level of education, capacity building, and potential for actions. Communities that have data and the tools usually feel more empowered and tend to be able to deal with issues in a more effective manner than in communities where capacity and tools are non-existent. Monitoring is certainly one of the greatest steps whereby communities feel that they can contribute, learn, and enhance awareness on very specific issues. This is where it is important to develop our science in assessing sustainability in our communities. Such capacity building can help communities increase sustainability and thus influence decision making for the benefit of all members. Partnership building between public, academic, private and community constituencies can help improve knowledge and develop decision making tools for greater sustainability. Through a regional example of the southern Gulf of St Lawrence, the discussion will include lessons learned and the challenges that face communities, decision makers, private and academic sectors in promoting sustainability and the possible actions that can be taken to improve awareness and decision making.*

Introduction

Over the last two decades, the entire approach to traditional resource management has been re-examined to strengthen efficiency and long term outcomes in accordance with principles of sustainable development. As early as 1982, the concept of sustainable management was developed. Ten years later, Agenda 21, approved at the Rio Conference, affirmed that sustainable development required a new management approach: an "integrated policy and decision making process, including all involved sectors, to promote compatibility and a balance of uses" (Bruntland 1987), that was to be practical and collaborative in its approach. This means that ensuring sustainability requires a process for developing the larger and longer term vision of how resources and ecosystems can be sustainably managed.

Talking about sustainability and ecosystems can be complex and often confusing, especially for the general public. In this paper, ecosystem can be defined as an astonishing assortment of species that interact and are interdependent in many ways and in which humans are a component like any other species (Vasseur and others 2002a). This leads to the understanding that management does not only involve general ecosystem components but also human activities and the decision making process that follows. This process, to be successfully implemented, should be inclusive as natural resources and habitats are integral components of any healthy or sustainable ecosystem along with the human communities (Canadian Round Tables 1993). Although ecosystem management issues can have global, regional or trans-boundary impacts, most activities need to be focused at the sub-regional and community level to be effective. The basic concept is that the community is the most efficient unit for change in conservation management. The main challenge is to first understand these concepts and then acquire the knowledge to sustain, use and protect natural ecosystems in order to reach more integrated ecological, economic, and social development. This knowledge must be promoted by professionals and decision-makers but also most importantly by the youth, women and men who have the most at stake (Vasseur and Hart 2002).

A regional or community approach can therefore be promoted as a way to reach as many stakeholders as possible and thus improve decision making efficiency and social acceptability. This paper examines the components of a model for ecosystem management of regional constituency that has as its main objective developing sustainability through public participation, education, communication, science and monitoring. The example described here represents one of the few groups established in Canada that focuses on sustainability and ecosystem management and attempts to improve efficiency and environmentally sound decision making at the regional level.

Table 1. Some criteria to achieve sustainability in communities upon which the SGSL-Coalition has been based.

1. Imply and reflect a clear vision and specific goals achievable on a yearly basis.
2. Reflect "higher" values and ethical principles and rules, leading to equity and respect.
3. Reflect a wide range of interests and groups existing in the region (inclusiveness).
4. Involve actors, stakeholders and public (high level of participation).
5. Accept and recognize that ecosystems are complex and dynamic (realistic approach).
6. Synthesize a wide range of information and knowledge from ecological to socio-economic (interdisciplinary approach) leading to knowledge and capacity building.
7. Be applicable to a wide range of ecosystem types and conditions.
8. Be open and transparent in the approach to enhance communication and consensus building.
9. Be inherently tentative and evolving as conditions and knowledge change (adaptive approach).

A Model for Sustainability and Ecosystem Management: Integrated Approach

In this model, sustainable/ecosystem management can be defined as the "integrated careful and skilful use, development and protection of ecosystems using ecological, economic, social and managerial principles to sustain ecosystem integrity and desired conditions, uses, products, values, and services related to all development over the long term" (Vasseur and Hart 2002, p. 42). Such management, which is based on sustainable development principles, includes different components that allow for flexibility, transparency and cooperation at all steps of the process, from the observation of an issue and decision making to the implementation of solutions and monitoring. The most important aspect of this system is that it is dynamic and allows conditions to evolve; therefore it has to be adaptive. This is a process balancing protection/maintenance and sustainable use of resources and the environment (including humans) and encompasses all interdisciplinary aspects of management, development, and decision making. For each issue tackled by the region or the community, all elements of the ecosystem, not only the human (and often economic) components should be considered. Under this framework, the goals of community actions towards sustainability should satisfy several criteria as proposed by Hardi and Zdan (1997) and Slocombe (1998) (table 1). Although the complexity of ecosystems should be taken into account in any regional action plan, it is essential that the plan itself be simple and understood by all stakeholders in order to be successfully implemented. In several cases, strategies are defined and developed without a good appreciation of all the components and their interconnections and this can lead to reduced efficiency or acceptability of the solutions (Vasseur and Hart 2002). It is essential to remind decision makers and all stakeholders for that matter that without ecosystem services and functions, human demands and health cannot be fulfilled.

There are several levels of public participation in the decision process (Hance and others 1990). Certain types of public consultation merely show the environmentally sound intentions of the policy makers, but they do not usually consider public concerns in a meaningful way. At another level, the decision makers have to consult the population each time a problem occurs. In this case, the population has to vote on an issue after having received the proper information and all the alternatives available to resolve the problem. This type of public participation is more likely to be costly and may be a very slow process. It is especially not adequate for solving an immediate problem. The main challenge is in defining an approach in which decision making and sustainable actions are well balanced. In addition, it is essential to define what the communities' stake is. In this paper, communities are defined as a group of people sharing a geographic context and interest in managing an environmental issue. Their involvement should lead towards consensus and social acceptability. The community can be small or large in size, number, or interests.

In the present paper, I describe an approach that was used and implemented in the Southern Gulf of St. Lawrence region in order to improve sustainability through inclusiveness, partnership and as an aid in decision making considering that all stakeholders can contribute to the building of regional sustainability. It can be shown that a region is the main unit for change when the components of this ecosystem, although larger in scale, are highly interconnected and therefore the actions of some people can affect the sustainability of others.

A Regional Example: The SGSL-Coalition

The coastal zone of the Southern Gulf of St. Lawrence, with its salt marshes, dunes and beaches, estuaries and forests, is an important ecological, economic, and social region of North America. It provides critical spawning, feeding and nursery habitats for numerous species of organisms. Communities in the region depend on its resources for income, recreational opportunities, and their quality of life. Over the years, the sustainability of this region has been threatened by several agents including overexploitation of natural resources, coastal ecosystem degradation, and pollution. In order to better integrate the concerns of all stakeholders in the region, through consultations and discussions involving different groups, the Southern Gulf of St Lawrence Coalition on Sustainability was formally created in November 1999. This multi-stakeholder regional body draws representation and membership from those portions of Nova Scotia, New Brunswick, Prince Edward Island and Quebec that are part of the Southern Gulf of St. Lawrence ecosystem. Its vision is a future in which the Southern Gulf of St. Lawrence ecosystem is environmentally, economically and socially sustainable (SGSL-Coalition 2004).

Sustainability requires integrating three key elements: ecological, economic, and social aspects. It also implies respecting cultural values, a topic of great interest in this region where French Acadians, First Nations people and English Canadians live together. The Coalition establishes a mechanism for enhancing horizontal communication among partners, which allows for the sharing of knowledge and attaining consensus. No one partner has the resources to implement a meaningful sustainability strategy for the Southern Gulf of St. Lawrence, but the Coalition allows the pooling of human resources for a meaningful and long-term impact on the sustainability of the region. The mission of the Coalition is to promote the long-term sustainability of its ecosystem and this is accomplished by developing a shared and strategic Action Plan that aims to provide the tools required to address issues of common concern (SGSL-Coalition 2004).

One of the biggest challenges to achieving an integrated planning process is to develop effective governance structures for sustainable development. This means adopting forums and processes that can foster open dialogue between governments, communities, and citizens (Vasseur and others 2002b). The Coalition represents one of the first official governance mechanisms established in Atlantic Canada to develop such an integrated planning process. This process is currently supported by and made up of diverse yet dedicated groups of individuals and representatives of non-government and community-based organizations, businesses and industries, academics, First Nations and municipal, provincial and federal agencies (SGSL-Coalition 2004).

Partnership with the Coalition: Challenges and Solutions?

The Southern Gulf of St. Lawrence Coalition on Sustainability is first and foremost a forum of partners who share a common vision towards defining solutions to ensure the sustainability of the region. The SGSL-Coalition is a door for cooperation and partnership between various groups and individuals and for implementing concrete actions. Being a voluntary body with limited resources, the Coalition tries to organize and/or facilitate meetings, workshops, forums, or task forces on topics that are of common interest for all of the stakeholders.

Considering that the community should be involved in some way in each stage of the process, communication and information sharing remains one of the challenges for regional organisations such as the SGSL-Coalition. The main hurdle to overcome in this situation is the recognition of the responsibilities of the various jurisdictions that make up the Coalition. For example, it is essential that government agencies recognize that they cannot achieve their departmental objectives by acting alone. Recognition of each other's roles within the regional community is also required in order to increase the effectiveness of environmental protection and conservation measures, to maximize monitoring and compliance activities and to realize sustainable development potential. Over the years, the SGSL-Coalition has struggled mainly in the area of industry involvement. It has been a perception from the industry side that if they open up to discussions and public participation they could face increased problems and demands and delays in their actions (Shepherd and Bowler 1997). However, under ideal circumstances the participation of all stakeholders can promote sustainable development for all constituencies through recommending priority strategies, policies, and regulations to government agencies and monitoring the progress of implementing them. Industries can profit from the local knowledge of the communities and understand the limitations and vulnerability of the system (Sheate 1991, Bisset 2000). Additionally, any type of governmental or corporate actions that might have impacts on the environment and therefore the sustainability of a region should be monitored in order to make sure that the solutions implemented are adequate and if not, new strategies can be implemented to improve effectiveness. In projects with limited or missing monitoring of the outcomes and the surrounding environmental conditions, the main danger coming from the implementation of a strategy is the lack of adaptive response to emerging or abrupt changes.

Academic institutions including universities, colleges, and schools also have a great role to play in this type of ecosystem regional management program. The Coalition provides universities and colleges with the opportunity to develop and apply sustainability concepts to a wide range of situations and different conditions. It is an open door to explore new methods for achieving sustainable results and a way to link research to real life situations (SGSL-Coalition 2004). Since 1999, at least five academic institutions from the region have been involved in this process. This number could increase but some limitations have yet to be overcome to improve their involvement such as limited resources and time allocation. Solutions can be found to improve levels of participation from academia. For example, the SGSL-Coalition created a Sustainability Scholarship in 2003 and it is given annually to a graduate student who has undertaken research in the southern Gulf of Saint Lawrence on issues of priority for the Coalition's members. This strategy has two goals: improving the involvement of researchers in the Coalition and also communicating the research results that are acquired by scientists in the region. It has been shown in the past that scientific information should also be available to members of the Coalition who need the information for decision making. The sustainability of the scholarship and other actions initiated by members of the Coalition will remain fragile unless in the long term, endowment instead of annual governmental funding can be secured.

Academic institutions have also played an important role in the sustainability of the organisation. For example, one of the universities has been able to host the offices of the Coalition. This has helped reduce the cost of office overheads. Other organisations might be able to play this role however this is often highly limited especially for NGOs that already have limited funding to support their own work. In addition, the question of neutrality and location always come up in discussions when such an organisation is created. Using the university has helped reduce neutrality concerns as it is not taking position in debates. Spatially, the Coalition is located in Moncton as it is relatively central to the region served by the SGSL-Coalition.

In-kind contributions in an organisation like the Coalition are crucial for its survival. Involving youth in this type of organisation is relatively difficult although they are the leaders of tomorrow (Vasseur and others 2002b). However, their involvement might become essential as it is frequently reported that volunteer burnout is increasing. This has been seen in many rural or small communities and especially in regions like the Maritimes where volunteering has been a way of life for generations.

Towards Sustainability Through Community Participation: Lessons Learned From the SGSL-Coalition

In recent years, we have become aware of growing opposition from the general population to decisions which could harm society and its environment. The concerns of the public about different management strategies are often due to a lack of knowledge and information or a fear of negative impacts. Public pressures have led to stricter and more demanding type of regulations regarding consultation prior to an environmental project. Since the population increasingly needs to be consulted in relation to environmental decisions and policies in North America, there is a move towards greater public participation in environmental debates. The example of the SGSL-Coalition shows the need for such groups to lessen this gap in knowledge and information. Community or regional monitoring is one of the main actions that can help improve such knowledge upon which decision making and strategies can be based. Subsequently, considering the data and information gathered through activities from regional groups, decision makers can better address concerns and opinions from the general public before making decisions on environmental issues and sustainable development. This raises questions such as, what kind of public participation should we consider? What advantages or disadvantages does public consultation pose? Which conditions do we have to respect to obtain successful public participation in decisions on environmental questions? (Vasseur and others 1997).

Although the SGSL-Coalition is a young organization, already some lessons can be drawn from past experiences regarding decision making and public participation in sustainability strategies. Assembling stakeholders from all sectors of society can be advantageous as it can lead to greater discussion, consensus building, and social acceptability.

It is, however, a victim of its own concept, as inclusiveness remains difficult to maintain. The first challenge which the SGSL-Coalition faced was the claim of objectivity and transparency. It is easy for some groups to target some of the stakeholders and complain about their level of involvement and influence. This has occurred in the past due to the link between federal government and financial support for the Coalition. In this case, accounting and communication have to be as transparent as possible to avoid complains. To reduce concerns on this issue of interfering in funding allocation, the SGSL-Coalition management committee includes all stakeholders but government agents are ex-officio, in other words, they remain neutral and do not vote during decision making for funding allocation.

The type of actions that the Coalition can undertake have to be thought through carefully as it is not in its mandate to compete for funding and duplicate activities of other groups in the region. In fact, synergy should be promoted through the use of the Coalition as a mechanism to apply for greater funding on behalf of several smaller groups in the region. This occurred in 2004 with the implementation of a new monitoring program on a coastal aquatic ecosystem. In this example, more than 10 community and non-governmental groups have been involved and linked with the use of a newly graduated student supported under a federal employment program. Without such funding, the various groups participating in this program would have been smaller in number and more limited in terms of their level of participation.

A concern that sometime limits the participation or collaboration of industries and certain types of groups is the level of activism or influence on the decision making process the Coalition could have. Going back to its mandate, the SGSL-Coalition is first and foremost an information clearinghouse and thus has the advantage of acquiring information and communicating it in a more neutral way. There has been some debate over the years as to whether the Coalition should advocate for issues that have been of great concern for some members of the Coalition. For example, on several occasions, the SGSL-Coalition has been pushed to take a position regarding oil and gas development and the construction of incinerators. In all of these cases, the management committee has kept its role by reminding its members that the mandate of the Coalition is to help the decision making process through discussion and information sharing, not by taking a position that could be against the values and wishes of some of the members. Activism or position taking has been avoided in all cases although this has caused several groups to reduce their participation in the Coalition. This neutral role has also been a disadvantage in the profile building of the SGSL-Coalition. Because of its limited mandate, it has been viewed by other organizations as less effective and lacking in terms of action. The situation in which the SGSL-Coalition is found can work as both an advantage and a disadvantage. The disadvantage is that it is more vulnerable to criticism of inaction. This perceived inaction of the Coalition has also lead to threats in reduction for funding support. But it has the advantage, when well established, to be highly powerful for helping decision makers as its credibility is enhanced and well accepted. Consensus in decision making is not automatically reached as soon as public participation is enhanced but it certainly increases the possibility. This is the main role that the Coalition is trying to achieve through greater participation and information sharing.

Conclusions

Environmental degradation, overexploitation, and pollution are affecting the health of ecosystems and sustainability, often impacting human health, quality of life and traditional uses. Regional or community actions and information sharing can help improve sustainability if certain conditions are respected. The SGSL-Coalition is one of the few examples of a regional participative and inclusive group that works towards promoting sustainability of the southern Gulf of St Lawrence ecosystem. Communities of interests such as academic institutions, municipal agencies, or First Nations, have the possibility to get together, discuss, and build consensus that can influence the decisions that affect them, their sustainability, and their environment. This group has been created from a community perspective and can therefore reach people from different constituencies.

The SGSL-Coalition, like many others, faces several challenges over its establishment and maintenance. To be true to its mandate, the SGSL-Coalition has chosen to remain neutral, inclusive, transparent, and objective leading the way to communication and information sharing. While this role is highly legitimate in the current society it also has some disadvantages mainly in the beginning of the establishment of the coalition. For the establishment of such a group, it is recommended that the mandate of the group is clearly stated to all members and non-members to ensure that there is not dissatisfaction regarding the work that the group can or cannot do. The group can, of course, evolve over time and integrate more activities or strategies. For example, it is envisioned that over the next few years, community-based environmental monitoring will become part of the normal actions of the SGSL-Coalition. It is clear that monitoring is an excellent approach for gathering long term data and trends, information greatly needed by decision makers for better sustainability of the policies or actions regarding the environment (Kappelle 2000, Yarnell and Gayton 2003).

The SGSL-Coalition is often perceived as a community group because it started at the grassroots/community level. Other such groups are often built from a science viewpoint with scientific partners. Exchanges on lessons learned with such groups showed that in the end, in order to sustain actions, a balance between community and science has to be established. In the case of the Coalition the community came first then the involvement of scientists. In other cases, when scientists were first involved in the creation of such groups, a community approach had to be added to maintain their actions and improve effectiveness. Decision making is a process that can be done rapidly without consultation and information sharing. If a region is to be true in terms of supporting sustainable development and environmental protection, however, information sharing and inclusiveness should be amongst the main principles by which it is doing business. While this strategy is more time and resource consuming, long term results should lead to greater social acceptability, consensus, and sustainability. It is hoped that through this process the region of the southern Gulf of St Lawrence can become a living example of these principles.

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Sustainability Traditional Knowledge

GLOBE ONE: A Community-Based Environmental Field Campaign

Rebecca Boger PhD, Peggy LeMone PhD, John McLaughlin, Sharon Sikora PhD, Sandra Henderson PhD

***Abstract**—The Global Learning and Observations to Benefit the Environment (GLOBE) program is an international environmental science and education program involving scientists, teachers and students in the collection, analysis, and display of data used in environmental monitoring and research. Since its formation in 1994, students have collected over 11 million data points in Atmosphere, Hydrology, Soils, Land Cover/Biology and Phenology investigation areas. At present, over 14,000 schools in 106 countries participate in GLOBE (www.globe.gov). In 2003, GLOBE scientists, K-12 teachers and students, and citizen volunteer groups in Black Hawk County, Iowa started collaborating on a multi-disciplinary intensive data collection effort called GLOBE ONE. Research questions for this campaign focus on a community-specific generated issue; the central scientific objective compares quantitatively the environmental effects of various soil tillage techniques in Black Hawk County. Multiple data sets are being collected over a two-year period with the bulk of data collection performed by GLOBE students collaborating with scientists. GLOBE ONE and GLOBE Iowa supply an infrastructure for community and partner aid to the GLOBE schools and supplement measurements when required. This low-cost campaign provides a model for future scientific partnerships involving GLOBE students, teachers, scientists, and community organizations. While providing scientific data, this community-based campaign sets the stage for sustainable environmental stewardship, monitoring and planning.*

Introduction

GLOBE ONE is a field campaign involving a first hand partnership between students and scientists to collect a structured, multidisciplinary data set designed to answer a research question. The campaign started in spring 2004 and will run through to fall 2005. GLOBE ONE was developed by GLOBE science Principal Investigators (PI) with the help of GLOBE Program Office to demonstrate the capability of GLOBE student-teacher-scientist partnerships to produce scientific results publishable in refereed journals.

The GLOBE Program (www.globe.gov) is an international science and education programs that involves K-12 students in meaningful science. Formed in 1994, GLOBE has grown to include 14,000 schools in 106 countries. GLOBE dedicates resources to develop and support over 50 protocols including data entry, storage, and access mechanisms that are capable of supporting true scientific research. GLOBE supports PI research teams charged with providing scientific publications based on GLOBE data. Students are collecting measurements in the areas of Atmosphere and Climate, Hydrology, Soils, Land Cover, and Phenology.

GLOBE is managed by the University Corporation for Atmospheric Research (UCAR) and supported by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the U.S. Department of State. Implementation in the United States depends upon the efforts of more than 100 U.S. Partners—universities, state departments of education, school districts, and other non-profit organizations. U.S. Partners raise their own funds, leveraged off the Federal investment in the program, to deliver GLOBE in their areas. U.S. Partners recruit schools, train teachers, provide follow-up support, and help in the adaptation of the program to state and local standards and requirements. Because broad international participation is integral to the implementation of the program, GLOBE enters into formal agreements with countries all over the world. In these partnerships, GLOBE provides the program infrastructure. Each international partner manages and provides funding for its own implementation, acquiring the resources from government, private sector, and non-profit sources. GLOBE partners determine implementation strategies consistent with their countries' educational systems and priorities.

Rationale

The GLOBE Program offers science and education materials that are used all around the world. The data, available from the GLOBE Web site, is used to help answer a variety of questions at local, regional and global scales. However, the data can lack temporal or spatial continuity, and thus limits the scientific usefulness. Furthermore, for an integrated Earth system approach, multiple types of data may be required at a given location or region. GLOBE ONE was designed to get a temporally and spatially intense data set. Furthermore, it was designed at the onset to have broad-based community interest and involvement. It is hoped that this will help set the stage for continued environmental monitoring and research by many different people and organizations (e.g., primary and secondary schools, universities, private sector, volunteer organizations) within the community.

Science Objectives

The science objectives of GLOBE ONE involve comparing the environmental impacts of tillage techniques used in agriculture. Specifically, scientists are investigating the impacts associated with varying the frequency and intensity of soil tillage and with varying the amount of crop residue left after crops are planted. The central question being asked is:

> *For corn and soybeans, what are the environmental impacts associated with different frequencies and intensities of soil tillage farming, and with different amounts of crop residue left after planting as compared to prairie and urban sites?*

Tillage is a manipulation of soil by physical means to create soil conditions suitable for plant growth (Gajri and others 2002). Conventional tillage, also known as intensive tillage, involves intense manipulation of the soil, generally via plowing, and leaves less than 15 percent of crop residues on the soil surface after planting (Koller 2003). This tilling practice is used to prepare the soil for seeding and to remove weeds. However, it also removes crop residue that protects the surface of the soil, and can make the soil vulnerable to erosion.

In recent years there has been a rise in the use of alternative tillage practices that serve to reduce erosion, namely reduced tillage, conservation tillage and no-tillage. Reduced tillage is a practice in which the soil is tilled to some degree and 15-30 percent of the soil surface is covered with crop residue after planting (Gajri and others 2002). Conservation tillage refers to any tillage practice the leaves at least 30 percent of the soil surface covered with crop residue after planting, the intensity and frequency of the tillage can vary but do not involve turning the soil completely upside down (Koller 2003). No-tillage refers to a practice in which the soil is not physically disturbed from harvest to planting (Koller 2003). The amount of crop residue left at the time of planting can be varied with no-tillage.

For each investigation area (Atmosphere, Hydrology, Phenology, and Soils), there are additional questions being asked. The multidisciplinary perspective that GLOBE ONE applies to assess the environmental impacts of an alteration in land management practices is key in assessing the environmental impacts.

Education Objectives

The involvement of GLOBE ONE Principal Investigators and local scientists with the schools may have tremendous impact on the accessibility of science as a career choice in addition to the overall attitude students have toward the nature of science. The National Science Education Standards for Professional Development of teachers include involving teachers in authentic research as a means of improving science education in their classroom. Teachers who have had research experience can positively affect the environment for learning science in their classrooms (Caton and others 2000, Johnson 2002, Odom 2001). Teachers and their students in GLOBE ONE will contribute to real science investigations of the effects of land use change on components of the Earth System.

Direct interaction with scientists occurs through a series of protocol workshops, field trips, and school site visits. As well, students will be encouraged to develop their own research questions and work with scientists on the development of these projects. In March 2005, an education workshop is scheduled for Iowa teachers to discuss the implementation of GLOBE ONE activities in the classroom.

Study Location

Black Hawk County, an agricultural area in northeastern Iowa, is the location of the field campaign. Black Hawk County was chosen for a number of reasons. The scientific questions match both the land-surface types found in the county and community concerns regarding land usage. Black Hawk County has a strong existing partnership with the University of Northern Iowa. The University of Northern Iowa offers the opportunity for support and collaboration. Also, there are several other local organizations that have been tapped into to join the GLOBE ONE effort.

Data Collection

GLOBE students and volunteers in collaboration with scientists are collecting most of the data in this field campaign. GLOBE ONE and GLOBE Iowa supply an infrastructure for community and partner aid to the GLOBE schools and supplement measurements when required.

GLOBE ONE currently involves students from thirty classrooms in the Waterloo School District, University of Northern Iowa summer enrichment programs, local girl scouts, and IOWATER (a volunteer water monitoring organization). The Waterloo School District is one of four school districts in Black Hawk County. Active recruitment efforts are underway to include teachers and students from the other three districts. High school students enrolled in the University of Northern Iowa's Upward Bound program are collecting data for GLOBE ONE. Upward Bound serves high school students from low-income families, high school students from families in which neither parent hold a bachelors degree, and low-income, first-generation military veterans who are preparing to enter postsecondary education. The rigorous academic nature of GLOBE ONE aligns well with the goals and objectives of Upward Bound. A local Girl Scout troop from Black Hawk County is also participating in the data collection.

The list of the protocols used, required instruments, frequency of measurements and type of site is listed in table 1 – Data Collection Details. Sites are designated as either intensive or extensive. Intensive sites are the actual investigative sites where the data will be rigorously collected, while extensive sites are external to the actual investigation providing additional metadata to assist in the interpretation of the results especially in the area of Earth as a system. Ten intensive sites are being used to characterize areas with tillage of notable frequency and intensity (four sites), no-tillage (four sites), and prairie (two sites). Extensive sites are located at schools and feature student-driven measurements.

Potential Impacts/ contributions of GLOBE ONE

GLOBE ONE is gathering numerous complementary datasets to support GLOBE and non-GLOBE scientists in their study of the interaction of land cover and land use with weather, water, and biota. These datasets are used for basic research and have many management applications. The participating students and teachers have a remarkable opportunity to work directly with these scientists, and obtain an inside view of a major research campaign. GLOBE ONE features measurements taken by students with the oversight and support of scientists. Both students and scientists will analyze the collected data to help answer the central and numerous related research questions.

In particular, some of the benefits of the GLOBE ONE include:

1. The current GLOBE ONE dataset is quality-controlled and continuous.

   In GLOBE ONE, quality-controlled and continuous data will be achieved through intensive PI involvement, active local supervision, incentive systems, and extensive community involvement. Some data will be gathered using automated weather stations. Students and PIs involved in answering the science questions will be looking at the data as it is collected both for data assessment and to obtain early insights into answering the GLOBE ONE research questions.

2. The GLOBE ONE data set is comprehensive.

   GLOBE ONE implements a large portion of scientifically-robust interdisciplinary Earth System Science (ESS) toolkit for measuring soil, atmosphere, hydrologic, land cover, and phenological states and processes that is provided by the GLOBE protocols.

3. GLOBE ONE involves the community.

   The central science questions of GLOBE ONE were developed in collaboration with scientists in Black Hawk County, ensuring both the collection of the proper data, and community interest. This is important because the ideal GLOBE implementation scheme requires participation from multiple sectors of the local communities. Having many different groups working together to collect data allows creation of a larger and more complete data sets than could possibly be obtained by individual schools. GLOBE ONE serves to set up a strong example of how these partnerships can work. Scientists and local groups are working hands-on with schools to collect data.

Conclusion

In GLOBE ONE, many scientists have a vested interest in the data being collected, and these scientists are coordinating their activities to create a multidisciplinary dataset among themselves while working with students and other members of the Black Hawk community. Likewise the

Table 1. Data Collection Details.

Protocol	Instruments and Supplies	Sites	Frequency
Soil temperature Soil moisture Air temperature Precipitation Relative humidity Wind speed Barometric pressure Wind direction	Automated weather stations	10 intensive	Continuous wireless or downloads every 3 weeks/ month
Soil characterization: texture, structure, color, consistence, horizon, bulk density, particle density, root and rock, pH, slope		10 intensive, and 4 extensive, smaller set of measurements for MUC and Soil-a-thon	One time
Soil organic matter, carbon and nitrogen, ,psd, fertility, .3 and 1.5MPA water, bulk density	Supplementary in lab of Dr. Sparrow and/or Levine	10 intensive	One time
Greenup/greendown	Ruler, color charts	10 intensive and 4 extensive	Twice weekly, seasonal
Hummingbird*	Feeder, optional; Nectar plants, optional	4 extensive	Daily, spring to fall
Water pH	Meter, calibration solution	10 intensive	Weekly (non-frozen)
Water conductivity	Meter and calibration solution	10 intensive	Weekly
Water turbidity	Turbidity tube	10 intensive	Weekly
Water dissolved oxygen	Probe and/or test kit	10 intensive	Weekly
Water nitrates	Probe or test kit	10 intensive	Weekly
Water temperature	Probe and/or thermometer	10 intensive	Weekly
Water alkalinity	Probe and/or test kit	10 intensive	Weekly
Rain	Rain gauge	4 extensive	Daily
Snow	Snow board and meter stick	4 extensive	Daily
Precipitation pH	pH meter and calibration solution	4 extensive	Daily
Clouds and contrails	Cloud charts, web photos	4 extensive	Daily
Aerosols	Sun photometer	2 extensive	Daily
Water vapor	GLOBE/GIFTS Water Vapor Instrument	2 extensive	Daily
Surface Temperature	Infrared thermometer	10 intensive	Daily or weekly
Land Cover Sample Site and Biometry (MUC-A-THON)	cameras, GPS', MUC Field Guide, densiometers, clinometers	many	Once a year
Mapping	satellite imagery, transparencies and markers or computers with MultiSpec	one per school	Once
solar insolation, and UVA**	Specially designed "full sky" instruments	2 extensive	Data logged, requires weekly download

* this protocol included due to educational benefits, and special request of Iowa schools.
** these measurements may be piggybacked to aid in PI research, but are not GLOBE protocols or essential to main research question.

community has a vested interest in the questions being asked and the types of research being conducted by scientists and students. By working together, a model for a learning community is being developed. This learning community enables students to use the environment as a focus of study while providing data that can be used for research, monitoring, and management. This broad-based community participation will hopefully continue after the completion of GLOBE ONE in Black Hawk County. In addition, the model can be adopted in other communities to address other research questions utilizing local institutions and organizations.

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Devil's in the Details: Using Archaeological and Historical Data to Refine Ecosystem Models at the Local Level

Don Hann, Forest Archaeologist, Malheur National Forest, John Day, OR

Abstract—*The United States Forest Service is charged with managing extensive and varied ecosystems throughout the country. Under the rubric of "ecosystem management" the goal has been to provide goods and services from Forest Service lands while maintaining ecological integrity. Recognizing that ecosystems are dynamic in nature, the concept of Historical Range of Variability (HRV) has been developed to capture the range of conditions expected within ecosystems. Over the last fifteen years extensive wildfires have occurred in many parts of the western United States at a scale that has rarely been equaled during the last century. Based on the assumption that the severity of many of these fires was amplified by unnaturally high fuel loads caused by decades of fire exclusion, a program of altering forest structure on the landscape scale has been proposed. In order to implement this policy at the scale required to have a meaningful effect on wildfire behavior, the Forest Service relies on a series of increasingly sophisticated computer models. These models allow managers to quantify and visualize the effects of various restoration actions, or inaction, on wildfire behavior. Although they are extremely useful tools, there are inherent limitations to models when implementing actions in the real world. Gaps in data and the simplification of complex natural processes are obscured during modeling. A variety of plant and animal macrofossils recovered in archaeological contexts and historical data from journals, newspapers, survey notes and photographs can provide critical information concerning the HRV of specific ecosystems. Use of local archaeological and historical data can be invaluable in refining large-scale models to more accurately reflect local ecological conditions. This paper examines the types of data available in the southern Blue Mountains of eastern Oregon and provides examples of the use of these data in ecosystem planning on the Malheur National Forest.*

The United States Forest Service was established in 1905 to manage vast tracts of forest and grassland held in the public domain, particularly in the western states. The primary charge of the new agency was to manage the timber and protect the water supply on public lands. This is still the case, although in recent decades there has been less emphasis on providing timber for market and more emphasis on maintaining or restoring forest ecosystems. The Healthy Forests Initiative (HFI) and the Healthy Forests Restoration Act (HFRA) represent recent policy initiatives that direct the Forest Service to focus resources on reducing the effects of wildfire on forest ecosystems and adjacent private property. These initiatives highlight the perceived catastrophic nature of recent large-scale wildfires in the western United States and emphasize the need to move quickly to alter forest ecosystems to make them less susceptible to large scale fire events. They direct the agency to use science to develop appropriate action plans but de-emphasize the use of National Environmental Policy Act (NEPA) procedures generally used to incorporate scientific data into planning efforts. Coarse–scale modeling of Fire Regime Current Conditions (FRCC) is being utilized at the local planning level with little fine-scale "ground truthing" of the affected stands. This paper examines the potential to use existent and readily available historical and archaeological data to help fine tune FRCC.

A spat of environmental and land management legislation from the 1960s and 1970s provide the majority of the legal and regulatory framework in which the Forest Service now operates (Meidinger 1997). These include the Multiple-Use Sustained-Yield Act, the National Environmental Policy Act (NEPA), the National Forest Management Act (NFMA), the Endangered Species Act (ESA), the National Clean Water Act, and the Clean Air Act. These laws, and the social setting in which they evolved, have increased the importance of integrating scientifically valid information into forest management (Cortner and others 1999). These optimistic and sometimes conflicting mandates are expensive, at least in short term, and do not provide the immediately apparent results conducive to long term political support.

Through implementation of these mandates Federal land managers and scientists developed a process referred to as ecosystem management (Cortner and others 1999). This process provides an adaptive framework to evaluate management goals and constraints using diverse scientific information in order to estimate how various ecosystems will respond to given actions. NEPA in particular mandates interdisciplinary analysis of proposed management actions in order to evaluate the possible effects on a range of resources (Bass and others 2001). Since ecosystems are dynamic in nature, it is important to understand the variety of plant and animal communities that occur in a given area over time. One way to approach this is the concept of Historic Range of Variability (HRV). In spite of a number of difficulties in applying HRV to project planning, it is still a widely used approach to account for ecosystem variability over time (Romme and others 2003). Historical records and archaeological data can provide useful information for the determination of HRV during planning.

Although not unusual when viewed at a time scale of multiple centuries, several fire seasons during the last 1 1/2 decades have been more severe than any since 1960 (Williams and Dellasala 2004). Increased human population and a preference for living in rural and suburban settings has resulted in a substantial increase in the number of residences built within or adjacent to forested land. Within these areas, now referred to as the Wildland/Urban Interface (WUI), thousands of homes have been lost during large wildfire events. A number of factors have contributed to the increased size and often the severity of wildfire over the last two decades. These include climatic variations, drought, disease, and heavy fuel load caused by increased vegetation density (Graham and others 2004). In many Western forests fuel loads have likely increased beyond historic levels at least partly due to almost a century of successful fire suppression actions (Romme and others 2003). This is particularly true in dry pine (*Pinus*) forest stands but less well understood in mixed conifer stands. Fire suppression has probably played an insignificant role in sub-alpine, moist fir (*Abies*) dominant and lodgepole pine (*Pinus contorta*) stands and other stands with fairly long historic fire return intervals. The current climatic situation, including "global warming" trends and several years of drought, are likely primary drivers of the current wildfire situation (McKenzie and others 2004). The overall effect of these uncontrollable climate and weather variables, versus fuel loading, which is controllable through management actions such as thinning and prescribed fire, is not well understood.

The extreme wildfire behavior during the last several years has led to significant new legislation and administrative rules/regulations aimed at expediting forest fuel reduction projects. The Healthy Forests Initiative (HFI) and the Healthy Forests Restoration Act (HFRA) are meant to guide Federal land managers out of "process predicaments" that are perceived to be delaying rapid implementation of fuels reduction projects (USDA Forest Service 2004). The interdisciplinary planning process mandated under NEPA can be time consuming and relatively expensive (Bass and others 2001). Ecosystems are complex. It takes time to consolidate and analyze the data needed in order to understand the effects of management actions on the multiple components of the ecosystems in a planning area. Fire is one of the most important disturbance processes in forests in the western United States and altering fire regimes through thinning and prescribed burning will have significant, and hopefully positive, environmental effects (McKenzie and others 2004).

Under the HFI fuels reduction projects 1000 acres or less in size and prescribed burning of 4500 acres or less can be addressed as "Categorically Excluded" under NEPA (USDA Forest Service 2004). Categorically excluded projects undergo only minimal environmental review under NEPA (Bass and others 2001). To qualify, these projects must either be in a Wildland-Urban Interface (WUI) or in an area that is rated a Fire Regime Current Condition (FRCC) Two or Three. A WUI is land that extends anywhere from ½ mile to 1½ miles from the boundary of residential land, depending on the environmental and topographic setting (USDA Forest Service 2004). FRCC is a rating of the estimated current stand fuel loading compared to its estimated historic fuel loading based on a course-scale model (GAO 2004a).

In order to consider these projects Categorical Exclusions under NEPA the HFI makes several assumptions (USDA Forest Service 2004). First, forest fuel loads are unnaturally high due primarily to 100 years of fire exclusion; second, large wildfires are catastrophic and cause significant resource damage; and third, environmental effects of prescribed fires and fuels reduction projects are well understood and generally minor. This last point is particularly significant since Categorical Exclusions under NEPA only apply to projects that do not "individually or cumulatively have a significant effect on the human environment" (Bass and others 2001). All of these assumptions are being actively debated (Beschta and others 2004, Brown and others 2004, Dombeck and others 2004, Everett and others 2000, GAO 2004, Graham 2003, Graham and others 2004, Kaufman 2004, McKenzie and others 2004, Omi and Martinson 2002, Pfilf and others 2002). As Everett and others note, "Fire regimes are site specific based on forest type, topography, microclimate, ignition sources, and past disturbance history. Land management is also site specific, requiring local information on fire regimes to manage for this important disturbance" (2000). For these reasons, among others, it is likely that most fuels reduction projects conducted on a landscape scale will be analyzed using the more complete NEPA processes of Environmental Assessments and Environmental Impact Statements (Bass and others 2001).

Regardless of the type of NEPA analysis to be conducted, FRCC modeling is still the tool used to estimate the priority for treatment for forest stands (GAO 2004a). In a resent review of the analysis of effects from wildfire and fuels reduction projects by the General Accounting Office it was made clear that there is a lack of consensus on how to describe and analyze potential effects (GAO 2004). The report lists 19 existing models and similar tools used in planning and managing fires (GAO 2004b). Most of these look at a limited range of effects and were not designed for extensive effects analysis. All ecosystem models are abstractions of reality and they intentionally simplify complex natural processes. This is an inherent limitation of modeling and does not invalidate the use of models so long as the assumptions used and data gaps present are made explicit.

The model used to generate FRCC was devised to estimate the condition of ecosystems on a national scale and is not intended for identifying condition class by watershed or stand at the local level. The team that developed the model has clearly laid out the assumptions they used and limitations of their data. "To assess fire regime current conditions, we needed a baseline of conditions from which to compare. A critical data layer developed to assess current conditions and departure from historic conditions was the 'Historic Natural Fire Regime' layer" (Schmidt and others 2002). This data layer was completed "using expert knowledge to assign fire regimes to General Land Cover Classes" and was refined by integrating "expert knowledge, remote sensing, and biophysical data to map fire regimes" (Schmidt and others 2002). "Expert knowledge" while certainly useful for many things, is difficult to quantify or verify in this context.

Their methodology was described as "similar to that used by Brown and others (1994), who integrated site characteristics, habitat types, topographic attributes, and vegetation to map fire regimes" (Schmidt and others 2002). In spite of being perhaps difficult to replicate, this methodology and the use of unspecified "expert knowledge" was perfectly valid for the stated goal of providing generalized national-scale data. It is only when this model is applied at the local project level, against the specific advice of the model's authors, that problems can arise. To compensate for this, "the Forest Service and the Department of the Interior are developing a project-level analysis tool [that] requires the field office staff to conduct a field visit to examine vegetation conditions, to consider them in context of past and current fire regimes, and to estimate the alteration of fire regimes and fire intensity if a fire were to burn in the current conditions" (GAO 2004a).

In to understand the ecological effects of modern wildfire, prescribed fires or mechanical treatment of fuels, an understanding of the historic fire regime is necessary (Everett and others 1999, Graham and others 2004, Romme and others 2003). Fire ecologists have developed a number of ways to estimate historic fire regimes for specific stands. The most accurate of these involve compiling fire histories from fire scarred trees and stumps or using data on stand age classes in situations (Everett and others 1999). Although accurate, these processes can be time consuming and relatively expensive. Since fire scars are a finite resource that is reduced as trees and stumps containing scars deteriorate from rot and fire, this expense may be worthwhile. Historic fire regimes for specific stands are often estimated from stands with known fire histories that appear similar in type and topographic setting. This often becomes a matter of applying "expert knowledge" in ways that are often inexact and difficult to explain. Estimates of FRCC, whether identified from course-scale models or extrapolation from similar stands, can often be checked against existing historical, archaeological and paleo-ecological data.

A wide range of historical, archaeological and paleoecological data can be used to provide important clues as to the veracity of estimated FRCC (Sullivan and others 1999). As with any data, it must be used critically and with an awareness of limitations in accuracy, completeness, and scale. It is important to bear in mind that ecosystems are in constant flux and most historical data provides only a brief snapshot of the ecological conditions at a given point in time. Understanding the source of the information can be useful in identifying potential reporter or transcriber errors. Some historic and archaeological data is specific to a given stand, but more frequently it is based on sources within the same or neighboring watersheds. When working with information that originated from stands other than those being analyzed it is necessary to consider the similarity in the environmental setting between the stands. Modern stand composition, aspect, elevation, soils type, and related environmental attributes can be used to determine how relevant the data is to the stand being studied. The greater the distance and the greater the variation in environmental settings between the data source and the study stand, the less confidence can be placed in the data.

Historical data can be found in a wide variety of forms (table 1). Journals, letters, and diaries of explorers and

Table 1. Sources of historical and archaeological data from the Malheur National Forest.

Type	Examples	Dates
Historic photo	long term family collections	1860’s-present
Historic photo	FS silvic	1908-present
Historic photo	FS admin, misc	1908-present
Historic photo	Osborn lookout panoramic	1935-1940
Historic photo	range photo plots	1938-present
Historic photo	aerial photos	1939-present
Historic documents	Hudson’s bay journal	1825-1831
Historic documents	army letters and journals	1865-1880
Historic documents	settler’s letters, diaries, histories	1862-1940
Historic documents	general land office survey notes and maps	1870’s-1960’s
Historic documents	FS silvic reports and maps	1906-present
Historic documents	FS fire reports and maps	1909-present
Historic documents	FS range reports and maps	1915-present
Historic documents	FS misc admin reports and maps	1905-present
Historic documents	Indian agency records and maps	1868-1880
Historic documents	American Indian ethnographic records and histories	1860-present
Historic documents	newspaper articles	1870’s-present
Archaeological	carbon 14 dating	7,000-200BP
Archaeological	botanical remains from excavation	7,000-100BP
Archaeological	faunal remains from excavation	3,000-100BP
Archaeological	land use inferred from site type	7,000-100BP
Paleoecological	pollen and plant macrofossils from sediment cores	7,000-100BP
Paleoecological	packrat midden analysis	3,000BP-present
Paleoecological	fire histories from scarred trees	1600-present
Paleoecological	fire histories from sediment charcoal	10,000BP-present
Paleoecological	geomorphological analysis	10,000BP-present
Paleoecological	relic plant communities	1900-present

early settlers can contain descriptions of general, and occasionally quite specific, environmental settings. The earliest sources of historical information for the Malheur National Forest in eastern Oregon are daily journals kept by the Hudson’s Bay Company fur trappers in the 1820s and 1830s (Davies 1961). Although specific locations can be difficult to identify, there are descriptions of forest type and condition in the journals. Several locations entries record forest stands thick with downed timber. For example on October 9th 1826 Ogden reported that “all along our road this day we came over a woody country, Norway pines, and from the number of fallen trees, our progress was very slow, course east, distance nine miles” (Davies 1961). Clearly this was not an “open park-like stand” like those often generalized as occurring through eastern Oregon before the advent of active fire suppression (Campbell and others 2003).

Early newspaper accounts and later published interviews with longtime residents likewise contain a variety of information about forest conditions and cultural practices that affected them. For instance in the late 1800s there were several accounts of Indian hunting parties setting extensive fires as they left the mountains in the Fall. A variety of government records contain a wide range of environmental data. General Land Office survey notes and maps often provide the earliest landscape scale environmental descriptions in the western United States (fig. 1). In the Blue Mountains the earliest of the surveys took place in the 1860s. The surveyors mapped out the landscape in a one mile wide grid pattern. Physical markers were left every ¼ mile and brief descriptions of the terrain and vegetation were recorded. The quality of the descriptions varied considerably with the interests and skills of the individual surveyors but at a minimum the extent and general types of vegetation were recorded and mapped. Internal Forest Service records dating back to 1905 can provide much information. These can be found in local or regional offices although many of the earliest records have been discarded over the years. Many of these records can be found in the United States National Archives. Some real gems are hidden in the archives but searching for records from this source can be time consuming. On the Malheur we have located early silvicultural survey reports, maps of forest stand types, early wildfire records, and grazing records.

Historic photographs can provide some of the cleanest data since they do not rely on the judgment of recorders of indeterminate ability. Any photograph with visible vegetation can be used as long as the approximate photo point and date can be determined. Re-photographic surveys, where modern photos are taken from the same location as historic photos, are effective records of ecosystem change (Gruell 2001). Many early agency photographs include information on location, date, time, and weather.

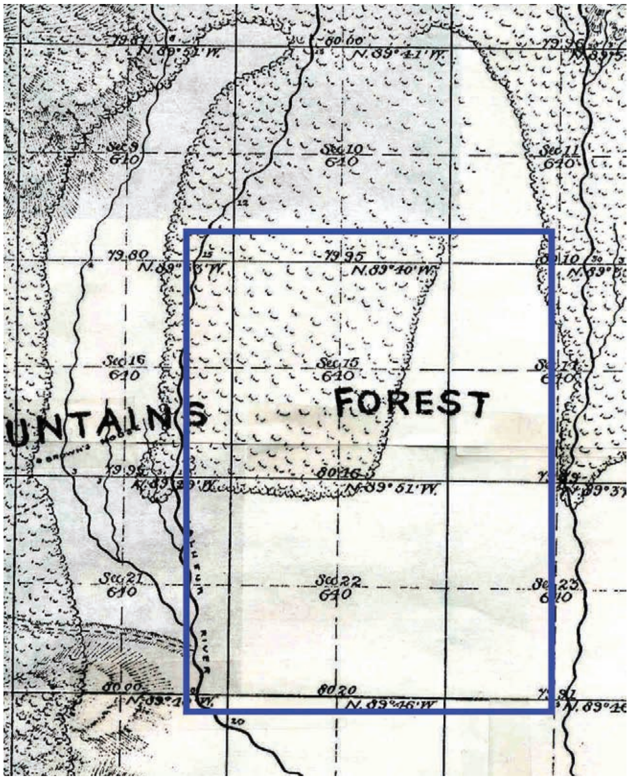

Figure 1. 1884 General Land Office map of Logan Valley. Box shows area of photo in figure 2.

Figure 2. Comparison photos from Antelope Lookout. Bottom photo 1935, top photo 1996. Note significant increase in tree density and loss of meadow.

Some of these are located in local and regional files but copies of many are also located in the National Archives. Range evaluation plot and silvicultural report photographs are extremely useful but relatively uncommon. The backgrounds from photographs depicting general project work, recreation, or buildings can also show significant landscape and vegetation information and are more common. Aerial photographs from the Malheur date back to the 1930s and provide detailed information on stand composition and density. In the Pacific Northwest a series of panoramic photos were taken from fire lookouts between 1929 and 1942. These Osborne photographs were completed at 999 locations in the region including 41 on the Malheur. They provide excellent overviews of several watersheds from each location. The photo points are easy to relocate and photograph in order to compare historic and current stand composition (fig. 2).

Archaeological and paleo-ecological data is more esoteric and frequently less readily available but it can be very useful in evaluating stand conditions over longer time periods. Wood charcoal recovered from archaeological sites and sediment cores can often be identified as to species and accurately dated (Sullivan and others 1999). In settings where an intact sediment core can be recovered a detailed fire history can often be constructed. Once wood has been converted to charcoal it preserves quite well and could be recovered from sediment in forest stands to develop site specific fires histories. Charcoal fragments as small as .3 grams can now be dated, but cost will likely limit this application since numerous samples would be needed.

A sediment core recovered from Lost Lake, just north of the Malheur National Forest, has produced a 7,600 year record of major wildfire events in a basin dominated by mixed conifer forest stands (Mehringer 1995). Sixteen charcoal lenses ranging from .2cm to 20cm thick were identified in the cores. Thickness of the charcoal lens is viewed as indicative of the size and intensity of the fire with the thicker layers of charcoal representing larger and/or more intense episodes. The largest fire by far took place immediately following the deposition of volcanic ash from the eruption of Mount Mazama at circa 7,600BP. The charcoal from this deposit is 20cm thick, compared with 3cm for the next thickest deposit and 1cm or less for the rest. It appears that the fine volcanic ash caused a major vegetation die-off that provided fuel for a truly catastrophic wildfire. Overall this core produced a record of amazing consistency of stand composition and long fire return intervals across seven millennia.

Other botanical remains recovered from archaeological sites on the Malheur National Forest include charred roots and seeds, phytolyths and pollens. Camas (*Camassia quamash*) bulbs recovered from steaming ovens dated to 600 years ago strongly suggest that the valley where they were recovered was wetter and supported more camas plants at that time than currently. Mortar bases recovered at sites dating to the last 1200 years contained significant amounts of pollen from Lomatium sp which were an import Indian root crop (Varney and others 2003). *Lomatium* sp. plants are still common on the dry ridges associated with these sites. This suggests a broadly similar ecological setting at this location over the last 1200 years. Pollen recovered from the soil adhering to the mortars, and analyzed as a control, indicate that the pine tree line has retreated upslope at one location. Pollen recovered from sediment cores, especially from springs, bogs or lakes, can be used to complete quite detailed local vegetation histories.

Additional archaeological and paleo-ecological data that can be useful for determining aspects of ecosystem history include faunal remains from archaeological sites, floral material from packrat nests, geomorphological analysis of sediments and landforms, and artifacts such as mortars and grinding slabs. The location of sites across the landscape can also provide general information about changes in the environment over time. For instance, the presence of sites in dense lodgepole or young ponderosa pine (*Pinus ponderosa*) thickets suggest that these locations were much more open when they were occupied. Similarly, subsurface testing at archaeological sites located in and adjacent to meadows often demonstrates that sites were restricted to margins or low ridges out of the lower parts of the meadows proper. This suggests that many of the dry upland meadows on the Malheur were much wetter historically.

None of the preceding examples of historical and archaeological data is sufficient to independently determine HRV for forest stands but they can provide an important piece of the puzzle when used in conjunction with other evidence. An example from a meadow "rehabilitation" project on the Malheur National Forest demonstrates how disparate historical and archaeological evidence can be used to verify, or in this case modify, the proposed model of HRV for this location. Logan Valley is a large upland meadow located at the headwaters of the Malheur River. It is a mix of dry, moist and wet meadows surrounded by pine dominated mixed conifer stands and bisected by several creeks with their associated riparian communities. The northern fringe of the meadow has fingers of mature ponderosa and lodgepole pine feathering into

Figure 3. 2001 aerial photo of Logan Valley section from box in figure 1. Horizontal road at center line on map. Note difference in tree line and "new" riparian in center of photo created by ditch. White boxes indicate pollen collection sites.

the meadow with a dense growth of young lodgepole pine occurring as a lower story within and between the mature stands. The young pine filling once open spaces between the mature stands fits the generally held model of aggressive meadow encroachment by lodgepole as a result of wildfire exclusion. For several years the Forest has conducted thinning and burning projects to remove the pine to improve sandpiper nesting habitat.

This was a perfectly logical, if primarily intuitive, model of the HRV for Logan Valley based on "expert knowledge." Figure 2 illustrates similar meadow encroachment at another location south of Logan Valley which provides tentative support for this model. However, while doing historical background research for an unrelated project, employees with the Heritage program came across some site specific data that seemed to contradict the pine encroachment model. Figure 1 illustrates the 1884 General Land Office survey map for the area where the pine eradication projects were taking place. Figure 3 is a 2001 aerial photograph of the same location. A comparison of the map and photograph show that the pine "encroachment" north of the road in the

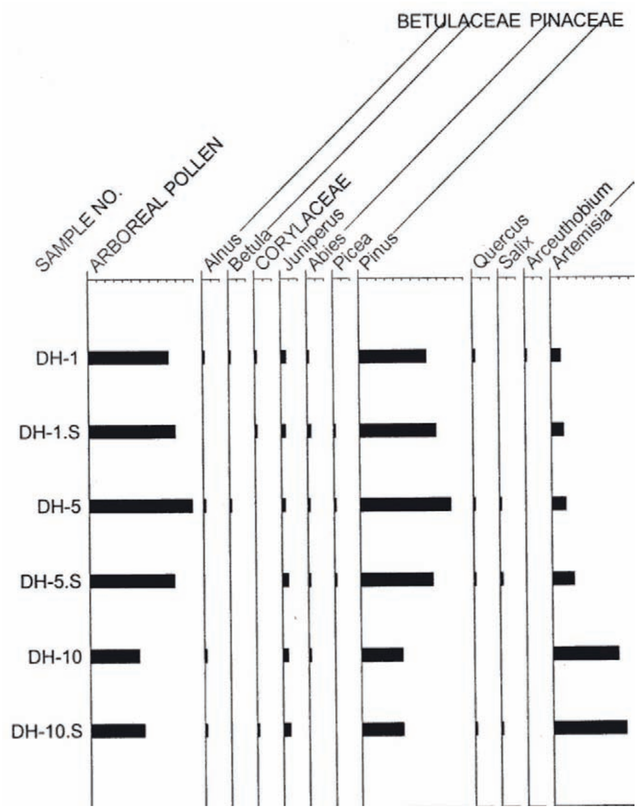

Figure 4. Chart showing pollen from three mortars and associated soil. Difference between pine (*Pinus*) and sagebrush (*Artemisia*) indicate DH-1 and DH-5 historically pine forest while DH-10 historically open sagebrush meadow. (Varney and others 2003).

center of the 2001 photo, is within the tree line as it is drawn on the 1884 map. This is compelling but it is possible that the tree line in the map either was in error or shows an anomalous expansion into the meadow.

During archaeological survey conducted during this same time three hopper mortar bases were collected sent to a lab for pollen analysis (Varney and others 2003). The artifacts were collected from three locations separated by one half mile (fig. 3, white boxes labeled dh1, dh5 and dh10). The chart in figure 4 shows that the ratio of pine (*Pinus*) pollen to sagebrush (*artemisia*) pollen from each of the mortars provides evidence that the 1884 tree line is accurate. The northern sample (dh1), which was recovered at the edge of the modern tree line, produced much more pine pollen than it did sagebrush. The middle sample (dh5), which was within the 1884 tree line but is now in open grass/sagebrush, had virtually the identical pine to sagebrush pattern. The southern most sample (dh10), well south of both the modern and 1884 tree line, produced almost twice as much sagebrush pollen as it did pine pollen.

The historic and archaeological evidence from Logan Valley does suggest that the pine "encroaching" into the meadow may be part of a natural process moving the valley closer to its HRV than it is at present. By applying the principles of adaptive management we can respond to this new information and alter our stand treatment as appropriate (Bass and others 2001). It is important to recognize that the new evidence has not "proven" that the original model of pine encroachment was wrong. It simply suggests that a different model better explains the existing data. New data could be found, or an alternative explanation of the existing data could be developed, that might convince us that pine is indeed encroaching. This is not meant to suggest that we should simply give up and either do no management at all or do anything we want since it won't matter anyway. The important lesson is that we should approach ecosystem management with an open mind and a reasonable dose of humility. Ecosystems are extraordinarily complex and we need to learn as we go.

The history of Federal land management contains notable cases where land managers, with the best of intensions, and using the best available science, made large-scale changes to western forests that we now regret (Langston 1995). One example is the heavy buildup of fuels in dry pine forests, much of which is the direct effect of decades of very successful fire suppression efforts (Graham and others 2004). There was an active scientific debate in the first part of the 20th Century as to whether total fire suppression or "light burning" was the proper way to treat pine stands. In one of several similar publications Snow and Kotok argued persuasively that repeated light burning killed most trees and rendered sites unproductive for decades (1924). The photographs of dense young pine that they used to illustrate "the return of the forest- when fire is kept out" are the same types of photos used today to illustrate dangerous fuel buildup. Cronon eloquently summed up the challenge (1995). "Even well intentioned management can have disastrous consequences if it is predicated on the wrong assumptions, and yet testing those assumptions is always much harder than people realize. To do so we must realize that ecosystems are profoundly historical, meaning that they exist in time and are the products as much of there own past as of the timelessly abstract process we think we see going on in them." Hopefully we can remain open, humble and adaptive as we search for the proper ways to implement the Healthy Forest Initiative and the Healthy Forests Restoration Act.

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Industrial Archaeology, Landscapes, and Historical Knowledge of Sustainability

Donald L. Hardesty, University of Nevada, Reno

Introduction

The emergence of industrial life support systems in the last three centuries dramatically changed human-environmental relationships. Industrial landscapes are repositories of historical knowledge about this ecological revolution. The key components of industrial landscapes include landforms (for example, waste rock dumps from mines), industrial buildings and structures, vegetation and other biotic patterns, spatial organization such as settlement patterns, transportation networks such as railroads and canals, and small-scale components such as fences and mining claim markers. Industrial archaeology records the landscapes of "industrial islands" that cover geographical areas ranging from small local places to large regions or beyond. The geographical boundaries and organizational structures of these industrial landscapes vary in time. Historical events and processes that affect human-environmental relationships operate on multiple time and space scales. Such landscapes reflect the sensitivity of geographical places as a habitat for human occupation. Managing industrial landscapes, therefore, is an important pathway to preserving knowledge about the history of human-environmental relationships in the modern world.

Mining Landscapes and Changing Environmental Relations

Consider, for example, mining landscapes as repositories of historical knowledge about the impact of industrial life support systems upon human-environmental relationships. Mining landscapes often can be conceptualized as the physical expression of cumulative networks or mosaics of microenvironments that reflect changing human-environmental relationships. The Cortez mining district of central Nevada illustrates the evolution of a distinctive landscape in this way (Hardesty 1988, 2001, Sullivan and others 1999). Several historical phases of landscape transformation can be identified. In the first phase, miners created the first microenvironments after the discovery of silver in the Cortez Mountains in 1863. They included (1) the Garrison Mine in what was called the Nevada Giant Ledge; (2) a Washoe Process pan amalgamation mill, later converted to a Reese River Process mill, in nearby Mill Canyon; (3) pinyon-juniper woodlands on the western slopes of Mount Tenabo used to fuel the mill; and (4) Pleistocene Lake Gilbert in neighboring Grass Valley used to supply the salt needed for the milling technology. The Phase 1 network of human-environmental relationships came to an end when the mill closed in 1869.

The second historical phase of the Cortez mining landscape began in 1886 with the establishment of a new network of microenvironments. Simeon Wenban, one of the original Cortez prospectors, developed a new mine at the mouth of Arctic Canyon and constructed a new mill nearby that used what was then state-of-the-art Russell leaching technology. Lime used in the new milling process led to the creation of a new limestone microenvironment nearby with an outcrop that could be quarried and processed into lime with kilns. The demand for wood as fuel at the new mill led to renewed harvesting of the pinyon-juniper woodlands. The Phase 2 network of microenvironments came to an end when Wenban's mill closed in 1892.

In 1908, the third historical phase of the Cortez mining landscape began when a new mining company refitted Wenban's abandoned mill with cyanide leaching technology and began to reprocess old mill tailings. Imported petroleum fueled the renovated mill and replaced the local woodlands. During this phase, Cortez miners, mostly lessees, dramatically changed landform patterns until the mill burned in 1915.

The Consolidated Cortez Silver Mines Company built a new mill equipped with cyanide leaching equipment closer to the Arctic mine in 1923, at which time the Cortez landscape entered its fourth phase of historical development. Tailings from the mill eventually formed a large tailings flow down slope about one mile to the valley floor. The mill changed to oil flotation technology in 1928 but closed the following year with the beginning of the Depression.

Not until 1969 did the Cortez mining landscape enter its fifth phase of historical development with the establishment of a new milling facility and the beginning of several open pit operations in and around the Cortez district. Cortez miners constructed, among other things, new heap leach pads, waste rock dumps, water pumps, haul roads, a refinery, assay office, administrative offices, and a carbon-in-column milling facility. This phase of development is still continuing.

Historical Knowledge and Resource Management

Mining landscapes as a repository of information about the history of human-environmental relationships have many implications for the management of natural resources. Consider, for example, what historical knowledge the Cortez mining landscape provides about the impact of mining upon local pinyon-juniper woodlands. The greatly increased demand for wood as fuel during the mining district's second historical phase of development intensified clear-cutting and thinning of the woodlands. Archaeological and dendroecological studies of Cortez landscape elements such as cut stumps, mine supports, rail ties, stacked cordwood, charcoal pits, and cabin timbers yielded information that countered the common belief that this episode of deforestation permanently changed the woodlands in the district (Hattori and Thompsen 1987). The studies documented the continued survival of many trees from the most intense period of deforestation and provided information suggesting that the woodland reestablished itself after 1897, when new fuels and materials stopped local deforestation, and continued its growth, and possible expansion, to the present day.

In the same vein, a recent comparative study of the recovery of desert vegetation in two mining landscapes in Death Valley, California, provided historical knowledge about the sensitivity of plants to different soils and geological histories (Brown 2000). The discovery of base and precious metals in the valley in the first decade of the twentieth century brought about the emergence of several short-lived boomtowns that were abandoned within a few years. Recent studies of two of the town sites, Skidoo in the Panamint Range on the west side of the valley and Greenwater in the Black Mountains on the east side of the valley, show significant differences in the recovery of native desert vegetation. The desert vegetation at Skidoo is rapidly recovering after 70 years with a mix of short-lived colonizing plants such as cheesebrush and long-lived native plants like creosote. In contrast, plants have barely begun to recolonize the contemporaneous site of Greenwater. The different ages of the soils in the two places seem to be the principal reason for the differences in the rate of recovery of desert vegetation. Greenwater's soil is at least 100,000 years old, but Skidoo grew up on a debris flow with soil less than 4,000 years old. Plants recolonize young soils, which are much coarser and resilient, faster than old soils.

The Social and Cultural Construction of Mining Landscapes

The historical knowledge contained in mining landscapes also reflects the social and cultural construction of human-environmental interaction. Mining settlement patterns in 19th-century Nevada, for example, reflect Comstock-Era ideas about the formation of gold-bearing ore bodies (Tingley and others 2003). The Comstock model visualized gold and silver-bearing 'lodes' that occurred within 500 feet of the surface. Miners for several decades after the Comstock discovery following this idea in searching for ore bodies and established mining camps accordingly. They completely overlooked the gold-bearing weathered silica ledges that did not conform to this model. The 1902 discovery of gold in this geological formation at Goldfield, Nevada, dramatically changed ideas about and created a new geological model that patterned mining settlement patterns for several decades afterwards.

The cultural construction of mining landscapes involves interpreting landscape elements (for example, buildings and structures, landforms) as symbols that evoke images and memories of the past. Such culturally constructed historical knowledge affects human-environmental interaction. The ideology of geomancy or feng shui as a component of Chinese culture and ethnicity is a good example. Feng shui is "an esoteric set of theories and practices … used in China to probe the landscape and to discern from the irregularity and asymmetry of mountains and waters appropriate locations for human settlement" (Fan Wei 1992). Feng shui practices may be expressed in such landscape components as settlement patterns and include orienting buildings to face south, calm water in front, placement at the confluence of streams but not at branching streams, square dwellings and settlement layouts, and alignment of buildings on a north-south axis. Archaeological studies of Overseas Chinese buildings and structures often provide the only source of information about the practice of geomancy as an active agent in the formation of mining landscapes. Certainly the extent to which Chinese immigrants applied the principles of geomancy varied enormously and depended upon local conditions and expediency. Exclusionary laws and policies, for example, or economic determinants such as high land prices appear to have limited the practice of feng shui by Overseas Chinese in some localities but not in others (Greenwood 1993). Mining landscapes reflect these differences in the geographical arrangement and relationships of buildings and structures, clusters, and landforms.

The so-called "Myth of the West," however, is perhaps the most classic example of the relationship between mining landscapes and the cultural construction of historical knowledge in twentieth century America. Mostly a creation of popular culture, the myth transforms abandoned buildings, structures, landforms, and other elements of historical mining landscapes into symbols of an imagined past, a theater of the wild, complete with all the trappings of "the western frontier" - tough and untamed with streets walked by six-gun toting white males, heroically good and bad, and soiled doves with golden hearts (Hardesty and others 1994). The Myth of the West, incidentally, also includes the idea of an empty wilderness untouched by human hands before Euro-American settlement, an idea often reflected in environmental management philosophies and practices in the American West. The archaeological record and other sources of historical knowledge (for example, oral tradition), however, document a long history of human settlement before European colonization of the region with a wide variety of impacts upon the environment.

Images of the mythic West are often evoked by the so-called western "ghost towns." Typically the ruins or archaeological remains of abandoned mining towns, ghost towns are icons of the myth. The Bodie Mining District in the Sierra Nevada Mountains of California offers a classic example. After a significant but short-lived boom period in the late 1870s and early 1880s, the silver mining district rapidly declined but continued to be worked off and on until the end of the twentieth century. The town of Bodie emerged as a popular ghost town in the early twentieth century that attracted tourists in automobiles and greatly changed human-environmental interaction and the meaning of the landscape to many observers (Delsyer 1999, 2003). Ghost towns such as Bodie teach the myth to visitors, not only through intentional interpretative programs but also through efforts to preserve the towns for posterity. The ghost town is a cultural construction that mobilizes public support for preservation and creates an historic significance much greater than would be justified by a more critical evaluation of its historical context.

Conclusions

In conclusion, mining landscapes are "historical analogs" of human-environmental interaction taking place over time periods of months to centuries that have significant implications for environmental management. They provide models of environmental change in the modern world that fill in the time gap between short-term or contemporary observations and long-term paleoenvironmental data. The components of mining landscapes provide detailed information about the history of human-environmental interaction that is both complementary to and independent of other sources of historical knowledge such as documents and oral tradition. Archaeological and other historical studies of mining landscapes have the potential to record detailed environmental histories of biota such as woodlands, stream drainages, and other hydrologic systems, and toxic waste such as mercury. Finally, mining landscapes provide information about how social and cultural constructions affect the history of human-environmental interactions.

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Social Memory of Short-term and Long-term Variability in the Sahelian Climate

Roderick J. McIntosh, Professor of Anthropology, Rice University, Houston, TX

The 170,000 km^2 interior floodplain of the Middle Niger (Mali) is a tight mosaic of alluvial and desert microenvironments. The interannual to intermillennial climate change profiles of this fluvial anomaly thrust deep into the Sahel and southern Sahara are masterpieces of abrupt phase shifts and unpredictability. Response has been of two kinds. The Office du Niger was France's largest colonial-period development project—and a failure of massive proportions. An older tradition of Social Memory allowed for the integration of increasingly-specialized producers and artisans in a generalized economy. High ethnic and corporate diversity grew into one of the world's most original, purely indigenous urban civilizations.

It all went horribly wrong. And it had such vast potential for Colonial pride and for Metropolitan investment. At the southern fringe of the Sahara, in its colony of l'Afrique Occidentale Française (now the Republic of Mali), France undertook the most ambitious of the development schemes of all her colonies: the Office du Niger. Through massive technical investment and rational economic centralization, a long-dead palaeochannel of the Sahara was to flow once again. This was to be Africa's Green Revolution, three decades before the Asian miracle.

As planned initially in the 1920s, the dam and canal system would annually inundate some 1.9 million hectares. Irrigated cotton would be transported to Mediterranean markets along a railroad of 3,270 km across the world's largest desert. Imperial would forbid the drift of dunes across the tracks! And monocropped Asian paddy rice (*Oryza sativa*) would eliminate the "irrational" cultivation of the local floating rice, *Oryza glaberrima*, whose yearly yields ranged from 4,400 kg/ha to barely subsistence levels. By the early 1930s, the Colonial authorities began to relocate, by brutal military operations, a projected 3.5 million southern peasants to this wasteland—in the process, breaking up traditional land-use and land-tenure—and substituting coercive sharecropping.

And the results? This was just the first of West Africa's long, sad heritage of development debacles, particularly during the Sahel Drought. All such projects were predicated upon large acreage, monocropping, and capital-intensive earth-modification. Rather than 1.9 million ha put into irrigation, today there are fewer than 50,000 ha, or 2.6 percent of projections. Rather than 3.5 million laborers, today there are less than 37,000, or just 1 percent of projections. The railway was never even begun.

What went wrong? Any reasonably-observant student of historical human ecology might have predicted defeat for the Office du Niger at the hands of a deep-time, local Social Memory. Social Memory is the long-term communal understanding of landscape and biocultural dynamics that creates a filtered perception of environmental variability, which ensures the curated knowledge of pertinent experience, and its intergenerational transmission. Social Memory enables the community to designate those of its members who have authority to act in times of stress. And its principal manifestation amongst the peoples of the Middle Niger is Ecological Resistance.

Ecological Resistance, a concept from historical ecology, is based on the recognizing that rigid, hierarchical decision-making structures are not always best positioned to deal with situations of abrupt, unpredictable climate and environmental change. Heterarchies can show greater resilience, a greater capacity long-term to deal with the attendant economic and social stresses. Under these circumstances, societies may develop persistent mechanisms of resistance to centralizing or coercive tendencies, those leading to hierarchy.

Ecological Resistance is written in the fluid concepts of landscape and ethnicity shared by the mosaic of ethnic and occupation groups of the Middle Niger. Ecological Resistance is inscribed also in the very ancient practice of "niche specialization within a generalized regional economy" that the archaeologist can read in the local response to several dimensions of ecological and palaeoclimatic risk endemic to the Middle Niger. This is risk in a landscape with, nevertheless, vast potential, if managed and massaged with Social Memory's ecological subtlety.

This risk derives from a highly volatile climate—one with variability along several scalar dimensions and, hence, described as "quasi-chaotic" by frustrated development engineers. The Sahel is infamous for high interannual variability of precipitation in: (1) total rainfall; (2) onset of the rainy season; (3) rainfall for each particular month during the short monsoonal wet season, and (4) areal patchiness of the rains. Interannual variability characterizes the annual flood (1) height, (2) staying power before evacuation, (3) date of arrival from the highlands of southern West Africa, and (4) timing and nature of the seasonal migrations and spawns of its rich fish load. Even variable temperatures over this vast evaporation basin and the deflating northeast trade winds of the dry months conspire to frustrate the considerable predictive skills of the Middle Niger's specialized farmers, fisherfolk, and pastoralists.

The second dimension of variability is mode-shifts: impulsive changes of the central climate tendency, with a threshold beyond a previous normal range of variability to a new set of boundary conditions. In other words, "global" climatic trends may be initiated here by abrupt events and they may be accompanied by periods of high temporal instability. Mode shifts may be interdecadal or multi-decadal in scale—such as the Sahel Drought that began in 1968 and that continues today as a high oscillation episode. Or, modes may last centuries or even a few millennia, as documented in lake-levels.

Our last dimension of variability is the landscape itself. The Middle Niger is a tight mosaic of landforms and floodplain soils of descending bathimetric progression. But, because of the dramatic interannual variation in rains and flood, a Nono (ethnic group) plot of high-yield African rice one year, may the next be used by a separate ethnic group, the Bambara, to grow flood recession sorghum, and during a future year of minimal flood it might be visited only by Fulani herds of cattle and small livestock. That is, the high variability of altitude (bathymetry), inundation-potential, and soil morphology invite a highly fluid concept of landscape. A particular microenvironment might theoretically redirect its seductions among five or six subsistence specialists within a decade—with inevitable potential for conflict when ethnic perceptions collide.

With over a dozen subsistence-defined ethnic groups in the Middle Niger, some conflicts are inevitable. But why has the floodplain historically not been a morass of bloodshed and conquest? What is the Social Memory of landscape that positively encouraged ethnic differentiation, elaborate niche specialization, and a shared commitment to a regional economy of reciprocity? Not only are fisherfolk divided ethnically into hand-net, shallow swamp fishermen, or deep-channel collective-net fishermen, or into the hunters of aquatic fauna such as crocodile, hippos, and giant Nile perch; not only can the fisherfolk absolutely count on the labor of rice farming Nono, Marka, and Rimaibe during the season of fish migrations; but also, the critical rituals of appeasement of the water spirits that obligatorily begin the deep-swamp fishing calendar of the Bozo can only be initiated by their Nono farmer neighbors.

Over deep time, there has developed an ethos of Ecological Resistance to a monolithic perception of landscape. This deep-time ethos encourages both niche specialization and a highly contractual web of surplus and labor exchange obligations. If diversification (broadening the subsistence system) and exchange (playing off temporal variability against spatial variability) are classic tools of risk-buffering, the peoples of the Middle Niger have gone beyond mere buffering to create a massive web of mutual aid obligations underlain by four the foundation stones of their Social Memory:

1. Critical Catalyst: The subsistence calendar of group "X" can only be activated by the scheduled ritual intervention of group "Y." To try to short-circuit this tradition simply invites disaster.
2. Bonds of Fictive Kinship: Legends of common origin and rules of obligatory common labor (including an elaborate web of joking relations).

   The template for these myths is an account, most likely fictive, of the sequential colonization of the floodplain, in which ethnic groups contracted with a hierarchy of occult guardians of prominent topographic features.
3. Undischargable Debt: Lore of extraordinary sacrifice by one group for another, under conditions of ecological stress, wrapping everyone in a fabric of expectations for future behavior.
4. Equation of Ecological Resilience with Resistance to any form of Centralization or Authority Monopoly: Locally, it is not considered to be at all remarkable that the 1,500 year archaeological record of urbanism, to date, shows no evidence of state formation, political or social hierarchy, or elites of any stripe.

What is impossible, of course, is to know how deep in time run any of these specific rules of ethnic accommodation. However, there is good proxy evidence that highly elaborated corporate identity and niche specialization are ancient institutions. We turn first to the best understood region of the Middle Niger, the vicinity of modern Jenne and its ancestral community, Jenne-jeno, where excavation and survey has gone on for some twenty years. Jenne-jeno is a six-meter high tell covering 33 ha, with evidence throughout a continuous sequence lasting from c. 300 B.C. to A.D. 1400. The Jenne-jeno sequence is a record of ever increasing numbers of specialists.

But more interesting is what we can say about the scores of satellite tells clustered near Jenne-jeno. Within a four-kilometer radius of Jenne, there are 69 such satellites, most if not all occupied simultaneously for up to a millennium. A complete surface recording of all 69 sites and preliminary excavations at 10 demonstrate some degree of corporate exclusivity at different mounds and of specialization in subsistence and craft activities.

Beginning some 2,000 years ago, we have an emerging urbanism based upon clustering—that is, a segmented community of specialists who voluntarily come together to take advantage of the services of others and of a larger market for their products, but who maintain physical separation in order to reinforce their separate identities. Clustering—physical separation with proximity—facilitated the reciprocal relations with other specialists that bind together the Middle Niger ethic mosaic to this day.

So, clustering appears to have been a stable solution to the complementary ecological problems of the Middle Niger–specifically, a rich environment, but one highly variable in its rain and flood regimes. Elsewhere, environmental unpredictability disperses people, but here, many specialized artisan and subsistence producers link into a generalized economy. Clustering does not substitute, however, for other "extensive" strategies: (1) sowing more land (and more heterogeneous plots) than the farmer has labor to harvest (2.5 ha/person at 400 mm., compared to 1 ha/person at 1,000 mm.) in order to anticipate spatial variations in rainfall or flood; and (2) mixing a variety of crops and grain varieties (42 of *Oryza glaberrima*) over a variety of micro-environments and along the bathymetric progression.

Settlement clustering is widespread over the 55,000 km^2 Middle Niger River Valley. Just how old are niche specialization and the values of horizontal complexity associated with it? Here we return to the senescent basin of the Office du Niger. Along the dry channels and distributaries of this "dead delta" are clustered early iron age communities of the mid-first millennium B.C. These are proto-towns of up to 33 components built atop Late Stone Age, clustered settlements going back into the second millennium B.C. Excavation at these sites is in its infancy. Yet, at Late Stone Age sites throughout the Middle Niger for which we can make an argument for contemporaneity, evidence suggests that specialist fisherfolk, pastoralists, and perhaps grain gatherers/early horticulturalists were purposefully living in separate hamlets, next to one another, at least seasonally. Pastoralists exchanged surplus meat for fish, and certain ritual items also passed hands.

Whatever the ultimate age of clustering and specialization in the Middle Niger, the values of Social Memory (especially Ecological Resistance) are arguably of considerable antiquity. An extremely fluid concept of landscape helped to turn endemic climatic stress into a culture of ethnic accommodation. These values were directly opposed to the Office du Niger bureaucratic belief in massive capital injection, monocropping of exotic crops, and homogenization of the landscape and the peasantry. The Office du Niger had no option but to fail. And in its place, the traditional Middle Niger remains, even thirty years into the Sahel Drought, the granary of West Africa.

Resource-Balance Design and Monitoring: Assessing Sustainability of FSEEC-LandLab as BSU's First Sustainable Built-site

J. L. Motloch, Professor of Landscape Architecture and Director of the Land Design Institute, Ball State University, Muncie, IN

Abstract—*This paper addresses the change from earth as self-managing ecosystem operating within local limits and natural laws, to a human-dominated ecosystem where people falsely believe they live outside natural limits and laws. It reviews the shift from low-technology and regional-economics to advanced technologies and globalization whose impacts exceed nature's ability to regenerate and that render the earth incapable of self-management. It calls for a shift from the present source-to-waste paradigm to one that promotes system regeneration; and for environmental management essential to a sustainable future.*

The paper reviews major built-environment impacts; and the absence in the planning and design professions of defensible processes that interconnect decisions to the health and sustainability of local and contextual ecosystems. It also addresses the lack of recognized methodologies to assess whether "sustainable" planning and design decisions facilitate ecosystem regeneration or, conversely, degrade contextual ecosystems.

This paper presents a model for designing built-sites that seek to sustain ecobalance; and for monitoring ecosystem indicators to assess whether decisions achieve this goal. It reviews application of this model to the site of Ball State University's proposed environmental education building and landlab green technology demonstration site (FSEEC-LandLab) as the university's first proposed green built-site. This application includes: 1) resource-balance as an initial site decision management tool, 2) GIS database development to facilitate design that sustains resource-balance, 3) proposed management systems for the overall site and its built-zone, 4) a decision framework of built-site goals, objectives, and guidelines, 5) a proposed feedback system of ecological indicators, baselines, benchmarks, and monitoring to determine the degree to which site-based management, planning, and design sustain resource-balance, 6) initial indicators, monitoring hierarchy, and monitoring station locations, and 7) proposed initial resource-balancing projects to build and monitor.

Systemic Shifts

Diverse global systems are degrading. Capra (1981) suggests that parallel degradation in diverse systems is symptomatic of a metacrisis; and that this degradation indicates the Earth is at a turning point that will profoundly affect human survival. Managing Human Dominated Ecosystems (Hollowell 2001) explored the recent shift of Earth from a self-managing ecosystem to a human-dominated one, where humankind decides whether the Earth is managed in sustainable ways.

Humankind arrived at this turning point due to social, economic and technological shifts from people living largely within local economies and using relatively low-impact technologies to a global economy and high-impact technologies. Unfortunately, these shifts were accompanied by a paradigm shift to a false belief that humankind operates outside local limits and natural laws (Quinn 1995). These shifts replaced production and infrastructural systems that were, in many cases, interconnected with local and regional systems; with disconnected production and infrastructural systems that overpowered the regenerative capacity of natural systems. They degraded resources (air, land, water), reduced local and global capacity to sustain life and build natural capital, triggered decline in every living system on Earth (Brown 2003), and turned Earth from a self-managing global ecosystem to one that can no longer self-manage.

Needed Shifts

There is a profound need to co-manage natural and human systems for sustainable health and production, and for human survival. This includes a need to shift technology, production, and infrastructure from systems that consume and degrade resources to ones that sustain and help regenerate resources. There is a need to manage human impacts within the limits of natural system regeneration, and co-manage natural and human systems to produce a just world that enhances living standards for all. Global societies need to shift from economic systems that mine and consume resources to ones that harvest and sustain resources (Quinn 1995); and from economies that degrade to those that facilitate regeneration. Global societies need to embrace an eco-economy that uses principles of ecology to integrate decisions with resource life-cycle flows and sustains ecobalance so that environmental potential after intervention is at least as great as potential prior to intervention. Survival requires that we sustain environmental resources and the ability of living systems to regenerate the natural capital (Hawken and others 1999) upon which we ultimately rely.

Needed Built-Environment Shifts

Natural systems sustain themselves through regeneration and cyclical life-cycle resource flows. Elements partner to regenerate system health and capacity. Outputs from one process are inputs to another, and the system regenerates its capacity and self-manages its health and productivity. People intervene in these systems to use natural capital to address human needs, often through manufacturing and the provision of infrastructure, buildings, and cities. The way human and natural systems interconnect profoundly affects natural system capacity to address human needs and sustain the natural capital upon which people depend. In a sustainable world, human systems augment natural system regeneration, health and sustained productivity. In our present unsustainable world, human systems fail to support regeneration and excessively convert resources to waste.

Like other professions, physical planners and designers urgently need to shift from waste-producing paradigms to regenerative ones. They need to implement processes and integrate decisions to produce sustainable local and contextual ecosystems; and to monitor whether planning and design facilitate regeneration or, conversely, degrade ecosystems. They need to embrace regenerative design (Lyle 1994) so that products, infrastructure, buildings, and cities function as appreciative systems (Jantsch 1975) that help regenerate natural system health and productivity. Planners and designers need to pursue a positive ecobalance between pre- and post-intervention system health and productivity. They need to replace decisions that mine resources in consumptive, waste-producing, chemically dependent ways; with decisions that promote sustainable harvesting, integration with resource life-cycle flows and regenerative dynamics, and impact mitigation.

Resource-Balancing Design for the FSEEC-LandLab

Methods, tools and datasets have been developed to integrate design decisions with resource flows (Odum, H. T. 1994; Peterson 1972; Fisk 1989) and to pursue ecobalance (Fisk 1997). Motloch reviewed some of these, the lack of integration of these tools into mainstream planning and design processes, and the need to implement design for regeneration and ecobalance (2001). Based on Fisk's work, he proposed the Eco-balancing Design Model to integrate ecobalancing methods into physical planning and design (fig. 1). This model sought to extend conventional GIS databases and data analysis to inform land management, use, and planning decisions based on the ecobalance implications of decisions. The model includes GIS life-cycle data-maps and productivity maps, and eco-balancing processes (balancing upstream and downstream productive potential). It includes a feedback system of ecological baselines (existing conditions or performance levels), benchmarks (targeted conditions or performance levels), and monitoring of sustainability indicators to assess the degree to which interventions promote change toward benchmarks. This model was proposed as an information-flow system for confirming and evolving the degree to which planning and design decisions promote sustainability.

As a step toward campus design for ecobalance, Motloch (2002) conducted a Ball State University (BSU) CERES Fellowship to: 1) develop an integrated environmental management system for the University's field sites, 2) generate a resource-balancing model adaptable to each site, 3) recommend a field site for the FSEEC-LandLab environmental education building and green technology demonstration lab, 4) adapt the resource-balancing model into a decision management tool for the site, 5) develop a GIS database to facilitate analysis and decision-making, 6) recommend locations for the education building and green technology demonstrations, 7) propose a conceptual management system for the overall site and developed management system for its FSEEC-LandLab zone, 8) generate a decision framework

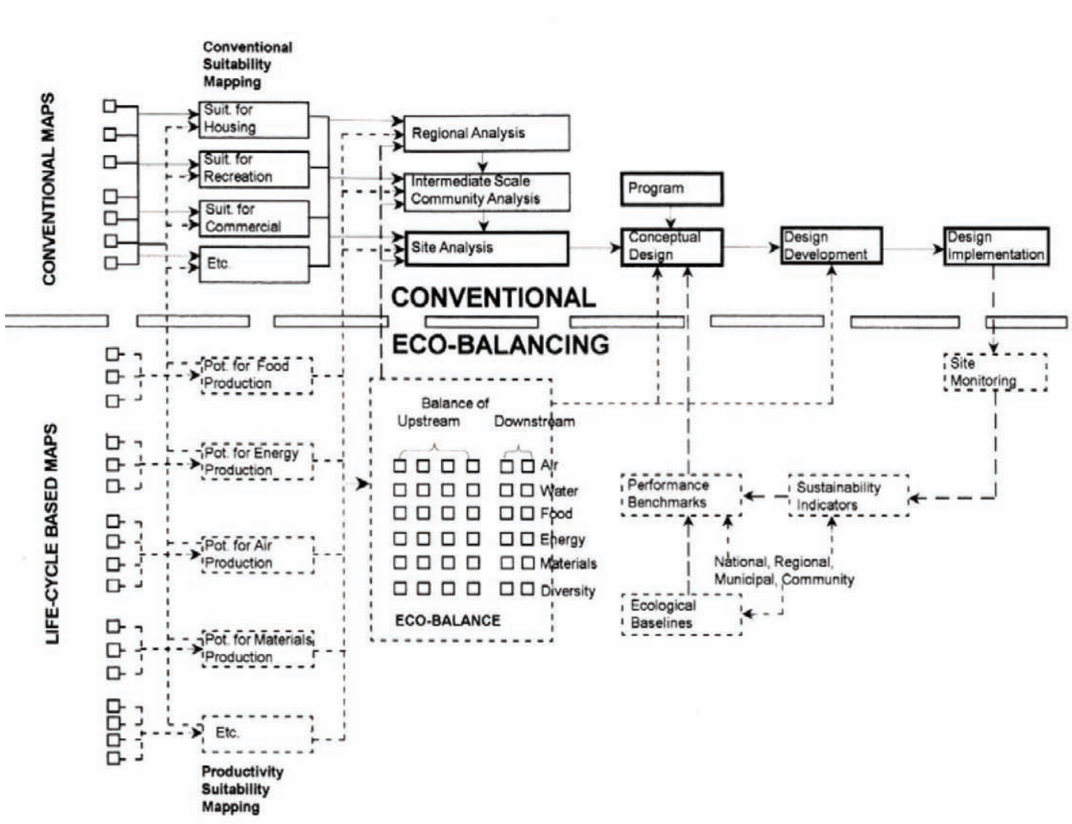

Figure 1. Eco-balancing Design Model (Introduction to Landscape Design, ed 2, J. Motloch, 2001, based on the Eco-balance GameTM and work of the Center for Maximum Potential Building Systems).

of planning and design goals, objectives, and guidelines for the FSEEC-LandLab and its environmental education building and site technology demonstration components, 9) propose a network of environmental Indicators and stations to baseline, benchmark, and monitor to determine how site management, planning, and design move Indicators in relation to benchmarks, 10) propose an initial program of site-based demonstration and resource-balancing projects to build and monitor, and 11) develop proposals for initial projects including designing, building, and monitoring the effects of interventions on site environmental health and productivity.

Integrated Property Management System

The study explored the BSU Field Station and its field sites as a single integrated education, research, demonstration, and outreach resource. It saw each site as an integral Field Station component as well as an individual resource. It sought to help the university manage each site for its value as an individual resource, contribution to the field station, and potential to enhance understanding of natural and human-dominated ecosystem regeneration and management. The Integrated Environmental Management System (IEMS) was proposed in this study to promote understanding of the potentials and management needs of each site based on its contextual relationships (urban to rural), site characteristics, land use needs, and allowable uses based on legal or other restrictions (fig. 2). The study also recommended baselining, benchmarking and monitoring environmental indicators based on site context, internal relationships, desired integration, and intended contribution to the University's

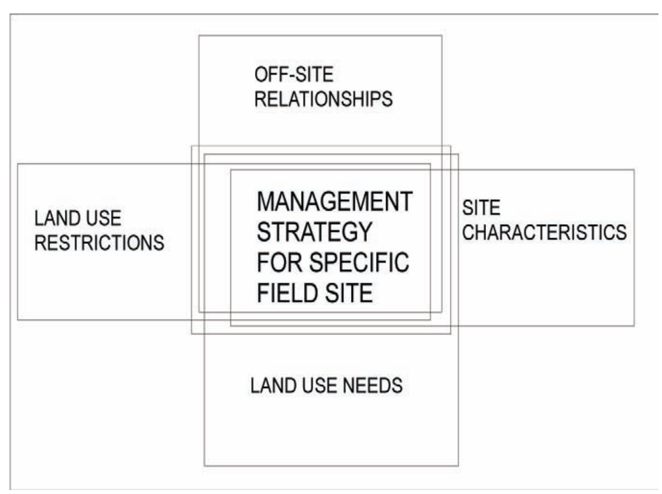

Figure 2. Integrated Environmental Management System (IEMS).

educational, research, demonstration, and outreach missions. It sought to facilitate monitoring to inform the University whether decisions sustain resource-balance. As better data and analysis techniques are developed, it will facilitate a shift from resource-balancing to eco-balancing decisions.

Resource-balancing Model as Site Decision Management Tool

The Resource-Balancing Model for BSU field sites (fig. 3) was evolved from the Ecobalancing Design Model (Motloch 2001, based on the Eco-balance GameTM and work of the Center for Maximum Potential Building Systems). The model integrates physical maps, productivity maps, and resource-balancing methods to facilitate sustainable decisions. It includes a feedback system of ecological baselines, performance benchmarks, and monitoring of environmental indicators to assess changes in Indicator performance in relation to benchmarks. This model is adaptable for each field site, in response to location, surrounding land uses, land use constraints, desired use, and site role in the IEMS. The Resource-balancing Model was recommended to predict outcomes of different alternatives, help the University make decisions and manage its field sites, and evolve future field site decisions based on Indicator feedback.

Planned Environmental Monitoring

The site recommended in the study for locating the FSEEC-LandLab includes diverse zones appropriate for its proposed environmental education building and green technology demonstrations. The site also offers opportunities for hands-on environmental education, research, demonstration, and outreach; and for integrated monitoring and management.

Previously planned monitoring

The site was selected, in part, to facilitate monitoring of environmental effects of several activities previously planned for the site including drainage improvements, creation of a wetland meadow, revegetation projects, and enhancement of regional biodiversity as part of the Field Station's restoration and environmental education programs. The study sought to help the University achieve permanent monitoring stations for biotic and abiotic components of its field site ecosystems, for its monitoring education activities, and for environmental research (FSEEC 2002). It also addressed University plans for monitoring plots to facilitate study of successional changes within the site's forested areas, monitoring of prairie plots to facilitate learning and research of different treatments in prairie restoration (for example, controlled burns, herbicide applications, machine treatments), and other site monitoring.

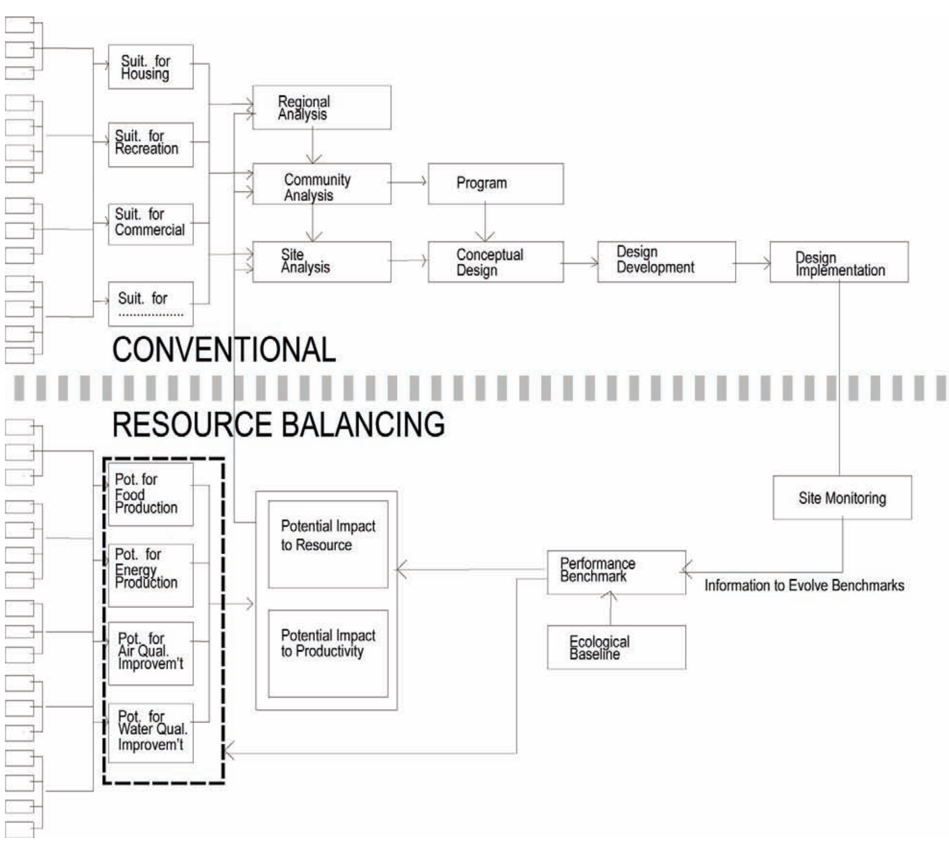

Figure 3. Resource-Balancing Model for BSU Field Sites (Evolved from Ecobalancing Design Model in Introduction to Landscape Design, ed2, J. Motloch, 2001, based on the Eco-balance GameTM and work of the Center for Maximum Potential Building Systems).

Proposed additional monitoring

The project recommended additional site improvements and associated resource-balance monitoring. This included changing site landform to isolate on- and off-site runoff; and monitoring site hydrology in relation to changes in landform, off-site land use (including change from rural to suburban), and off-site hydrology. In the area of the proposed environmental education building and green technology demonstrations, it included landform changes to redirect off-site water around watersheds proposed for monitoring site-generated impacts; and recommendations for designing the built-site as an intervention, monitoring, management, and educational resource. It suggested placing the proposed building and site developments within the watershed of a proposed lake for fisheries research; and monitoring the ability of the built-site to be designed, built, and operated so its runoff helps sustain the health and productivity of the pond ecosystem.

Resource-balance assessment

The project recommended monitoring of environmental indicator performance before and after site adaptations including building and green technology construction and operation. It recommended simultaneously monitoring of changes in site- and context-generated impacts, and comparing on- and off-site changes over time as feedback to the environmental management system. It included recommendations for monitoring building and technology demonstration effects on existing and proposed wetlands and ponds, and the ability of wetlands and ponds to balance building- and technology-induced impacts.

GIS Database Development

Development of the site's resource-balancing database began by integrating existing GIS datasets into a single geo-referenced database. This database was then extended to include additional data-maps (for example, wind and solar energy) and productivity suitability maps (for example, suitability for biomass productivity). The study proposed later addition of ecobalancing suitability maps (for example, suitability for carbon-balance considering O2 production and CO2 sequestering) subject to future funding.

Site Management

The project recommended the site be managed at two levels: overall-site and built-site. For the overall-site, the study recommended monitoring and mitigating the impacts of near-site changes, including changes from rural to suburban land use; and comparison of the impacts of on-site and off-site changes as the site undergoes sustainable development and near-site areas undergo conventional suburban development. It recommended integrated monitoring of Environmental Indicators before and after building and site interventions, to measure the effectiveness of the resource-balancing management system.

The study recommended that the area proposed to include the environmental education building, associated site development, and integrated building-site sustainable technologies be managed as a built-site. It recommended this built-site be managed for integrated research, education, and demonstration. It conceptualized an integrated built-site water-wastewater-energy-landscape system that would facilitate integrated management of resource harvesting, processing, use, reuse, regeneration and balancing.

Management Zones

Based upon contextual-landform and site-landform, and relative ability to isolate site areas from off-site water-borne pollution, the study structured the overall-site into seven management zones (fig. 4). It identified the ability of each zone to be isolated, managed, and monitored independently from off-site runoff for controlled research, education, and demonstration. Within each zone it identified drainage units and their opportunities for isolation from other drainage units for management and controlled monitoring purposes.

Overall site management and monitoring system

The study proposed environmental indicators within these management units. It proposed the Modified Resource-Balancing Model (fig. 5) as a conceptual management system for the overall site, with monitoring of general and habitat-specific indicators within each zone to assess the impact of decisions on resource-balance.

Resource-Balancing Management System for FSEEC-Lanllab Built-Site

The study recommended that the environmental education building be built within the drainage unit of the existing pond used by the University's fisheries group (fig. 6). It recommended that off-site runoff be redirected around this unit. It recommended that the area below the existing pond be managed as a second drainage unit for integrated built-site water-wastewater-energy-landscape research, education, and demonstration. These decisions sought to optimize opportunities for integrated knowledge-based management informed by monitoring the changes induced by prior interventions.

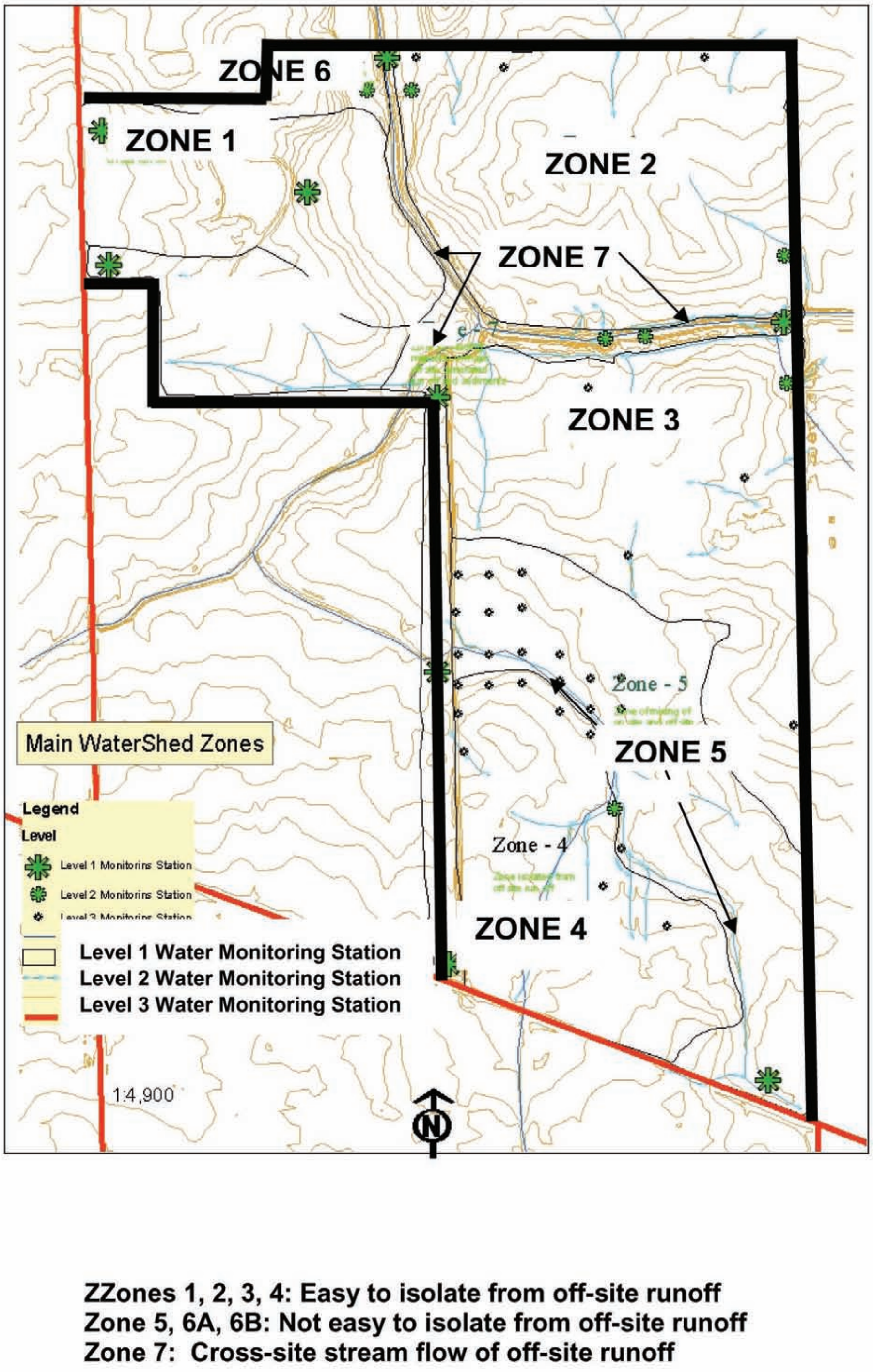

Figure 4. Site Management Zones and Hierarchical Water Monitoring Stations.

The Resource-Balancing Management System for the FSEEC-LandLab Built-Site Zone (fig. 7) recommended that Stella system dynamic modeling software (ISEE SystemsTM 2004) be used to predict Incubator performance. It recommended that once the University decides what areas, Indicators, and stations to monitor, that Stella be used to model anticipated Indicator performance under alternative management scenarios. It recommended monitoring of Indicators and comparison of monitored results to Stella-predicted performance to assess and evolve the design of the model and its dynamics (equations and performance curves), and to identify whether decisions to sustain resource-balance achieved this goal. It recommended fine-tuning the model and future management decisions based on monitored movement of environmental Indicators in relation to benchmarks, and based on insight provided by comparing monitored changes in Indicators to changes predicted by the model.

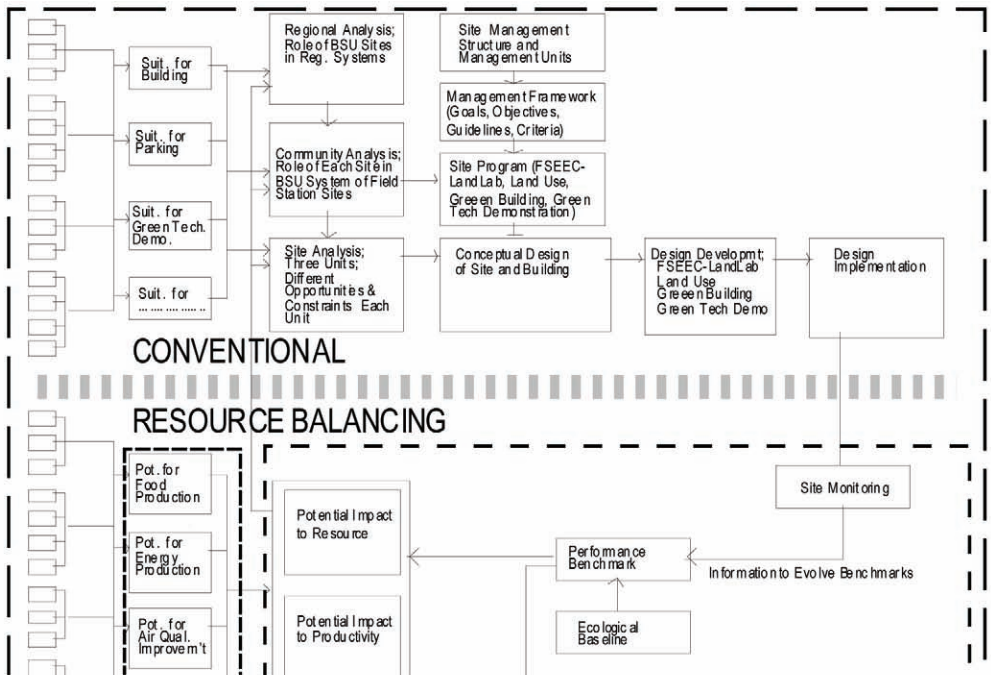

Figure 5. Modified Resource-Balancing Model for FSEEC-Landlab Site.

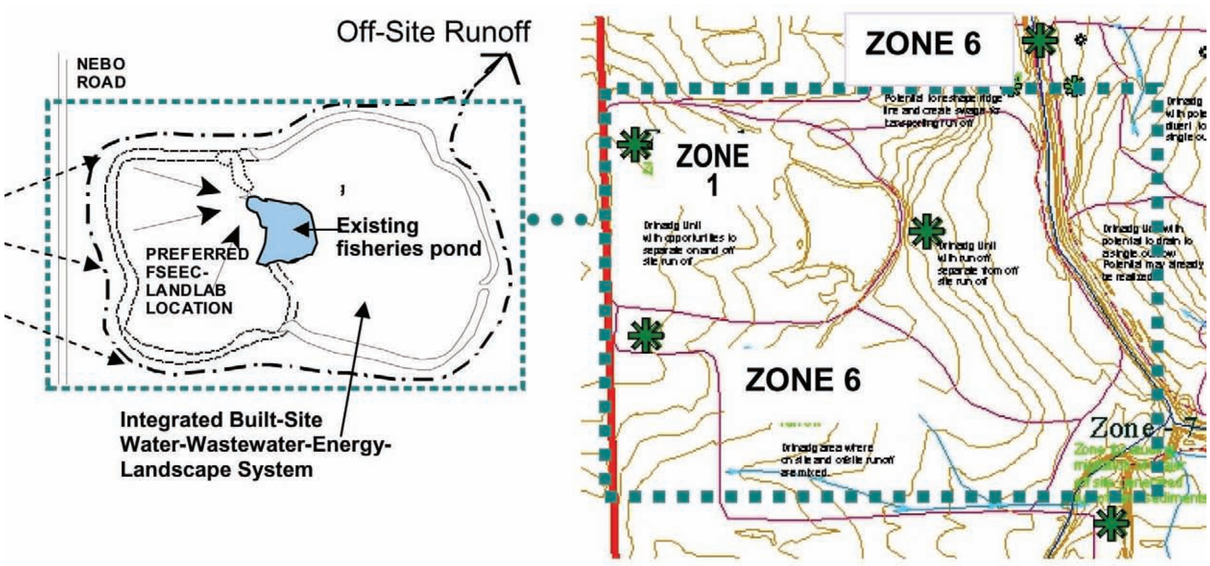

Figure 6. Environmental Education Building Location and Drainage Units.

Built-Site Framework

The built-site planning/design framework—including goals, objectives, concepts, guidelines and standards—grew from the missions of the Field Station and Environmental Education Council (FSEEC) and the Land Design Institute (LDI). The framework grew within the context of the integrated environmental management system (IEMS) described above, and with an understanding of desired land uses and management. This framework pursued four goals. The first goal was multi-disciplined environmental education in natural and built settings for students of all ages. The second was to increase understanding of regional resources and human impacts. The third goal was to help lead society to a sustainable future; and the fourth was to optimize short-term and long-term potentials. The built-site framework sought to guide the planning and design of buildings, infrastructure, and demonstration projects and to integrate diverse activities, participants, and timeframes.

Zoned Green Technology Demonstration

The study recommended site demonstration structured into two zones (fig. 8). The Near-Zone included integrated water-wastewater-energy-landscape systems (buildings,

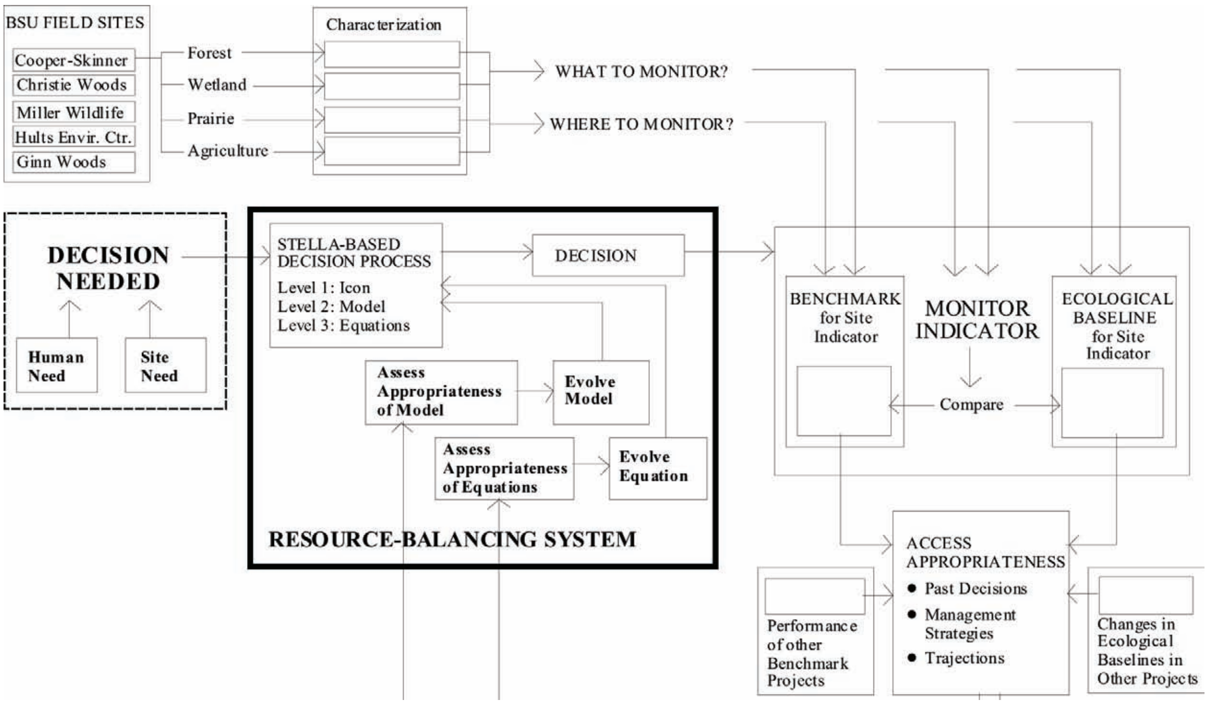

Figure 7. Resource-Balancing Management System for Landlab Built-Site Zone.

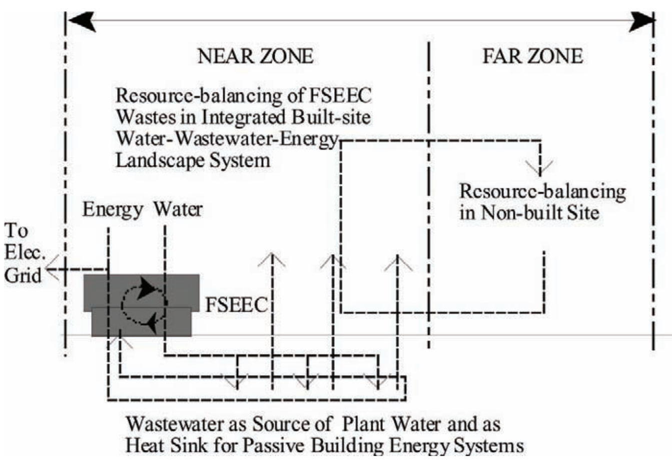

Figure 8: Zoned Green Demonstration.

shade structures, water walls, building extensions, living fences, landscape elements) with energy harvested by roof surfaces and water harvested by building and site surfaces. It included demonstration of biologic wastewater systems that restore water quality, and provide this restored water to landscapes that enhance performance of building and site passive energy systems. The study recommended that larger demonstrations (constructed wetlands, wet and dry prairies, agro-forestry) be located in the Far Zone.

Integrated Water-Wastewater-Energy-Landscape System (IWWELS)

The study recommended demonstration of built-site integrated water-wastewater-energy-landscape systems that harvest, distribute, use, reuse, and return resources to the site. It recommended that the system's *Water-Wastewater Component* (fig. 9) demonstrate how built-site systems can harvest, store, and distribute water for building and site use and reuse; collect wastewater and biologically restore water quality (living machines, rock-reed systems, constructed wetlands), and deliver restored water to the root zone of landscape components. It conceptually designed the *Energy-Landscape Component* (fig. 10) to demonstrate solar energy harvesting for building and site use, building bioclimatic benefits of soil saturated by restored water, and potentials to contribute harvested energy to the web. It recommended that the *Landscape Component* (fig. 11) demonstrate how built-site systems can provide habitat for wastewater treating organisms, maintain desired soil conditions, convert nutrients in effluent

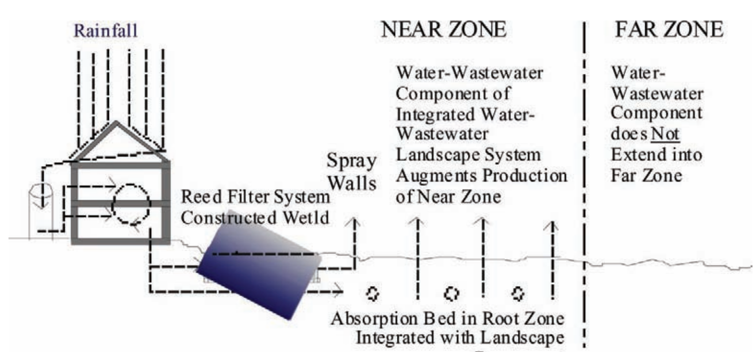

Figure 9. Water - Wastewater Component of IWWELS.

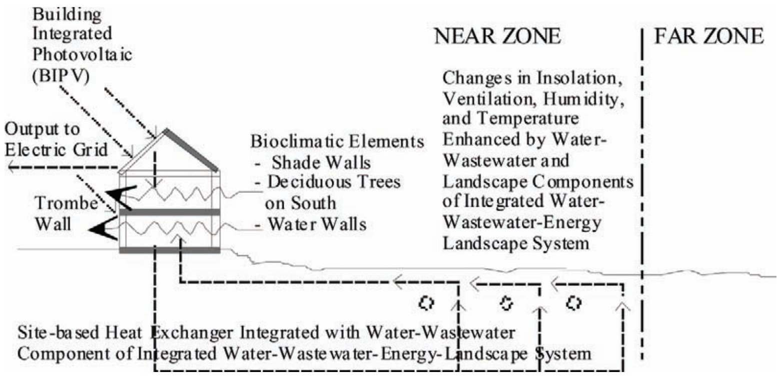

Figure 10. Energy - Landscape Component of IWWELS.

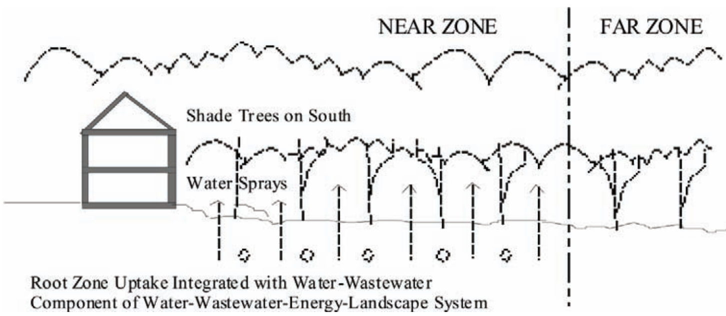

Figure 11. Landscape Component of IWWELS.

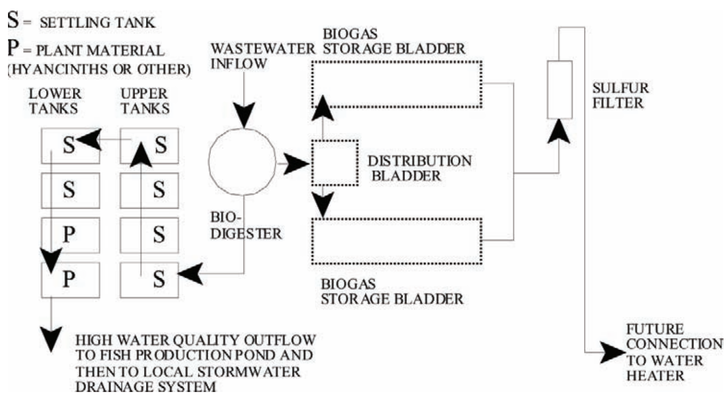

Figure 12. Biogas - Energy Landcape Component of IWWEL.

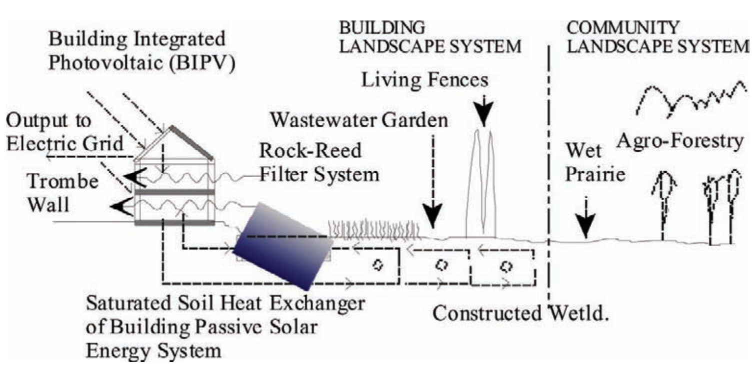

Figure 13. Solar Energy - Landcape Component of IWWEL.

into plant biomass, reduce building energy demands, and enhance building and site bioclimatic comfort. The *Bio-energy-Landscape Component* was conceptually designed to demonstrate how built-site systems can harvest biogas from human wastes while regenerating water quality (fig. 12). Recommendations for this component included a biogas harvesting system, biologic wastewater treatment system, and pond ecosystems that together harvest biogas, treat wastewater, and produce fish. The *Solar Energy-Landscape Component* (fig. 13) was conceptually designed to demonstrate landscape harvesting and use of solar energy. It also demonstrated how plants can contribute energy to building energy systems and the grid while producing functional, aesthetic landscapes. Integrated monitoring of the IWWELS was proposed as a means to assess performance of each component, to assess benefits that accrue to individual components and systems, to evaluate benefits due to the integrated nature of the systems, and to assess the value of integrated technologies to reconnect people to nature's integrated systems.

Monitoring Within Management System

The proposed management system included recommendations for baselining, benchmarking, and monitoring overall and habitat-specific Environmental Indicators for the overall site and the LandLab Zone to assess whether site management sustains resource-balance. It recommended a hierarchical system of water monitoring stations, and station locations in relation to water management zones and drainage units (fig. 4). It recommended that monitoring be integrated into academic, research, and demonstration programs; and that dynamic modeling software be used to model performance. It recommended that environmental Indicators be monitored and compared to baselines, benchmarks, and modeled performance to assess and evolve the model and to propose future land use and management decisions.

Monitoring of Habitat-Specific Indicators

The project included recommendations for monitoring habitat-specific Environmental Indicators. Recommended indicators were identified based on habitat types, typical Indicators for those habitat types, site conditions, and University land use and management needs. In recommending Environmental Indicators, this study benefited from an earlier report (FSEEC 2002) that assessed site habitat and potential Indicators.

Habitat Benefits, Ecological Considerations, Recommended Indicators

The property recommended in this study for the FSEEC-LandLab includes a range of micro-environments and habitat. Each offers habitat-specific opportunities for hands-on environmental education, research, and demonstration. Each also provides management opportunities and constraints. For each habitat, this project recommended Indicators with potential to be monitored to assess change in relation to baselines and benchmarks. Interventions that result in Indicator movement toward benchmarks were deemed to be desired actions that help the university realize the educational, research, and demonstration potentials of site habitats, while sustaining these habitat.

Based on available information (FSEEC 2002), the study identified site habitat types, benefits of those types of habitat, and ecological considerations in managing those habitat types. Based on the FSEEC report, the study also identified development activities generally seen to adversely affect that habitat type's health and to offer challenges to effective management of that habitat type. For example, *benefits* in wooded areas are generally understood to include carbon sequestering, nutrient recycling, reduced runoff, nutrient filtering from runoff, improved water quality, increased infiltration, sustained groundwater resources, stabilized soil, and wildlife habitat. Ecological considerations are generally seen to include successional increases in the interrelatedness of vegetation associations with climate, landform, soil, hydrologic regime, disturbance regime, and land use. These benefits are usually seen to be affected by the size and number of canopy layers; and by disturbances that affect ecological function (for example, fire, wind-throw, adverse changes in water regime, grazing, and pest outbreaks). Pressures that are usually expected as a result of development include forest fragmentation, increases in diseases and pests, atmospheric and runoff pollution, introduction of exotic species, and landscape disturbance by foot and motorized traffic.

Typical *habitat-specific Indicators* in wooded areas are usually understood (FSEEC 2002) to include Indicators of Fragmentation (ratio of woodland interior to total woodland area; indices of landscape fragmentation and connectivity), Biological Pressures (spatial extent of exotic species, pests, and diseases; population of grazers), Plant Community Health (extent and distribution of vegetative associations; density of snags and woody debris; extent and distribution of key plant species; ratio of vulnerable species to total forest dependent species), Atmospheric and Water Pollution (changes in sensitive species), Productivity (rate of tree growth indicated by number, volume, or diameter; population of key animal species in each tropic level), Nutrient Cycling (spatial extent of land with significant erosion; changes in soil thickness, compaction, density, structure), Hydrology (amount of storm runoff; time of concentration of runoff, percentage of stream length with vegetative barriers, width of barriers), and Disturbance (frequency of pest/disease outbreak).

Through discussions with University faculty and field station managers, the study identified *Environmental Indicators to baseline, benchmark, and monitor* on the project site. These included overall-site and habitat-specific Indicators. Recommended Indicators were those seen as most likely to provide opportunities for monitoring to support management, educational programs, research, and demonstration of environmental change with alternative management. For example, in the site's wooded areas, key site Indicators identified for baselining, benchmarking and monitoring included water quality, turbidity, BOD, and key chemical constituents (pH, nitrogen, salt) of runoff.

Initial Phased Demonstration and Monitoring

The study included a LandLab program for integrated technology demonstration to be implemented in phases. This program was designed to begin with low-investment ecological restoration and resource-balancing constructions and experiments. The study recommended phasing to more costly, complex and sophisticated hybrid technologies and systems. These more complex systems are anticipated to provide opportunities to harvest resources more efficiently, provide more sophisticated environments with greater control, promote positive resource-balance, and serve as benchmark projects.

Phased Construction of FSEEC-LandLab

Proposed *Phase One* education, research, and demonstration projects included establishing the site management system; initiating the program of baselining, benchmarking and monitoring at key Indicator stations; implementing low-cost ecological restoration projects; and implementing key design, build and monitoring projects. For example, the "FSEEC-LandLab Test Module" was designed to develop insight for future planning, design, management, and monitoring of FSEEC-LandLab facilities. *Phase Two* included design and construction of FSEEC-LandLab Core Facilities including the Environmental Education Building and the Green Technologies Demonstration site. *Phase Three* included design and implementation of other buildings and site demonstrations (caretaker residence, dormitories, ancillary structures, and infrastructure) as a monitored resource-balancing FSEEC-LandLab demonstration campus. The study proposed integrated monitoring of the LandLab's integrated water-wastewater-energy-landscape system (buildings, infrastructure, other interventions), monitoring of built-site harvesting of resources (energy and water), monitoring of building performance, monitoring of site conversion of built-site wastes to resources (including soil and biomass), and monitoring site Environmental Indicators to assess resource-balance. The proposed integrated monitoring and demonstration projects were intended to raise understanding and awareness of the resource-balancing potentials of integrated built-site systems and regenerative technologies (greenhouses, rock-reed filter systems, wetlands, wastewater and washwater gardens, and so on).

Phased Monitoring, Baselining and Benchmarking

The study recommended that, as soon as possible, the University baseline and benchmark the most crucially-needed Environmental Indicators and stations. It recommended water quantity and quality as the first variables to be monitored. It recommended that the University implement its initial Environmental Indicator monitoring program and extend the site database through periodic mapping of Indicator performance.

Phased monitoring recommendation

The study recognized that monitoring can be costly and time-consuming. To help control costs, it included a hierarchical system of water monitoring stations (fig. 7) with essential and less-costly monitoring to begin pending more substantial institutional investment. It identified urgently-needed stations and recommended that these stations be immediately baselined, benchmarked, and monitored. These included stations for monitoring runoff entering and leaving the site and its major drainage areas, and runoff from the area planned for the environmental education building, green technology demonstration, and other areas of on-going and impending habitat establishment and ecological restoration projects. Since planning, design and construction of the building might take several years, it proposed designing and building a module for testing green building and site materials, technologies, and monitoring. This test module was proposed as a Self-contained Workstation and Toilet with resource-balancing integrated systems (water-wastewater-energy-landscape) for research, education, and demonstration purposes. The study recommended monitoring performance of this test module in the drainage unit that will later receive the environmental education building and associated site development.

Implementing baselining

The project recommended that baselining of site areas be achieved prior to activities that induce landscape change. Since changes, in many cases, were already occurring or anticipated in the near future, it recommended baselining begin immediately on Level One water monitoring stations. It identified these baselines as highest priority due to on-going and planned changes in land cover and use, and the need to compare on- and off-site trends as these changes occur. It recommended the University commit to a location for the environmental education building and areas for major green technology demonstration. It recommended that the University determine baselines for key areas (including drainage units of planned buildings, and areas of on-going or planned habitat establishment and ecological restoration) to enable the university to monitor changes that occur in relation to building and landscape establishment and restoration.

Implementing benchmarking

The study recommended that the University benchmark Indicator performance at each monitoring station; and that these benchmarks be used to assess appropriateness of past site intervention decisions. It proposed that this feedback system also be used to inform future site activities. It recommended that processes for establishing benchmarks be participatory to promote broad understanding and attachment to these benchmarks as goals.

Implementing monitoring

Since monitoring of environmental indicators is a long-term, time-consuming, and costly venture, and competition for resources is severe, the study recommended the University identify concurrences between what can be monitored to enhance education (academic degrees, K-12 support, Globe International) and research programs; and what needs to be monitored to promote resource-balance. It recommended the University initiate a process to assess its educational programs (degree and non-degree) and research programs to identify potential synergies and associated monitoring. It recommended results of this process be used to design a sustainable monitoring program that facilitates resource-balancing site management while enhancing the quality of educational and research programs.

Benefits of Monitoring

The study identified benefits of monitoring to include *Curricular Benefits* of hands-on learning including monitoring of environmental Indicators to assess change over time and to predict the outcome of anticipated interventions. It suggested that the activity of monitoring environmental Indicators can enhance curricula in various disciplines and different types of learners. It identified benefits of monitoring activities as a means of connecting university students, K-12 students, and adult and community learners to sustainability. It also suggested *Benefits to Research* by strategically integrating the monitoring of research projects (including narrowly-focused ones) into this broader system of baselining, benchmarking, and monitoring Environmental Indicators. It suggested that this integration would allow focused research projects to assess performance at a deeper level based on better existing data, while allowing these projects to contribute to the ability of future research to do the same.

Integration of Monitoring, Research, Demonstration, Academic Programs

The study recommended that the university initiate an integrated study of the potential to implement the resource-balancing model on the proposed site. It recommended that this study integrate: 1) the ability of baselining, benchmarking, and monitoring of Environmental Indicators to enrich the University's academic programs in various disciplines and audiences, 2) the potential for University classes, public school programs, and adult and community education to contribute to baselining, benchmarking, and monitoring in cost-effective ways that enhance learning, 3) the ways in which the system of baselined, benchmarked and monitored Indicators could enhance the potential, ability to implement, and benefits of research to various audiences; and 4) potentials of specific research projects to contribute to baselining, benchmarking, monitoring, and integrated resource-balancing. Completion of this integrated study will allow the University to develop a program for integrating its field site management, education, research, demonstration, monitoring and resource-balancing programs.

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Sustainability for the Americas Initiative: Land Design Institute, Ball State University

J. L. Motloch, PhD, Professor of Landscape Architecture and Director of the Land Design Institute at Ball State University, Muncie, IN
Pedro Pacheco, PhD, Professor of Architecture, TEC de Monterrey (ITESM), Monterrey, Mexico
Eloy F. Casagrande Jr., PhD, Mineral Resources Engineering and Environment, Professor of Sustainable Development, Federal Center of Technological Education, Paraná, Brazil

Abstract—*The Ball State University Land Design Institute (LDI) pursues ecologically and culturally sustainable land design through education, research, outreach, and demonstration. LDI seeks to lead communities (local, regional, global) to sustainable futures. It connects communities and sustainability experts to optimize education about land management, planning, and design for sustainability; and innovative monitoring approaches and technologies for measuring ecosystem implications of these activities. LDI is building its biome-based global network, including inter-national sustainability consortia, to enhance understanding of sustainability by sharing information and partnering to translate global calls for sustainability into regional agenda.*

Introduction

Sustainability for the Americas (SFTA) is LDI's first regional initiative within this network. The SFTA's pilot project, the US-Brazil Sustainability Consortium (USBSC), emerged in 2002 to include four universities and two community-based sustainability research-education organizations. It is funded by US and Brazilian departments of education (US-FIPSE and Brazil-CAPES programs). The USBSC is currently building its "education for sustainability" curriculum to include hands-on and web-based sustainability experiences and environmental monitoring science experiences. The USBSC is developing projects including environmental monitoring and interdisciplinary-international sharing of monitoring science knowledge. This second SFTA consortium, the North American Sustainability, Housing and Community Consortium (NASHCC), including 6 universities and 2 community-based organizations, emerged in 2003. Its proposal is currently being reviewed by US, Canadian and Mexican departments of education (US-FIPSE, Canada-HRDC, Mexico-SEP). The NASHCC will include hands-on and web-based sustainability and environmental monitoring science experiences, monitoring projects, and interdisciplinary-international sharing of monitoring science knowledge. The LDI is facilitating emergence of other SFTA sustainability consortia and their environmental monitoring science dimensions. Knowledge from the USBSC, NASHCC, and SFTA Initiative will also inform sustainability consortia and environmental monitoring activities LDI is beginning to facilitate in other global regions.

Global Network of Regional Sustainability Partners

Through the agricultural and industrial ages, cultures moved away from living within resource flows and local limits, and pursued globalization instead of local integration. This produced environmental degradation, loss of community, and other symptoms of a metacrisis of disconnect (Capra 1984). Current global system breakdown is driving the move to sustainability that, in the U.S., includes recognition that key universities need to lead society to a sustainable future. In an effort to help society reconnect with flows and live within limits, the Land Design Institute (LDI) at Ball State University is facilitating emergence of a network pursuing innovation for sustainability; reconnection with local and regional physical, ecological, and human dynamics; community transformation; global-local partnering; and collaboration to enhance knowledge-flow about sustainability.

LDI Sustainability Consortia

LDI's sustainability network includes a consortia network pursuing global-local partnering to integrate

Figure 1. Global Biomes.

with local and regional dynamics. Environmentally, these consortia see global biomes, figure 1, as patterns of physical, chemical, and biological resources and dynamics into which they seek to integrate decisions. Culturally, consortia pursue decisions that integrate with cultural, socio-political, economic, and technological systems and dynamics. They realize that developed regions often sustain their lifestyles at the expense of distant ecologies and cultures, while people in developing countries often pursue markets in ways that destroy their local culture and lifestyle. Both contribute to global ecological and cultural system breakdown and, as resources dwindle, lead to conflict. LDI is building its biome-based consortia network, figure 2, to integrate with biome resource flows, sustain local and distant cultures, help people address their needs, and sustain the health and productivity of physical, ecological, and human systems.

LDI sees the Internet transforming information-flow, accelerating communication, and shortening distances; but often in ways that increase resource consumption and exclude poor people. Through BSU's Global Media Network, LDI seeks to increase accessibility to IT, the knowledge society, and sustainability knowledge-flow. It pursues sustainability in emergent markets (as well as established ones), where poor people benefit from collaboration with industry, government, and international organizations that promote local solutions that improve living conditions, generate local employment, and avoid social and environmental problems (Pauli 1998). LDI develops partnerships among institutes, landlabs, and multi-sector entities to address local and global dimensions of sustainability. It promotes consortia members as regional nodes of sustainability information-flow and behavioral change (Ferguson and Motloch 1996) that connect people to sustainable relationships with resources, build regional sustainability agenda; and function as a global sustainability-implementing network that includes universities that promote a sustainable ethic, educate students to integrate solutions into contextual systems, and empower graduates to lead communities to a sustainable future.

U.S. Partners

Charter U.S. partners of this network include Ball State University's Land Design Institute (LDI), the University of Texas at Austin's Institute for Innovation, Creativity, and Capital (IC2), and the Center for Maximum Potential Building Systems (CMPBS). IC2 is a global innovation institute; CMPBS a global leader in sustainability; and LDI a builder of partnerships that apply innovation and sustainability expertise to identify solutions that integrate with local, regional and global dynamics to help regenerate the health and productivity of environmental and human systems. These partnerships seek to develop tools, identify low-impact regionally-appropriate methods, and implement facilities that demonstrate sustainability. To enhance information-flow and facilitate sustainability, LDI is partnering with IC2 and CMPBS to create international sustainability consortia.

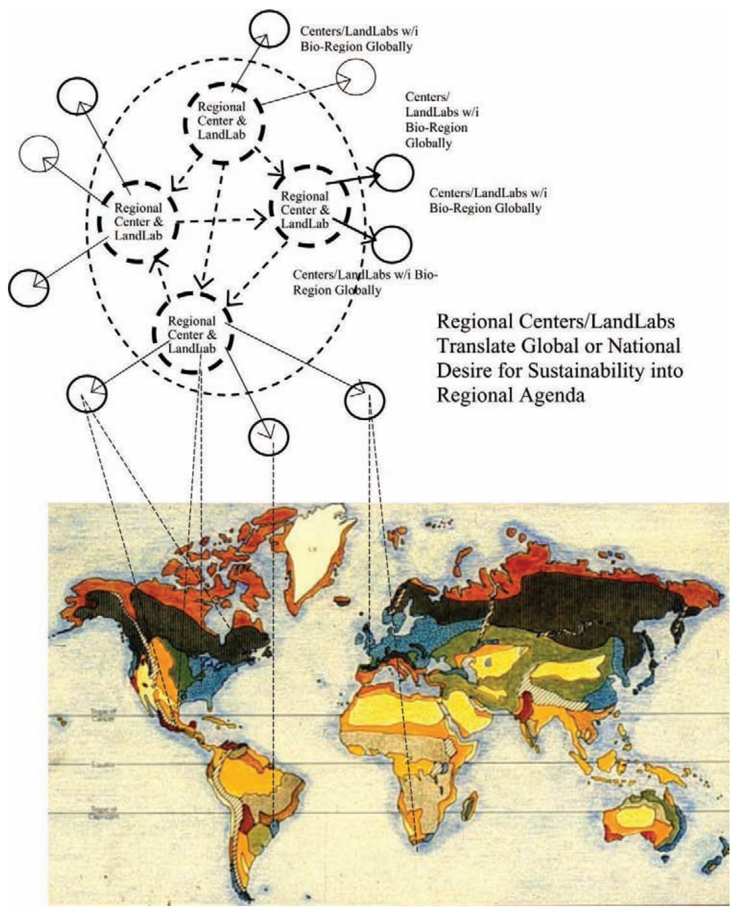

Figure 2. Global Network of Regional LandLabs (from Motloch 2003).

International Consortia-Building

LDI is facilitating LDI-IC2-CMPBS partnering in multi-national consortia; and is networking those consortia into a global network. Non-US partners and their socio-political contexts are different in each consortium, and therefore the process of formation is unique. However, consortia tend to share four developmental stages: emergence, institutional commitment and seeding, implementation start-up and sustained implementation. To facilitate Emergence, LDI identifies and brings together people with experience as sustainability change agents into an intense visioning session (workshop, videoconference, or teleconference) that includes a search for fit, collective visioning, agenda setting, identifying potential projects; and partner commitments to work together to enrich the consortium's sustainability agenda and project list. Partners also agree to pursue Institutional Commitment and Seeding funds from their institutions. Institutional commitment usually includes Letters of Intent and Memoranda of Understanding. Institutional seeding usually includes funding to visit partner facilities, meet administrators, review existing curricula, identify opportunities for sustainability curricula, sign formal inter-institutional agreements, visit benchmark projects and potential consortium projects, meet with potential community partners, develop locally-appropriate strategies for leading communities to sustainability; build community awareness of issues and potential projects; and generate proposals for mid-term funding. Consortium enter Implementation Start-Up by receiving multi-year academic and/or project funding that allows partners to meet regularly, implement sustainability curricula, complete short-term projects, and pursue long-term funding (based on track record of short-term projects). Consortia achieve Sustained Implementation upon receipt of long-term or over-lapping mid-term academic or project funding to sustain the consortium and lead society to a sustainable future (funding in-place for four years; funding targeted for ten years).

Sustainability for the Americas

Sustainability for the Americas (SFTA), the first regional group of this global consortia network, figure 3, promotes innovation and sustainability that connects people, ideas, and resources. Its first consortium, the US-Brazil Sustainability Consortium (USBSC), emerged in May 2002 and entered implementation start-up with receipt of four-year funding in June 2003. The second consortium, the North American Sustainability, Housing, and Community Consortium (NASHCC) emerged in October 2003 and received four-year funding in August 2004. The USBSC and NASHCC are pilot consortia of the SFTA, which is the pilot program for the LDI's global sustainability network.

Parallel Academic and Project Funding

Members of SFTA consortia have agreed to pursue parallel academic and project funding as the strategy for consortia funding. This includes internal consortium seed funding, academic and short-project start-up funding, and major projects for sustained consortium funding

Nested Sustainability Curricula

As part of four-year funding by the Departments of Education in all four countries (US, Brazil, Mexico, Canada) both the USBSC and NASHCC have committed to a nested sustainability curricula at consortia universities, to be delivered using a range of methods (Internet, visiting lectures, local classrooms, virtual classrooms, projects, field experiences, and others). This curricula has four levels. Level 1, an Internet-based Introduction to Sustainability Core Course, addresses interrelationships of ecology, environmental ethics, and environmental economics in managing, planning, and designing sustainable solutions (in the case of the NASHCC there is also an Introduction to Housing and Community core course). Level 2 is a series of hands-on and web-based Workshops (resource-balancing, systems dynamic modeling, GIS, sustainable economics, etc.). Level 3 consists of hands-on and web-based courses and practical experiences applying sustainability knowledge and skills in academic projects leading to Sustainability Certification. Level 4 is future development of Degree Extensions or Cognates. Graduates of the certificate program can work as interns on anticipated projects that help lead society to a sustainable future.

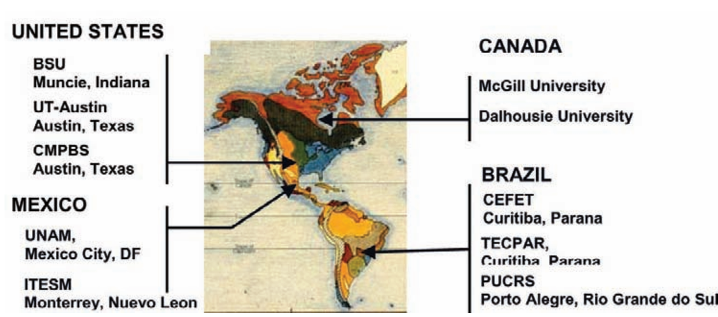

Figure 3. Emerging Suitability for the Americas Network.

Commitment to Collaboration

Organizations that work together use at least six different types of partnerships: monopoly, parallelism, competition, cooperation, coordination, and collaboration (Cervero 1988). These six types differ in their degree of interdependence among organizations. Collaboration is the most interdependent and most widely used by organizations dealing with social and environmental programs. Collaboration builds the highest levels of commitment and perceived authorship of decisions by all members. The SFTA is committed to collaboration as its operational model as a consortium and in its community projects.

U.S. Brazil Sustainability Consortium

The USBSC facilitates sustainability through collaborative knowledge-building and knowledge-sharing among university, public, and private sectors. U.S. partners are Ball State University (BSU), the University of Texas at Austin (UT), and the Center for Maximum Potential Building Systems (CMPBS). Brazilian partners are the Federal Center of Technological Education – Parana (CEFET-PR), the Pontifical Catholic University of Rio Grande do Sul (PUC-RS), and the Technology Institute of Parana (TECPAR).

Sustainability Leadership

The USBSC integrates and expands knowledge networks. It integrates four universities with sustainability leadership, a State-level sustainability agency, and a community sustainability not-for-profit. By accessing the knowledge networks of its members, the USBSC can partner with experts and access information in both countries and globally. By partnering with local, national, international experts, building accessible knowledge networks, and committing to local and biome-based information-flow, the USBSC can help lead societies to a sustainable future.

Sustainability Processes, Tools, Techniques, and Projects

The USBSC seeks to apply existing, and develop new, sustainability processes, tools, techniques, and projects for enhanced flow (resource, energy, capital, information) to all people to promote stable relations, community attachment, and integration with complex contextual systems (Ramina 2003). It seeks to identify, create, and implement integrative tools and technologies including industrial ecology, ecological footprinting and ecobalancing techniques, and sustainable land use and project planning and design (Fisk 2003). It seeks to create and implement tools and techniques that educate through collaboration, build social and psychological contracts and link people, and place through sustainable decisions (Pacheco 2003). The USBSC partners to develop and implement tools and techniques that promote regionally-appropriate, socially-equitable, and economically-viable interventions in complex ecological, physical and cultural systems; and projects that facilitate sustainability education, monitoring science, research, and demonstration (Motloch 2003).

Monitoring Processes, Tools, and Techniques

During its seeding and start-up implementation, the USBSC has begun to identify its program of monitoring processes, tools, techniques, and Brazilian and U.S projects at a range of contexts and scales.. At the Site Scale, U.S. projects include proposed integrated environmental monitoring at predefined strategic control points within an ecobalancing feedback system for making sustainable land management, use, and planning decisions on a BSU field station site, figure 4 (Motloch 2004). This project includes life-cycle based data-mapping (for example, incident radiation, biomass), productive potential mapping (for example, food, energy, clean air, material resources.), ecobalancing methods (balancing upstream and downstream productive potential), and a feedback system of ecological baselines, performance benchmarks, and environmental monitoring of sustainability indicators to assess site changes in relation to baselines and benchmarks. This ecobalancing design model (information-flow system, environmental monitoring, and comparison of environmental performance in relation to benchmarks) is proposed as a process for confirming the efficacy, and desired evolution, of planning and design decisions that seek to implement sustainability.

Potential site scale projects in Brazil include a case-study that addresses Brazilian Environmental regulations that require large enterprises that could have environmental or social impacts to obtain an operation license, granted only after local Environmental Agency approval of an Environmental Impact Assessment-EIA. Although basic guidelines have been identified for conducting the EIA, methods have not been established to guarantee that proposed monitoring considers synergy of all potential impacts. On-going research seeks to develop a simple GIS-based tool that permits consideration of all potential impacts at predefined strategic control points. This case-study is within an Atlantic Forest biome conservation unit

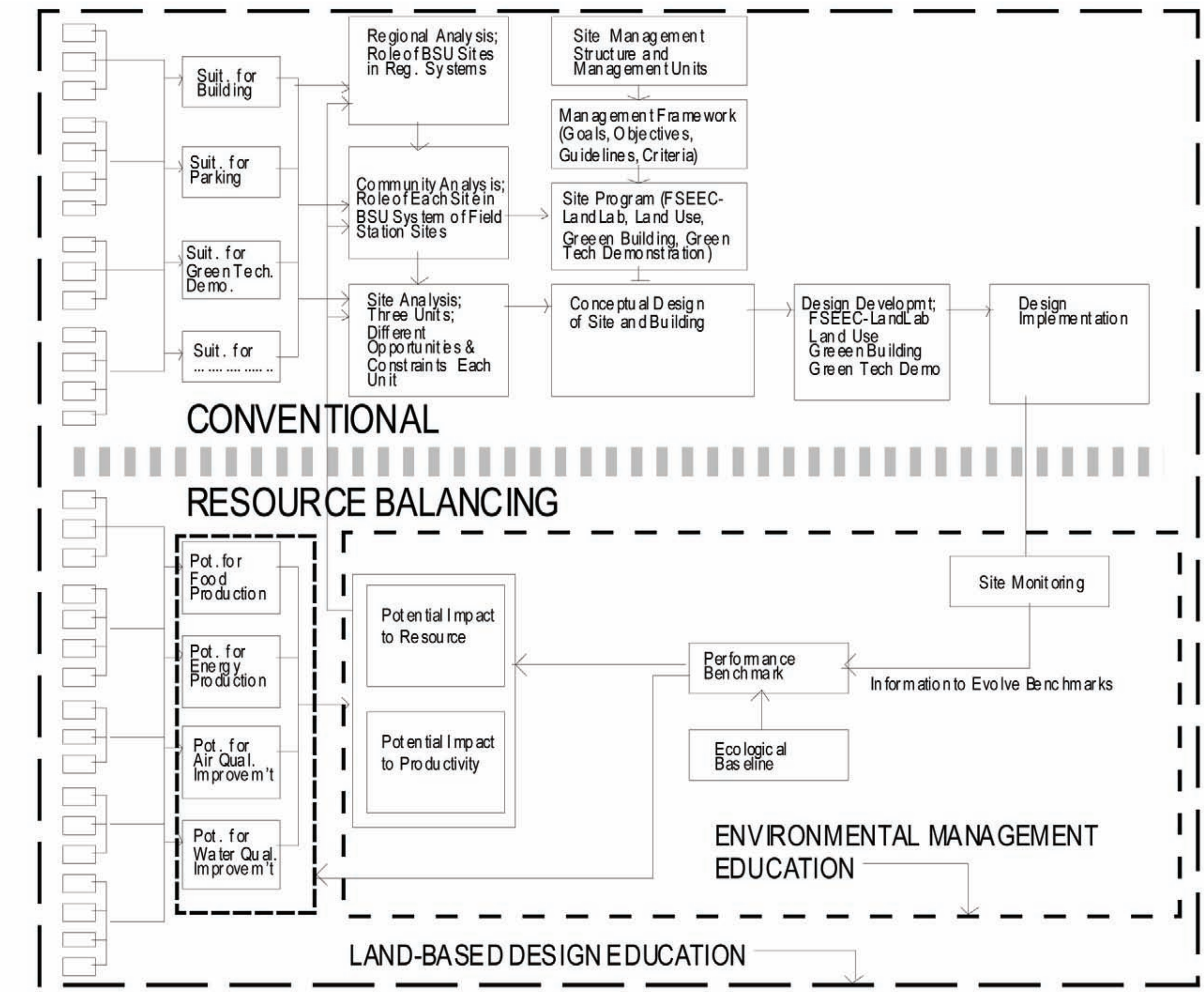

Figure 4. Ecobalancing Design Model (Introduction to Landscape Design, ed2, J. Motloch, 2000) Based on Ecobalance GameTM (CMPBS) and Ecobalancing Work of CMPBS.

currently affected by severe nearby mining activities. Data (water, soil and air quality, forest integrity, infrastructure and built surroundings, and socio-economic) are being collected, quantitatively and qualitatively assessed, and ranked (minor to highly impacted). Using simple GIS database facilities, data will be examined in synergy and areas (defined by points) submitted to easily conduct correlation analyses that allow simultaneously assessment of several impacts. This method assists in identifying the cause and nature of impacts and contributes to identification of areas of risk. It is believed that impacts can be categorized according to different levels of disturbance detected. The inclusion of socio-economic data is aimed to develop a coupled socio-environmental understanding. This is believed to represent the basis for the identification of Indicators that could support future development initiatives and decision making at the local level. This methodology enables the collaboration of specialists from different areas, facilitates decision-making, and gives a systemic perspective to definition of strategies for implementing environmental interventions. It is also a cost-effective tool for implementing monitoring to understand the sustainability of existing enterprises. It is anticipated the method can be disseminated and improved by international interactions proposed by the USBSC via a blended Web-Based Training (WBT) approach where students and professionals communicate, discuss the case-study, and learn through the Web and once a year meet face-to-face in one partner's country to visit sites where the method is being tested.

At the Regional Level, the USBSC is proposing that a similar method be applied to assess possible development scenarios for the Metropolitan Region of Curitiba in the State of Paraná. The area is of interest due to its fragile limestone geological structure and because the water caption reservoirs of the city are located nearby. Strategies to conduct this study include: 1) understanding the ecological function of that landscape using GIS techniques and local expertise, 2) understanding the impacts of existing regional economic activities such as limestone extraction and agriculture, 3) exploring organic agriculture as a potentially sustainable economic and social regional strategy, and 4) establishing a monitoring plan for organic farming based on environmental and social Indicators. Variables and specific aspects within these two sets of Indicators can be assessed quantitatively or qualitatively in different combinations. This study could define parameters for monitoring the sustainable performance of strategies and correct implementation methods considering ecological and socio-economic aspects. It can include case-study projects where monitoring techniques, land design, and alternative technique models are implemented and tested, and results are assessed and information disseminated as options for regional development

At the regional scale the USBSC also envisions multi-biome and multi-national studies. For example, the USBSC and NASHCC (see below) are proposing a Brazil-Mexico-US bamboo research project that includes monitoring bamboo growth, water quality enhancement, impacts of alternative product manufacture, bamboo treatments to resist insects and fungus, and so on. Proposals are being developed for components of this integrated research in ways that facilitate integrated monitoring and comparative assessments in different biomes. Also, income generation for poor communities engaged in the bamboo technology should be in the guidelines of the projects. The CEFET-PR is developing a pilot project in the Metropolitan Region of Curitiba where 30 families will benefit from 6 years of research. The bamboo project is financed by a private bank through its social care external policies (Casagrande Jr. 2004).

At the Global Scale, the USBSC could document and exchange ideas about hands-on experiences that could be used to build a database of successes and difficulties that could be widely accessed and promoted by the use of IT facilities. These case studies could be the basis of Web-Based Training (WBT) materials that could be built into the education for sustainability dimensions of the network of sustainability consortia and BSU's Global Media Network.

USBSC as Proof of Concept

As pilot study of the SFTA and global sustainability consortia network, the USBSC provided "proof of concept." Rapid movement through emergence and seeding and into start-up implementation spoke to the ability to incubate sustainability consortia. Its nested curriculum and integrated academic-project approach offered opportunities to advance sustainability throughout the universities involved and their contextual communities. The web-based Introduction to Sustainability course offered potential for students within and outside USBSC institutions. During emergence and start-up, the USBSC identified more than 30 potentially fundable community-based projects including information-flow, curricula, ecological sustainability, social sustainability, community development, green demonstration, integrated energy systems, learning games, and information-dissemination projects. This list continues to grow and to serve as excellent community service projects for courses in sustainability curricula of USBSC member institutions as well as projects for which to pursue funding.

North American Sustainability, Housing and Community Consortium

Based on USBSC successes and with North American partners with a somewhat broader agenda, LDI facilitated emergence of the North American Sustainability, Housing, and Community Consortium (NASHCC). U.S. members are the same as the USBSC: Ball State University (BSU), The University of Texas at Austin (UT), and the Center for Maximum Potential Building Systems (CMPBS). Mexican partners are the Autonomous University of Mexico (UNAM), TEC de Monterrey (ITESM) and the Group to Promote Education and Sustainable Development (GRUPEDSAC). Canadian partners are McGill University and Dalhousie University.

NASHCC Evolution

LDI facilitated NASHCC emergence by including its future TEC member in all USBSC activities. The NASHCC emerged in fall 2003, as a BSU-TEC-McGill led consortium with an expanded vision of sustainability, housing, and community. NASHCC seeding began even before all members were on-board. BSU and TEC provided support based on USBSC success and a history of the future NASHCC partners working together on projects. These BSU and TEC partners met on numerous occasions in the U.S., Mexico and elsewhere from May 2002 to April 2004, pursuing multiple agenda. During this time, BSU and TEC committed to enhancing their curricula with interdisciplinary richness in the areas of sustainability (environmental, social, economic), dignified housing, and community. Additional consortium partner institutions were identified based on past partnering of faculty within those institutions. BSU and TEC approached McGill University and with McGill invited Dalhousie University. UNAM was identified as the sixth university partner. The full team adopted parallel academic and project funding strategies; and conceptualized a sustainability, housing, and community curriculum with international courses and practical experiences that plug into degree programs to address institutional and program needs. With receipt of FIPSE-SEP-HRDC funding, NASHCC entered Implementation Start-up. A number of projects (mainly U.S. and Mexican) have been identified. In Fall 2003 and Spring 2004, BSU and TEC partners worked on a number of these projects together and with their students. During the upcoming year LDI envisions interconnecting the USBSC and NASHCC in projects that involve U.S., Mexico, Canada and Brazilian faculty, students, and communities.

Sustainability, Housing, and Community Processes, Tools, Techniques, and Projects

Like the USBSC, the NASHCC applies existing, and develops new, sustainability processes, tools, techniques, and projects for enhanced flow, increased accessibility, and integration with complex contextual systems. It seeks to identify, create, and implement integrative tools and technologies that educate about sustainable interventions in complex ecological, physical and cultural systems; and projects that facilitate sustainability education, research, and demonstration. With its broader agenda – sustainability, housing, and community – the NASHCC is also committed to accessing, creating, and implementing housing and community development processes, tools, techniques, and projects. This includes emphasis on multi-sector and inter-agency collaboration and International Collaborative Partnerships (ICP), figure 5, that partner residents, government, the private sector, NGOs, and educational institutions on community projects. It sees ICPs offering opportunities for not-for-profit and for-profit organizations to partner to exchange information, expertise, and dollars. ICPs also provide opportunities for community to partner with the NASHCC to access its network of universities, not-for-profits, and agencies, and together partner with industry in inter-agency learning laboratories where each partner contributes knowledge to identify solutions.

Monitoring Sustainability, Housing, and Community Processes, Tools and Techniques

As the NASHCC enters implementation start-up it is beginning to identify monitoring processes, tools, techniques, and projects at a range of scales and contexts in the U.S., Mexico, and Canada. Some of these, like the Brazil-Mexico-US bamboo research project mentioned above are multi-site projects in different environmental and socio-economic contexts. It is anticipated that these will present many challenges to identify and monitor Environmental and Social Indicators in ways that respond to local contexts, promote community attachment, and provide quantitative and qualitative results that can be assessed for comparisons of performance in different environmental and socio-economic contexts.

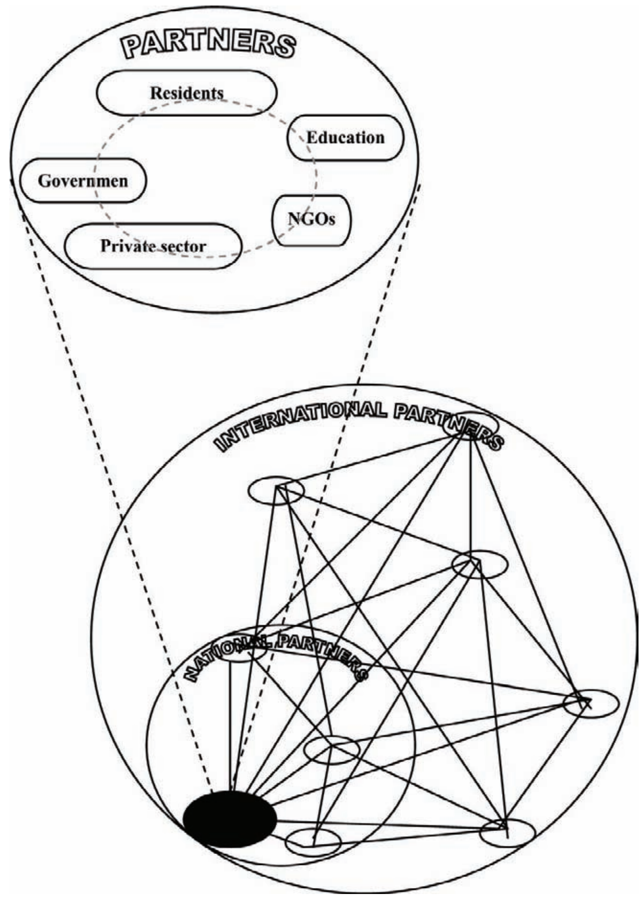

Figure 5. International collaborative partnership (Modified from Pacheco, 2003).

Many of the projects that have been identified by the NASHCC are capacity-building projects in the area of sustainability, housing, or community. For these, monitoring will be essential to quantitatively and qualitatively assess performance and trends in relation to baselines and benchmarks.

As the NASHCC develops its agenda of site, regional, and global scale projects, it will benefit from, and in many cases interconnect with, monitoring projects of the USBSC. At the Site Scale, it can link with Ball State integrated environmental monitoring at predefined strategic control site locations as part of the field station site's ecobalancing decision feedback system (Motloch 2003A). It can include projects that address US, Mexican, and Canadian regulation of environmental and social impacts, agency approvals of impact assessments, and guidelines and methods for monitoring potential impacts. The NASHCC can include case-study monitoring projects of existing and alternative land uses and technologies using methods that easily and effectively identify multiple impacts, the nature of these impacts, and areas of risk. It can embrace collaboration of specialists from different areas taking a systemic approach to define and implement intervention strategies. It can implement cost-effective tools for monitoring sustainability, housing, and community performance of existing, anticipated, and implemented conditions. It can promote information dissemination to all relevant populations and blended Web-Based Training (WBT) where students use the Web and NASHCC members visit monitoring sites in the US, Mexico, Canada (and Brazil and elsewhere).

At the Regional Level, the NASHCC can develop understanding of the ecological function of regional landscapes using GIS and other techniques and local expertise. It can assess the impacts of alternative regional economic activities and identify potentially sustainable economic and social regional strategies. It can assess environmental and social Indicators and establish monitoring plans for alternative regional land uses based on these Indicators. The NASHCC can include quantitatively and qualitatively assessments of Indicators and definition of parameters for monitoring sustainable performance and defining best implementation practices considering ecological and socio-economic aspects. It can include case-study projects where monitoring techniques, land design, and alternative models are implemented, tested, and disseminated as options for regional development Like the USBSC, the NASHCC can envision multi-biome and multi-national studies like the Brazil-Mexico-US bamboo research project program mentioned above that include monitoring plant growth, water quality, and the impacts of bamboo treatments, product manufacture, and so on.

At the Global Scale, members of the NASHCC and USBSC are pioneer partners in the North American and South American portions of the SFTA. These partners include universities that can serve as regional portals for web-based teaching about sustainability, housing, and community. These pioneer partners and future consortia members can lead efforts to document, exchange ideas about hands-on experiences, and participate in building databases of successes and difficulties; and widely disseminating this information via networks, including IT, that are accessible to all. As they do, monitored case studies projects will be essential in database development and program assessment including web-based teaching about sustainability, housing, and community.

Lessons From the SFTA

The following are some of the lessons we have learned already from the SFTA. They include lessons about sustainability and lessons about monitoring.

Observations about Sustainability

From years of individual work in sustainability and in the short time that we have been partnering in the SFTA, several observations can be made.

Place-based definitions of sustainability

Brundtland said that sustainability is a global concept that must be implemented locally (1987). Each culture has a world view through which they define the problems of existence and strategies for coping and addressing these problems; and through which they create socio-political and physical manifestations to address these problems. (Beck and Cowan 1990). Throughout the world many people talk about sustainability in terms of the Triple Bottom Line: ecological responsibility, social equity, and economic viability. They contend that all three must be met for sustainability; and they seek to achieve balance among the three. Partnering among sustainability experts in developed and developing countries and with people in communities in these different contexts reveals that this balance is seen very differently in developed and developing countries. People in developed countries who promote sustainability speak of the Triple Bottom Line but tend to focus primarily on environmental responsibility. People in developing countries who promote sustainability speak of the Triple Bottom Line but focus much more on social equity. The divergence is even greater in the general populations than in the population of sustainability experts, a disproportionate number of whom have studied formally in universities in the developed world where instructors generally teach based on the world view of developed countries.

Data and decision-making

At any given time and place, assessment of sustainability is based on available data; and the nature of data varies significantly among SFTA contexts. For any specific project, the SFTA can assess sustainability at levels appropriate to available data. When feasible, SFTA consortia can pursue projects to develop data to allow more sophisticated analysis. For example, the sustainability of product manufacturing can be assessed using

Input-Output Life Cycle Assessment (I-O/LCA) methods only if all data on inputs and output are available for each sector. In most SFTA partners adequate data does not exists for true input-output analysis. In this case, one SFTA project could conduct process-level LCA, based on levels of data available, rather than true I-O/LCA. Another project could assess available datasets; and to the degree allowed by existing data, develop best guesses of sector impact rankings. It could suggest what industries might be most problematic and suggest these for improvement. Within a targeted industry, it might also identify those areas where maximum impact might be expected to occur as potential targets to address for maximum potential benefit. Another project might identify the scale and type of data needed to assess sustainability at the next level. This could motivate funding to develop the scales and types of data necessary and then initiate true I-O assessment based on this data.

Environmental and social indicators

There is a major need for Environmental and Social Indicators of sustainability that are widely embraced as "good" Indicators. Agencies seek consistent Indicators, so they can manage consistently among different projects and so that they will be confident that Indicators used on a given project are widely perceived as being appropriate. Researchers, especially those involved with parallel projects in different biomes and socio-economic and political contexts need consistent Indicators for reasons of data comparisons among these projects. On the other hand, environments and people vary regionally and locally; and for Indicators to be implemented local communities must embrace these Indicators and implement decision that respond to them. SFTA International Collaborative Partnerships (ICP), using collaboration (most interdependent form of partnering), can build the sense of commitment and authorship of decisions in diverse sectors of the society necessary for the community to embrace Environmental and Social Indicator sets that include Indicators that allow agency management and research interpretations, as well as Indicators that build local multi-sector attachment. These ICPs can engage in projects to identify Environmental and Social Indicators and recommendations for processes that promote decisions informed by these Indicators.

Suggestions for Monitoring

Based on our experiences to date, we have the following observations about anticipated monitoring science opportunities and challenges.

Challenges of different definitions of sustainability

As the USBSC, NASHCC and future members of the SFTA share their views and partner in sustainability projects, we anticipate that place-bound definitions of sustainability will be challenged. This challenge will be most direct in projects that compare case-studies in the different cultures (like the Brazil-Mexico-US bamboo project), where results need to be correlated for different sites in different biomes and socio-economic-political contexts. This will raise many monitoring science challenges in each context. Also, researchers in developed countries and developing countries will be challenged to monitor environmental and social issues (sometimes including upstream and downstream impacts) they may not have previously monitored. They will need to do so with quantitative and/or qualitative methods recognized as valid by the scientific communities in both contexts. Developing methods that will meet these challenges can best be achieved by SFTA ICPs committed to collaboration as the type of partnering, as the ones suggested by the Atlantic Forest and Urban planning Brazil-US project.

Data and decision-making

The monitoring science challenges introduced by cross-biome and cross-cultural research are compounded by the additional challenges of different available type and nature of data in specific SFTA operational environments Where the types and nature of data are inconsistent the SFTA can propose monitoring projects to complete missing data to allow assessment at the next highest level. Where industries that might be most problematic are identified and suggest for improvement, case-study projects can be monitored. When areas with maximum impact are identified within these industries, monitoring programs can assess actual impacts and alternatives for anticipated maximum benefit.

Environmental and social indicators

Once Environmental and Social Indicator are established including consistent Indicators and project-specific ones, and these Indicators and baselined and benchmarked, case-study monitoring is needed to validate these as "good" Indicators. To do this, protocols will need to be developed and tested for their acceptability in diverse biomes and socio-economic and political contexts. Consistent Indicators and protocols will need to be identified collaboratively, and tested in diverse places and audiences, if they are to be widely accepted. Once consistent Indicators and protocols for these are identified, tested, and evolved, case-study projects will need to be identified collaboratively, tested, and embraced. These Indicators can be baselined, benchmarked, and monitored over time to see whether they move toward benchmarks. The monitoring science challenges introduced by the combination of cross-biome and cross-cultural research, different available type and nature of data in specific SFTA operational environments, the need for consistent Indicators for equitable agency management and data comparisons, and the need for wide multi-sector acceptance of Indicators will be significant. The tools, techniques, and methods embraced by the SFTA including its International Collaborative Partnerships, positions the SFTA to play a significant role in meeting these challenges.

Epilogue

The USBSC and NASHCC are pilot consortia of the SFTA, which is the pilot program for the LDI's global sustainability network. Knowledge and insight gained from these pilot consortia and the SFTA network and its two pilot consortia are helping evolve the consortia vision, operational model (including emergence, seeding, start-up, and long-term sustenance), and tools, techniques and processes to seeks to develop and implement. With USBSC, NASHCC, and SFTA successes, discussions are on-going with potential partners in other regions, including Europe, the Far East, and Africa. The LDI is eager to build consortia with universities in other global regions. We invite people interested in multi-national partnering to enter a dialog that can lead to emergence of a sustainability consortium. To explore consortia or partnerships with the SFTA, with Ball State University and other U.S. partners, contact John L. Motloch, Director, Land Design Institute, Ball State University 765-285-7561, jmotloch@bsu.edu. To discuss opportunities to partner with the Federal Center of Technological Education or Brazilian Universities contact Eloy Casagrande Federal Center of Technological Education of Parana 55 41 310-4719 fassi@ppgte.ainfo.cefetpr.br. To know more about the Atlantic Forest and the Curitiba projects contact Dr Patricia Peralta at the Institute of Sustainable Development, pperalta04@brturbo.com. To explore opportunities to partner with TEC de Monterrey and other Mexican partners, contact Pedro Pacheco, Department of Architecture, TEC de Monterrey ppacheco@itesm.mx.

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The Role of Indigenous Knowledge in Biodiversity Assessment and Monitoring: A Case Study in Uganda

Robinah K. Nanyunja, Research Scientist, Makerere University Institute of Environment and Natural Resources (MUIENR), Kampala, Uganda, East Africa

Abstract—*Biodiversity is being lost at unprecedented rates through destruction of habitats and ecosystems for short-term economic gain. Concern about this has led governments, multilateral organizations, scientists, environmentalists, and others to look for ways to promote the conservation of biodiversity. This concern has led to the development of rapid biodiversity assessment approaches based on indigenous knowledge of the local people to provide information on biodiversity suitable for use in conservation planning and environmental monitoring.*

The study, which was funded by UNDP/GEF Cross-Border Biodiversity Project in Uganda and implemented by myself on behalf of Makerere University Institute of Environment and Natural Resources (MUIENR), was carried out in the communities living in Moroto forest reserve and those living adjacent to the forest reserves of Sango Bay area. Moroto forest reserve is found in the Northeastern part of Uganda, while Sango Bay area is found in Southern part. The study was meant to identify, select indicators for biodiversity assessment and monitoring, and determine the trends of the resources since 1950 to 2001 using indigenous knowledge of the local people. The criteria for the selection of biodiversity indicators based on the following resource categories: Resources whose alternatives cannot be obtained from outside the forest; Medicinal and food plants; Resources with considerable pressure from the people; Sources of income; rare resources and large mammals. The results obtained indicated that there has been biodiversity loss based on the selected categories since 1950 to 2001, due to mainly change of peoples' livelihoods, over-harvesting, policy, and institutional failures. The major conclusion drawn from the study was that, the use of indigenous knowledge is a cheaper method in biodiversity assessment and monitoring, and it encourages the participation of local communities in resource management decisions thus empowering them to undertake sustainable management initiatives. However there is use of a unified knowledge system for effective biodiversity assessment and management.

Introduction

Most of Uganda's biodiversity can be found in the natural forests, but a considerable amount is found in open waters, wetlands, and dry/moist savannah. The major biodiversity ecosystems in Uganda include forests, woodlands, savannah, wetlands, and aquatic biodiversity (NEMA, 2000/2001). The biodiversity hotspots in Uganda include Mgahinga Gorilla and Bwindi Impenetrable National Parks, Rwenzori Mountain National Park, Sango Bay wetlands and forest ecosystem, Kibaale National Park, dry mountains of Karamoja (Napak, Morungole, Kadam, Timu and Moroto), Lake Victoria and papyrus swamps of Lake Edward, George and Bunyonyi (NEMA, 2000/2001).

Uganda is well known for the richness of its biodiversity, both terrestrial and aquatic, and it has a comprehensive system of protected areas under the management of the forestry department and Uganda Wildlife Authority (Pomeroy and others 2002). Despite this, the report on the state of Uganda's Biodiversity 2000 showed that the rate of biodiversity loss was high estimated at 1 percent per year.

A value and threat analysis conducted by UNDP/GEF Cross-border biodiversity project in the Sango Bay forests showed that the people were aware of the threats they impose on the forests. The following are some of the perceived threats to the Sango Bay forests by the communities: cutting young trees for poles and firewood, poor harvesting palm leaves, debarking trees for medicines, over harvesting of timber, selective harvesting of tree species, over harvesting of palm leaves, over harvesting of Marantochloa spp for baskets and poor pastoral practices (Nabanyumya and others 1999).

Figure 1. Map of Uganda showing location of study sites.

Biological diversity, the variability among living organisms from all sources is of critical value to the world. It forms the basis of our food supplies and provides raw materials for our pharmaceuticals and a growing number of industrial products (Tamanga and Bhattachan 1999). Unfortunately, biodiversity is being lost at unprecedented rates through the destruction of habitats and ecosystems for short-term economic gain. Concern about this has led governments, multilateral organizations, scientists, environmentalists, and others to look for ways to promote the conservation of biodiversity.

As concern about the loss of biodiversity has risen, so has the appreciation for the knowledge of the indigenous peoples about the natural resources they have lived with for centuries. This knowledge has an important scientific and strategic value. The majority of the worlds' people rely on indigenous knowledge of plants, animals, insects, microbes, and farming systems for either food or medicines. Eighty percent of the worlds' population depends on indigenous knowledge to meet their medicinal needs (Tamanga and Bhattachan 1999). It is therefore likely that the people closely watch and know how the resources are consumed and change.

Since the rate of biodiversity loss in Uganda is very rapid, methods by which trends in biodiversity may be assessed rapidly and efficiently are urgently required (Burley and Gauld 1994.). This need has led to the development of rapid biodiversity assessment approaches such as PRAs which aim to provide information on biodiversity suitable for use in conservation planning and environmental monitoring, in situations where detailed taxonomic investigations of the species concerned are not necessarily available (Oliver and Beattie, 1993).

Furthermore, Basemera quotes Gadgil and others (1993) as recognising the awareness of local people of the variety of uses of local biodiversity, such as medicines, which has been incorporated in the modern pharmacopoeia. Rural indigenous people are often knowledgeable about plant and animal species, including their identification and ecology (Hellier and others 1998).

Materials and Methods

Study Areas

The study areas were Mt. Moroto Forest reserve in the Northeastern part of Uganda and Sango Bay in the southern part of Uganda.

Selection of Indicators for Assessing Biodiversity Loss

A study carried out by MUIENR and funded by UNDP/GEF Cross-Border Biodiversity Project in Uganda designed criteria for selection of biodiversity indicators for monitoring and evaluation in Moroto and Sango Bay cross border biodiversity sites (Nanyunja 2001). The current study adopted some of these criteria and made some modifications to suit its objectives. They included the following resource categories (not necessarily mutually exclusive):

- Medicinal plants
- Food Plants
- Plants
- Resources with considerable pressure from the people
- Sources of income; rare resources
- Large mammals.

Sampling Procedure and Data Collection

Participatory rural appraisals (PRAs)

Participatory Rural Appraisal (PRA) has become an established procedure for investigating indigenous resource management systems (Webber and Ison 1994). It is defined as an "intensive, systematic but semi-structured learning experience carried out in a community by a multidisciplinary team which includes community members" (Theis and Grady 1991). One of the main advantages of PRAs is that they help provide a holistic vision from the perspective of the end-user, and makes use of their experience, which is integrated with that of the researchers, in order to broaden the common knowledge-base (Chambers, 1994a,b).

A PRA technique can include rapid surveys of local knowledge as tools for investing human perceptions to biodiversity loss. In this study, group interviews were used as information gathering tools for assessing trends in biodiversity loss (changes in abundance and changes in the use of indicator species from 1950 to 2001). These tools were earlier designed and used to develop a biodiversity monitoring and evaluation framework for Moroto, Napak and Sango Bay cross-border biodiversity sites in Uganda (Nanyunja 2001). The PRAs consisted of local histories/time lines, resources rankings, and abundance scores. I collected data using these tools with prepared data sheets (figs.2-5).

The people in Bukora parish of Sango Bay were predominantly pastoralists while those in Kanabulemu and Minziro parishes were predominantly cultivators. The people in Lwamuhuku Parish adjacent to LMNP were predominantly pastoralists while those in Kiribwa were predominantly cultivators. In Rubaale, the people of Kaina Parish were pastoralists while those of Katooma and Kyobwe Parishes were cultivators.

One PRA was carried out in each of the three parishes of Sango Bay and Moroto. Each PRA consisted of a group of 15 to 20 men and women participants—some cultivators and others pastoralists—ranging in age between 20 to 80 years. Community mobilization and the selection of participants for others were done with the help of the community forest officers.

Local histories/time lines

This technique taps participants' memories to recall local important historical events to help date other changes, such as changes in the environment in this case (Nabasa and others 1995). I used this method to collect information on trends of indicator species use, and changes and reasons for those changes in species frequency from 1950 to 2001. Elders were very much involved and played a large role in providing this historical information. Old people possess most of the indigenous knowledge and therefore provide the best (Basemera 2002) hence the exercise included elders and long-term residents.

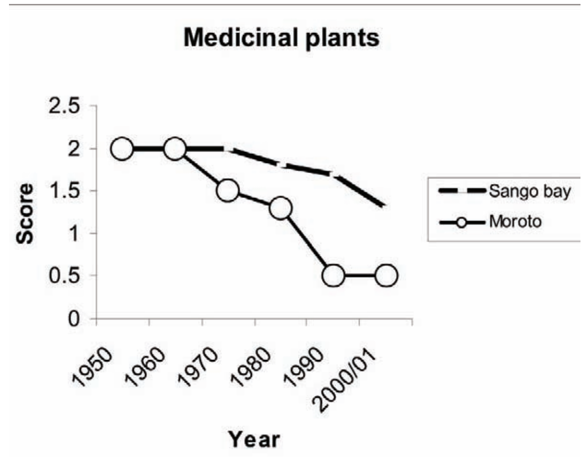

Figure 2. Trends of medicinal plants.

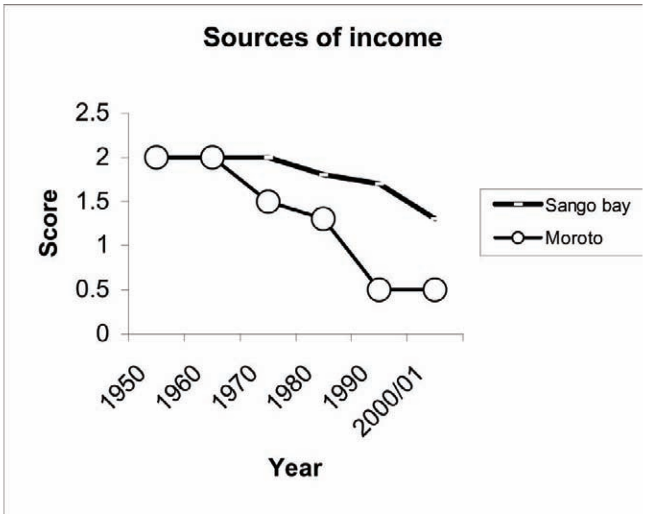

Figure 3. Trends of sources of income.

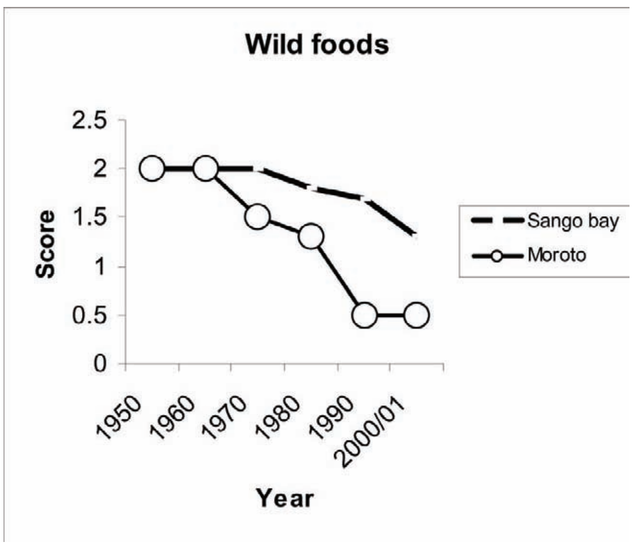

Figure 4. Trends of wild food plants.

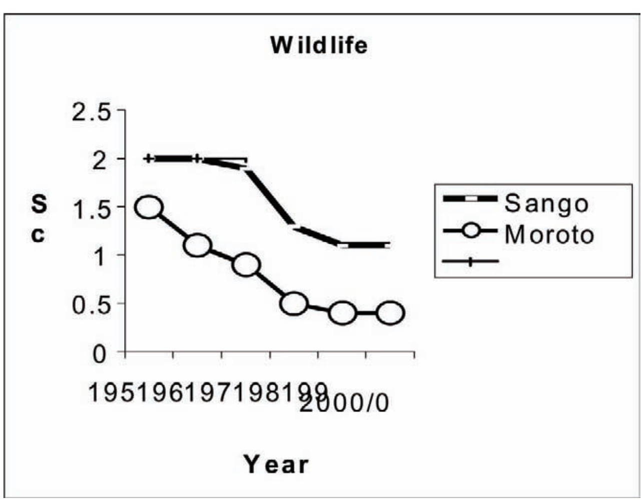

Figure 5. Trends of wildlife.

Resource rankings

During the discussions, the participants were asked to list about 10 to 15 resources (plant or animal species) in each category. Among these, I asked them to choose the 5 key resources. One person would suggest a resource name, and this would be subjected to debate. The people in support of it would then put up their hands. If the number supporting it exceeded the others, then we would accept it as a key resource. Indicator species and abundances were established in a similar manner.

Abundance scores

Abundance scores reflected the availability of indicator species during periods from 1950 to 2001. I asked the participants to score the availability an indicator species. The scores ranged from 0 to 2 where: 0 reflected none or nearly none; 1 a few or some; and 2 many or readily available (Nanyunja 2001). Comparing these scores between time periods would reflect a trend in change in biodiversity.

Data Analysis

The data collected in form of scores were entered and analysed, and graphed in Microsoft Excel by use of descriptive statistics. These illustrations show the trends of the biodiversity categories. The abundances of all the indicator species for a corresponding year (for example, 1950) were summed and averaged across parishes for each site.

Results

Figure 2 shows trends of medicinal plants. Of the medicinal plants trends' rapidly in Moroto Forest Reserve and least rapidly in the Sango Bay.

Figure 3 shows trends of sources of income of the plants being lost that people use as sources of income. The Moroto forest reserve is losing them more quickly than the Sango Bay site.

Figure 4 shows trends of wild food plants. Plants that people use as wild foods are being lost more quickly in Moroto than in Sango Bay.

Figure 5 shows trends of wildlife. In Moroto, wildlife is decreasing more steadily than in Sango Bay.

Therefore, the results clearly show that Moroto forest reserve is more degraded than Sango Bay.

Discussion

The trends in biodiversity loss as identified by human perceptions are illustrated in the graphs above. A general trend of biodiversity loss is found in all the sites. However, the magnitude of change varies within sites, and considerable variation is found between the study sites. The reasons for the change across the sites are related to the land use changes and statuses.

Trends of Medicinal Plants

The medicinal plants in Moroto forest Reserve were being lost faster than in Sango Bay. The rapid loss in Moroto Forest Reserve can be related to the fact that there are communities living within inside the forest reserve, where as in Sango Bay forest reserves, people are living adjacent to the forests. The need for charcoal burning, settlement and expansion of agriculture has contributed to the clearance of vegetation within Moroto Forest Reserve. This shows a contrast in biodiversity status between the Park, which is a protected area, and the adjacent community, which is a non-protected area.

The medicinal plants, in both study sites, besides performing their medicinal roles, are mainly trees, which are harvested for timber, charcoal burning, firewood, and building poles. The diversity of roles these plants perform exposes them to a higher harvesting pressure.

Trends of Plant Sources of Income

The plants being used as sources of income are declining more rapidly in Moroto Forest Reserve than in Sango Bay. The plant sources of income, in both study sites, are mainly trees, used for commercial purposes such as for timber, charcoal burning, firewood, and building poles. The diversity of roles these plants perform exposes them to a higher harvesting pressure.

During the 1960s and 1970s, the market for wood products was very selective. High value tree species such as Mvule (Melicea exelsa), Mahoganies, Elgon olive and Lovoa spp were depleted from the natural forests through selective logging. Large volumes of what at the time were considered 'undesirable' or 'weed' species were cleared using the charcoal refining method or poisoned with arboricides. The logged areas were later enriched with desirable tree species. Much biodiversity was lost through this process of exploitation. Uncontrolled harvesting and poor harvesting methods from the 1960s to the mid 1980s also contributed to biodiversity loss although estimates of such losses have not been documented (NEMA, 2000/2001).

Pressures on biodiversity from habitat loss, climate change and other causes are particularly high in East Africa (Groombridge and Jenkins 2002). Globally, the living planet index (WWF, 2002) shows a decline of 37 percent of biodiversity from 1970 to 2000, with the rate per decade at about 15 percent in the 1980s and 1990s.

Trends of Wild Food Plants

Wild foods are being lost more rapidly in Moroto forest reserve than in Sango Bay. In Moroto Forest Reserve, communities were gazetted inside and wild food plants contribute a significant role in their food security. In Sango Bay area, which is comprised of protected reserves of grasslands, wetlands and forests, communities, don't depend on wild food plants for food. The difference in the two land management statuses, for example, Sango Bay under reserves and Moroto being inhabited, explains the difference in change in biodiversity.

Through domestication and direct harvesting from the wild, Ugandans derive food, medicines, and a wealth of raw materials from plants. The importance of biodiversity to Ugandans is therefore not confined to natural ecosystems but includes agro-biodiversity especially in altered or anthropogenic ecosystems such as Rubaale (NEMA 2000/2001). Meanwhile, human settlements are encroaching on protected areas such as national parks, forest reserves, and wetlands. Uganda's population is growing very fast, at about 2.5 percent per annum, and this population is largely rural. Increased demand for food is resulting in new land being cleared for agriculture. Hence, large tracts of land are deforested annually (NEMA 2000/2001).

Trends of Wildlife

The numbers of wildlife species have been declining more rapidly in Moroto Forest Reserve than Sango Bay. The factors, which could have led to the significant reduction of in Moroto Forest Reserve, include:

- Hunting for meat which supplement food sources
- The clearance of forests, woodlands, bush and swamps, which had been habitat for wild animals, for expanded agricultural settlement
- Massive killing for settlement

Within wildlife-protected areas, poaching for both subsistence and commercial trade has been responsible in the past for the drastic reduction in wildlife populations. Fines for various wildlife offences are insufficient to act as effective deterrents, and the enforcement of the wildlife protection laws is weak (NEMA 2000/2001).

The loss of wildlife has been significant in Uganda. Although wildlife management was relatively efficient up to 1970, thereafter particularly during the 1970-1986 period, the status of wildlife was seriously undermined through indiscriminate poaching. This resulted in major reductions in the number of species and populations, for example, between 1960 and 1998; Uganda lost 71 percent and 76 percent of its antelope and other large mammals (UWA 1999).

Although wildlife and wild plant resources in Uganda constitute a great asset, the country risks losing them altogether. Uganda's biodiversity decline is being experienced at the ecosystem, species and genetic levels. For example, both the northern white and the black rhino have been hunted for commercial purposes to extinction. Biodiversity is also being lost through the disappearance or alteration of habitats, and the introduction of alien species (NEMA 2000/2001). Examination of a composite index of biodiversity (1970=100) revealed that Uganda's biodiversity richness declined steeply from the 1960s to the 1990s (NEMA 2000/2001). Losses of biodiversity have been registered in forests and woodlands, wildlife-protected areas, wetlands, and aquatic ecosystems.

Conclusions and Recommendations

The results of this study of changing biodiversity based on local human perception reveals a decline in all biodiversity categories across the study sites, with Moroto being more degraded than Sango Bay. To counteract this, tree-planting programmes may be initiated in the study areas with immediate attention being given to Moroto Forest Reserve. Trees of high interest to the community, such as those that are used as sources of income or medicine, may be prioritised.

The methods used in the study are important tools for monitoring and assessing change in biodiversity based on human perceptions. However, we cannot rely on one data source to assess and monitor biodiversity. There is therefore a need to use a unified knowledge system involving biodiversity inventories, both ground truthing and aerial surveys, besides the indigenous knowledge for effective sustainable biodiversity assessment and monitoring.

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Landscape Conservation and Social Tension in the Brazilian Atlantic Forest: Challenges for Implementing Sustainability

Libia Patricia Peralta Agudelo, PhD, Landscape Ecology, GIS Senior Lecturer & Research Associate, CEFET-PR, Institute of Sustainable Development, Paraná, Brazil
Maristela Marangon, Sociologist and Masters Degree Candidate, CEFET-PR, Paraná, Brazil

Abstract—*The study is based in the Environmental Protection Area of Guaraqueçaba located in the Atlantic Forest of the State of Paraná, southern Brazil. EPAs in Brazil allow private ownership, resource extraction, and agriculture according to predefined land use laws. A systems' approach was adopted to define the main interacting variables needed to understand the local socio-economic context and the causes of an observed increase in illegal activities. The Atlantic Forest is of particular importance as it was declared a "hotspot" in 1992 for its endemic biodiversity and high risk of destruction; today only 7% of the original cover remains as scattered fragments. A series of increasing social and environmental conflicts have been observed in the EPA because the Law restricted traditional agricultural practices without defining alternatives to sustain locals. As a result, new forms of illegal behaviors emerged, such as indiscriminate extraction and hunting, with devastating effects. The methodology adopted herein assists in understanding the core of these conflicts and permits the formulation of strategies to minimize them. Based on the redefinition of the perception of sustainability both from the local people and law enforcement perspectives and through the reconciliation of traditional practices and cultural issues, it allows the reconnection of people to their place and its ecological dynamics.*

Introduction: Ecological System

The Environmental Protection Unit (EPA) of Guaraqueçaba was created in 1985 under the Law Decree n° 90.883/85. It has an extension of 191.595 ha located in the coastal region of the State of Paraná, southern Brazil. The EPA contains the largest continuous fragment of the 7 percent of the remaining areas of the Brazilian Atlantic Forest ecosystem (Floresta Ombrófila Densa) and the so called Coastal Biome composed of dunes, mangroves, and estuaries. The Atlantic Forest was declared a hotspot in 1992, by Conservation International due to its high endemic biodiversity, imminent danger of destruction and established social conflicts. The EPA also contains archeological sites; traditional populations defined by indigenous groups, fisherman and subsistence agriculture peasants that inhabit the region for over a century (IPARDES, 2001). In that sense, the EPA of Guaraqueçaba is characterized by a vast heterogeneity of social and environmental systems that are in constant dynamic exchange.

The importance of the EPA of Guaraqueçaba relative to the State of Paraná is also evident when analyzing its history in retrospective. At the beginning of the 20th century, 80 percent of the original landscape of the State was covered by forests, namely the "ombrófila mista" with its characteristics Araucaria Pines (Araucaria angustifólia) and semi-deciduous forests in altitudes superior to 900 m, and the "ombrófila densa" or Atlantic Forest in the hill slopes of the Serra do Mar alongside the Atlantic Ocean's coast (fig. 1). Today, the State has only 8 percent of its original Araucaria forest cover and only 3 percent of the original Atlantic Forest cover, with the EPA containing the largest continuous fragment of that biome of the country (SOS Mata Atlântica 2002.

According to Maack (1968) in Jacobs (2002), the greatest forest loss occurred between the 1960s and the 1980s decades (table 1), a period that coincides with the greatest deforestation cycles observed in the Amazon region and with the dictatorships regimes in Brazil.

With the aim of protecting the endangered forest areas and natural resources, several conservation units were established in the Brazilian territory since 1938. Nevertheless, problems persisted due to land tenure

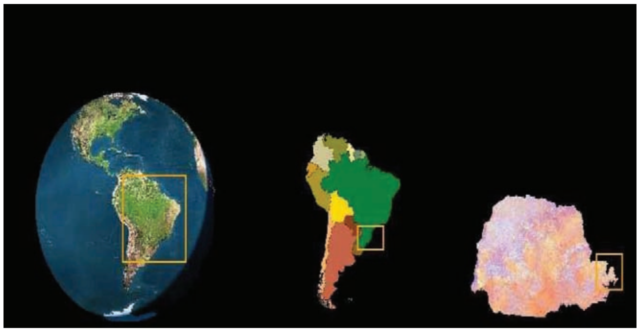

Figure 1. Location of the EPA of Guaraqueçaba at global, regional and local scales. Source: SPVS, 2000.

conflicts and poor demarcation techniques that in many cases resulted in superposition of land titles and border inadequacies. The State of Paraná addressed these problems only in 1980 through the creation of the EPA, a category of conservation unit that allows human settlements and restrictive natural resources' exploitation according to pre-established laws.

The EPA of Guaraqueçaba was officially demarcated in 1985. It is believed that the creation of such conservation units has, to some extent, prevented greater losses of biodiversity in the State of Paraná (as in the entire Brazilian territory). However, forest degradation is still taking place. Research is showing that agriculture pressure over these areas remains high. In spite of law enforcement and monitoring efforts, selective extraction of woods, plants, and endangered animal species continues and, in some cases, it is reported to have been accentuated. According to Jacobs (2002), this is due to the small extent of some of the Paraná's conservation units and small or inexistent participation of local populations in the management and profits generated by tourism and research undertaken in these areas. In this paper, we investigate these and other factors that might have contributed to the increasing deforestation and natural resources' depletion observed in the EPA of Guaraqueçaba. The main aim was to establish the nature and causes of these actions that resulted in activities that are actually contrary to the ones expected when the legal implementation of the EPA.

Table 1. Deforestation dynamics observed in the Paraná State between 1895-2000.

Year	Area (ha.)	Percentage of State	Source
1895	16.782.400	83,41	MAACK, 1968
1930	12.902.400	64,13	MAACK, 1968
1950	7.983.400	39,68	MAACK, 1968
1965	4.813.600	23,92	MAACK, 1968
1980	3.413.447	16,97	PELLICO NETO, 1984
1990	1.848.475	9,19	SOS-Mata Atlântica, ISA & INPE, 1998
1995	1.769.449	8,79	SOS-Mata Atlântica, ISA & INPE, 1998
2000	1.594.298	7,98	SOS-Mata Atlântica Atlas of 2000

From: Jacobs (2002).

Systemic Approach to Understand Social and Environmental Conflicts

It has been said that when adopting a systemic approach to a given problem, simulations that do not have a real basis are constructed. Nevertheless, it is argued that these are constructed and compared with what is known about a given reality, thus allowing the testing of various hypotheses (Marzall and Almeida 1999). Clayton and Radcliffe (1996) argue that the intrinsic complexity and chaotic nature of systems determine the difficulty in predicting their behavior. Nonetheless, it is also argued that a systemic approach does not provide solutions but unveils problems that might go unforeseen other way (Morin 2001).

The first step to implement the systemic analysis of the conflicts observed in the EPA is to identify the characteristics of main systems operating there – namely the social, environmental, and economic. In sequence, as proposed by the Lalone Scheme (1974), the main interaction flows between these and other operation subsystems should be identified. Main subsystems can be defined as educational, health, agricultural, religious, legal, law enforcement and physicosocial. The interaction between systems and subsystems can be illustrated better as taking place in an imaginary sphere where exchange flows are constant and occur at three main scale levels: local, regional and global (fig. 2).

The social subsystem of the EPA is composed by a series of actors that are involved in the Guaraqueçaba situation and that have sometimes conflicting interests. Main actors are described as governmental (State environmental agencies, Law enforcement, Monitoring Agencies such as IBAMA and IAP and Research Institutions such as universities and research centers), local communities (indigenous communities, fisherman, land owners and peasants) and civil society (tourists, NGOs, enterprises, industry and others). When assessing just a few of the main expectations of each of these groups, some important aspects were uncovered:

Governmental: protection of natural resources through clearly defined land use restrictions, law enforcement, preservation of endangered species, regulation of illegal

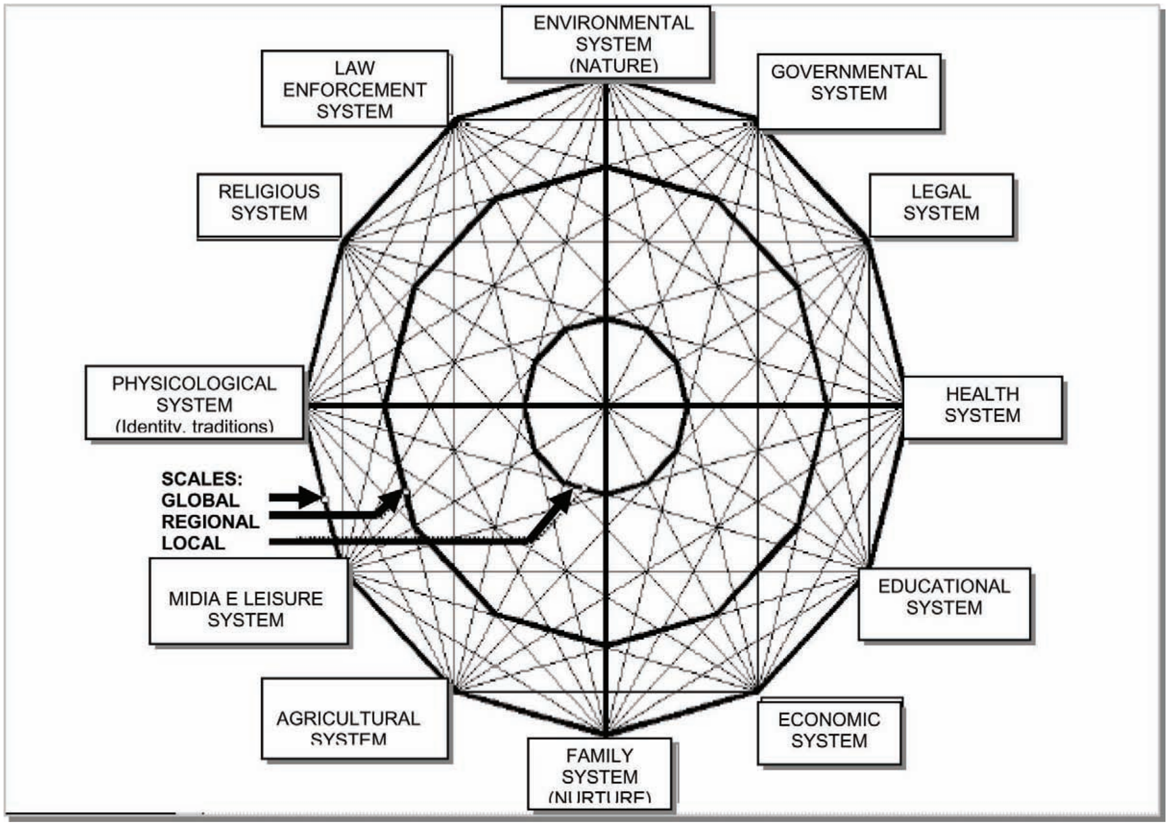

Figure 2. The Lalone Complex System Model. Adapted from Lalone 1974 in Chaves, M., 1998.

activities, information, research and scientific knowledge generation, regional sustainable development.

Local communities: improvement of living conditions through better access to goods and services, modern comforts, desire to practice their traditional economic activities, access to education, information and technology, freedom to decide their future, participation in decision making, safety, more communication with urban centers, development that brings income.

Civil society: preservation of natural heritage and cultural traditions, access to natural areas, information, participation in decision making, participation in revenues if any, leisure, education, recreation, sustainable development.

Since it is known that deforestation and other illegal activities in the EPA are said to be taking place as a result of social and economic interests conflicting with environmental preservation purposes, a study on the interaction flows between the social, economic, and environmental subsystems was undertaken.

Social, Economic, and Environmental Dynamics in the EPA of Guaraqueçaba

When assessing the demographic evolution in the Guaraqueçaba region, it is observed that in 1980 only 17 percent of the total population lived in the urban areas and by the year 2000, 31 percent of the population was living there (table 2). This represents an increment of 205 percent of urban population increment in two decades.

Although rural areas in the EPA still embrace the majority of the population, there has been a considerable emigration from the rural to the urban areas in that region. These results are contradictory to the purposes of the EPA where traditional rural economic activities are said to be an asset to be preserved and the rapid expansion of urban areas can trigger unwanted changes in traditional social and economic practices.

A study conducted as a PhD thesis in the Federal University of Paraná (UFPR-MADE 2002), examined the type of economic activities conducted currently by the

Table 2. Demographic evolution in the EPA of Guaraqueçaba, 1950 to 2000.

	Year						
Population	**1950**	**1960**	**1970**	**1980**	**1991**	**1996**	**2000**
Total	7174	7713	7648	7662	7751	8035	8288
Urban	707	1134	1348	1298	1742	2239	2582
Rural	6467	6759	6306	6372	6020	5776	5706

Source: Demographic Census of IBGE, 1950 to 2000.

Table 3. Main and Secondary economic activity of populations of the EPA of Guaraqueçaba.

	Main		Secondary	
Occupation	**Nº**	**%**	**Nº**	**%**
Agriculture	434	19,41	337	15,07
Fishing	65	2,91	28	1,25
Employed in Agriculture	120	5,37	78	3,49
Artisan	59	2,64	20	0,89
Small business	29	1,30	16	0,72
Employed (not in agriculture)	79	3,53	37	1,65
Employed by Government	67	3,00	9	0,40
Employed by landowner, maid	59	2,64	15	0,67
Retired*	317	14,18	0	0,00
Student	487	21,78	10	0,45
Housewife	298	13,33	202	9,03
Other	64	2,86	477	21,33
Not declared	13	0,58	0	0,00
Unemployed	145	6,48	1	0,04
Without secondary occupation	0	0,00	1006	44,99
Total	**2236**	**100**	**2236**	**100**

Source: UFPR-MADE / CNRS - Relatório de Pesquisa (2003).
* 60,88 per cent of retired persons were previously involved in agriculture.

rural populations in the EPA of Guaraqueçaba (table 3). Data was divided into two economic activities' categories: main and secondary. Results showed that although a significant number of main and secondary activities were related somehow to agriculture, a more complex scenario started to emerge, which could be described as an "economy defined not by agriculture (as traditionally was), but through agriculture. This was called a defined as a new rural pluri-activity (Hugues Lamarche in Ferreira 2002).

Data shows that in the past most inhabitants of the EPA were directly involved in agriculture (almost 61 percent of retired people declared that). Today economic activities seem to be more varied. Currently, just over 19 percent of the EPA's population does have agriculture as a main activity and 15 percent as a secondary activity. These are owners and/or employees practicing subsistence and commercial agriculture. Results also show a proportion of almost 8.5 percent of people indirectly employed with agriculture either as a main or secondary economic activity.

It is possible to conclude that most people of the rural areas of the EPA, more than 65 percent, are not involved in any agricultural activity, either as a main or secondary source of income either because these are students, house wives, artisans, fisherman, etc., while 21 percent of the population declared to be involved in 'other' activities. These results are intriguing, given the remoteness of the place and the very limited offer of alternative jobs and activities that can be developed in the region. So how are people surviving in the EPA?

These findings are also supported by evidence that show that only 12 percent of people living from agriculture in the EPA are really making their livelihoods from it. According to that, most people in the EPA are obliged to sell their labor to be able to sustain themselves (Rodrigues and others 2002). The question as to how these people are managing to do that in such remote areas and in face of the land use restrictions imposed by the Law that applies in that conservation unit remains still unanswered.

At the same time, increasing allegations of illegal activities are being reported by law enforcement agents, forest police, and NGOs members. These activities range from the illegal extraction of palmito (*Euterpe edulis*), wood, plants, and animals that are commercialized through an intricate web of transgressors to accusations about the existence of illegal agricultural plots in remote areas in the forest interior. Again, studies show the need that the local populations have to diversify their economic activities shifting from an agricultural base to a pluri-activity base.

Legal Land Use Restrictions and Social Conflicts

In order to address further the impacts that land use restrictions are having on the social and economic dynamics operating in the EPA, some aspects of the current Law are enumerated below:

- Compulsory authorization for opening new agricultural plots – This is granted by the federal or local environmental regulating agencies, namely IBAMA and IAP.
- Agriculture alongside river margins (20-50 meters) and in riparian(?) forest and areas of water wells is forbidden.

- Agriculture in hill slopes and river floodplains is restricted and subjected to previous approval.
- Activities of hunting and extraction are considered illegal.

Some studies (Zanoni and others 2000, Rodrigues and others 2002) indicate that these restrictions have affected directly the traditional economic practices. Main impacts are described below:

- Bureaucracy has in many cases prevented families to establish their subsistence agriculture plots.
- Restrictions to plant in the river margins have affected banana and corn plantations, main commercial cultures in the region.
- Restrictions to plant in hill slopes have reduced slush and burn activities affecting the traditional cycles of production.

Quality of Life Indicators for the EPA of Guaraqueçaba

In order to asses further how the legal interventions have benefited or affected negatively the quality of life of the traditional populations, a series of indicators were established through quantitative and qualitative studies conducted during 2003. Main results are presented below in the form of simplified negative and positive scores:

Negative indexes included aspects such as high criminality, high stress levels, alcoholism, reported use of drugs, high incidence of infecto-contagious diseases such as HIV, high migration indexes, law education standards, high unemployment, lack of job opportunities, precarious infrastructure and services, low health assistance, lack of information, poor access and transport, high incidence of resentment against governmental actors, ignorance about the relationship between natural preservation and tourism.

Positive indexes included high eco-tourism potential, high associativism and self-management potential, strong desire to remain in the region, high awareness about the local problems, high environmental quality, high biodiversity and natural resources potential, access to electricity.

This study also established that aspects such as cultural preservation, local productive potential, and human and ecosystem carrying capacity were not considered important by the local populations.

Main Contradictions Identified

Some contradictions generated by the above mentioned factors:

- The illegal extraction of palmito increased after the demarcation of the EPA. It has been reported that this illegal activity is coordinated by people from outside the community that serve as a middle man between the extractivists (locals) and the companies that process and commercialize the product (Santos, 2001).
- Illegal deforestation has also increased. Local families are opening clandestine agricultural plots in remote forest areas without respecting the traditional cycles and rotation schemes thus degrading the local ecosystems.
- Illegal hunting has also increased since populations are still hunting for subsistence purposes but also to commercialize endangered species animals in an established black market. Hunting is now taken place without regarding age, sex and species as it used to be practiced in the past. (Zanoni and others, 2002).
- Tourism related economic activities have increased but the local populations have not yet established a direct link between the local ecosystem preservation and tourism.
- Local populations allegedly report not having seen improvements in their quality of life, nor have they received access to services and infrastructure after the creation of the EPA.

These considerations suggest that local ecological limitations (environmental subsystems) have imposed restrictions to traditional practices (economic subsystem) without real intervention form the state and/or scientific sectors (government and education subsystems). What we are seeing is that sustainability is a variable directly dependant on social sustainability (Rodrigues and others 2003).

Analysis of the Dynamic Flows Occurring in the EPA

The idea of adopting a systemic approach to assess conflicts identified in the EPA derives from the need to: firstly, establish the main interactions between main aspects and actors involved in the EPA and secondly, to identify areas where these interactions are truncated and/or not flowing properly. In that sense, main problems identified between the analyzed flows can be described as:

- Government and scientific efforts were mainly directed to protect the natural environment with no or poor interest in the local social environment.
- Public policies defined for the area had a strong ecological basis and a weak local social understanding.
- Resources, science and technology has been employed to understand ecosystems specific aspects such as species habitats and characteristics, but have failed to address basic landscape ecological interactions and processes which are the basis to define management strategies by identifying critical areas, areas of risk, fragmented ecosystems, etc. The result is a poor or inexistent knowledge for establishing priorities for development and/or conservation, i.e., which areas can be devoted to agriculture, which are in need to be restored, where to establish ecological corridors, where can urban expansion take place, etc.
- Information has not been produced to be understood and passed adequately to decision makers such as environmental regulation agencies so that they could use it for law enforcement, monitoring and planning purposes.
- Information has not been produced in formats that can be of use to the local populations about ways for them to benefit from their local environment
- When designing laws to restrict land use in the EPA, no other alternatives that were consistent with the EPA ecological limitations were designed to allow the subsistence of local populations
- Initiatives of dialogue between all actors involved seem to have failed due to inability of negotiations and/or lack of understanding about the other needs and expectations
- Although it is now known that one of the biggest potential of the region is based on tourism, information and science produced until now is not organized in a manner to plan that activity sustainably and mitigate its potential social and environmental impacts.
- Local populations are not aware of the importance of their participation to develop and manage tourism in the EPA. They need to be reconnected to their landscape and land.
- Considerable effort is now needed to restore trust between local populations and governmental authorities and research institutions. This can only be done through results reflected in the real improvement of services and income generation.
- Technological knowledge and science need to be directed towards strategies that address sustainable pluri-activities, considering low impact selective forest management, organic agriculture, agroforestry systems, sustainable landscape design, eco-tourism, and other alternative technologies developments consistent with the EPA's social and ecosystem preservation.
- Local cooperatives and associations need to be adequately implemented and supported by the local governments and public policies until they become self-sustainable.

Basically, what all these considerations suggest is that although science and information has been produced, it has not been adequately generated in order to assess real needs of all actors involved and also, that the necessary dialogue and interaction amongst actors has not been properly established. There seems to be the need to identify a hierarchical scale of information generation, namely starting from the local to the regional and global levels (fig. 3) and through the implementation of a strategy to make this information flow in a multidimensional manner so that it includes all aspects relevant to the systems and subsystems operating in the EPA.

Conclusions

This study has shown a clear breakdown in the information flows that take place between the actors that interact in the Guaraqueçaba situation. In order to assess clearly were these flows should be (re) established they have been organized in three main categories according to their scale of interaction:

1. *Local Scale Information Flow*: relating to information that should be produced and disseminated at the local level, namely in the Guaraqueçaba area. It should be produced with the assistance of local populations, with high technical input and content but derived in a way that is easily digested by the native communities. It should address items such as: local ecological properties and limitations, economic potential, alternatives for natural resource use and agricultural activities that are sustainable, inform about reasons for legal land use restrictions, include traditional knowledge, include local human priorities in preservation strategies, robust technological input to implement sustainability, prepare locals to manage and profit from tourism activities that are educative, sustainable and lucrative.
2. *Regional Scale Information Flow*: This type of information should be derived from the local level information and expanded to address the interests and scope of the regional actors, such as government, academia, scientists, etc. In that sense, it should subsidize development plans, law enforcement, investors, and other decision making processes at a regional scale. It should never be derived using a bottom down

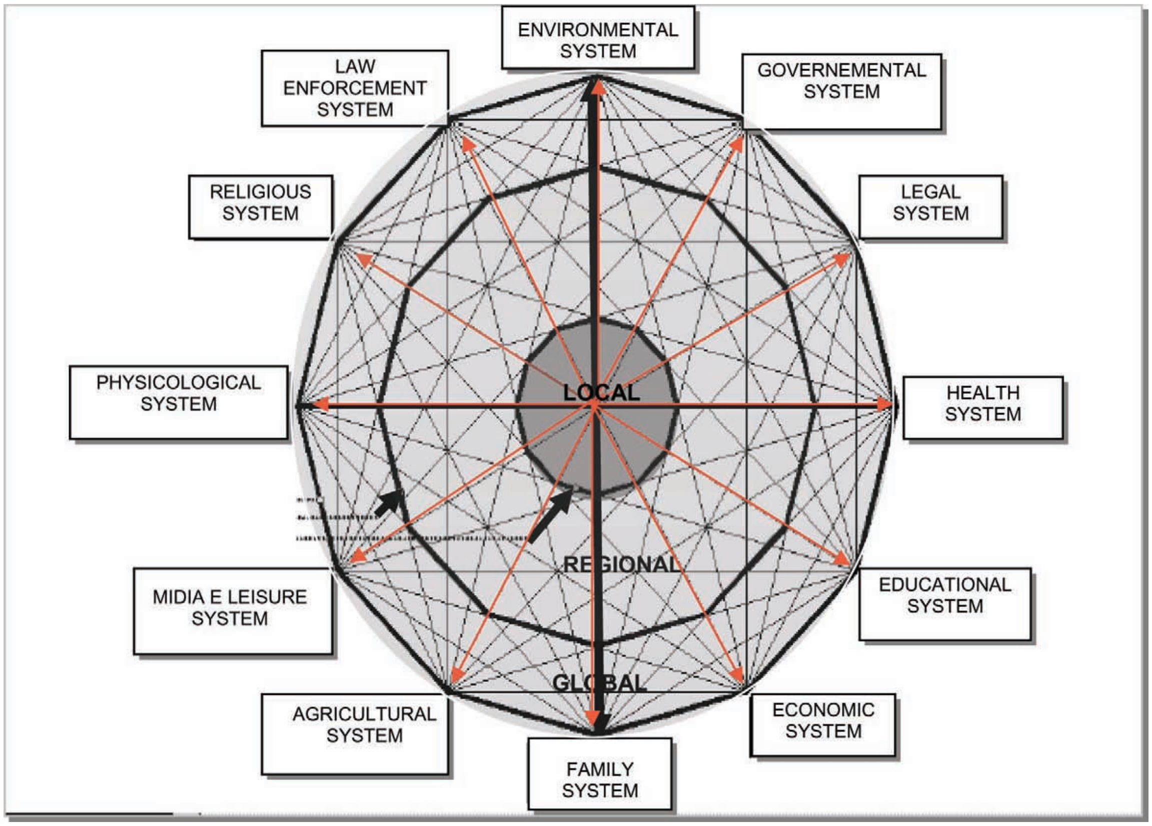

Figure 3. Information generation flow from local to regional and global.

approach (global to regional) and always adopt a bottom-up approach (local to regional). At this level, knowledge and information on how diversify production in Guaraqueçaba should be developed. Regional markets should be implemented and prepared to absorb local production. Tourism activities should be formulated and implemented.

3. *Global Scale Information Flow*: This type of information should be generated always from the local and regional information flows and expanded to meet the demands of the global society. It should provide the global actors with information on the local, regional, and global perspectives of the area in question. It should address the need to promote science, education, and understanding of the importance of adopting a systemic and scale dependant approach to promote a balanced social, economic and ecological sustainability.

Although some initiatives are already taken place, these are still on their onset in Guaraqueçaba. Information is still sparse and actors experience difficulties in negotiating and establishing dialogue. It is believed that dialogue will flow better if from now on efforts are devoted to produce only the right and strictly essential information and shared among actors. Also, in order to achieve the adequate formats to the meet the needs of the various audiences involved, a hierarchical approach as the one here suggested should be implemented.

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Visualizing the Anthropocene: Human Land Use History and Environmental Management

Richard D. Periman, Ph.D., Research Archaeologist, USDA Forest Service, Rocky Mountain Research Station, Cultural Heritage Research, Albuquerque, NM

Abstract—*The term "Anthropocene" defines the current, human-dominated, geological epoch of human-caused environmental influences. Some researchers believe that the beginning of this epoch coincides with the inception of the Industrial Revolution (Crutzen and Stoermer 2000). Research is revealing that humans have affected environments on global and local scales for millennia. Contention over land management often hinges on disparate beliefs about the environment and the ways in which policy makers and the public visualize the past. There is a need to communicate the complexities of anthropogenic environmental change, on a local scale, through a medium that transcends different disciplines and cultural backgrounds. This paper discusses ongoing research of long-term human land use, and the ways human-environmental interactions have shaped the landscapes we encounter today. Environmentally based landscape visualizations are crucial forms of communication, which can be used to establish benchmarks for ecosystem restoration, future land management planning, and as a venue for better communication with the public. A picture may be worth more than a thousand words in bridging conflicting visions of nature, past, present, and future, in environmental disputes.*

Introduction

The Anthropocene: Climate Change Linked to Humans

The Anthropocene epoch has been described as the period in which past human effects have altered the global environment. Just as geological phenomena take place on global, as well as regional and local levels, anthropogenic environmental change also has occurred across geographic scales. Initially, the Anthropocene was defined as beginning with the Industrial Revolution, in the latter part of the eighteenth century. Crutzen and Stoermer (2000) argue that greenhouse warming began with the Industrial Revolution, based on their analysis of aerosols trapped in glacial ice. Yet, by defining the beginning of the Anthropocene as a geological epoch beginning only 200 years ago, Crutzen and Stoermer truncate thousands of years of human interactions with the global environment.

Examination of older glacial ice levels shows intriguing evidence of human-caused climate change, beginning nearly 8,000 years ago. The initiation and intensification of human impacts coincide with the divergence of Holocene Greenland ice core CO^2 (carbon dioxide) and CH^4 (methane) concentrations from levels predicted by previous interglacial patterns. The anomalous variations in CO^2 and CH^4 concentrations in the middle and late Holocene are well outside levels that prevailed over the previous 300,000 years (Ruddiman 2003:263). Late Holocene ice core evidence suggests that increased levels of greenhouse gasses coincide with the development of agriculture and other technologies (Ruddiman 2003). Paleoenvironmental research around the globe indicates that human societies have cumulatively influenced a wide variety of ecosystems. Around 5000 B.C., CH^4 levels began a slow increase, culminating in completely anomalous levels by the beginning of the Industrial Revolution. By then, methane levels were already as high as they had been at the end of the Pleistocene, 14,000 to 12,000 years ago. Carbon dioxide output also grew with increasing human populations and technological advances. Small-scale deforestation and the use of fire for clearing land dumped carbon directly into the atmosphere. Landscapes across the world were cleared of forests to produce grazing lands for domesticated livestock (Zolitschka and others 2003). Deforestation increased as wood was cut for household use, firing pottery and bricks, metal production, and for use as building material. Fewer trees led to likely resulted in less carbon sequestration (Ruddiman 2003:274). This trend in anthropogenic change grew larger with the development of metallurgy and other fuel-intensive technologies.

Metal production added CO^2, as well as heavy metals to the atmosphere. Scientists have discovered correlations between elevated atmospheric lead levels in peat bog deposits in Switzerland, and the development of European silver mining and smelting. Beginning around 400 B.C., European peat bogs exhibit increased levels of lead isotope around 400 B.C. These deposits show a steady increase in lead levels through the second century A.D., which corresponds to increased European silver smelting (Shotyk and others 1998:1637). This lead isotope signal also appears in ice cores from Greenland glacial deposits, perhaps indicating the world-wide effects of Roman era pollution (Hong and others1996). Cumulative environmental change, at local and regional scales, when viewed over thousands of years, may add up to significant shaping of the global environment.

The Anthropocene at Regional and Local Scales

At local and regional scales cumulative environmental change, when viewed over thousands of years, may add up to significant shaping of the global environment. Researchers have found a range of evidence indicating long-term, human-induced change at regional and local levels in environments around the globe (Baker and Biger 1992, Cotton 1996, Norton 1989, Pearsall 2000). Pollen and charcoal studies from Western Europe, Africa, Asia, Australia, and North and South America show that humans have been changing Earth's ecosystems for millennia (Walker and Singh 1993:108). Increases in microscopic charcoal, changes in fossil pollen assemblages, and faunal extinctions may be used as proxy indicators of human-induced ecological change (Burney 1993 and 1997; Chambers 1993; Walker and Singh 1993).

Since the end of the Pleistocene, people in Europe have altered, manipulated, and domesticated ecosystems, transforming the continent into a system of interconnecting and overlying cultural landscapes (Caseldine and Hatton 1993, Hope and Golson 1995, Simmons 1989). Archaeological investigations provide ample evidence of human impacts on long-term soil formation, at local and regional scales (Acotte 1998:74-75, French and others 2003).

The first New World settlers first arrived more than 12,000 years ago. Their technology, including the use of fire, initiated a slow and cumulative process of broad-scale environmental change (Brown and Hebda 2001). As populations expanded, groups of people spread throughout North and South America. Native peoples increasingly modified and managed landscapes to heighten the production of vital resources. By 4000 B.C., Andean landscapes were already being cleared by local societies for agriculture (Chepstow-Lusty and others1998). In the southern region of the United States, during the late-Holocene, Appalachian Oak-Chestnut communities were the product of landscape management by Native Americans. Pollen and charcoal-particle analyses indicate that for thousands of years, Native Americans influenced biological diversity and maintained a heterogeneous landscape mosaic using fire (Delcourt and Delcourt 1997). Prior to the arrival of Europeans, Native Californians altered thousands of hectares of forests, grasslands, wetlands, and river valleys, through intensive land management (Blackburn and Anderson 1993). Native peoples lived in settlements that ranged from villages, with small family units, to cities housing tens of thousands of individuals. In the Southwestern United States, native cultures affected soil development, erosion, and hydrology, as demonstrated in the remains of water control features, irrigation canals, and specialized agricultural technology (Deneven 1992:370, Periman 2001).

Current Geoarchaeological Research

My research focuses on human-environmental change in New Mexico's desert landscapes and in the forests of western Montana. A main objective of this research is to develop an integrated, interdisciplinary approach for reconstructing extended landscape history, and identifying cumulative anthropogenic effects on landscapes through time. I use archaeological data, as well as paleoenvironmental data collected from alluvium, bogs, and wood rat middens, to produce visual models of how different landscapes may have appeared during various periods. Computer-generated visualizations create representations of past environments that enhance understanding of the dynamics of landscape changes. Such visualization technology mediates challenges in resource management, by providing models of landscapes during specific periods and under a variety reference conditions (Appleton and Lovett 2003).

In the Rio del Oso study, located on the Santa Fe National Forest in New Mexico (fig. 1), I use a wide variety of scientific techniques to construct three-dimensional representations of past landscapes. These temporal and spatial visualizations, based on paleoenvironmental and archaeological data, help tie conceptualizations of past human land use to existing landscapes. First, I created archaeological site area, vegetation, and soil data layers using a digital elevation model and the geographical information system (GIS) software ArcInfo and ArcView. Using these GIS map layers, and vegetation density data derived from fossil pollen and phytolith analyses, I then

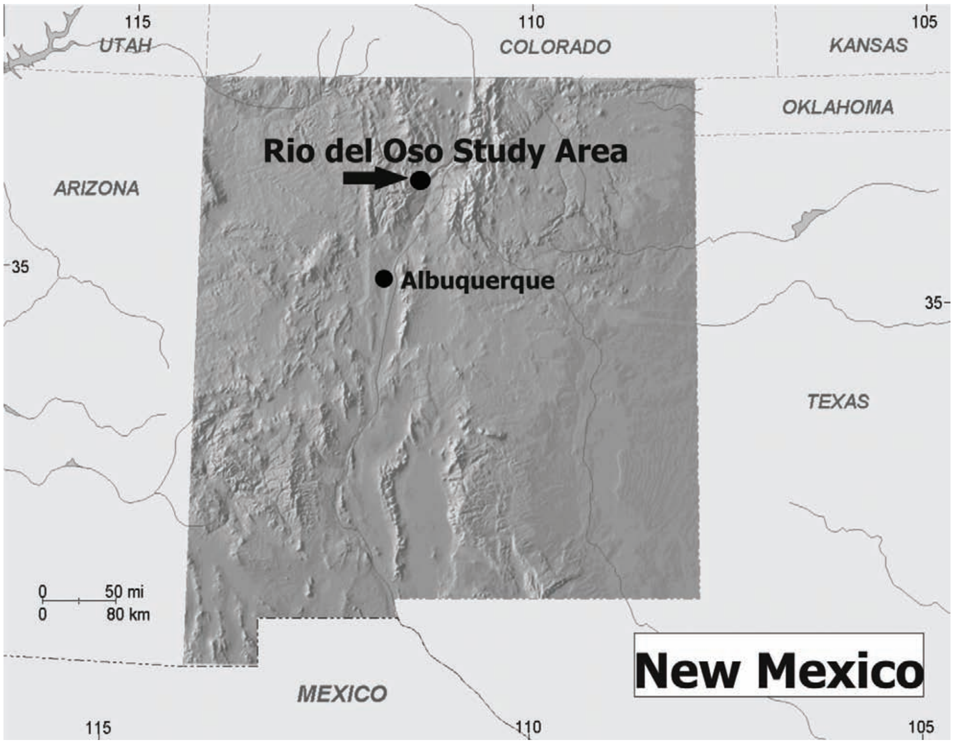

Figure 1. Rio del Oso study area, northwest of Santa Fe, New Mexico.

produced the landscape models using Visual Nature Studio (3DNature). The landscape models are organized by economic strategy, i.e., hunting and gathering, Puebloan horticulture, Spanish colonial and Mexican era subsistence ranching, and post 1850commercial grazing. I construct the landscape models taking into account the ways in which each strategy may have affected the landscape through time. During the Archaic period (5500 B.C. to A.D. 600), vegetational change in the Rio del Oso was likely driven by a combination of climatic conditions, lightening fires, and human activity including burning to increase desired resource production. Fire and disturbance-related vegetation was common. This past landscape was dominated by grassland, with juniper densities ranging from approximately 0.5 tph (trees per hectare), to less than 2 tph, with less per-hectare density of pine in the lower drainage. During this period, the sedimentation rate was between 4.5 and 8 centimeters per century. The high incidence of late Archaic period microscopic charcoal, consisting of a high percentage of 10 to 25 micron particles, suggests the burning of grassland on a landscape scale (Periman 2001). These smaller particles represent airborne particulate from landscape-level fires; while large particles indicate localized fires (Clark and Royall 1996, Delcourt and Delcourt 1996). Interestingly, there is a lack of archaeological evidence for the period from A.D. 600 to 1200.

During the Puebloan period (A.D. 1200 to 1600), the Rio del Oso floodplain was at least 5 to 8 meters higher than current levels, and the frequency of Puebloan archaeological sites in the valley is the highest of any period. Archaeologists have recorded 237 sites with a total site area of approximately 196 hectares. The fossil pollen record shows high levels of disturbance-related vegetation, and sedimentation rates increased to >14 centimeters per century. This increase in floodplain accumulation represents more than a doubling of the sedimentation rate from the Archaic period rate of 6.25 centimeters per century. From A.D. 1400 to 1765, the sedimentation rate increased to 16.42 centimeters per century (Periman 2001).

Landscape level fire in the Rio del Oso appears to have diminished between approximately A.D. 400 and1600. Pine and juniper densities were within the same range as they were during the Archaic period. The Puebloan landscape consisted of open grassland, dominated visually by a central village, with fields dispersed in the floodplain, and supplementary agricultural features on Pleistocene terraces (fig. 2). As the population of the centralized villages and surrounding areas grew, the creation of fields and frequently used trails increased the exposure of soil to wind and water erosion, and likely resulted in greater sediment deposition in the floodplain.

The Spanish period and subsequent Mexican period landscape, A.D. 1700 to 1848, differed greatly from its predecessors. Colonial documents from the eighteenth century reveal that by the 1730s, Spanish settlers lived in the upper portion of the Rio del Oso canyon (Periman 2001). Archaeological sites recorded from this period cover an area of 63 hectares. These communities imposed

Figure 2. Visual model of the Rio del Oso landscape during Puebloan period (ca.1400). The Landscape was dominated by grassland, with juniper densities ranging from approximately five trees per hectare, to two trees-per-hectare. The light patches in the middle ground are Anasazi agricultural fields.

an Old World model of subsistence farming and livestock grazing upon the Puebloan landscape. By doing so, the Spanish helped to create a composite landscape upon the ruins of the older, Puebloan land use systems.

Floodplain erosion began with the intensification of Spanish era ranching in the eighteenth and early nineteenth centuries. In the Rio del Oso valley, fire levels fell sharply and Spanish period juniper density increased to >10 tph, while disturbance vegetation, once utilized by Puebloan peoples, declined to levels below any period of the past 6,000 years. The alluvial record in the lower portion of the valley ceased aggrading, terminating after A.D. 1765. Although the valley floor had been stable for nearly 7,000 years, Spanish period erosion dramatically altered the Rio del Oso ecosystem. The meandering stream and riparian area became a hydrological system of braided channels. The remnants of the former floodplain are now arid, supporting mostly juniper and cholla cacti.

With the expansion of the cattle industry in the 1870s, severe erosion occurred in the Rio del Oso. Overgrazing caused massive decreases in vegetation cover, plant vigor, and the suppression of natural fires (Wozniak and others 1992). The floodplain, stripped of vegetation by grazing, became a labyrinth of arroyos when seasonal rains returned, following prolonged drought during the latter part of the nineteenth century. Presently, the Rio del Oso landscape has juniper densities of >50 tph, and pine densities of 15 tph (fig. 3).

My research of human land use and fire in riparian ecosystems has expanded to other areas in New Mexico, and the mountainous, forested landscapes of western Montana. The Rio Puerco study area, in New Mexico, was occupied for at least 10 millennia, as indicated by numerous archaeological sites. Soil thin section microscopy of samples collected from the Rio Puerco show that successive fires within riparian ecosystems, over approximately 7,000 years, have helped shape geomorphology and ecology through time. Thin section analysis of in situ burned sediments show that intensive fires, with high fuel loading, have changed soil structure in what was once a rich riparian habitat. I have found riparian fire events preserved in stratified sediments, which show periodic fire over thousands of years. In June 2004, I discovered a hearth in sediments upstream from one sampling area. Charcoal from this feature was dated to a conventional radiocarbon age of 2170 BP (Beta – 196423). Although not directly associated with individual, large-scale riparian fire events, this type of archaeological evidence places humans in the area, using fire, during a period with frequent riparian fires (Billmoro 1993).

My research focuses on the local, landscape scale. Such studies can illuminate understanding of large, global

Figure 3. Today, the Rio del Oso landscape has juniper densities of >50 trees per hectare, and pine densities of >15 trees per hectare. The valley bottom has eroded 6 to 8 meters below the level attained at the end of Puebloan occupation.

scale, human-caused environmental change. Preindustrial burning of vegetation within watersheds added carbon to the atmosphere. Geoarchaeological analysis indicates that fire was one of the main tools that shaped vegetation patterns and soils. Regions are made up of such landscapes. The Anthropocene begins to emerge when we consider human-environmental activity at a local level, compounded by thousands of years, affecting vast areas of interlocking landscapes. Such change would have a lasting geological effect on a given area.

The physiographic alteration of soil and geomorphology, through successive land use, creates a human defined landscape. The cumulative and geographic expansion of such physically changed areas instigated the Anthropocene.

Human Perceptions and Communicating the Past

Although humans have had an effect on greenhouse gases for thousands of years, human-induced environmental change continues to take place on a local, landscape level. Localized activities, such as burning a landscape to provide better grazing for livestock, inject carbon into the atmosphere; clearing land to grow wetland rice produces methane. Cumulative land use, the repeated application of fire for example, can potentially change the physical structure of soils and their biochemistry (DeBano and others 1998:78). Over time, this type of influence would affect ecosystems at a landscape level. The local landscape may be the common scale at which humans change the Earth. In a sense, we can see the Anthropocene at the scale of human experience, the scale of landscape.

Within the ideology of ecological restoration is the goal of returning natural ecosystems to conditions resembling those of the past (Society for Ecological Restoration 1993). Ultimately, an understanding of a landscape's historical processes and changing ecological dynamics applies to present management of environments. Ecological cycles, although of central importance in landscape dynamics, represent only one dimension of understanding. Human influences tend to change the developmental trajectory of ecosystems (Winterhalder 1994:29-30).

A holistic understanding of human-environmental interactions is applicable to natural resource management, planning future conservation, and economic development. Environmental archaeology can describe ecological conditions that existed before people "overgrazed the land, put out all the fires, and liquidated most of the old-growth trees" (Covington and Moore 1994:45). The accumulation of excellent archaeological data can provide a way to visualize how layers of a cultural landscape fit within the ecological matrix of the floodplains, terraces, and mesas of a specific area.

Monitoring the environment implies visualizing; conflict over environmental issues often forms over how we see the past. There is a growing need for effective ways to communicate environmental planning and information to non-expert participants, and improving the quality of land management (Bishop 1994:61; Orland and others 2001). Groups often hold disparate beliefs about the environment, how it should look, and be used or managed. This extends to how we may envision an ecosystem's history, its present condition, and thus, its future. People often imagine past landscapes as idealized, preindustrial, pristine, and uninhabited. This view is contradicted by the complex archaeological record of thousands of years of human-environmental interactions throughout the globe (Baker and Biger 1992). The computer-generated visualizations of past landscapes, as depicted in the Rio del Oso study, create a common reference at the local scale. Using such methods to communicate past environmental conditions provides managers a greater range of choices for management.

Monitoring the Anthropocene

We can identify extensive and cumulative changes at local and regional scales, regardless of when humans began to affect the global atmosphere. Although we may be witnessing accelerated anthropogenic climate change today, humans have altered and managed landscapes through millennia. Successful management implementation, with the goal of sustained ecological health and resource production, is simply part of the continuum of human interactions with environments. Effective management decisions need to be depicted and implemented at the same landscape scale that our ancestors encountered when they were hunters and gatherers. Although large-scale industries significantly affect greenhouse gasses, carbon sequestration, habitat rehabilitation, and resource production can only be implemented on a given number of hectares at a time. Management decisions may be made on national, or even continental, levels, but making positive change begins with localized activity. Computer-aided visualization techniques help us view and monitor the Anthropocene. Studying how people have interacted with, altered, and created landscapes through time enhances our understanding of the Anthropocene's complex dynamics.

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Globalization Then and Now: Increasing Scale Reduces Local Sustainability

Joseph A. Tainter, Project Leader, Cultural Heritage Research, USDA Forest Service, Rocky Mountain Research Station, Albuquerque, NM

Abstract—*One consequence of globalization is that parts of the world that were once remote and minimally influenced by broader political and economic developments now find themselves profoundly affected by forces beyond their comprehension. Communities that were once self-sufficient and resilient come to depend on larger systems, no longer control their own destinies, and confront adverse environmental changes. Such local consequences result from changes in the vertical scale of political and economic integration. While the term globalization is much used today, the processes vand consequences of globalization have been evident in human history for some time. This paper presents case studies of the effects of distinct episodes of globalization on historical and contemporary societies. Analyses of Epirus, Greece, and northern New Mexico show how disjunctures in scaling between information and power reduce local resiliency and sustainability. Changes in the scale of problems affecting localities impose a requirement for corresponding changes in the scale of environmental information that local community's process.*

Few matters seem more important today, or more urgent, than the issues of sustainability and resiliency in social and biophysical systems. One problem in addressing such issues is the change in scale that occurs when local people become embedded in larger systems at the national and international levels. Today we consider this to be part of the phenomenon termed "globalization," a process that has widespread and lasting consequences. Globalization is not, however, a recent phenomenon. It has been part of the human experience since people began long-distance trade, and it has influenced the evolution of ecosystems for an equally long time. Episodes of globalization have social and environmental repercussions that may last centuries. Globalization produces consequences so far dispersed that the connection of cause and effect may be difficult to perceive.

While material and economic flows are its essence, globalization subtly influences the flow of information. A periphery incorporated into a global economy experiences change in the scale of economic and political relations, but the information pool remains primarily local. Not only do local populations lose autonomy, they may not know that they have done so. Being unaware of larger forces that affect them, local societies lose control of their destinies. As local autonomy disappears, dependency and environmental deterioration follow.

This disjuncture of scale became apparent when I read Sander van der Leeuw's (1998; van der Leeuw and others 2000) and Sarah Green's (1995, 1997a, 1997b, Green and others 1998, 1999) descriptions of historical changes in Epirus in the northwest of Greece. In both structure and process, they could have been describing changes with which I was familiar in my home state of New Mexico. How could such distant and unrelated places have experienced changes so parallel that their descriptions are almost interchangeable? The answer, I suggest, lies in the disjuncture in scaling of economic, political, and informational relations in world systems. This disjuncture has implications for how the relationship between global and local processes may be managed in the future.

Figure 1. Location of Epirus, Greece. Illustration by Joyce VanDeWater.

Epirus, Greece

Epirus has long been one of the most remote and inaccessible parts of Europe (fig. 1). This marginality derives from the mountain terrain that made travel difficult before paved roads. Epirus began to change substantially after World War II. In the aftermath of the civil war of 1946-49, upland cereal cultivation and most vineyards were abandoned. As gardens were abandoned, the fields were turned to pasture, and animal husbandry became dominant. Economic conditions forced workers to emigrate during the 1960s. Then from the late 1960s through the late 1970s many development projects were implemented, focusing on drainage, mechanized farming, electricity, paved roads, and irrigation.

Greece became a full member of the European Union in 1981, and thereafter the E.U.'s Common Agricultural Policy affected the region. Commercial agricultural production has greatly increased on the plains, while economic production has declined in the mountainous areas. There has been a steep reduction in transhumant pastoralism, and subsistence farming has sometimes been abandoned. Many young Epirotes immigrate to urban areas for work. Mountainous regions now have small, ageing populations, who live substantially on government pensions. Many who work elsewhere maintain a house in ancestral villages, to which they go during festivals and holidays, or for retirement. Some of these returnees cultivate vegetable gardens in the villages, using the land in a manner that Sarah Green characterizes as "suburban" (Green and others 1999: 10).

The transhumant pastoralist economy maintained mountain vegetation as a combination of woodlands and open meadows. With the decline in pastoralism and prohibition of burning, the mountain vegetation changed rapidly. Many areas have become overgrown with scrub vegetation. The higher elevations are now largely closed off to herbivores. Epirotes consider this a degradation of their landscape.

Epirote villages were formerly isolated and closed, most corporate activities were consensual, and knowledge was homogenous. There were few social, economic, or technical differences among people. As one informant described the situation, "Everyone knows everything about everybody else..." (Green 1995: 271).

As Sander van der Leeuw (1998) has described, substantial changes occurred since roads were introduced after World War II. The information pool began to differentiate. Villages acquired headmen, who now serve as intermediaries with the external world. Wage-earning brought social and economic differentiation. Cash became increasingly important, and people are stimulated to acquire material goods. In such a situation, "progressive" and "conservative" factions inevitably develop. There are now conflicts between personal and social interests. No longer does everyone know everything about everybody else.

Upon joining the E.U., Greece became a candidate for development projects. Incorporation into the E.U. brought new directions with the development funds. One E. U. program concerns the preservation and development of "marginal" areas.

The E.U. approach has been to "...focus on protecting, conserving or preserving what was increasingly seen as a 'natural wilderness' containing 'traditional' village settlements" (Green and others 1999: 49). The E. U. sought to develop the cultural heritage of mountainous areas by emphasizing eco-tourism, attracting visitors to an area of "unspoiled" natural beauty.

The E.U. program, in turn, influenced the Greek national administration. There is now greater concern to protect the environments of remote areas. Several national parks have been established, including one in Epirus, and they bring new regulations. One cannot graze animals within the national park, nor can one dig, drill, or build outside village limits. There are further bans on camping or lighting fires within the forests, on swimming in the rivers, and on clearing areas for cultivation.

These new restrictions generate predictable conflicts between local people and administrators. Projects have become enmeshed in village factionalism, with some residents favoring conservation and others preferring the development of better facilities and services. Among the new regulations, houses must be built of "traditional" local materials. These materials are now expensive, but no longer freely available. Those who can afford to build in such materials are ex-residents who return seasonally to the villages with savings from urban employment.

Older residents did not see the landscape as an external, objective entity, but as the place in which they live, and of which they are a part. Now Epirus is presented dialectically as the converse of the urban environment. The environment is to have its architecture and cultural practices frozen in an "original" traditional form, while the landscape is to be kept, or even made, "natural" by removing the local people and their traditional activities. The people and the landscape are marketed to those who travel to experience "authentic," indigenous places.

Once initiated, E.U. projects become part of local social, political, and economic relations. On the local level, E.U. projects are not about heritage tourism or protecting the environment. A successful project from the Epirote perspective is one that has become enmeshed in social relations. It is important to involve many people, and have them benefit economically. This appears to Brussels as corruption.

In the urban ethos, culture happens in villages and during festivals, while nature is the wilderness outside villages. To the local opponents of E.U. projects, the "wilderness" that is to be preserved is seen as grazing lands, sources of wood, and fields, even if disused and overgrown. The removal of human activity from the landscape, in turn, diminishes cultural heritage.

As local self-sufficiency declined, the region has become dependent on the commercial economy and the government. Becoming embedded in larger systems has meant a transformation from autonomy and self-sufficiency to dependency and environmental deterioration.

Northern New Mexico

Spanish explorers of New Mexico found Indians living in settled villages they labeled "pueblos." These were soon joined by Hispano farmers. The last to arrive is the group known locally as Anglo-Americans. This discussion emphasizes the Hispanic settlers of New Mexico, and the consequences of their absorption into the United States.

Beginning in the 17th century, the economic basis of colonial New Mexico was provided by a system of granting lands to both Pueblos and Hispanos (fig. 2). New Mexico was administered stintingly as a missionary obligation. There was little money and few firearms. Priests were in short supply, and visitors commented adversely on the way that ceremonies were performed.

Colonial New Mexico was one of the most distant outposts of the Spanish world empire. Metal was so scarce that plows were tipped in wood. Archaeological sites show that some colonists experimented in making stone tools, at which they were not adept (Chapman and

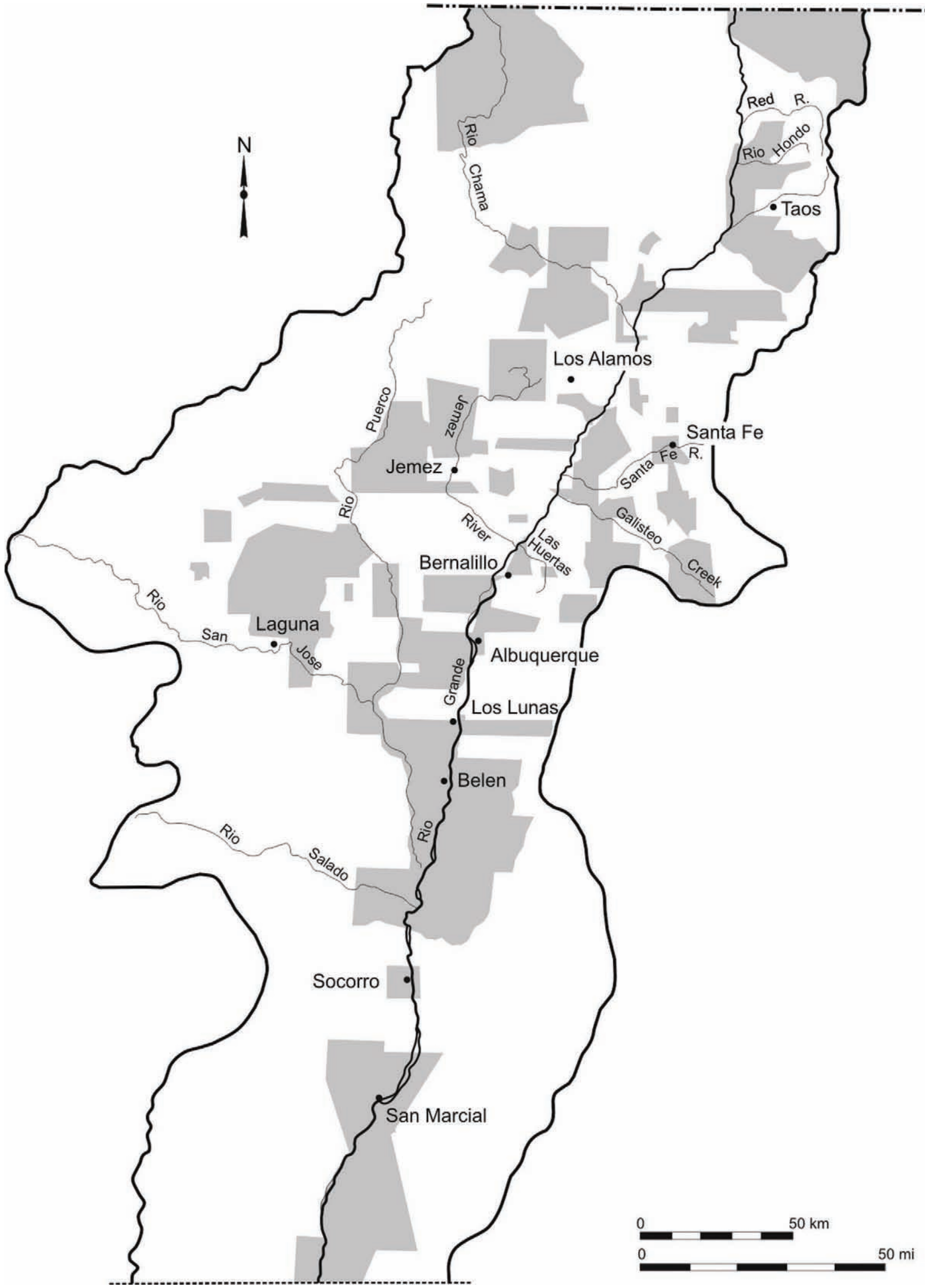

Figure 2. Land grants of the middle and northern Rio Grande basin (after Scurlock 1998: 111). Illustration by Joyce VanDeWater.

others 1977). Houses contained no furniture except that produced locally. Books and schooling were rare. As early as 1776, a visiting priest found the local language to be full of archaicisms and hard to understand. During the period of Mexican independence, New Mexico was referred to as Mexico's Siberia (de Buys 1995).

Within land grants, individual houses and fields were privately owned. If the grant contained suitable river valley, each settler would have a strip of land extending linearly from the river to the main ditch. These lands were divided among a farmer's sons, so that Hispano fields became renowned for their narrowness. Beyond the cultivated lands lay the commons, used for grazing or timber cutting. Depending on terrain, there might be high mountains beyond the common lands.

With independence, Mexico opened its borders, and American traders descended on Santa Fe. They brought manufactured goods, which soon began to transform New Mexico. To obtain such goods took surplus production and cash. When war broke out in 1846, New Mexico quickly became part of the United States.

Two institutions united rural New Mexico: the church and the irrigation system. Since colonial New Mexico lacked governing institutions at the local level, ditch associations are to this day often the only local government. Villages were organized by kinship and cultural uniformity. Many villages are isolated, gaining paved ingress only in the 1960s, and telephones and television in the 1970s. Everyone in a community had personal knowledge of everybody else (Harper and others 1943, Horvath 1979, Kutsche and Van Ness 1981, Rivera 1998).

Hispanic villages' poverty shielded them initially from the full force of the Anglo-American economy. Without schools, English penetrated slowly. Village land, however, was vulnerable. Land grants had to be confirmed in American courts. At first the villagers understood little of the new judicial requirements, and were unaware that their lands might be in jeopardy. Soon lands started to be lost for failure to pay taxes that villagers did not know they owed. Sometimes Hispanos continued to occupy these places, unaware that they had lost ownership years before. Lawyers who were retained to establish the claim to a grant could only be paid with part of the same land. Lands beyond the grants that had been available for anyone's use became public domain.

As the land base shrunk, Hispanos lost the ability to produce sufficient food. They were pushed off large tracts of pasture. Men had to leave villages to work on the railroads or in Colorado mines. More and more became dependent on contractual sheep-raising (de Buys 1985, Rothman 1989).

Loggers cut the timber from thousands of hectares of forests, with no thought for regeneration. These lands became an early target for scientific management when the Forest Service was established in 1906. The largest timber-cutting operation exemplified how quickly New Mexico had become integrated into the world economy. It was undertaken in response to the building of the Panama Canal. To remain competitive, the railroads decided to increase speed and efficiency by laying a second set of tracks. The operations to produce the 16 million railroad ties logged every suitable stick up to the tree line.

Anglo-American ranchers soon overstocked the grasslands. Drought in the 1890s precipitated erosion that is still underway. An area such as the Rio Puerco Valley was largely abandoned when the Rio Puerco itself became deeply entrenched. Topsoil was washed away, and grasses could not grow as quickly as they were grazed. Woodlands extended downward in elevation, into former grasslands (de Buys 1985, Rothman 1989).

As the environment and traditional economy of New Mexico deteriorated, the Hispanic and Indian cultures and the area's natural beauty attracted artists and intellectuals. In small, communal villages they believed that they would find to antidote to urban life. The artists and intellectuals understood that Hispanic village culture could not be preserved without an economic basis. Their solution was that Hispanos would become artisans and craftsmen. They would produce "traditional" arts and crafts for a burgeoning tourist market. An idealized version of traditional architecture became the norm in Santa Fe and elsewhere. "Traditional" festivals were created anew for Santa Fe and Taos.

In the Great Depression, many New Mexicans survived on government relief. Today many Hispanos rely on government subsidies, commute to jobs in cities, or have moved to cities. They may return to the home village for weekends and holidays. For those who remain in the villages, or maintain close ties to them, there is perpetual struggle. Many keep small cattle herds, which must have a permit to graze on the Forest Service land that Hispanos still consider theirs. The Forest Service regulates access to all resources on its lands, including the timbers needed for traditional construction. The region continues to receive funds for development, but projects become socially embedded, and part of both kin relations and local politics. Contracts are frequently given to relatives, qualified or not, leading to charges of corruption.

There is conflict with a new adversary, environmentalists. This conflict concerns the environmentalist value of using forested lands little or not at all, and the Hispanic tradition of using forest resources as necessary. Affluent environmentalists know how to impede agencies such as the Forest Service. The villagers, who still depend on the forests for such vital needs as winter firewood, are reduced to asserting heritage, identity, and traditional rights (de Buys 1985, Forrest 1989, Rodriguez 1987, Raish 2000).

Summary and Discussion

Epirus and New Mexico are separated by history, geography, and tradition. Yet they display congruence in structure and process, in form and substance, and even in such minute details as the encroachment of woodlands into former grasslands, and the relationship of traditional architecture to national land management policies (table 1).

In both regions, formidable terrain and economic marginality kept villages isolated, closed, autonomous, and self-sufficient. The pool of information was homogenous, and everyone knew everything about everybody else. Environments were maintained to support the subsistence regime. In both areas, the end of isolation brought manufactured goods, so that self-sufficiency declined and cash became increasingly important.

Life within villages began to differentiate. Men emigrated to find work. People acquired new information about the larger world, and about opportunities and ways of doing things. Village information pools lost homogeneity. It was no longer possible to know everything about everybody else. Communities bifurcated into "progressive" and "conservative" factions. Personal and group interests began to conflict.

As traditional subsistence practices declined, the biophysical environment lost the capacity to support such practices. Fire stopped being used to control vegetation. In both places there has been growth of undesirable woody plants, and increased erosion.

Many people now survive on government subsidies. Traditional cultural practices have become difficult to maintain in the face of "modernity," and without an adequate economic base. Upland forests and lands are now controlled by national governments. There is frequent conflict between villagers and land managers. Traditional resources are now regulated or proscribed by national policies. Traditional architecture is either encouraged or mandated, yet there is no longer free access to the raw materials that it requires, and many cannot afford to buy such materials. In both regions, émigrés return for holidays and other special occasions, and use ancestral villages in a manner than can be labeled "suburban."

Outsiders are concerned to preserve the natural beauty and cultural traditions of both regions. External organizations promote projects to integrate economic development with preservation. The natural beauty and cultural heritage of both areas are now marketed by urban residents to other urban residents. The landscapes are to be managed to match an urban conception of nature. Heritage is to be preserved rather than lived. Divorced from its connection to land use, cultural heritage is to be expressed as craft products and performances. Development projects become socially embedded within each region, which outsiders consider corruption. In response to outside pressures, both regions are developing explicit manifestations of cultural identity that mobilize local people even as they reinforce stereotypes.

The parallel transformations in Epirus and New Mexico arose from these regions becoming enmeshed in commercial systems, and controlled by national governments that are themselves embedded within larger systems. For places like Epirus and New Mexico, the scale of their economic and political contexts has grown from the locality to the national government, and to the international community. The scale of information has not kept pace with these developments. In this regard, Epirotes and New Mexicans are like people everywhere. Their scale of information is local. The information that

Table 1. Aspects of Convergent Evolution in Epirus and New Mexico.

1. Remote areas incorporated into world economy.
2. Villages differentiate socially, economically, and in information pool.
3. Emigration for work.
4. Progressive and conservative factions develop.
5. Traditional subsistence practices decline.
6. Environment loses capacity to support traditional economy due to decline in human maintenance.
7. People depend on government subsidies.
8. Traditional culture becomes difficult to sustain.
9. Upland forests controlled by national governments.
10. Traditional resource use limited or proscribed.
11. Young adults return to villages for holidays.
12. External organizations promote preservation of landscapes and cultural practices.
13. Culture divorced from land use; fossilized as crafts and performances.
14. Natural beauty and cultural heritage marketed by urban residents to other urban residents.
15. Landscapes managed to match urban conception of nature.
16. Development projects socially embedded.
17. Increasing expression of ethnic identity.

matters is that which pertains to local affairs: community, politics, employment, government services, and the like.

In an age of globalization, this inclination to value local information conflicts with the scale of events and processes that affect localities. There is, for example, much concern in New Mexico about water. In 1998 I challenged participants in a conference to consider the connection between irrigation agriculture in the Rio Grande Basin and the East Asian economic crisis that was then underway. The connection is through Intel Corporation's chip manufacturing plant near Albuquerque, which uses great quantities of water. To the extent that the East Asian economic crisis might cause Intel to reduce its output of chips, and thus to use less water, it could be possible to perpetuate irrigation as well as the cultural traditions that are linked to it (Tainter 1999). Today, in updating this analysis, we would wish to explore the connections among irrigation agriculture, Intel's manufacturing output, and the SARS virus. The lesson is that unless New Mexicans, Epirotes, and other local people become knowledgeable about the full range of factors that affect them, they will continue to be vulnerable to distant processes, and to those who profit from their ignorance.

One implication of this discussion is that local social and environmental problems that arise from processes at the national and international levels must in part be addressed at those same levels. If globalization is the source of a local problem, then addressing only the local manifestation will likely prove ineffective and frustrating. Land managers, and land-managing agencies, who address only the local manifestations of large-scale problems, will probably fail. The broader context will simply continue to generate the problem.

A common exhortation of the environmental movement is to think globally but act locally. The problem we encounter is that most people do not think globally. In our history as a species there has never been selective pressure to do so. The question facing those affected by globalization is: How do we change a behavior pattern that is so ingrained, and that previously conferred survival value?

Perhaps a radical change in how people think could be accomplished through the education system. There would need to be programs to teach children, starting at a young age and continuing through all levels, to think about systems and interconnections at all scales. Students would be trained to consider global processes that affect local viability, whether a new virus, the economy of far-off lands, or distant political upheavals. They would be taught to think at all scales, to be curious about things that are distant in space and time, and to sense connections that are not obvious. It would be an attempt to make thinking about the connection of the global to the local so ingrained that, within a generation or two, it becomes normal and unremarkable. As the populace comes to think more broadly, politicians, business leaders, and managers would learn, and be expected, to do so as well. Journalists, sensing new needs and new opportunities, would also explore global connections.

This proposal is, of course, not a panacea. Not all people would be inclined to pursue global analysis, although it is still worthwhile that they be familiar with it. Among those who are so inclined, the understandings they develop will often not be accurate. Yet all that would be required is for enough persons to implement their training in global thinking to lead the rest. Intermediaries would emerge who would facilitate the transmission of global information to local communities. Books, magazines, and television broadcasts, showing the connection between global and local, would expand in response to an increased market.

This idea is radical, utopian, and perhaps unrealistic. Yet today's globalization demands that we attempt something like it. The only certainty is that failing to try such a course will condemn many places to follow Epirus and New Mexico down a bewildering slide into poverty, dependency, and environmental degradation.

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Natural Processes and Impacts

Assessment and Monitoring of Forest Ecosystem Structure

Oscar A. Aguirre Calderón, Facultad de Ciencias Forestales, U.A.N.L., Apartado Postal 65, 67700 Linares, N. L., México
Javier Jiménez Pérez, and Horst Kramer

Abstract—*Characterization of forest ecosystems structure must be based on quantitative indices that allow objective analysis of human influences or natural succession processes. The objective of this paper is the compilation of diverse quantitative variables to describe structural attributes from the arboreal stratum of the ecosystem, as well as different methods of forest inventory to obtain such indices.*

For the evaluation of the species structure the indices of Shannon H′ and species profile A, segregation S of Pielou and the species mingling index Mi are discussed. The aggregation index R of Clark & Evans and the contagion index Wi, were included in order to describe the horizontal structure of the ecosystem. Finally, for the characterization of the dimensional structure, the homogeneity coefficient H and the indices of diameter differentiation TDi and height differentiation THi were analyzed.

Introduction

One of the aims of the forest management is the search for new inventory and planning methods of the forest ecosystems, particularly in an era in which discussions on the conservation and promotion of biodiversity are rivaled, by the increase in the demand of forest products. A gradual transformation of medium- and long term silvicultural policy is taking place with the abolishment of even-aged pure forests and a greater preference of uneven-aged mixed forests. For such ecosystems indices that quantitatively characterize the structure and diversity are required. Uneven-aged forest management has become an important factor significantly influencing forestry research. The challenge is to obtain the new indicators of sustainability of forest resources.

The indices for characterizing the structure and diversity of the ecosystems allow a better reproduction of the condition of the forest in a given moment and of its evolution in time. Such indices would have to be considered in addition to conventional variables such as diameter, height, basal area, volume, age, and density, in order to achieve a better description of the stands.

The objective of this work is to discuss variables for the quantitative description of the structure and diversity of forest ecosystems. The characterization levels considered include species diversity and structure, spatial structure and the dimensional diversity of the ecosystem. Case studies results of the application of such indices in Mexican forests are presented.

Species Diversity and Structure

Index H′ of Shannon

The Shannon index (Shannon 1948) is one of the most employed variables for the estimation of species diversity; for its determination is employed the formulation:

$$H' = -\sum_{i=1}^{s} p_i \cdot \ln(p_i)$$

S = number of present species
p_i = proportion of the species $p_i = n_i / N$
N_i = number of individuals of the species i
N = total number of trees

As an example of the application of this index the following types of ecosystems with different species composition are presented. These conditions were found in forest ecosystems in the Federal State of Nuevo León, Mexico:

- 100% *Pinus pseudostrobus*; H' = 0.00
- 80% *P. pseudostrobus*, 20% *Quercus rysophylla*; H' = 0.50
- 50% *P. pseudostrobus*, 20% *Q. rysophylla*; H' = 0.69
- 70% *P. pseudostrobus*, 20% *Q. rysophylla*; 10% *Juniperus flaccida*; H' = 0.80

The value H' increases according as a greater number of species occurs and the individuals proportion of the species is more homogeneous. H' depends not only on the number of species present in an ecosystem, but on the frequency with which they are represented (Pommerening 2002).

Species Profile A

To characterize the vertical structure of the species of a forest ecosystem, Pretzsch (1996) based on the index of Shannon, developed the variable profile of species A:

$$A = -\sum_{i=1}^{s} \sum_{j=1}^{z} p_{ij} \cdot \ln\left(p_{ij}\right)$$

S = number of present species

Z = number of height strata (3 in this case)

P_{ij} = proportion of species in the height strata

$$p_{ij} = n_{ij} / N$$

n_{ij} = number of individuals of the species i in the zone j

N = total number of trees

Pretzsch defines three strata for the application of the index A; stratum I comprises from 80 percent to 100 percent of the maximum height of the trees; stratum II 50 percent to 80 percent and stratum III 0 to 50 percent.

Differing from the index of Shannon, index A characterizes the location of the species in different height strata. A takes values between 0 and a maximum value A. A value A of 0 means that the stand consists of only one species that occurs in one sole stratum. A maximum is obtained when all of the species occur in the same proportion in the stand as well as in the different strata.

In an ecosystem constituted by 11 arboreal species, values of A = 2.07 and Amaximum = 3.50 were obtained.

Segregation Index S of Pielou

The segregation index S of Pielou (1961) describes the combination or mingling of two species, that is, the spatial classification of a species in relation to the other. This index is based on the ratio between the observed and the expected number of mixed pairs. To obtain it the species of all the trees of a given surface and that of their nearest neighbor is determined, obtaining the number of individuals of the species 1 and 2 (m, n), as well as the number of trees with neighbors of the same species (a, d) and neighbors of different species (c, b). The index S is obtained then as:

$$S = 1 - \frac{\text{observed number of mixed pairs}}{\text{expected number of mixed pairs}}$$

S is calculated as of the following data:
nearest neighbor
species 1species 2total
reference treespecies 1abm
reference treespecies 2cdn
vwN

through the formulation:

$$S = 1 - \frac{N \cdot (b + c)}{(v \cdot n + w \cdot m)}$$

S takes values of -1 to 1; -1 represents the maximum possible mutual attraction among the two species, 0 shows an independent distribution and 1 corresponds to the maximum possible positive segregation. Values of $S < 0$ mean an association between the species; $S > 0$ corresponds to a segregation, this is, spatial separation of the species.

In figure 1 two fractions of ecosystems with different distribution of the species are presented. In the area a) S = - 0.72, by it the species present an evident association; opposite to the foregoing, in the area b) with a value of S = 0.79, a clear segregation of the species is observed.

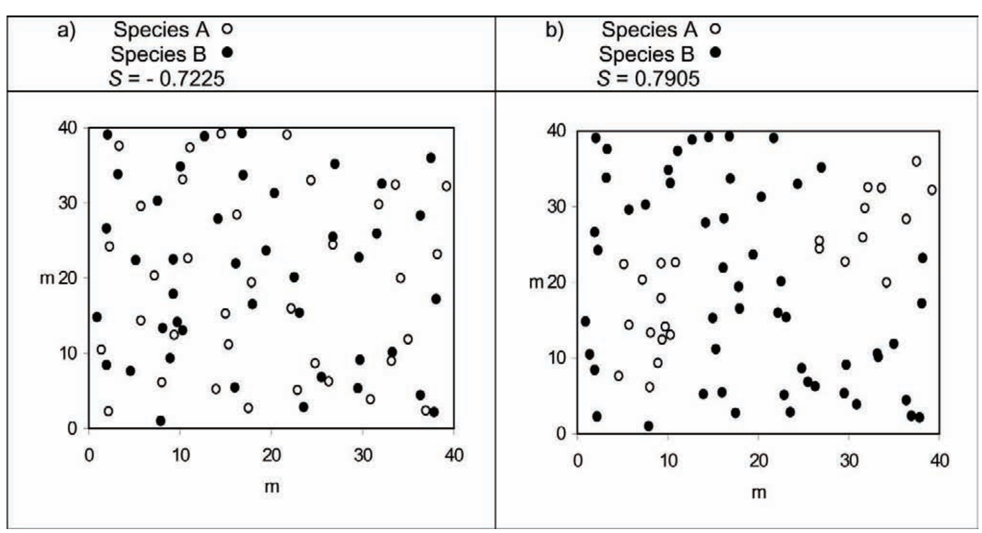

Figure 1. Index of segregation S of Pielou for two fractions of ecosystems.

Species Mingling Index M_i

The species mingling index M_i is defined for a reference tree and its four nearest neighbors as the relative proportion of neighboring trees of different species (Gadow 1999). This index was developed in order to avoid the limitation of the index of Shannon, which does not allow inferring information on the spatial distribution (vertical and horizontal) from the species. Forests with equal H' can present a very different spatial distribution of the trees.

The species mingling index is obtained from the function:

$$M_i = \frac{1}{n}\sum_{j=1}^{n} m_{ij}$$

m_{ij} takes a value 0 when the neighbor belongs to the same species of the reference tree; otherwise it has a value of 1.

Since small m_{ij} it is a discrete binary variable, capital M_i can take the following values:

0.0 when all the individuals of the group (five) belong to the same species;

0.25 when one of the neighbors of the reference tree belongs to other species;

0.50 if two of the neighboring trees belong to other species

0.75 if three of the neighbors of the reference tree belongs to other species and

1.00 if the neighboring four of the reference tree belong to different species

The middle species mingling value is calculated through:

$$M = \frac{1}{N}\sum_{i=1}^{n} Mi$$

N = number of trees in the stand

Figure 2 shows species mingling values for a stand of *Picea chihuahuana*, *Abies durangensis* and *Cupressus lindley* in the Federal State of Durango, Mexico. The mingling distribution of *Picea chihuahuana* shows that the species is surrounded by either three or even four neighbors that belong to a different species. In contrast, *Cupressus lindleyi* occurs in a variety of mingling constellations: either in pure groups (about 10 percent), in groups where half of the trees are *Cupressus lindleyi* (about 35 percent) and in groups where none of the neighbors is *Cupressus lindleyi* (about 10 percent). *Abies durangensis* does not form pure or almost pure groups, but occurs most frequently as a single tree among other species.

Spatial Structure

Index of Aggregation R of Clark & Evans

The aggregation index R of Clark & Evans (1954) describes the degree of regularity in the distribution of tree positions. This index is based on the relationships of distance between neighboring trees and, although widely used in botany and vegetation science, is rather unknown in the practice of forestry. It is simply calculated as the ratio between the observed and expected average distance for a random distribution between neighbouring trees:

$$R = \frac{\text{r observed}}{\text{r expected}}$$

R takes on a value of 1 if the distribution of tree positions is random and trends toward zero with increasing aggregation. The maximum possible value is 2.15. Values greater than 1 indicate increasing tendency to regularity.

The index of Clark & Evans is based on the relationships of distance between neighboring trees. For all the trees N of a surface A the distances r_i, i = 1. N to their nearest neighbor are obtained. The mean distance is calculated through:

$$\text{r observed} = \frac{\sum_{i=1}^{N} r_i}{N}$$

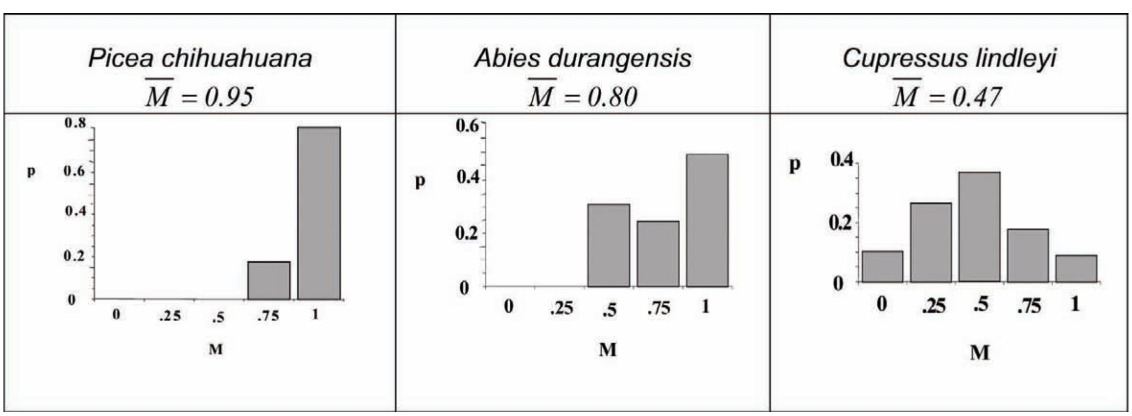

Figure 2. Distribution of the species mingling index in a mixed ecosystem.

r observed is related to the mean distance expected for the random distribution of the trees:

$$\text{r expected} = \frac{1}{2\sqrt{N/A}}$$

An example is presented in the figure 3, showing the distribution of the trees in fractions of two stands of pine-oak in Northeastern Mexico's. Stand a) has a value of R = 0.98, that indicates a random distribution of the trees. In stand b) R is 0.89, thus presents a distribution with trend to the conformation of groups.

Contagion Index W_i

The contagion index W_i (Hui and Gadow, 2002, Aguirre and others 2003) describes the regularity of the distribution of the neighboring trees to a reference tree. The determination of this index is based on the measurement of the angles between two neighbors of the reference tree and its comparison with a standard angle obtained through:

$$\alpha_o = 360/n \pm 360/10n$$

n = number of neighboring trees considered

The contagion index W_i is then defined by the proportion of the smaller angles α to the standard angle α0:

$$Wi = \frac{1}{n}\sum_{j=1}^{n} w_{ij}$$

w_{ij} has a value = 1 when the jth angle between two next neighboring trees is smaller or equal to the standard angle α0, otherwise it takes a value of 0.

If n = 4, W_i can present the following values:

0.0 if none of the angles is smaller to standard angle,

0.25 if one of the angles is smaller to standard angle,

0.50 when two of the angles α are smaller to standard angle,

0.75 if three of the angles α are smaller to standard angle, and

1.0 when the four angles α are smaller to standard angle.

The average value of the contagion index is calculated through:

$$\overline{W} = \frac{1}{N}\sum_{i}^{N} w_i$$

Values of $\overline{W}$ 0.5 correspond to a random distribution of the trees, those greater to this value represent a grouping trend. Smaller values indicate a trend towards regularity. For the ecosystems of figure 4 $\overline{W} = 0.53$ indicates a random distribution of the trees while $\overline{W} = 0.59$ corresponds to a trend to a grouping of the trees.

Dimensional Diversity

Homogeneity Coefficient H

The homogeneity of a stand can easily be described through the employment of the homogeneity coefficient (H) of De Camino. H is expressed through the percent relationship between number of trees and volume by diameter classes (De Camino 1976). In a totally homogeneous forest all the trees have the same volume; in heterogeneous one a high percentage of trees represent a small proportion of volume, while few individuals contribute with the greater proportion of the volume.

The homogeneity coefficient H is determined through:

$$H = \frac{\sum_{i=1}^{n-1} SN\%}{\sum_{i=1}^{n-1} SN\% - SV\%}$$

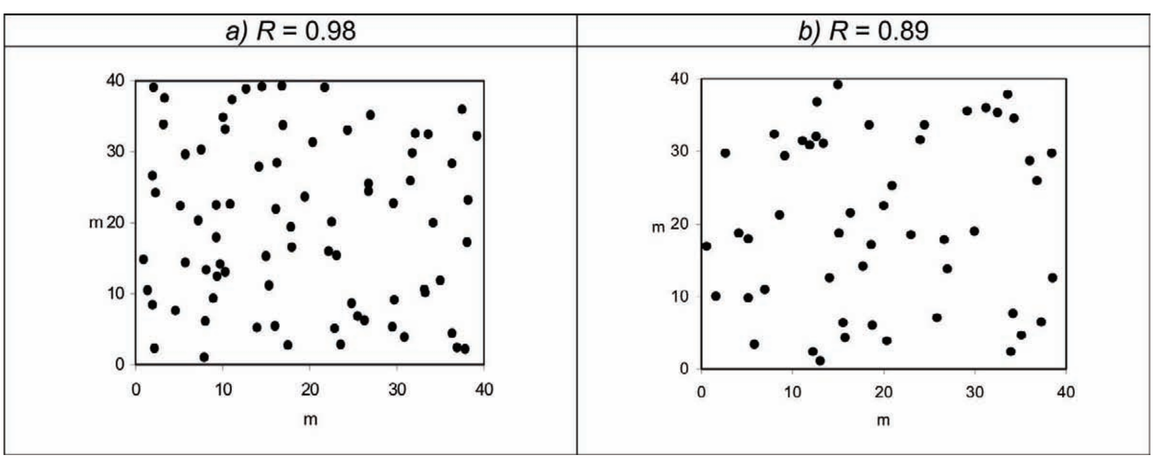

Figure 3. Index of Clark & Evans for two ecosystems with different horizontal structure.

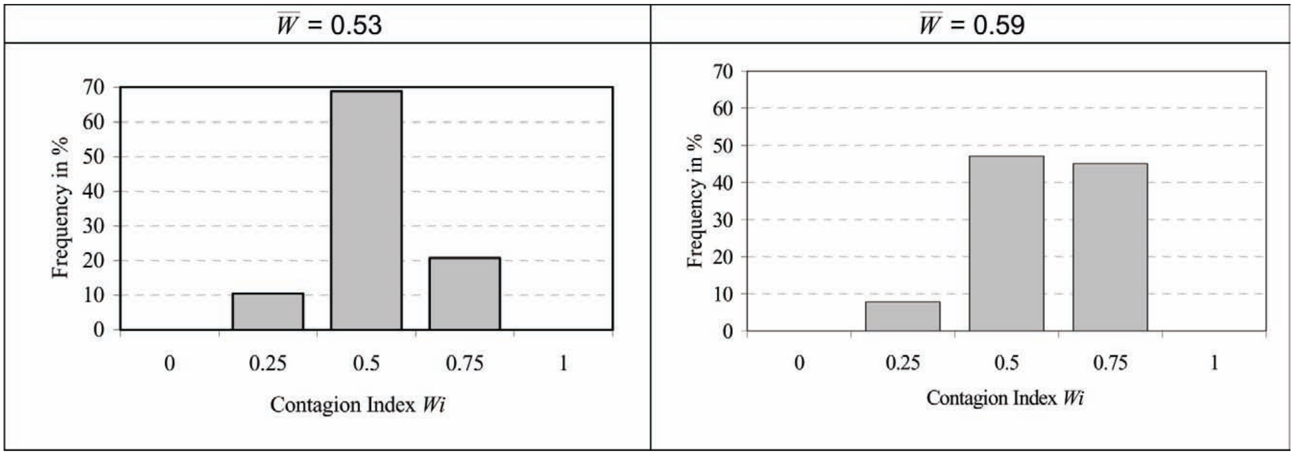

Figure 4. Distribution of the trees in the contagion index W_i, in two stands with different horizontal distribution.

SN% = sum of the percentages of number of trees to the diameter class i

SV% = sum of the percentages of volume to the diameter class i

Figure 5 shows the homogeneity coefficients (H) obtained in the unthinned and thinned fractions of a stand of *Pinus cooperi* and *P. leiophylla*, as well as the corresponding Lorenz curves. A greater homogeneity of the thinned area is observed here, the H value is greater (6.03) and the Lorenz curve is found accordingly nearer the reference line.

Dimension Differentiation Indices

The dimension differentiation indices describe the relationship between a given tree and its nearest neighbor and are defined by the quotient between a dimensional variable of the smaller tree and the corresponding of the bigger tree, subtracted form 1. The diameter differentiation TD_i, for example, is obtained through the function:

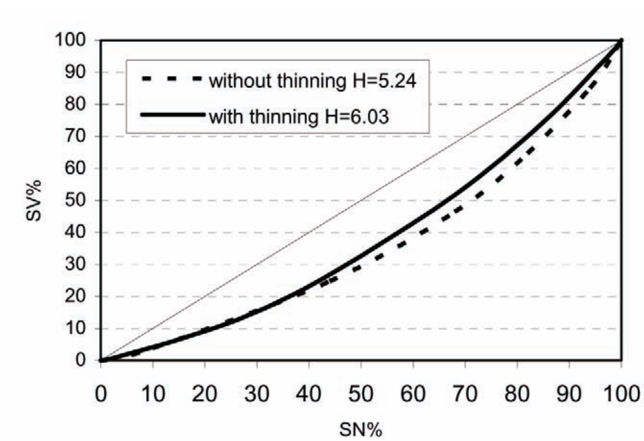

Figure 5. Homogeneity coefficients and Lorenz curve for the unthinned and thinned fractions of an ecosystem.

$$TDi = \frac{1}{n}\sum_{j=1}^{n} td_{ij}$$

td_{ij} is derived from the relationship of the diameters from neighboring trees deducted from 1:

$$td_{ij} = 1 - \frac{smaller\left(d_{1.3i}, d_{1.3j}\right)}{bigger\left(d_{1.3i}, d_{1.3j}\right)}$$

The middle diameter differentiation value is:

$$TD = \frac{1}{N}\sum_{i=1}^{N} TD_i$$

N = number of trees of the stand

A TD*i* value of 0 means that both trees have the same diameter. As the difference of the diameters increases, the value of TD*i* also grows.

Other dimensional variables may similarly be employed in addition to the diameter differentiation TD*i*. These would include, for example, the indices of height differentiation TH*i*, and of crown cover differentiation TKS*i* (Aguirre and others 1998, Jiménez and others 1998, Del Río and others 2003).

Figure 6 shows the distribution of the trees of a mixed forest in the classes of diameter differentiation 0.0-0.2, 0.2-0.4, etc. For *Pinus pseudostrobus* a greater proportion of the trees present a scarce diameter differentiation with respect to their neighbors (class 0.0-0.2); *Quercus rysophylla* shows a similar frequency, which has more than half of the cases with a diameter difference to their next neighbor smaller than 20 percent. *Juniperus flaccida* behaved differently in that the greater proportion of trees shows differences of diameter between 40 and 60 percent (class 0.4-0.6).

The frequency of height differentiation classes for the previous species is observed in here. P*inus pseudostrobus* presents smaller height differentiation that the rest of the species, about 60 percent of the trees has values smaller

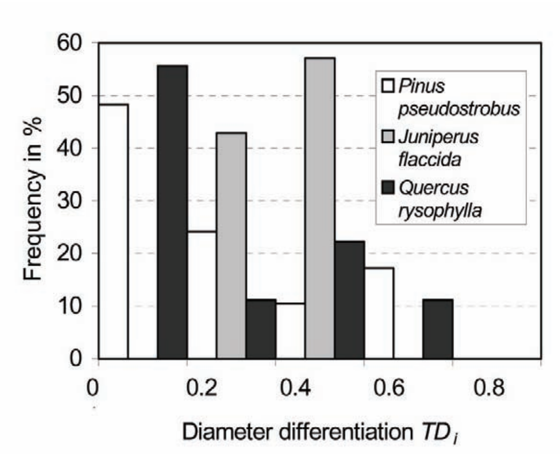

Figure 6. Distribution of the trees in the classes of diameter differentiation.

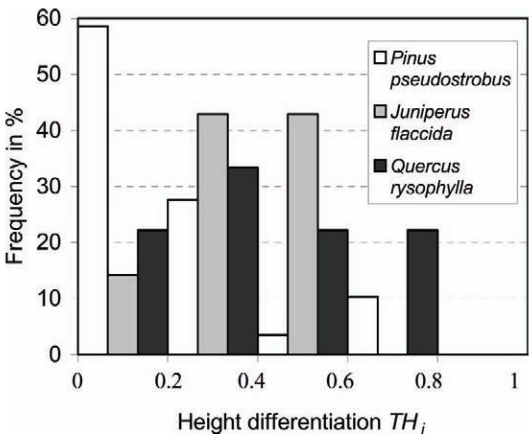

Figure 7. Distribution of the trees in the classes of height differentiation.

than 0.2 (fig. 7). In contrast to diameter differentiation, *Juniperus flaccida* showed a minor height differentiation, while for *Quercus rysophylla* the tree frequency in the class 0.6-0.8 is increased, this is, more than 20 percent of the trees showed a height differentiation greater than 60 percent.

Concluding Remarks

The indices considered in this paper constitute an alternative for the evaluation and monitoring of the structure and diversity of forest ecosystems on quantitative grounds. The application of such indices in an integral method of forest inventory allows a better description, reproduction and monitoring of ecosystems, as well as the development of indicators of sustainability of forest resources management.

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International Center for Himalayan Biodiversity (ICHB): Conserving Himalayan Biodiversity—A Global Responsibility

Ram Bhandari, Coordinator, International Centre for Himalayan Biodiversity, ICHB Secretariat

Biodiversity is a global endowment of nature. Conservation of biodiversity includes all species of plants, animals and other organisms, the range of genetic stocks within each species, and ecosystem diversity. Food, many types of medicine and industrial products are provided by the biological resources that are the basis of life on Earth. The value of the Earth's biological resources can be broadly classified as direct and indirect. Consumptive and productive uses are direct values, whereas non-consumptive uses and options for the future constitute indirect values. One of the most fundamental direct benefits of biological resources is in providing the world's food. Wild species have also provided many of our medicines.

Ensuring conservation of biodiversity is one of humankind's important global responsibilities. Consequently, biodiversity has become a growing concern of central significance to all sectors of society. In Chapter 13 of Agenda 21, adopted at the United Nations Conference on Environment and Development (UNCED 1992), mountains are defined as "storehouses of biological diversity and endangered species." This great wealth of biological diversity is attributed to the wide variety of environments in the mountains, particularly the Himalayas.

Hence, UNCED gave biodiversity an important place on the agenda. Over 150 states have now signed the Convention on Biological Diversity (CBD), which entered into force at the end of 1993. By 1994, several countries from Asia and Pacific had ratified the Convention. Nepal was the 34th nation in the world and the 14th nation in the then Asia–Pacific region to ratify the Convention, on 23 November 1993. The Convention is a framework agreement that allows individual countries to determine how most of its provisions are to be implemented.

The Himalayan region is the largest, highest, and most populous mountain chain in the world, and it is one of the world's richest ecosystems in terms of biological diversity. Extreme variations in altitude, aspect, geology, and soils over short distances have resulted in a wealth of natural ecosystems. The Himalayas are home to hundreds of endemic plant species and some of the world's rarest wildlife species. These rich biological resources have traditionally served as the foundation for the economic and cultural life of mountain people.

The Hindu Kush-Himalayan (HKH) region is host to the world's highest ecosystems. Extending over 3,500 km the region of different types of environments, these mountain environments are extremely rich in biodiversity because of the varied altitude, climatic conditions, geological-biophysical conditions, and soil formations. Historically, human interactions with mountain environments have further enriched biodiversity, in particular the distribution patterns of plants, animals, and genetic diversity. For example, a long list of medicinal materials can be found in the higher mountains, and these provide actual and potential benefits. This fact is illustrated by an annual fair held in Dali in Yunnan province, China, where as many as 550 species of medicinal herbs and hundreds of food plants are traded by the mountain people. The conservation of such biodiversity through sustainable use also improves the standards of living and the cultural diversity of the existing population. The botanical wealth of the Indian Himalayas and Nepal consists of more than 8,000 species belonging to 200 families; about 30 percent of the Himalayan flora is endemic. Nine thousand plant species have been reported in the virgin forests of Eastern Himalayas of which 3,500 or 39 percent are endemic to the region. The total number of species of plants in the Hindu Kush-Himalayan Region is estimated to be as many as 25,000 or 10 percent of the world's flora.

Human beings use the environment heavily. Projected population growth and economic activity will mean loss of biodiversity at a greater rate. Although biological resources are renewable, their overuse is usually associated with loss of biodiversity. Among the major threats are overexploitation of forest and vegetation resources for fuel, fodder, manure, grazing, fishing, and hunting, expansion of agricultural land for an ever-increasing population, and the practice of slash-and-burn agriculture in mountain regions.

Biological resources are deteriorating rapidly throughout the world, primarily because of unsustainable approaches used in human activities, leading to the following changes and potential impacts:

- A decline in biological diversity, as evidenced by accelerating extinction of species and the destruction, modification, and fragmentation of habitats and ecosystems at all scales.
- A decline in the health and functioning of ecosystems, as evidenced by biodiversity loss, degradation of air and water quality, and loss of soil.
- A decline in the quality of human life, as evidenced by increasing world poverty, disparities of wealth, and particularly conflicts over natural resources.

Need for Research and Action on Himalayan Biodiversity

Against this background, the Himalayan Resources Institute (HIRI) with its partners organized an "International Conference on Himalayan Biodiversity (ICHB-2003)" from 26 February 2003 to 28 February 2003 in Kathmandu, Nepal, on the occasion of the International Year of Mountains (IYM, 2002). The conference was attended by more than 200 research scientists, technical specialists, and resource managers involved in various issues related to Himalayan Biodiversity, representing more than 50 national and international organizations. Over 150 technical papers covering various fields of Himalayan biodiversity were presented by more than 50 national and international organizations and institutions from abroad.

The participants at the conference recognized that:

- The Himalayan range is a unique chain of mountains with fragile ecosystems and high endemic, rare, and endangered species of wild flora and fauna that fulfill basic daily needs for millions of people living in mountains and plains.
- These mountain ecosystems are largely neglected and are greatly threatened by human pressure.
- Exploration of flora and fauna and their habitats and mechanisms for maintenance of biological diversity are inadequate at present.
- Degradation and loss of biological diversity are at high levels.
- Appropriate approaches needed to address these issues are lacking, but recent developments (for example, large-scale conservation) appear positive.
- Traditional practices (forestry, agriculture) and indigenous technology are disappearing.
- There is a lack of coordination and communication among scientists and a lack of partnership among scientists, planners, and managers.
- A comprehensive Red Data Book is lacking.

There is a need for habitat mapping using geographic information systems and global positioning system techniques.

There is a lack of appropriate teaching curricula and infrastructure and research capabilities in the area of biotechnology to assign and use biodiversity for the betterment of society.

As a result, the Conference passed a series of resolutions in the ICHB-2003 Declaration.

Kathmandu Declaration of the International Conference on Himalayan Biodiversity

- Realizing the lack of effective implementation of earlier conventions and treaties (such as CBD, Kyoto, Johannesburg), this conference strongly demands that nation states in the region incorporate/translate the provisions of treaties and conventions into national legislation.
- This conference strongly recommends the creation of a Himalayan Biodiversity Database for the long-term research and monitoring of natural resources for sustainable development, including human dimensions.
- Realizing the rapid depletion of biological resources and the indigenous knowledge system (IKS), this conference strongly recommends the meaningful participatory biodiversity conservation approach based on indigenous knowledge.
- Realizing that mountain ecosystems are fragile and unique repositories of immense biological and cultural diversity, this conference recommends that the international community pay special attention to the conservation and sustainable development of these mountain ecosystems and cultural landscapes.
- Recognizing the lack of coordination and communication among the scientific community and institutions involved in Himalayan biodiversity conservation, this conference strongly recommends the establishment of institutionalized networking among policymakers, scientists/researchers, and institutions.
- This conference strongly recommends that the World Trade Organization respect the CBD, particularly by

protecting the rights of the communities and farmers who are the true custodians of biological diversity.

- This conference opposes the extension of an intellectual property rights (IPR) regime specifically patenting life forms and genetic processes, which are the creation of millions of years of natural evolutionary processes.

Need of "International Center for Himalayan Biodiversity" for Research and Development

In considering the mandate of the Kathmandu Declaration of ICHB-2003, the ways in which Governments and local, national, regional / global level organizations could help achieve a better understanding of biological diversity and its related issues and greater cooperation in ensuring the sustainable development and poverty alleviation of Himalayan regions, "International Center for Himalayan Biodiversity (ICHB)" has been set up in close coordination, collaboration and cooperation with institutions and individuals working in education, research, and development in the field of conservation and sustainable use of biological diversity supporting Himalayan people in their search for sustainable development. The center is running as an autonomous and self governed institution and is supported by the Himalayan Resources Institute (HIRI). The CENTER brings out to the public about various national/international events, information, and links. Specifically the social, economical including scientific aspects of the sector and management, appropriate alternative technologies, indigenous knowledge and community management will be the further coverage of the program. The CENTER is committed to the dissemination of information about current conservation issues to the researchers and development professionals. To this end, the Network maintains active affiliations with a variety of local organizations and provides educational opportunities through community speakers, speaker series, Conservation Forum, Himalayan Biodiversity Day.

The vision of the CENTER is to improve human welfare through the sustainable use of Himalayan biodiversity. The CENTER provides education, research, training and development opportunities, and a unique intellectual environment for the development of solutions to ecological questions and problems facing Himalayan Biodiversity. The Center is committed to attracting students from Himalayan countries that will play leadership roles in future conservation efforts, as well as graduate students from Nepal and abroad seeking expertise in Himalayan Biodiversity, systematics, and conservation biology. Students associated with the center study both the Himalayan and Tropical ecosystems with particular strengths in Himalayan plant-herbivore dynamics, population biology and conservation of birds in the Himalayas, ecology of forest fragments, systematics of flowering plants, evolution of genes and genomes, population genetics of Himalayan and tropical flora and fauna. The Network associates have active research programmes in the economics and politics of biodiversity conservation and sustainable development. The Network in future will not only maintain state of the art equipment, laboratories and Himalayan and Tropical green houses to conduct biochemical, molecular, eco-physiological and ecological research but also develops research and international training programs and activities through out the Hindu Kush-Himalayan (HKH) and other mountain countries in the world.

In this way, the center will maximize the impact on this sector by bringing together all stakeholders in a common forum to exchange expertise.

Goal

Bringing in all the diverse stakeholders of various field of Himalayan biodiversity in a common forum to strengthen the partnership in collaboration with government, international and national non-governmental organizations, consultants, academic institutions, agriculture, forestry and environmental management professionals and others with the objective of exchanging information and technical expertise.

Objectives of the ICHB

The objectives and activities of the CENTER include:

- To establish local, regional and global networking on Himalayan biodiversity conservation to exchange experiences, information and technologies at local, national, regional/global levels to provide a local, regional/global forum for Himalayan biodiversity professionals to share knowledge, experiences, and ideas on recent biodiversity conservation and management approach.
- To support for CBD including sub-regional and inter-regional agreements on protection, sustainable and equitable development of Himalayan regions.
- To explore regional/global cooperation for effective implementation of biodiversity action plans and biodiversity strategies to support the government policies

and programs of the Hindu Kush- Himalayan (HKH) and other mountain countries in the world.

- To plan future strategies in Himalayan biodiversity conservation, management and development through biodiversity education, research, training.
- To organize meetings, workshops, seminars, conferences and congresses on Himalayan Biodiversity to exchange information and technologies in Himalayan biodiversity among development professionals, academic communities and concerned authorities in Nepal and the world.

Activities of the Center

Major activities of the CENTER include:

- The Center will actively establish an information management system with the support of the various national and international organizations to meet the needs of non-government, rural, and indigenous organizations and individuals working on biodiversity conservation in both the developed and developing countries.
- Store and plot information about geographical areas and record or attach area attributes such as species' distribution, habitats, management plans, surveys, and reports.
- Store web site addresses and information characterizing the sites and their developers, and record mailing lists, use net discussion groups, and site management information.
- Catalogue and annotate treaties, conventions, protocols, legislation, customary laws, regulations, and other legal instruments.
- File contact information and profiles of client groups, NGOs, government agencies, businesses, and services.
- Keep track of information on indigenous peoples, cultures, and ethnic groups.
- Track projects, together with complete project profiles - including key contacts, locations, funding, project descriptions, reports, and evaluations.
- Catalogue scientific and traditional knowledge of plants and animals - species' distribution, references to source materials, bibliographies, surveys, taxonomy, research, management, protective status, and experts.
- Publication and dissemination of a Newsletter of Himalayan Biodiversity.
- Publication of Yearly an "International Journal of Himalayan Heritage" a publication of the "International Center for Himalayan Biodiversity" for scientific community.
- Collection of books, newsletters and e-publications from various institutions and individuals from HKH and abroad.
- Organize regular international training course, workshops, seminars, conference, and congress on Himalayan Biodiversity on series wise events.
- Organize periodic talk programs on Himalayan Biodiversity and its related topics.
- Compilation of new ideas evolved and disseminating it to the partners through mail and e-mail.
- Compilation, record keeping and documentation of the indigenous knowledge on successful strategies, lesson learn and case studies.
- Preparing and publication of the directories and the relevant information of all the stakeholders and experts in the field of the Himalayan Biodiversity.
- Preparing, maintaining, and dissemination of relevant publications, books and other documents.
- Develop and maintain regional and international network for future cooperation, collaboration, and coordination on Himalayan Biodiversity.
- Develop and maintain the biodiversity website.

Integrating Vegetation Classification, Mapping, and Strategic Inventory for Forest Management

C. K. Brewer, I.A.A.A. Program Leader, U.S.D.A. Forest Service, Remote Sensing Application Center, Salt Lake City, UT
R. Bush, Inventory and Analysis Specialist, and D. Berglund, J. A. Barber, and S. R. Brown are GIS/Remote Sensing Specialists, U.S.D.A. Forest Service, Northern Region, Missoula, MT

***Abstract**—Many of the analyses needed to address multiple resource issues are focused on vegetation pattern and process relationships and most rely on the data models produced from vegetation classification, mapping, and/or inventory. The Northern Region Vegetation Mapping Project (R1-VMP) data models are based on these three integrally related, yet separate processes. This paper describes the integration of vegetation classification, mapping, and inventory to produce the basic vegetation data for land and resource planning and management for the USDA Forest Service Northern Region. The conceptual relationships between classification, mapping, and inventory are discussed and the operational integration of the resulting data is described.*

Introduction

Existing vegetation is the primary natural resource managed by the USDA Forest Service and most forest landowners and land management agencies. The agency is charged with managing vegetation for a variety of human uses while maintaining the integrity of ecosystem components and processes at national, regional, and local scales. One of the fundamental informational needs in land management planning is consistent and continuous existing vegetation data of sufficient accuracy and precision to address resource analysis objectives. These analyses rely on the data models produced from vegetation classification, mapping, and/or inventory processes. This paper discusses the integration and utilization of these data models in the Northern Region Vegetation Mapping Project (R1-VMP).

R1-VMP provides robust existing vegetation information for a wide variety of analysis applications. R1-VMP data models are based on three integrally related, yet separate processes: vegetation classification, vegetation mapping, and vegetation inventory. The integration of these processes and the resulting data models represents the basic vegetation information used in resource planning and management by the USDA Forest Service Northern Region.

Maps are the most convenient and universally understood means to graphically represent the spatial arrangement and relationships among features on the earth's surface (Mosby 1980). A map is indispensable for recording, communicating, and facilitating analysis of such information relating to a specific area. Maps are commonly used for inventorying, monitoring, and managing numerous resources on National Forests.

Historically, vegetation inventory and mapping was conducted through two-stage sampling of forest stands. This process consisted of the delineation of "timber stands" with stereo aerial photography. The basis for delineation of stands was discontinuities in texture (reflecting stocking and crown size differences) or apparent tree height (Stage and Alley 1972). The second stage was normally field sampling of all the delineated stands or a stratified random sample of the stands with subsequent inference to unsampled stands within the strata. This process also involved transferring the photo delineations to a base map. These stand delineations reflected management considerations as well as vegetative composition and structure and often included several vegetation types that were different in terms of composition and structure, but were similar in terms of management implications and/or history. The term stand was also extended to specifically describe conditions other than forested stands, such as non-forest vegetation, rock/barren areas, or water bodies. While extending the stand-mapping concept made these maps more comprehensive, they did not map fundamental units of vegetation that could be interpreted to address numerous questions. Another limitation of these data is that they apply almost exclusively to the suitable timber base, those areas outside the suitable base have few stand exam inventory data even though many of the questions

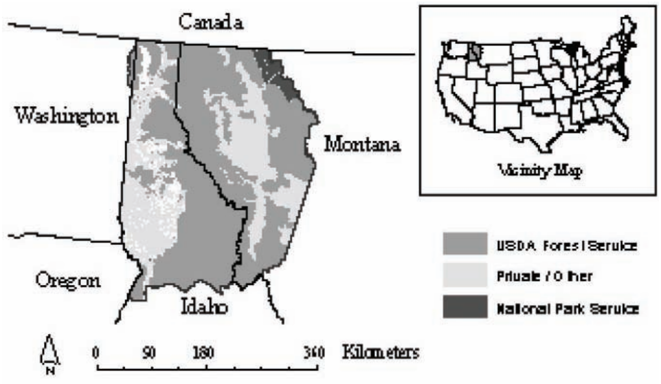

Figure 1. Northern Region Vegetation Mapping Project area.

and issues apply to all lands. Additionally, these maps represent a dynamic ecosystem component and have a finite period of currency.

In response to this informational need, the Regional Forester for the Northern Region initiated a R1-VMP to provide the Region and cooperating agencies with a geospatial database of land cover produced following consistent methods and mapped continuously across all ownerships. This database with associated inventory data provides the basis for vegetation pattern and process analyses to support land management planning. The project area for R1-VMP encompasses approximately 27,000,000 acres (11,000,000 hectares) of the USDA Forest Service, Northern Region (fig. 1).

In the early stages of the project it became obvious that R1-VMP was not a mapping project but, in fact, a classification, mapping, and inventory project. Numerous problems had been identified with the existing Regional classification logic and associated algorithms including the fact that the classes were not exhaustive and/or mutually exclusive and concerns regarding the integration of the maps inventory data were also raised. The R1-VMP team coordinated the effort to modify the classification logic and integrate strategic inventory data collected through the USDA Forest Service Forest Inventory and Analysis (FIA). Accordingly, this paper describes the general relationship of vegetation classification, mapping, and inventory and describes these processes relative to R1-VMP. A more detailed discussion of these relationships is included in Brohman and Bryant (2004).

General Relationship of Classification, Mapping, and Inventory

Vegetation classification is the process of grouping of similar entities into named types or classes based on shared characteristics. Vegetation classification defines and describes vegetation types and/or structural characteristics (in other words, what is it?). **Vegetation mapping** is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and/or structural characteristics. Vegetation mapping spatially depicts the distribution and pattern of vegetation types and/or structural characteristics (in other words, where is it?). Vegetation inventory is the process of applying an objective set of sampling methods to quantify the amount, composition, and condition of vegetation within specified limits of statistical precision. Vegetation inventory quantifies the amount, composition, and condition of vegetation (in other words, how much is there?). The conceptual relationships between classification, mapping, and inventory are schematically depicted in figure 2.

A one-to-one relationship between vegetation types (from a classification) and vegetation map units is uncommon given the limitations of mapping technology and the level of floristic detail in most classifications. Mapping, therefore, usually entails trade-offs among thematic and spatial resolution and accuracy, as well as cost. The goal is constrained optimization, not perfection. This problem is reduced somewhat when vegetation types, such as dominance types, and structural classifications are designed to be applied to mapping projects. Similarly, there is rarely a sufficient sample size to quantify all vegetation types so inventory compilation usually involves trade-offs to aggregate vegetation types and/or structural classes to achieve the desired sample size.

Because these ecosystems are dynamic, evolutionary, and have limited predictability many of the analyses needed for ecosystem management strategies require a variety of simulation models. The majority of these simulation models rely heavily on accurate and relatively detailed vegetation data. These models vary in the specific vegetation data needed and the detail needed in those data, but most of them require continuous spatial data with consistently classified attribute data. Classification, mapping, and inventory each contribute data to these simulation models.

Vegetation Classification

Following the general principles and the mid-level classification standards included in the Brohman and Bryant (2004), the Northern Region developed and adopted the following vegetation and landcover classifications.

Physiognomic and floristic classification

Physiognomic and floristic composition are the most fundamental components of a vegetation map. The

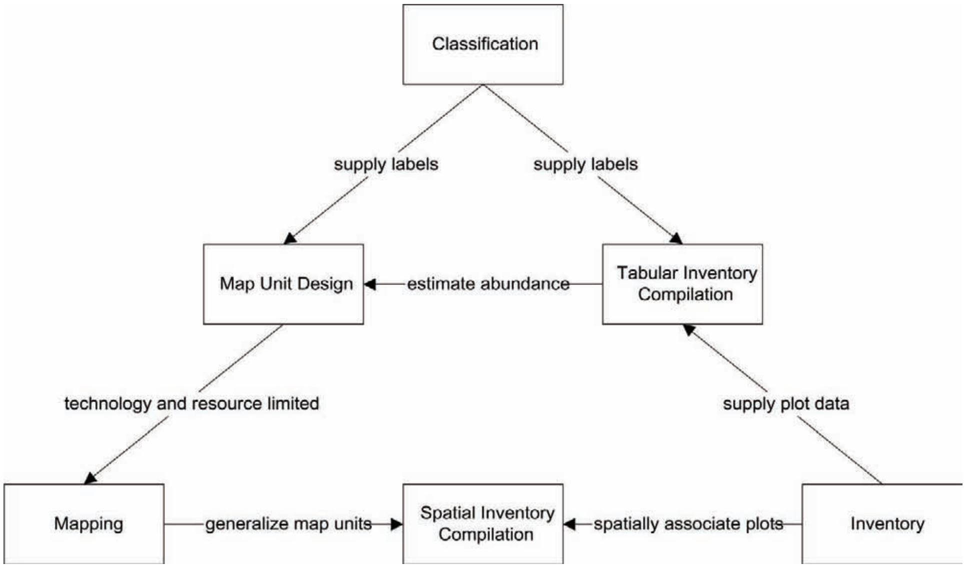

Figure 2. Relationships of vegetation classification, mapping, and inventory.

National Vegetation Classification (NVC) (FGDC 1997) has defined a hierarchical system for arranging these components into taxonomic units, which is the foundation for this mapping hierarchy.

Mapping continuous areas requires using land use and cover as well as vegetation classification systems. While many areas of the National Forests could be mapped using map units defined by vegetation physiognomic classification only, sparsely vegetated and non-vegetated areas mapped solely as such, give little information to the map user. Water was explicitly included as a lifeform-level land cover class and classes such as snow, clouds, and shadows were replaced using adjacent lifeforms. The lifeforms mapped in R1-VMP included:

- Grass/forb dominated lifeform
- Shrub dominated lifeform
- Tree dominated lifeform
- Water landcover
- Sparsely vegetated landcover

Floristic map units were based on a consistent classification of dominance types. Dominance types have been widely used in the development of map units where remotely sensed imagery is the primary basis for map feature delineation. "Dominance types provide a simple method of classification based on the floristic dominant (or group of closely related dominants) as assessed by some measure of importance such as biomass, density, height, or leaf-area cover (Kimmins 1997). They represent one of the lowest levels in several published classification hierarchies (for example, Cowardin and others 1979; Brown and others 1980)." The dominance type classification adopted for R1-VMP is based on relative canopy cover and is exhaustive and mutually exclusive. The basic classification logic is illustrated in the following tree dominance type key:

A. Single most abundant species > 60% of total canopy cover
List single species
A. Single most abundant species < 60% of total canopy cover
Go to B
B. 2 most abundant species > 80% of total canopy cover and each species individually is >20% of total canopy cover
List 2 species, in order of abundance
B. 2 most abundant species < 80% of total canopy cover
Go to C
C. 3 most abundant species > 80% of total canopy cover and each species individually is >20% of total canopy cover
List 3 species, in order of abundance
C. 3 most abundant species < 80% of total canopy cover
Go to D
D. Shade intolerant species total CC > shade tolerant species total CC
IMXS
D. Shade intolerant species total CC < shade tolerant species total CC
Go to E
E. GF+C+WH canopy cover > AF+S+MH canopy cover
TGCH
E. GF+C+WH canopy cover < AF+S+MH canopy cover
TASH

Tree diameter classification

Tree diameter class is defined here as any of the intervals into which a range of tree diameters may be divided for classification (Helms 1998). In R1-VMP the mean diameter at breast height (4.5 ft. 1.37 m. above the ground) is calculated for the trees forming the upper or uppermost canopy layer (Helms 1998). This mean is calculated as the canopy-cover-weighted mean diameter (in inches). The tree diameter classes mapped in R1-VMP included:

- Seedling/Sapling (0 to 4.9)
- Small tree (5 to 9.9)
- Medium tree (10 to 14.9)
- Large tree (15 to 19.9)
- Very Large tree (20 +)

Tree canopy cover classification

Tree canopy cover is defined here as the total non-overlapping tree canopy in a delineated area as seen from above. (Note: Tree canopy cover is not defined by a hemispherical projection as seen from below.) Tree canopy cover below ten percent is considered a non-tree polygon. The tree canopy cover breaks are consistent with the physiognomic class breaks for vegetation. The tree canopy cover classes mapped in R1-VMP included:

- Low (10 to 24.9 percent)
- Moderate (25 to 59.9 percent)
- High (60 to 100 percent)

Map Design

Map design involves two fundamental processes: map unit design and map feature design. Map unit design identifies the vegetation characteristics to be mapped and assembles or develops classification keys for each of the map attributes used to describe those characteristics. This process establishes the relationship between vegetation classification and mapping. Map feature design, concurrently, identifies the spatial characteristics and structure of the map.

A vegetation map unit is a collection of areas defined and named the same in terms of their component classes from the classifications described above (adapted from USDA, Soil Survey Division Staff 1993). The map unit design process establishes the criteria used to aggregate or differentiate vegetation classes to establish corresponding map units. Therefore, a mapping unit is comprised of one or more classes from one or more specific classifications. The criteria used to aggregate or differentiate within physiognomic types, dominance types, or structural classes to form mapping units will depend on the purpose of, and the resources devoted to, any particular mapping project (Jennings and others 2002). For example, map units designed to provide information on existing forest structure to characterize wildlife habitat or fuel condition would be based on a combination of tree canopy cover classes and tree diameter classes. The map unit design process is more complex for floristic classifications than for relatively simple structural classifications.

Map units depicted on maps within individual areas or delineations that are non-overlapping and geographically unique are referred to as **map features** (in other words, polygon delineations or region delineations). Typically, one map unit is repeated across the landscape in many individual map feature delineations. The map design process for the primary R1-VMP map products is described in the following sections.

Physiognomic and floristic map design

The lifeform and landcover classes described above were adopted and mapped as classified. A variable minimum map feature (MMF) standard was implemented as follows:

- Grass/forb dominated lifeform (2.5 Acre MMF)
- Shrub dominated lifeform (2.5 Acre MMF)
- Tree dominated lifeform (5 Acre MMF)
- Water landcover (1 Acre MMF)
- Sparsely vegetated landcover (5 Acre MMF)

The dominance type map units, tree canopy cover map units, and tree diameter map units, described above nest hierarchically under lifeform and follow the same minimum map feature standard.

The dominance type classification described above was aggregated and generalized using the following logic to identify the map units used in R1-VMP.

Dominance Type 1 – Elemental Classification (Dom1)

Classification Rule set:

1species >60% tot CC
that species
2species >80% tot CC
those 2-species - listed in order of abundance
3species >80% tot CC
those 3-species - listed in order of abundance
Shade intol > Shade tol
IMXS [intolerant mixed spp.]
Shade tol > shade intol
G, WRC,WH > AF,ES,MH
TGCH
G, WRC,WH < AF,ES,MH
TASH
Results in Over 850 Different Types

Dominance Type 4 –Species Groups (Dom4)

Classification Rule set:

1-species: same as DOM1

2-species: All 2-species DOM1-types with the same most abundant species are grouped into SPPP-1MIX [for example ABGR-PSME, ABGR-PICO, etc = ABGR-1MIX]

3-species: All 3-species types with the same most abundant species [from DOM1] are grouped into SPPP-2MIX [for example ABGR-PSME-PICO, ABGR-PICO-LAOC, etc = ABGR-2MIX]

IMXS, TASH, TGCH: same as DOM1

Results in 42 Different Types

Dominance Type 4m –Species Groups Map Units [Dom4m]

Map Unit Design

A frequency distribution of DOM4 types is made from FIA PSU data.

If either the single-species or the single-species-1MIX are less than 1% of the total number of forested FIA PSUs, they are collapsed into a single-species mega-mix [SPPP-MMIX].

All 3-species DOM1 types [or DOM4, SPPP-2MIX] are collapsed into IMXS, TASH, or TGCH.

Results in 15 To 18 Different Types

Tree diameter class and tree canopy cover class map designs

The tree diameter classes and the tree canopy cover classes described above were mapped as classified.

Vegetation Mapping

Vegetation mapping is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and/or structural characteristics. Satellite-based remote sensing classifications with their associated GIS coverages or grids and attribute databases have increasingly been used for large area, low-cost vegetation and landcover mapping (Lachowski and others 1996; Redmond and others 1996; Johnston and others 1997; Cohen and others 1998; Mickelson and others 1998; Stoms and others 1998). These satellite-based classifications are gradually replacing aerial photography as the primary image data for vegetation mapping. Wynne and Carter (1997) compare characteristics of satellite remote sensing data and aerial photography relative to these mapping applications:

- Satellite images are digital; they provide direct and cost effective GIS coverages and databases. The spatially accurate conversion of aerial photo delineations to digital coverage is expensive and time consuming.
- Digital images are easy to send over computer networks; they can be delivered within hours of acquisition.
- Given a specified resolution, satellite images typically provide greater coverage than aerial photography.
- Satellite images often have better geometric fidelity than aerial photos because of their altitude and stability of orbits.
- Some spaceborne sensors include wavelengths band, such as mid-infrared, and thermal infrared, that cannot be detected by film.
- Repeat coverage is easily obtained; it is easily co-registered and used for applications such as change detection and monitoring.

The USDA Forest Service national direction contained in Brewer and others (2004) reflects the trend toward the use of satellite remote sensing classification for vegetation mapping. The following sections, exerted and condensed from Brewer and others (2003), describe the analytical logic and general methodology utilized in the R1-VMP mapping process.

Acquisition and pre-processing of image and ancillary data

Landsat TM imagery was chosen for this work because the near-infrared and mid-infrared reflectance of vegetation is strongly related to important vegetation canopy characteristics. Additionally, the high spectral resolution of Landsat TM imagery was preferred above the high spatial resolution of other sensors, such as SPOT. Additionally, Landsat TM data are acquired continuously and archived data could be purchased to meet the time and area needs. Landsat TM data can also be purchased as "floating scene" or "path-level" data purchasing the equivalent of up to three TM scenes as a single field of view, thereby reducing the image handling and preprocessing requirements as well as costs.

A good seasonal image data acquisition window for forest vegetation opens slightly after the date at which the forest vegetation is fully mature and closes just prior to its senescence. In this case, the "peak green" and "fall" image data were obtained from the EROS Data Center. All images were ortho-rectified to previously terrain-corrected images for the respective paths using the Geometric Correction Module and the Landsat orbit model in ERDAS IMAGINE as well as 7.5-minute digital elevation models.

Ecogeographic stratification

Lilles and and Kiefer (2000) discuss the commonality of using ancillary data to perform geographic stratification of an image dataset prior to classification. They further describe the aim of this process is to "…subdivide an image into a series of relatively homogeneous geographic areas (strata) that are then classified separately."

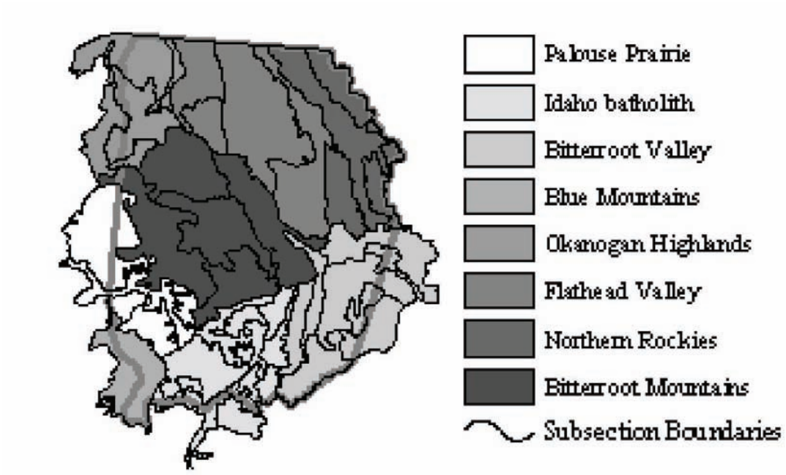

Figure 3. Section- and Subsection-level delineations in the ECOMAP hierarchy.

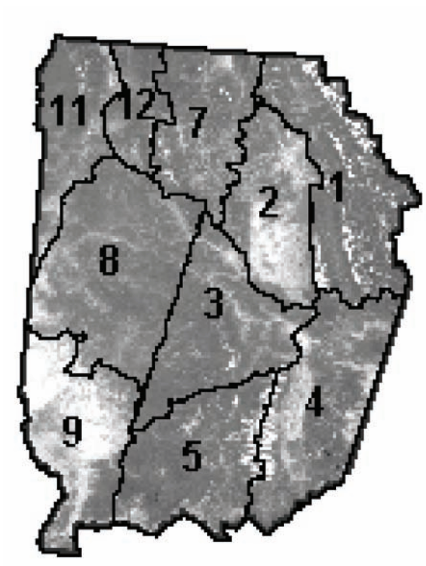

Figure 4. Sub-path data models used for ecogeographic stratification of Landsat ETM floating scenes.

The homogeneity of these geographic areas is largely determined by the composition of biophysical environments included in the stratification. These biophysical environment settings are important for stratification in this type of project because they facilitate the delineation and description of ecosystems that behave in a similar manner and influence the natural disturbance processes that create finer-scale vegetation patterns (Jensen and others 1997). The USDA Forest Service National Hierarchical Framework of Ecological Units (Bailey and others 1994) provided the delineations used for geographic stratification of the R1-VMP project area. The appropriate level of this hierarchy for ecogeographic stratification in this project is the section-level delineation described by McNab and Avers (1994) and illustrated in figure 3. These delineations were used to stratify Landsat ETM floating scene sets resulting in ten sub-path data models (fig. 4) rather than eight Landsat TM scene models. This stratification improves model performance by limiting the variance associated with vegetation types and increases the utility of reference data.

Image segmentation

As stated in Ryerd and Woodcock (1996), "Image segmentation is the process of dividing digital images into spatially cohesive units, or regions. These regions represent discrete objects or areas in the image." This segmentation and merging process is influenced by the variance structure of the image data and provides the modeling units that reflect life form composition, stocking, tree crown size differences, and other vegetation and/or landcover characteristics (Haralick and Shapiro 1985; Ryerd and Woodcock 1996). Segmentation and merging of Landsat ETM satellite imagery in R1-VMP utilized the segmentation functionality within the software eCognition (Baatz and others 2001). The segmentation process in eCognition is based on both the local variance structure within the imagery and shape indices. This segmentation process produced image objects that served as the base classification units within the object-oriented classification programs. The image objects delineated through the R1-VMP image segmentation process and modeled in eCognition readily aggregate thematically and comprise vegetation and landcover patches that represent the various map units in the hierarchy.

Change detection

Change detection methodologies using digital data have been used extensively for a wide variety of analysis applications including: fire impact studies (Parra and others 1996), land cover change in wetland areas (Hashem and others 1996; Mahlke 1996), air pollution damage detection (Hogda and others 1995; Solheim and others 1995), and forest-canopy change (Coppin and Bauer 1994; 1995). Within the context of the vegetation mapping objectives R1-VMP, the change detection method is designed to exploit phenological differences in vegetation types (in other words, deciduous tree or shrub species dominance types or senescent grasses and forb species dominance types). Coppin and others (2001) demonstrated that a solid biophysical link is found between forest canopy features and the Kauth-Thomas transform, a particular case of a principal components analysis. The three main components of Kauth-Thomas variability are termed brightness, greenness and wetness and are the result of a Gram-Schmidt orthogonalization process (Kauth and Thomas 1976). Changes in these three components constituted the basis of the R1-VMP analytical logic to exploit phenological differences in vegetation types.

Ecological modeling and other ancillary data

Ecological modeling and other ancillary data were used extensively by R1-VMP to improve classification results. These ecological modeling approaches were incorporated into the multi-source system through knowledge-based classification and reference data stratification within the object-oriented image analysis software, eCognition (Baatz and others 2001). This process facilitated the use of additional data such as potential vegetation settings (Pfister and others 1977; Mueggler and Stewart 1980; Cooper and others 1991), subsection level ecological units (McNab and Avers 1994), topography, and image illumination strata for grouping or splitting classes to improve classification accuracy (Cibula and Nyquist 1987; Bolstad and Lillesand 1992; Cohen and Spies 1992; Brown and others 1993; Coppin and Bauer 1994; Goodchild 1994). In addition to PNV and subsection level ecological units, R1-VMP incorporated two indices of insolation derived from combinations of slope and aspect generated from 30m DEM data. R1-VMP also stratified the image data by the illumination at the time of image acquisition. Additional ancillary data were provided by fire severity data classifying recently burned areas, operationally produced by the USDA Forest Service (Gmelin and Brewer 2002) following major fire events in 2000 and 2001 and were used to characterize first order fire effects on vegetation. These data were generated from a Normalized Difference Burn Ratio (NBR) analytical approach, following Key and Benson (1999) as adapted by Brewer and others (In press).

Reference data

The most common sources of reference data for remote sensing projects are aerial photo interpretation and field data collection. It is quite common for remote sensing projects to use photo interpretation as a primary source of reference data or to combine these two sources. In R1-VMP, training and accuracy assessment data were generated through a structured aerial photo interpretation process that integrated a variety of field sampled inventory datasets. Our experience suggests that an aerial perspective is often useful for remote sensing training data acquisition and that skilled interpreters can add local knowledge and experience to the classification process. Additionally, resource aerial photography remains the most commonly available remotely sensed data source. Common image interpretation techniques were used to characterize elements of vegetation pattern that comprise lifeform, dominance type, tree size class, and tree canopy cover (Avery 1977; Campbell 1987; Lillesand and Kiefer 1987; Lachowski and others 1996). The variables collected include lifeform/landuse class cover percent and connectivity, dominance type cover percent and connectivity, tree size class cover percent, tree canopy cover percent, and connectivity, and total vegetation canopy cover percent. Field-sampled tree, vegetation composition, and ground-cover composition data were collected on a subset of a randomly-selected set of region-polygons as a means to validate the photo interpretation reference data collection.

Hierarchical classification

A nested hierarchical classification scheme (described above under vegetation classification) was applied in R1-VMP that used membership functions derived from knowledge bases for the physiognomic and structural classifications and fuzzy-set classifiers based on reference data and nearest neighbor algorithms for the dominance type classification. This design provided a consistent linkage between the dominance type and structural classifications commonly used by the agency at the mid-level and the physiognomic classifications used at the broad-level and national-level and required by the FGDC vegetation classification standards (Brohman and Bryant 2004).

Implementation of this classification hierarchy produces separate GIS coverages, grids, and associated geospatial databases for four primary attributes. These attributes include lifeform, dominance type, tree canopy cover, and tree size class. The hypothetical dominance type, tree size class, and tree canopy cover map products included in figure 5 illustrate the relationships of these attributes to the original image objects. These original image objects were merged following the minimum map feature standards. The merged image objects were then used to produce the GIS coverages and grids for the four primary map products. Any combination of these four primary map products could be produced to meet specific analysis objectives, with the logic of the combination defined by the end user.

Vegetation Inventory

The vegetation inventory data for most land management agencies and private companies only partially covers their ownership, are often out of date, and are rarely compatible with adjacent landowners. This is particularly true for federal land management agencies such as the USDA Forest Service, Northern Region, that manage large geographic areas for a variety of management objectives. Historically, most ground-based inventory data have been collected using standard plot

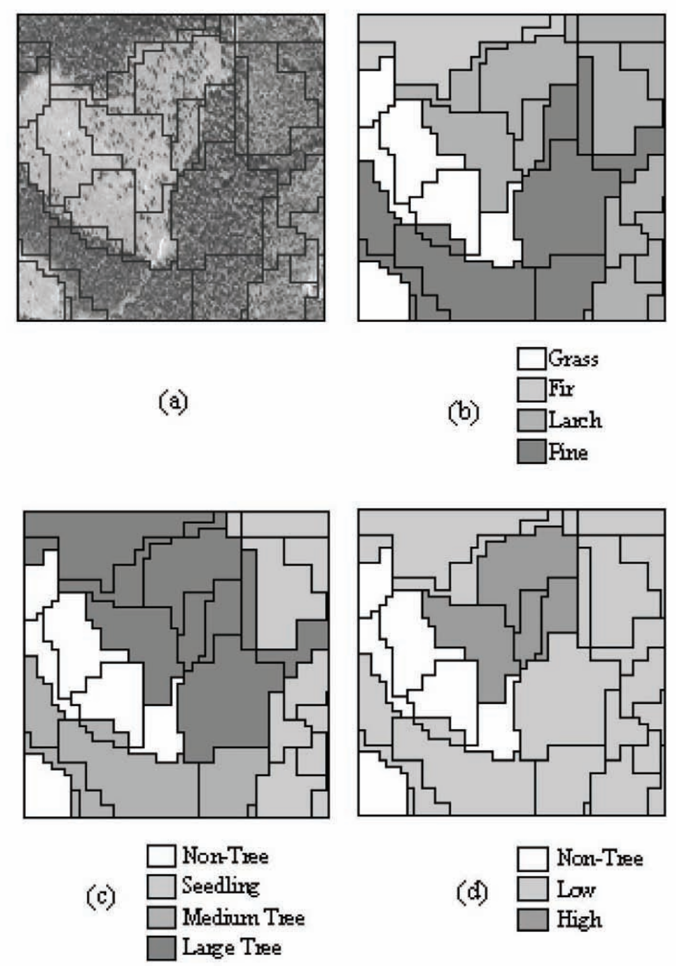

Figure 5. Hypothetical classification attributes (map units) and image objects. a) base imagery, b) dominance type, c) tree size class, d) tree canopy cover.

and quick plot stand exams (USDA Forest Service, FSH 2709). Using the USDA Forest Service, Northern Region, as an example, Brewer and others (2002) observed that most of these data apply almost exclusively to the suitable timber base, as defined by the National Forest Management Act of 1976 (US Public Law 94-588 1976). The remaining areas outside the suitable base have few stand exam data even though many of the resource questions and issues apply to all lands. The collection of stand-based data on part of the land base introduces an unknown bias when these data are used to represent the whole land base. In addition, there are no specific design considerations for the collection and storage of these data to facilitate their use by other land management agencies or private landowners.

Declining budgets for public land management agencies have resulted in dramatic reductions in the amount and geographic extent of current, detailed inventory data. The precipitous decline in standard plot and quick plot stand exams reflects budget trends for inventory programs throughout the USDA Forest Service. Brewer and others (2002) describe the effects of these reductions on current data and graphically depict the status of stand exam based inventory data for the USDA Forest Service, Northern Region (fig. 6). This graph illustrates the decline in acreage of stand exams, by year, from 1980 to 2001.

Reductions in timber sale programs on public lands, particularly National Forests, have had effects on the management (in other words, harvest schedules) of both industrial and non-industrial private forests (Flowers and others 1993). This change in harvest schedules has affected the currency and completeness of inventory data from private forests; proprietary data private forest landowners are reluctant to share.

Given the discontinuous and incomplete nature of most forest inventory data, as well as the difficulty in maintaining currency and sharing with other landowners, data generated by the Forest Inventory and Analysis (FIA) program of the USDA Forest Service provides a viable alternative. FIA utilizes a systematic random grid of plot clusters, re-measured periodically, to monitor the extent, condition, uses, impacts of management, and health of forest ecosystems across all ownerships in the United States. These data provide an unbiased sample for many inventory related questions. The Society of American Foresters (2000) state that "FIA is the only program that monitors the extent, condition, uses, impacts of management, and health of forest ecosystems across the United States." They further state… "FIA data serve as the foundation of large-scale policy studies and perform a pivotal role in public and private forest planning." They cite examples of regional and sub-regional analyses that influence major economic and ecological management decisions including:

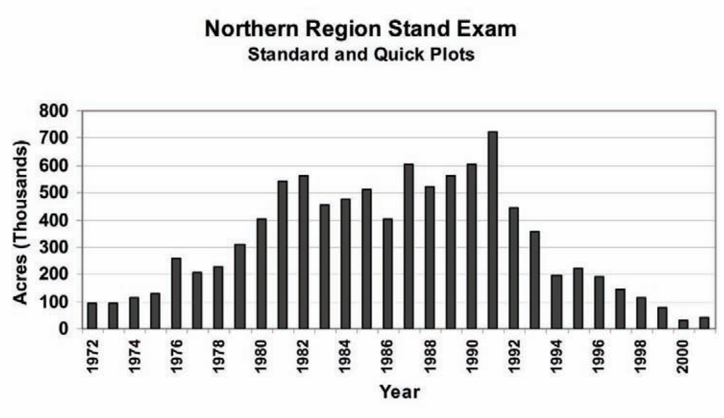

Figure 6. USDA Forest Service, Northern Region, stand exam program status summary for 1980 to 2001. USDA Forest Service, Northern Region, stand exam program status summary for 1980 to 2001.

- Strategic planning efforts by wood-using industries routinely incorporate FIA data into timber supply and timber product outputs.
- Development of criteria and indicators of forest sustainability depend on the growth removals, and inventory data compiled by FIA (Reams and others 1999).
- National forest carbon budgets for reporting under international agreements are dependent on FIA data (Heath and Birdsey 1997).
- Assessment of ecological change and economic damage resulting from disasters such as hurricanes or widespread wildfires.

Van Deusen and others (1999) suggest a current and accurate forest ecosystem inventory is prerequisite to substantive discussion of issues like sustainability, national forest policy, carbon sequestration, changes in growth and productivity, changes in landuse and demographics, ecosystem health, and economic opportunities in the forest sector.

Over the past decade concerns have been raised regarding the currency of FIA data, historically re-measured every 6 to 18 years (Gillespie 1999). These concerns prompted the American Forest and Paper Association (AF&PA) to convene two Blue Ribbon Panels on FIA (AF&PA 1992, 1998). The high level of user community support and concerns regarding currency of FIA data surfaced by these panels and subsequent Congressional hearings resulted in legislation to implement an annualized forest inventory and monitoring program to reduce the re-measurement interval (Czaplewski 1999). It is expected that the annualized inventory design will result in substantial improvements in the currency of FIA data.

Historically, the FIA program produced area estimates of forest types in two phases following a double sampling design (Reams and VanDeusen 1999). Phase one placed a systematic random grid on aerial photography (normally 1:40,000 scale National Aerial Photography Program NAPP). These points (with a minimum area of at least 1 acre or a strip at least 250 feet wide) were then classified as forest or non-forest based on the FIA definition of at least 10% tree canopy cover. The second phase sub-sampled the first phase points in the field to confirm the classification. This process provided the forest area estimation for the application of the field sampling of the permanent plot clusters in the third phase. Reams and VanDeusen (1999) suggest the following three problems associated with this historical method:

- No forest non-forest map is produced
- The photo interpretation process is time-consuming and labor intensive
- Current aerial photography is not always available

These issues become increasingly problematic with the shift to an annualized inventory program. R1-VMP utilizes FIA data for two important processes. In the map unit design process FIA data are classified and utilized to estimate abundance of dominance types. These estimates are used to define the dominance types with sufficient aerial extent to include as a map unit and to identify logical aggregation strategies for dominance types with insufficient extents. The FIA data are also used for the development of sample-based map unit descriptions. In this process the FIA data are spatially associated to the R1-VMP map products and are then compiled to quantify various vegetation characteristics for each of the thematic classes in the map product (for example, dominance types, tree diameter classes, and/or tree size classes). The compilation of the FIA data by R1-VMP map classes represents the final step in the integration of classification, mapping and inventory to support forest management in the USDA Forest Service Northern Region.

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High Resolution Wind Direction and Speed Information for Support of Fire Operations

B. Butler, Research Engineer, J. Forthofer, Mechanical Engineer, M. Finney, Research Forester, and L. Bradshaw, Meteorologist, USDA Forest Service, Rocky Mountain Research Station, Missoula, MT

R. Stratton, Forester, Systems for Environmental Management, Missoula, MT

B.W. Butler, J.M. Forthofer, M.A. Finney, L.S. Bradshaw, R. Stratton

Abstract—*Computational Fluid Dynamics (CFD) technology has been used to model wind speed and direction in mountainous terrain at a relatively high resolution compared to other readily available technologies. The process termed "gridded wind" is not a forecast, but rather represents a method for calculating the influence of terrain on general wind flows. Gridded wind simulations are typically produced at resolutions of 100 m using laptop computers. Resolution is limited only by elevation data resolution and computer memory. Initial comparisons between simulated winds and measured average wind speeds and directions for specific locations indicate excellent agreement. Results suggest that as the upper air wind speed increases the relative magnitude of uncertainty in the simulated winds decreases. The modeled winds generally seem to be most accurate for simulation scenarios associated with large scale strong pressure differences such as cold front passage, Foehn (Santa Ana), and onshore/offshore winds. This high resolution wind information has proven useful for identifying areas and/or conditions around a fire perimeter that may produce high fire intensity and spread rates and for identifying specific locations where fire spotting might occur. Currently the output from the process can be summarized in the form of a shaded relief map with wind vectors overlaid on the terrain image, GIS shape files, and custom wind direction and speed files that can be utilized by the FARSITE fire growth simulation program. The accuracy of FARSITE fire spread predictions is improved in the few cases where gridded winds have been used.*

Introduction

Wind is one of the primary environmental variables influencing wildland fire spread and intensity (Rothermel 1972, Catchpole and others 1998). Nevertheless, methods to model local wind speed and direction are not readily available. In many cases, wind information available to fire incident personnel is limited to that available from weather forecasts and/or weather observations from a few specific locations, none of which may be actually near the fire. Mountainsides, valleys, ridges, and the fire itself, influence both the speed and direction of wind flows. A major source of uncertainty in fire behavior predictions is the lack of detailed wind speed and direction information for use in the fire behavior calculations. Wind and its spatial variability in mountainous terrain was a major factor in the fire behavior associated with recent fire incidents that resulted in firefighter entrapments and/or fatalities: South Canyon Fire 1994 (Butler and others 1998), Thirtymile fire (USDA Forest Service 2001), and Price Canyon Fire (Thomas and Vergari 2002). Fire behavior forecasts, fire growth projections and firefighter safety could greatly benefit from detailed local wind information.

Some efforts are underway to approach the problem from the atmospheric modeling standpoint. Ferguson (2001) is using atmospheric scale models to assess the dispersion of smoke from natural and prescribed fires. Zeller and others (2003) are exploring the application of meso-scale atmospheric flow models for the prediction of surface winds. And this year (2004) the National Weather Service provided public access to the National Digital Forecast Database (NDFD). The NDFD currently provides 2.5 km resolution, 8-day digital forecasts (and GIS support) for the conterminous US (NWS 2004). These approaches include many of the important physical processes but suffer from relatively coarse scale surface wind predictions (nominally 103 m scale) and large computational requirements and/or times. And, importantly, the meso-scale model approach is not easily configured for "what if" applications wherein a single user can simulate various scenarios ahead of time to explore the relative effects of model inputs on surface wind flow and their impact on fire intensity and growth.

Lopes and others (2002) and Lopes (2003) describe a software system that calculates a surface wind field and includes topographical influences. The wind field simulator has been used to generate wind inputs to a fire growth simulator. Lopes and others (2002) implement two methods for producing wind fields: a diagnostic model called NUATMOS (Ross and others 1988) and a Navier-Stokes solver called CANYON (Lopes 2003). Typically, models like NUATMOS cannot accurately predict flow effects such as the recirculation on the lee side of ridges in mountainous terrain. More detailed submodels including conservation of momentum and turbulence are needed to account for the interactions between wind and surface structures such as ridges and canyons.

With the advent of digital computing a tool has become available for the study of fluid dynamics. This technology termed computational fluid dynamics or CFD is widely used within the engineering disciplines (Launder and Spaulding 1974; Volker and others 2000; Barman 2001; Patankar 1980) to resolve flows in enclosures such as ducts, furnaces, or wind tunnels. However, it is only within the last few years that CFD has become available at a cost and in a form that allows a broad range of practitioners to approach complex fluid flow problems, for example modeling of the dispersion of toxic gases from hazardous waste spills, the selection of optimal sites for wind turbines, and wind loads on high rise buildings. As a result some previous studies have focused on the application of CFD technology for simulating wind flow over complex terrain (Raithby, Stubley and Taylor 1987, Alm and Nygaard 1995, Montavon 1998, Kim and others 2000). A few studies explored the interaction between wind and mountainous terrain within the context of wildland fire, but none have linked the wind simulations to wildland fire management efforts.

This study was initiated with three objectives: 1) explore the utility of CFD software for simulating surface wind flows in mountainous terrain, 2) identify how detailed surface wind information can assist wildland fire operations, and 3) develop a methodology by which the technology may be accessed by wildland fire incident management teams. This document outlines current work on objective #1 and efforts to quantify the accuracy of the high resolution wind-based fire growth simulations.

Discussion

The process of producing gridded wind information occurs in three steps and is detailed elsewhere (Forthofer and others 2003). Basically it consists of importing elevation data in the form of digital elevation model (DEM) files into the CFD software and solving the Navier-Stokes equations to determine the flow speed and direction everywhere within the domain. The results from this set of calculations are then used to determined surface wind speed and direction at a resolution of nominally 100 m everywhere on the terrain of interest.

Wind modeling for a specific fire typically consists of simulating several different combinations of wind speed and direction. The simulations are selected to match a forecasted scenario or are based on historical weather patterns. The simulation accounts for the influence of elevation, terrain, and vegetation on the general wind flow. Output files are geo-referenced so that they can be incorporated into standard GIS information systems.

Transfer of results from the wind simulations to fire managers and field personnel can occur in three different forms: 1) Images consisting of wind vectors overlaid on a shaded relief surface image. The fire perimeter and marked prominent landmarks can be added to orient the viewer (fig. 1). These images display the spatial variation of the wind speed and direction and can be used to identify high and/or low wind speed areas along the fire perimeter caused by the channeling and sheltering effects of the topography. 2) ARCView or ARCMap shape files of wind vectors. These vectors can be incorporated into a GIS database and custom maps/images developed. Some useful combinations are wind vectors over fuels maps, IR based fire perimeters, and 7.5 minute quad maps with contour lines, roads, and trails. The process can also produce input files for use by the FLAMMAP and FARSITE programs (Finney 1998). Naturally, the accuracy of fire growth projections are limited by the accuracy of the weather and wind forecasts used to develop the gridded winds. This implies that the uncertainty associated with both wind and fire growth projections will increase as the simulation progresses forward in time. Gridded wind simulations have been used to provide wind input to a small number of FARSITE fire growth simulations, in all of the simulations completed so far (less than 5) the accuracy of short term (< one day) fire spread projections, as compared to actual fire spread histories, has increased.

These simulations assume a neutrally stable atmosphere, meaning that they do not take into account density driven flows (diurnal winds and fire induced winds). Neglecting these flows introduces some error (especially at low wind speeds); however as the upper air wind speed increases the relative magnitude of this error decreases. Nor does this methodology account for momentum transfer due to thermal instability in the atmosphere.

Two methods have been utilized to quantify the accuracy of CFD based wind simulations. The first is to

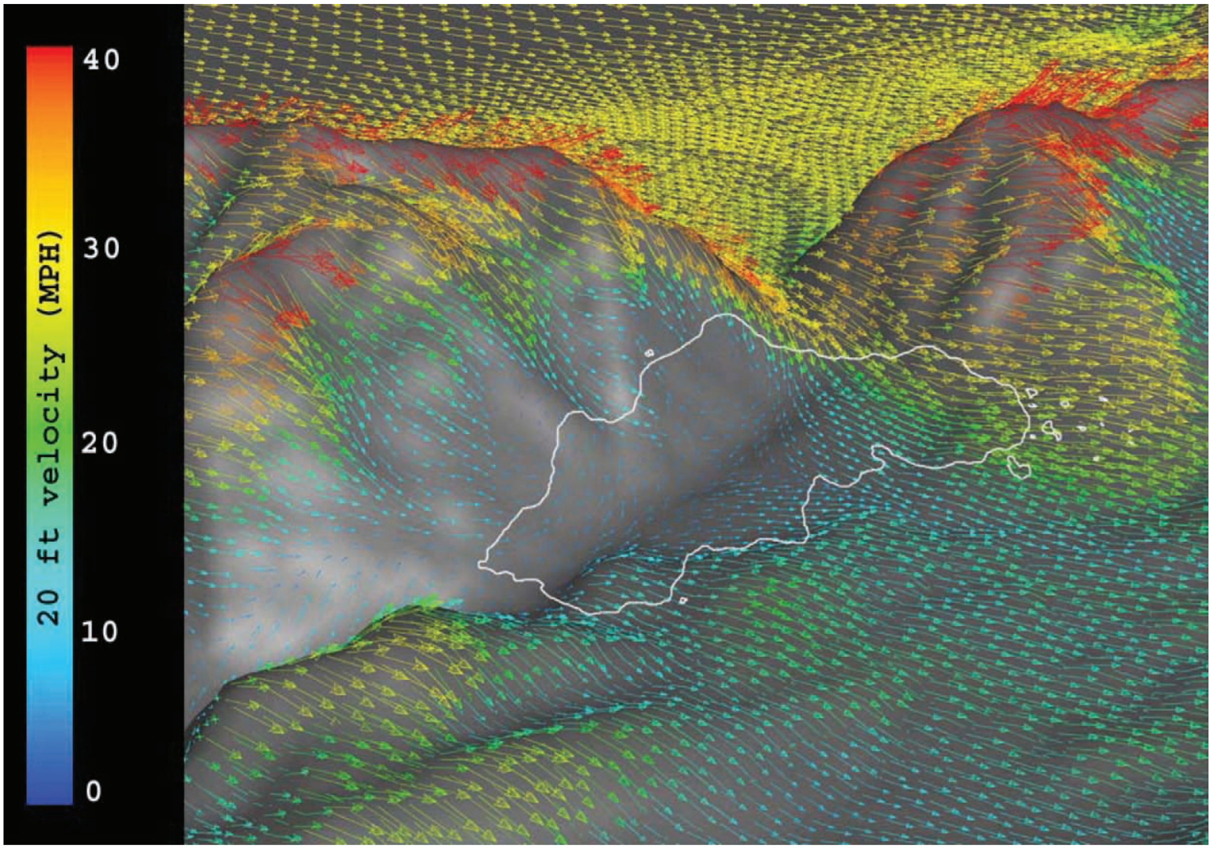

Figure 1. Example of gridded wind simulation for the Hungry Horse fire that burned in Northwestern Montana during the summer of 2003. The white line represents the fire perimeter.

compare modeled wind speed and direction against direct measurements. The second is to compare fire growth simulations with and without gridded wind against actual fire growth.

A set of measurements were collected specifically for the purpose of characterizing surface wind simulations (Taylor and Teunissen 1987). The site was a 116 m high hill located on the west coast of the island of South Uist in the Outer Hebrides of Scotland. Vegetation was relatively uniform and consisted primarily of heather and grass. Winds were measured using over 50 10 m tall towers instrumented with cup anemometers. The towers were deployed along three lines (fig. 2). Ten minute mean wind speed and direction measured 10 m above ground level were recorded during the 3 hour experiment. The overall mean direction and speed were 210 degrees and 8.9 m/s respectively. Using an input flow speed and direction of 10 m/s from 210 degrees a CFD-based simulation was completed (fig. 3). The simulated wind speeds along line A were compared against measured wind speeds (fig. 4). Generally the modeled wind speeds were within 9 percent of those measured except for the location approximately 198 m downwind from the intersection of the A and B lines were the simulated wind speed was 32 percent greater than the measured value. This location is approximately midslope on the leeward side of the hill and is likely related to differences between the steady state calculations produced by the CFD-based model and the transient nature of turbulent eddies forming on the leeward side of the hill (Castro and others 2003). This result suggests that the CFD-based methodology may not capture the transient nature of the flow. Simulated wind direction was also compared against measured values (fig. 5). As shown the agreement is not as good as that of the speed comparison but is still less than 13 degrees for all locations. The largest difference between the simulated wind direction and measured values were greatest near the base of the hill for both the upwind and leeward sides.

While the Askervein hill is topographically relatively simple, the comparison between simulated and measured winds suggests that the CFD-based methodology for simulating surface wind flow over mountainous terrain can provide relatively accurate information. A second evaluation of the relative impact of gridded wind on fire behavior modeling was explored by comparing the results of two FARSITE simulations of fires spreading over the Askervein hill. For the fire growth simulation a point ignition was applied near the southwest end of the AA line. The first simulation assumed a uniform (constant)

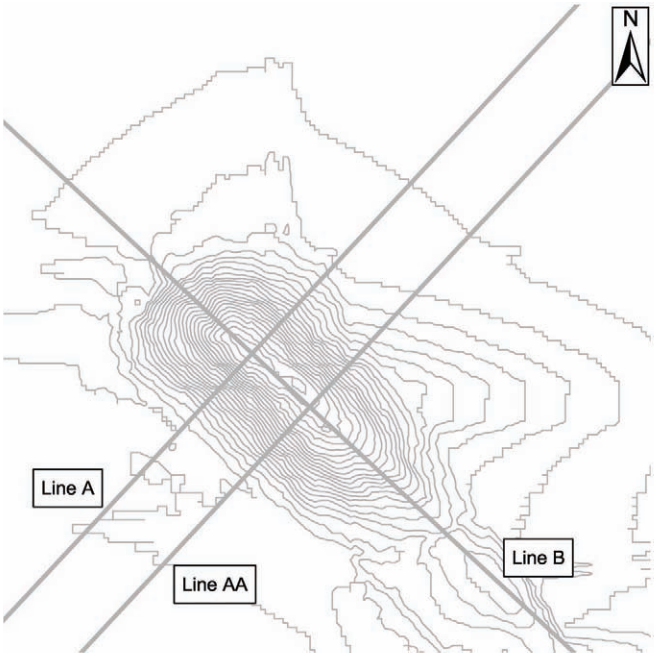

Figure 2. Topographical image of Askervein hill. Anemometer towers were deployed along lines A, AA and B. Contour interval is 5 m.

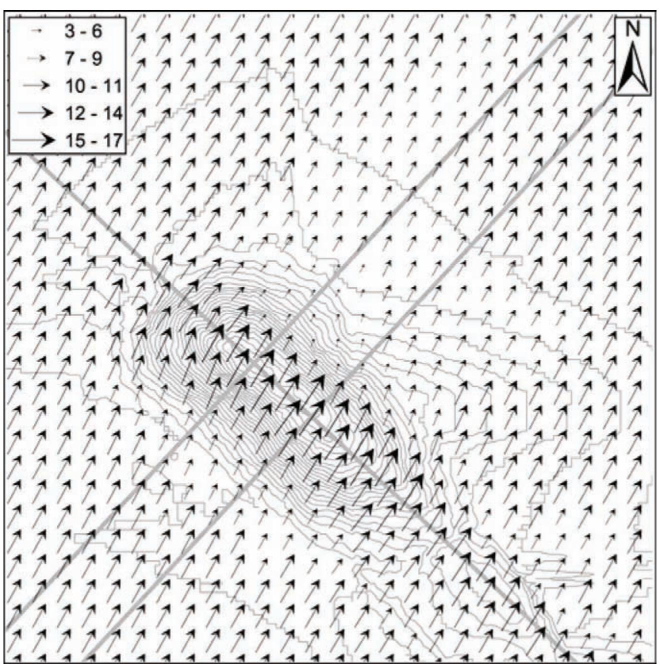

Figure 3. Gridded wind simulation results for general input flow of 10 m/s from an angle of 210 degrees.

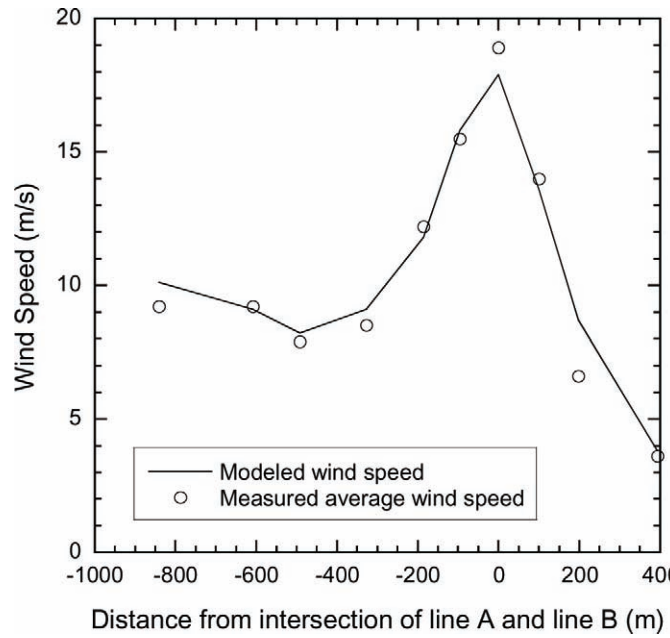

Figure 4. A comparison of measured and predicted wind speeds along line A.

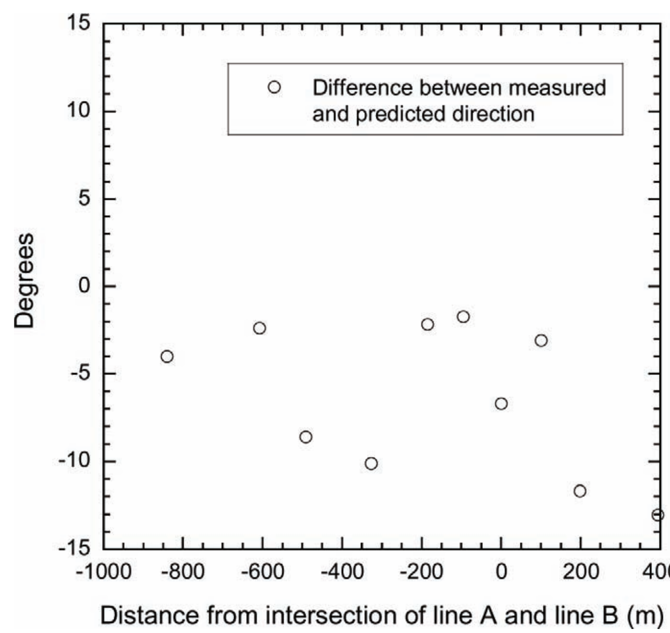

Figure 5. A comparison of the variation from the overall 210 degree flow direction for the measured and predicted winds along line A.

wind field in both speed and direction (fig. 6). Because the winds are everywhere uniform the simulation does not account for the influence of terrain on the wind field, except through a slight impact on the midflame wind (Rothermel 1972, Finney 1998), and the effect of slope on fire spread rate. A second simulation was completed using the gridded wind and keeping all other factors equal to those of the uniform wind simulation. The fire growth over time is indicated by the succeeding fire perimeters (fig. 7). A comparison of the relative differences between the two images suggests that wind speed and direction dramatically affect fire spread even in simple terrain like that of the Askervein hill. While no actual fire burned, these comparisons illustrate the impact that terrain influenced wind can have on fire growth simulations even over relatively short (< one day) periods.

As noted previously, a second method for evaluating the accuracy and impact of this technology is to compare fire growth simulations against those demonstrated by actual fires. Simulations were performed for the Price Canyon fire that burned in Southern Utah on June 30, 2002 (Thomas and Vergari 2002) using the FARSITE fire area simulator. The first assumed a constant wind speed and direction for the time period of interest based on measurements obtained from remote weather stations in the vicinity. The increase in fire size over time is displayed by the fire perimeters (fig. 8). As in most naturally burning fires, the only method for comparing the accuracy of fire spread and growth simulations is by comparing predicted fire perimeter at some point in time to that recorded from either infrared images, observations from over flights, or witness accounts. In this case the fire growth predictions for the conditions on June 30 are compared to the final fire perimeter published by the incident review team (Thomas and Vergari 2002). As shown in the image there is significant under prediction of the fire growth on the north edge of the fire and over prediction of fire growth on the southern edge of the fire. A second set of simulations were completed using gridded wind data for the same period keeping all other factors the same (fig. 9). Agreement between the actual and predicted final fire perimeters is much better. The discrepancy between predicted and actual perimeters on the right (west) edge of the fire area is due to a burnout operation that was conducted by the firefighters, and was not simulated in the FARSITE runs. While these initial test cases are not conclusive they suggest that surface wind modeling based on commercial CFD software captures variations in wind speed and direction at the 100 m scale and that wind information at this scale increases the accuracy of short term (< one day) fire growth simulations.

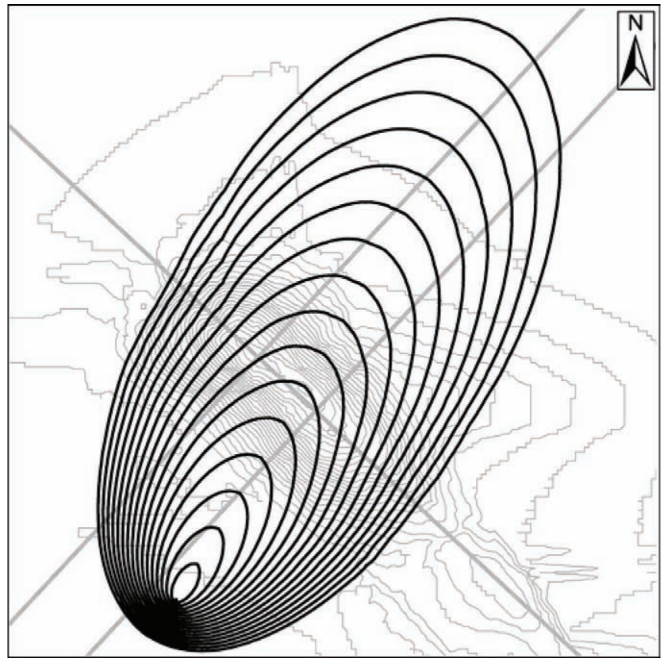

Figure 6. FARSITE fire area growth simulation assuming uniform wind speed and direction.

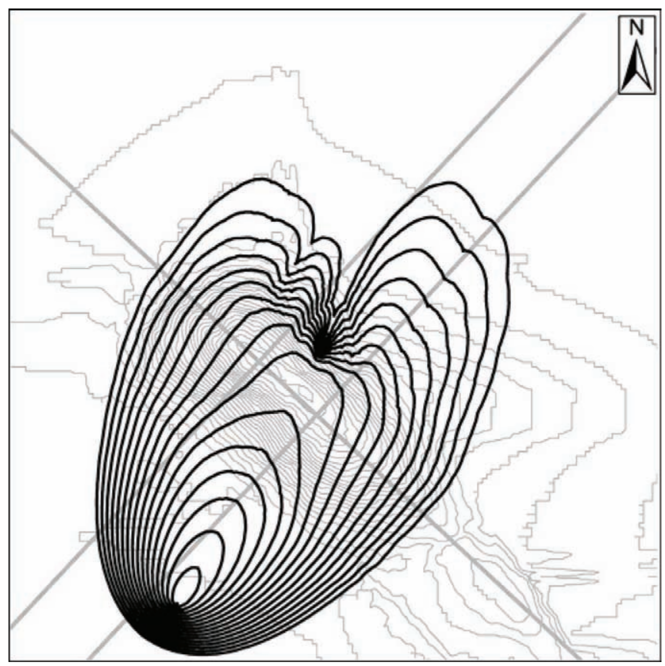

Figure 7. FARSITE fire area growth simulation using gridded wind simulation.

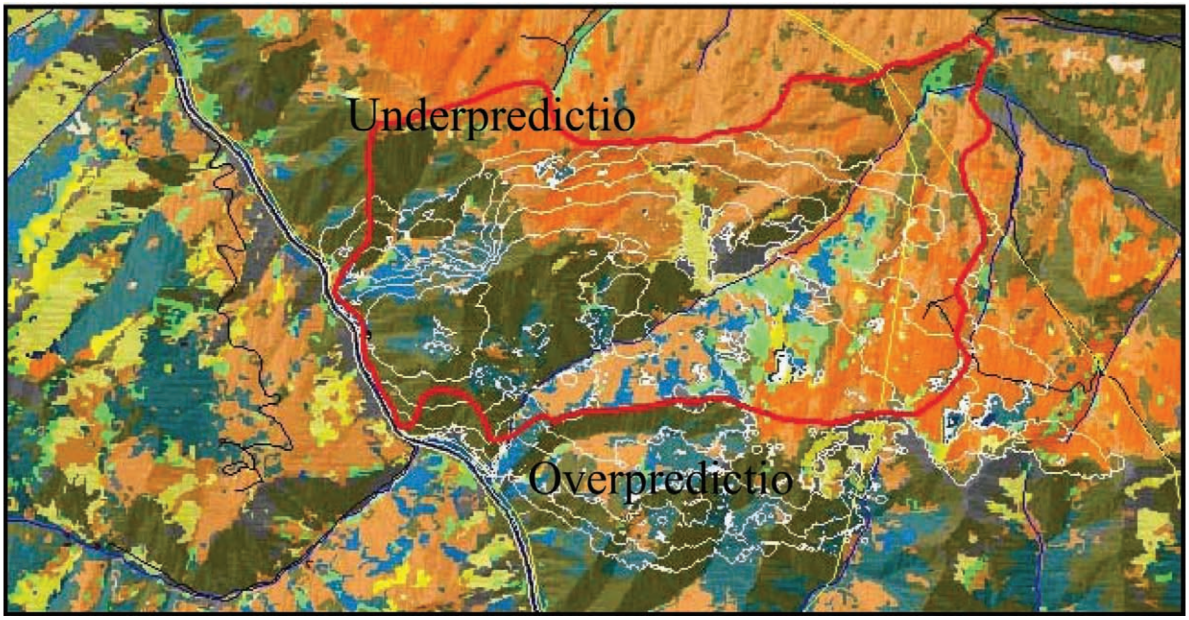

Figure 8. FARSITE simulation of the Price Canyon Fire assuming uniform wind speed and direction from the left to right (west winds). White lines represent successive fire perimeters produce from the FARSITE simulation, heavy red line represents actual final fire perimeter. Fire started on the extreme left edge of the perimeter along the railroad on the canyon floor.

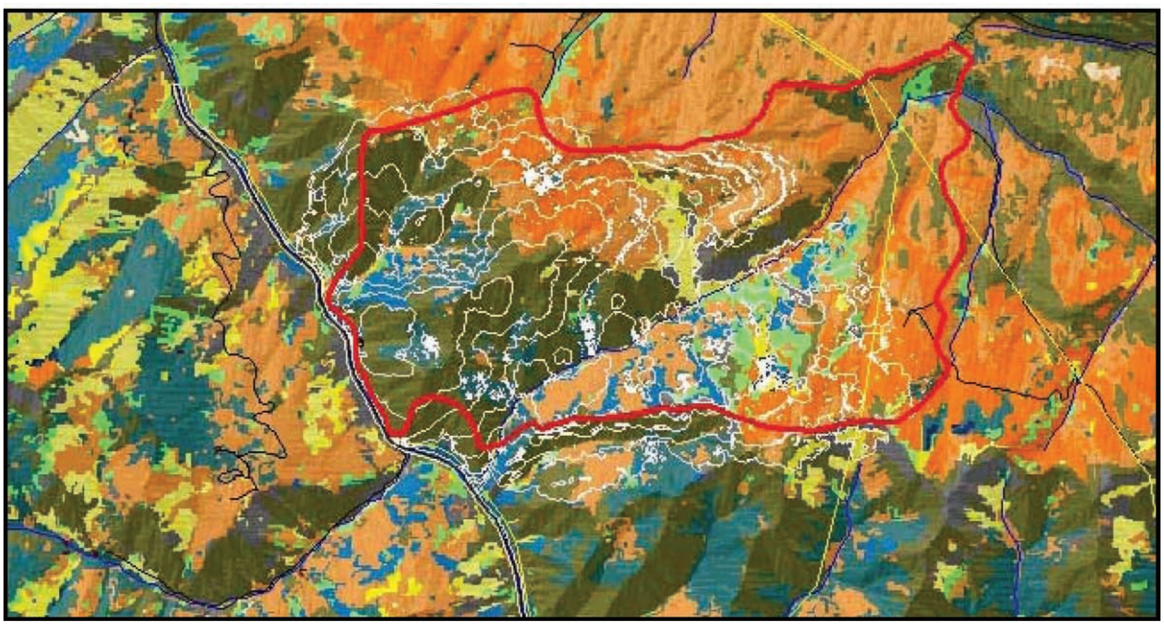

Figure 9. FARSITE simulation of the Price Canyon Fire using gridded wind data from CFD-based simulation. General wind flow input to CFD was from the left to right (west winds). White lines represent successive fire perimeters produce from the FARSITE simulation, heavy red line represents actual final fire perimeter. Fire started on the extreme left edge of the perimeter along the railroad on the canyon floor.

Conclusions

The CFD-based methodology for simulating the influence of terrain on surface wind flow represents a new technology, at least from a fire management perspective. Research efforts over the past two years have demonstrated that this technology, termed gridded wind, can provide highly detailed wind speed and direction information in time frames suitable for use by fire incident management teams (Price Canyon Fire-Thomas and Vergari 2002; Hayman Fire- Graham 2002). Although computationally intensive, the process has been refined so that a typical solution (10 to 100 m resolution wind speed and direction) on a grid measuring 40 by 40 kilometers can be completed in a matter of two to three hours using a laptop computer.

The accuracy of the wind simulations has been evaluated by comparing gridded winds against measured wind averages at discrete points. The results indicate general agreement and that the simulated gridded wind speeds and directions are most accurate for pressure gradients such as cold fronts, Foehn (Santa Ana), onshore/offshore winds and are less accurate for the low speed density driven flows such as those associated with diurnal heating and cooling of the earth's surface.

Gridded winds are simulations not forecasts. They are simulations of what the wind flow would be under different general (synoptic) wind scenarios. Gridded wind information has been used to identify areas and/or conditions that may produce high fire intensity and spread rates and for identifying locations where fire spotting might occur. Comparison of fire growth simulations using the FARSITE fire growth simulator with and without gridded wind information have demonstrated that the accuracy of short range (< one day) fire growth predictions is significantly higher using gridded wind than without it.

Acknowledgments

Funding for this study was provided by the Joint Fire Sciences Program and the USDA Forest Service. Technical support to deploy and maintain portable weather stations was provided by Robert Schuette and Paul Sopko. The work of Dan Jimenez to develop the methodology by which gridded wind could incorporated in GIS based shape files has been essential. The efforts and support of Kyle Shannon to run and trouble shoot the process are sincerely appreciated.

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Exploring Use of Climate Information in Wildland Fire Management: A Decision Calendar Study

Thomas W. Corringham, Department of Economics, UCSD, La Jolla, CA
Anthony L. Westerling, Scripps Institution of Oceanography, Climate Research Division, La Jolla, CA
Barbara J. Morehouse, Institute for the Study of Planet Earth, University of Arizona, Tucson, AZ

Abstract—*Wildfire management is an institutionally complex process involving a complex budget and appropriations cycle, a variety of objectives, and a set of internal and external political constraints. Significant potential exists for enhancing the use of climate information and long-range climate forecasts in wildland fire management in the Western U.S. Written surveys and interviews of fire and fuels managers at local, regional, and national levels, provide information and insights into the decision processes, information flows, and decision nodes used in wildfire planning and management, and allow the construction of decision calendars showing how climate information needs vary seasonally, over space, and through the organizational network.*

Potential exists for fostering use of climate information, including seasonal to inter-annual climate forecasts at all organizational levels, ultimately opening possibilities for improved targeting of fuels treatments and prescribed burns, more effective positioning and movement of initial attack resources, and improved staffing and budgeting decisions. Longer-term (decadal) forecasts could be useful at the national level in setting budget and research priorities. We examine the kinds of organizational changes that could facilitate effective use of existing climate information and climate forecast capabilities.

Introduction

Devastating wildfires flaming across large expanses of the United States in recent years have galvanized politicians, fire managers, and ordinary citizens alike in an effort to understand the processes driving catastrophic fire and to develop ways to anticipate when and where severe fire is likely to occur over time and space. Scientific knowledge and information contributes to better fire prediction and management, but requires successful dissemination to and use by decision makers. An essential first step in this process involves identifying optimal points in the decision networks of agencies charged with wildland fire management where such information may be inserted into decision processes. This, in turn, requires understanding the annual cycle of decision making throughout the wildland fire management organizations. The study reported here identifies points in decision calendars where climate-fire knowledge may be productively introduced and examines the potential value of such information in strategic fire planning processes.

Background

Since the 1970s, a dramatic trend has emerged in the size of the annual area burned by wildfires in the western United States with the average annual reported area burned increasing by approximately 85 percent per decade in the eleven contiguous western states. Concomitant increases in variability in annual area burned and in fire suppression costs pose a serious challenge for Federal and State land and resource managers.

The variance in annual area burned in the last decade is nearly 22 times higher than in the 1970s. Since managers must be prepared for the worst possible scenarios in every fire season, increased uncertainty about the scale of the western fire season each year imposes high costs on public agencies to sustain appropriate levels of preparedness. Recent progress in our understanding of the links between climate and wildfire, and in our ability to forecast some aspects of both climate and wildfire season severity a season or more in advance, offers some hope that these costs might be reduced through the increased integration of climate information into strategic planning for fire and fuels management.

Western wildfires have imposed steep costs in recent years. Real average annual suppression costs for the U.S. Department of Agriculture's Forest Service alone have increased by a factor of 2.6 over the last two decades, and have exceeded $1 billion in three of the last five years. Costs for Department of Interior agencies have also increased, exceeding $300 million per year in the last four years, more than double the average of the preceding six years. While federal agencies' fire suppression budgets have increased recently, funding still reflects what would likely be spent in an "average" year. Given that average years seldom occur, actual costs tend to fluctuate between low and high extremes. Modeling area burned and suppression costs as a function of climate variability alone, Westerling and others (2004) found that the probability of the Forest Service's suppression expenses exceeding the current annual suppression budget has been over 50 percent since 1987; this is a substantial increase over the preceding 40 years, when the probability was closer to one in three.

In addition to the effects of climate variability on wildfire, long-term biomass accumulations in many western ecosystems have fueled an increased incidence of large, stand-replacing wildfires in areas where such fires were previously rare (Allen and others 2002). These severe large fires can result in erosion and changes in vegetation type, with consequences for water quality, stream flow, future biological productivity of the affected areas, and habitat loss for endangered species. Apart from deleterious ecological consequences, severe fires can also dramatically affect amenity values of public land for recreation and for homeowners living in the wildland-urban interface.

In response to the buildup of fuels following a century of active suppression, the National Fire Plan (USDA/USDOI 1995, 2001, 2002) has charged land management agencies with reducing fuels on millions of hectares of public lands through mechanical removal, prescribed fire and wildland fire use. The project is vast in scope, and will take many years to implement. The effective application of climate information and climate forecasts to fuels management could significantly reduce the costs of both fire and fuels management, by allowing managers to strategically target areas with the highest risks on a seasonal to inter-annual basis. This is one of several uses of climate information in wildland fire management. In this paper, we identify several more, as the results of a decision calendar survey of fire and fuels managers in the Western United States.

Organization of Fire Management

Wildland fire management in the US is integrated across agencies by the National Interagency Coordinating Center (NICC) located in Boise, Idaho, and by 10 Geographic Area Coordination Centers (GACCs) (fig. 2). At the same time, wildland fire suppression and preparedness activities continue to be managed by a variety of national, state, and local agencies. Over half of the land in the Western United States is managed by federal agencies, encompassing most of the West's wildlands (fig. 3). Each agency works at different organizational levels, ranging from federal agency offices in Washington D.C. and the National Interagency Fire Center in Boise, ID, to regional agency offices, GACCs, and local administrative units managing the crews and equipment needed to actually carry out fire suppression and fuels management.

Figure 2. Geographic Areas for wildland fire management.

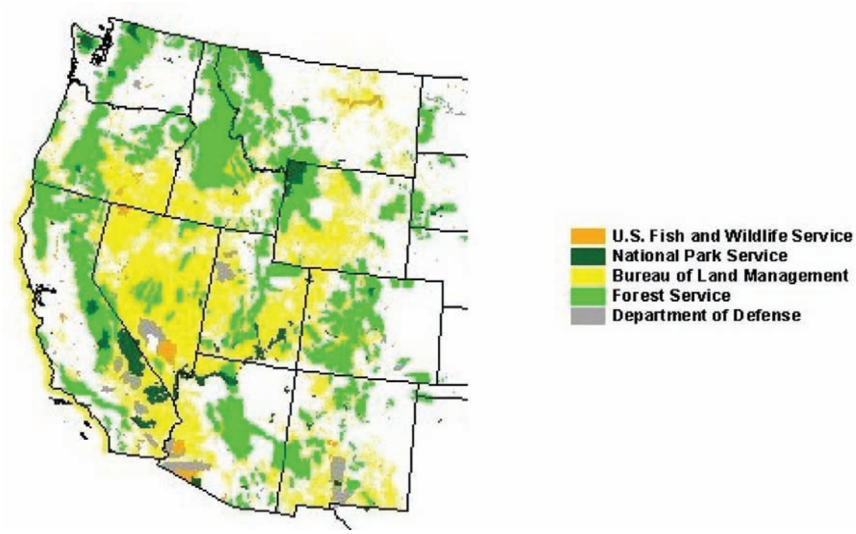

Figure 3. Federally managed land in the Western United States.

To keep the survey process manageable, we focused on two agencies, the Forest Service (USFS) and the National Park Service (NPS) and on three organizational levels of management: the local level, the regional level, and the national level. Locally, fire managers, fuels managers, and fire chiefs work within National Parks and Forests, which are overseen by regional offices of the NPS and the USFS. These positions report to national offices of the NPS and the USFS, which are located, respectively, within the Departments of the Interior and Agriculture.

National Parks and Forests also coordinate their fire suppression and fuels management activities under the auspices of regional interagency fire management organizations and administrative bodies: GACCs mentioned above and MAC groups (Multi Agency Coordination Groups), which operate during the peak fire season to coordinate all the resources available in the different agencies so as to maximize efficiency in fighting wildland fires. Outside of the fire season, most interaction between the National Parks and Forests and their regional and national offices involves budgeting and planning activities. Some planning and fuels treatment work is coordinated with the GACCs and NIFC also. A simplified flow chart shows the organizational levels and links of interest in this study (fig. 4).

Fire weather and climate information and forecasts feed into the decision processes at different levels from several sources. At the national level the Fire Weather Service, a division of NOAA's National Weather Service (NWS), provides a variety of weather and climate products for use by fire managers. At the regional level, the GACCs have Intel and Predictive Services divisions that gather and disseminate weather and climate information from the NWS, from Regional Integrated Science and Assessment programs (RISAs), and from their own fire meteorologists. The use of climate products varies from region to region, partly due to the different climatic conditions in the different regions, partly due to different levels of interest and experience among regional personnel. At the local level, climate and weather information is obtained from the GACCs and the NWS, and, at some parks and forests, from staff fire meteorologists. Local fire managers are generally highly sophisticated users of short-term weather information as it relates to suppression activities; however, the use and comprehension of longer-term climate products is highly variable.

Traditionally short-term weather information has been used to great effect operationally in wildland fire suppression during the fire season. With increasingly long and severe fire seasons, and with an increased emphasis among federal agencies to restore natural fire regimes to ecosystems through use of fuels treatments such as mechanical thinning, prescribed fires and wildland fire use, longer-term climate information products are finding use to support longer term planning decisions.

Climate Science and Climate Forecasts

Over the past several decades, there has been increasing interest in developing a better understanding of the use of scientific and forecasting information by decision makers (Sarewitz and others 2000, Stern and Easterling 1999). The Regional Integrated Science and Assessment Program funded by the US National Oceanic and Atmospheric Administration's Office of Global Programs (NOAA-OGP) funds research specifically designed to identify climate information and forecast needs and foster utilization of climate information in the regional scale in the United States. The Climate Impacts Group (CIG) in the US Pacific Northwest, for example has been working with water managers to integrate long-term climate change information into their decision processes (Miles and others 2000). Likewise the California Applications Project (CAP) works closely with water managers and administrators to incorporate climate change information into planning at state and sub-state scales. In the US Southwest, water and rural livelihoods are among the research foci of the Climate Assessment for the Southwest (CLIMAS) project (Morehouse and others 2000).

Scientific information and forecasts can provide important guidance to decision makers who are concerned about reducing risks to vulnerable populations, ecosystems, and the built environment, reducing their

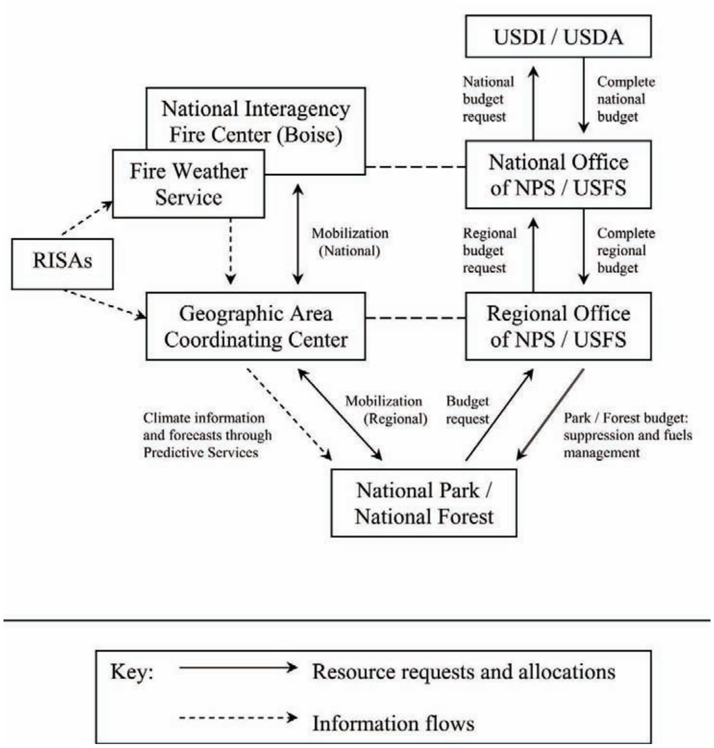

Figure 4. Wildland Fire Management Organizational Flowchart.

operational costs, diminishing the potential for lawsuits or other challenges to their decisions and activities, and managing in a more rational manner the resources for which they are responsible. For example, information about past climatic conditions can prompt decision makers to change their assumptions about what constitutes "normal" climatic conditions; this in turn can influence the degree and nature of extreme conditions they include in their infrastructure planning and construction activities. Historical climate information is also useful for anticipating the potential intensity of threats to life and property in planning for emergency preparedness. The recent drought conditions in Arizona and New Mexico, for example, have been outside the norms assumed by water managers, fire managers, and forest managers. In providing information about the swings in climatic conditions over time scales of more than 100 years (the length of the historical record in this region), scientists provide information that is useful for developing new and better plans for responding to severe drought stress, and for refining models used to anticipate biophysical drought responses such as likely streamflow and reservoir levels, and fuel moisture conditions.

With the phenomenal growth in the provision of information via the internet over the past decade, access to all sorts of scientific information has become virtually ubiquitous. Indeed, complaints are frequently heard that there is so much information that people have difficulty not only knowing what information to use, but also in assimilating the vast amount of information available into useful syntheses. Climate forecasts, for example, are readily accessible via the NOAA web site and from other entities such as the International Research Institute (IRI). Knowing which forecasts are useful for what purposes, as well as the temporal and spatial distribution of forecast accuracy and skill is daunting. Workshops such as those conducted by CLIMAS for fire and fuel managers and decision makers (Morehouse 2000, Garfin and Morehouse 2001, Garfin and others 2003), provide opportunities to learn about the information that is available, how forecasts are made, and how much confidence forecasters place in their products over time and geographical space. Through interactions with climatologists, participants are also able to determine which types of information are most useful for what purposes, over what time periods, and in what areas.

Similarly, recent advances in assessing the skill and accuracy of climate forecasts promises to reduce some of the perplexity in using forecasts (Hartmann et al 2002). Such information provides decision makers with insight into how much weight they should place on certain forecasts, given the set of variables they must evaluate. Because climate forecasts are probabilistic in nature, it is never possible to have a 100-percent dependable prediction. However, scientific information about forecast skill and accuracy provides a means to understand how much reliance to place on any given forecast. This type of information has been identified repeatedly as among the most-needed types of knowledge, for scientific information to be integrated into decision processes.

Examples of Climate Information Uses in Wildland Fire Management: Budgeting, Staffing, Suppression, and Fuels Treatment

Several examples may be identified where scientific information and forecasts can play an important role in fire management. First, the National Fire Plan requires planning out 10 years (Departments of Agriculture and Interior 2001). In contrast, forecasts of wildfire season area burned can be made with reliable confidence for up to two years in advance in the Southwest, up to a year in advance in some interior basins, and up to a season in advance in many other parts of the western United States. For longer time horizons, instrumental and paleo records can provide analogous scenarios that can be used to explore the possible extent in space, time, and impact of extreme conditions that might affect fire regimes in wildlands. Such information can be incorporated into long-range forest and fuels planning.

Second, at more immediate time scales, forecasts and other information provide support for annual budget requests for fire management, and at the seasonal level, for emergency funding requests. In the West, such requests are formulated in February when enough of the winter has passed for managers to have an early insight into the likely severity of the upcoming fire season. These funding requests are predicated on an assessment of the resources needed to suppress fires. As the fire season approaches, shorter-term climate information can provide decision makers with information that is useful for refining plans for suppression activities, for possibilities related to fire use (for example, allowing already-ignited fires to burn in areas where such burns would be beneficial to the landscape), and for allocating resources. Fiscal-year suppression-expenditure estimates, which are based on observed and forecast climate, and are updated on a regular basis throughout the fire season, are also used to keep the USDA, USDI and Congress apprised of funding needs.

Prescribed burning is another area where scientific information is essential. Climate information for the past several years and for the upcoming season or year allows managers to determine the relative risk of carrying out prescribed burns, based on current and predicted conditions. For example, managers can compare existing conditions to those of analogous years in the past, based on scientific analysis of the instrumental and paleo records of fire occurrence and climate conditions in the region. Forecasts provide insights into the likelihood of anomalous wet or dry conditions, as well as of "normal" conditions (for example, those that were statistically prevalent over the thirty-year record; currently the base data are for 1970-2000). Prescribed burning plans can also be informed by scientific information such as that produced by remote sensing; for example, NDVI "greenness maps," which provide geo-referenced information about vegetation moisture conditions.

All of the above decision activities at some point require plans and action with regard to assembling and allocating resources. The number of fire fighters and support personnel needed must be identified, vendors to provide support services must be contracted, and aircraft and other equipment needs must be detailed. The decision calendar that we have employed in this study highlights these types of decision nodes, and the entry points where climate and related scientific information may be most readily and effectively introduced. It is at these points that use of scientific information and forecasts is most likely to improve district and forest-level fire management planning, budgeting, and decision-making.

Survey Methods

To construct fire management decision calendars showing the use of climate information, a survey was conducted in 2002-2003 of nine fire management officers and decision makers based in the Southwest and California, and of several dozen members of wildland fire management groups assembled for other purposes. Conversations with several key decision makers responsible for interagency coordination provided supplemental background information. We selected a structured, key-informant survey approach for our study as this was the most efficient way to obtain the required information, and it provided a means of gathering information from informants in a consistent format.

The survey was designed to gather a range of information. First, we asked respondents to complete a decision calendar, specifying when during the fire year key prevention and suppression decisions are made, and indicating the extent to which climate information and climate forecasts are used to support these decision-making processes. We asked informants to specify what climate information and climate forecasts are used, where these products are obtained, and what additional climate products managers would find useful. We asked respondents about their perceptions of the limitations of these products, in terms of the accuracy of forecasts and in terms of other constraints in the decision processes. We asked if agencies kept records of yearly management goals and of post-season evaluations, and if respondents could provide examples of climate information successes and failures. Finally, we asked respondents to rank a set of wildland fire management objectives in terms of importance.

The inclusion of a decision calendar format was a key feature of our survey design. Decision calendars, as we define them here, are temporally organized structures that reflect the timing of planning and decision making in the course of a regular fire year. Decision calendars have been used previously in integrated climate assessments. We based our calendar format on that used by Weiner (2004). Using this approach allowed us to determine what sorts of plans and decisions were important at which times of the year. This in turn allowed us to associate the timing of decisions, historical climate conditions during those periods, and forecasts for those time periods.

The survey selection process itself was structured, rather than random. We chose to focus geographically on the Southwest and the Pacific Southwest Regions. Second, within these regions, we targeted fire managers in national parks and forests where we had an existing connection or that were relatively accessible. Third, we took advantage of meetings we were attending for other purposes to conduct interviews with selected attendees. The small number of Parks and Forests we survey happen to have high levels of prescribed fire activity, which may bias our results. In spite of these limitations, we collected a comprehensive and varied sample of respondents in the targeted regions. The framework we employ could readily be extended to generate a more complete picture of climate information use for fire and fuels management throughout the United States.

Survey Results

While the number of respondents was too low to conduct a statistical evaluation of responses, valuable insights emerged from the project's focus on key informants who provided information that could be generalized across all fire management groups in the Forest Service and Park Service.

The decision calendars obtained (fig. 5) from our respondents show several interesting patterns. The types of decisions that are made throughout the year can be broken into several groups: pre-season planning, staffing decisions, monitoring of conditions, prescribed fire activities and other fuels management activities such as thinning and pile burning, peak season suppression activities, regular season budget requests and allocation decisions, and emergency severity funding requests.

The timing of these activities varies over the geographical extent of our study areas. In particular, the peak suppression season differs in length and actual time of year from region to region. Southern California has a long season with a special concern in the late fall/early winter season when strong Santa Ana winds are dominant. The Sierra Nevada in central and northern California has a relatively short season in comparison, while New Mexico and Arizona fire seasons depend heavily on the onset and wetness of the June-August monsoon season. Of particular concern is the probability of dry lighting igniting fires in the pre-monsoon period. Monsoon rains typically end the spring/summer fire season, although a second fire season may occur in the fall after the end of the monsoon season. Similarly, optimal windows for prescribed fire and fuels management activities also vary greatly across the study areas.

The decision calendars also differ across organizational levels. Local staffing decisions involve seasonal staffing, training, and determination of hiring and lay-off dates. Local budgeting involves the internal allocation of funds, annual funding requests, and peak season severity funding requests. Local pre-suppression activities include fuels treatments, prescribed fire, broadcast burns, pile burning, and mechanical thinning projects. Local suppression activities include the pre-positioning of local resources, movement of resources, mutual aid decisions, severity requests, large fire management (planning and implementation), fire use (planning and implementation), fire prevention, restrictions, and area closures. Other local activities reported by survey respondents include outreach, public education, special staffing, training, 5-year planning and analysis, and Geographic Information System (GIS) analysis.

Regional and national level activities include suppression support for large fires or multiple fire events, or widespread high fire danger or preparedness levels, strategic pre-positioning and movement of resources, again, generally when high danger conditions are present, planning and budgeting work, and the dissemination of information. Research and changes in overall organizational structure are managed at the national level.

Potential for Improved Use of Climate Information

Based on survey responses, we have identified the following decision processes that would benefit from enhanced use of climate information.

At the national level (NIFC and Washington DC offices of the NPS and USFS), national annual and inter-annual budget requests and allocations are conducted in the late winter and early spring. Budgeting procedures could be improved by explicitly taking seasonal to inter-annual climate forecasts into consideration, as could communications with Congress throughout the fiscal year. National suppression activities and mobilization decisions during the peak fire season, and preparedness and presuppression planning and budgeting in the off-season could be made more cost-effective through greater reliance on climate products. Finally, inter-annual and decadal forecasts could be considered in the formulation of the research agenda of the Joint Fire Science Program (JFSP) Board.

At the regional level (regional offices of the NPS, USFS, and the GACCs), regional budgeting and resource allocation activities occur before and during the fire season. Annual hiring, training, and staffing decisions are made leading up to the fire season, as are decisions concerning the pre-positioning of initial attack resources. These decision processes could benefit from increased use of seasonal and annual climate forecasts. The allocation of resources to fire suppression and prescribed fire activities occurs throughout the year, and regional mobilization decisions and mutual aid decisions are made during the peak fire season. These decisions could be improved through greater reliance on seasonal and

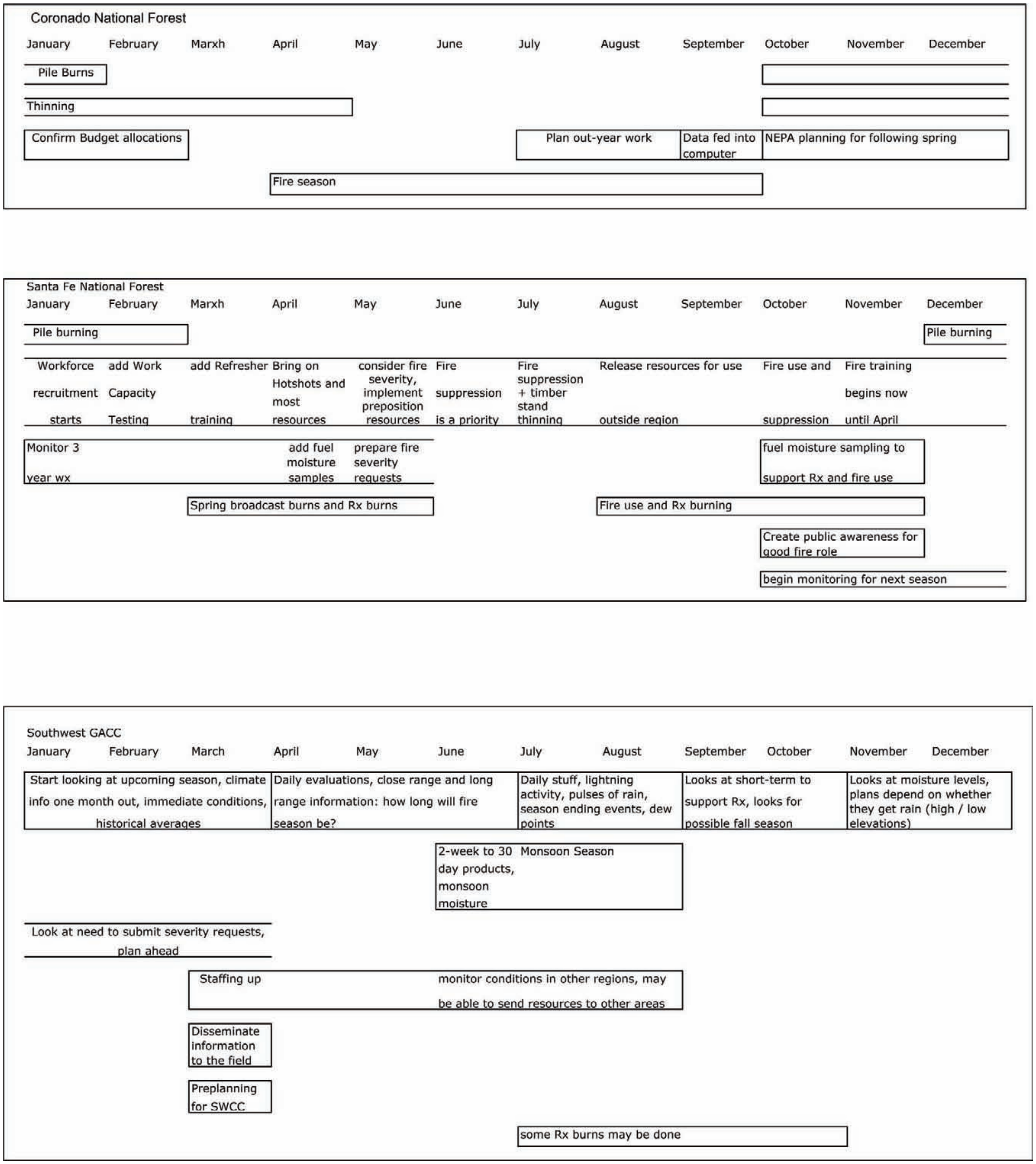

Figure 5a. Decision Calendars.

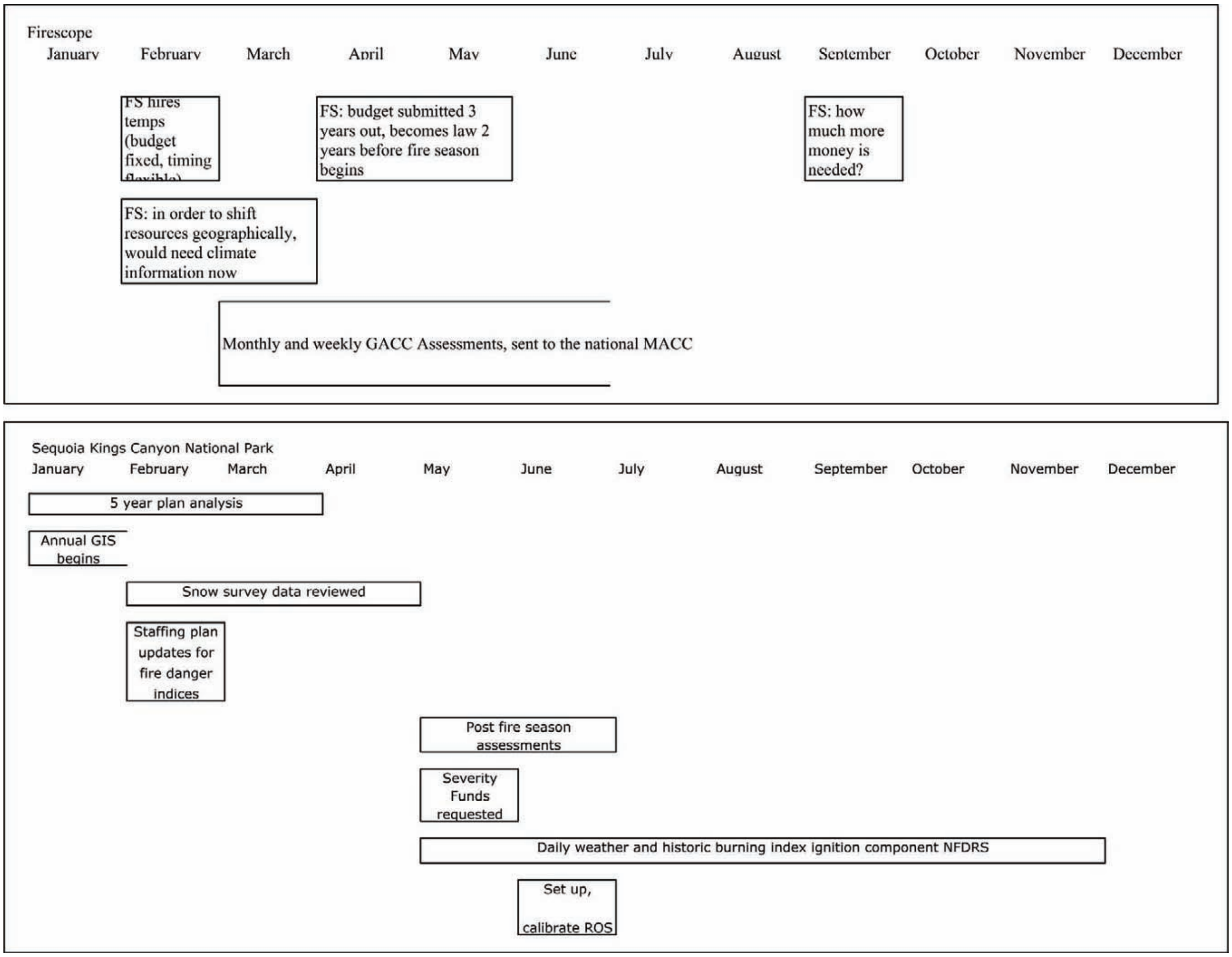

Figure 5b.

monthly climate forecasts, and through a standardized and integrated use of climate information products and climate forecasts.

At the local level, hiring, training, and staffing decisions are made leading up to the fire season, and could benefit from specific forecasts of expected fire season timing, length, and severity. The internal allocation of resources to suppression and prescribed fire activities is conducted before and during the fire season, as is the setting of annual targets for prescribed fire, fire use, and fuels treatment. These decisions could be improved through greater reliance on seasonal forecasts. External budget requests are made annually a year in advance, to regional offices, and could be set more accurately with the aid of annual climate forecasts, potentially reducing the need to rely on severity funds during the peak season.

From a longer-term perspective, Fire Management Plans (FMPs) are revised on a five-year cycle in conjunction with land management plans. In addition to responding to political and economic pressures, these FMPs could also be tuned to climate outlooks (for example, setting burn targets, prescriptions, and boundaries conditional on long-range climate trends and cycles). A potential difficulty involves the varying levels of access to climate information and to trained climatologists from unit to unit. A program could be established through which Predictive Services meteorologists at the GACCs provide oversight and assistance.

Also considering long-term objectives, at the national level the Joint Fire Science Program (JFSP) Board sets the national wildland fire research agenda. A greater emphasis on climate information systems and the role of climate forecasts in wildland fire management decisions could lead to improvements in the quality of forecasts available to wildland fire managers.

Institutional Barriers to Using Seasonal Forecasts in Fire Management

Several important institutional barriers exist to the use of seasonal forecast information by fire managers. One is the federally required two-year budget cycle,

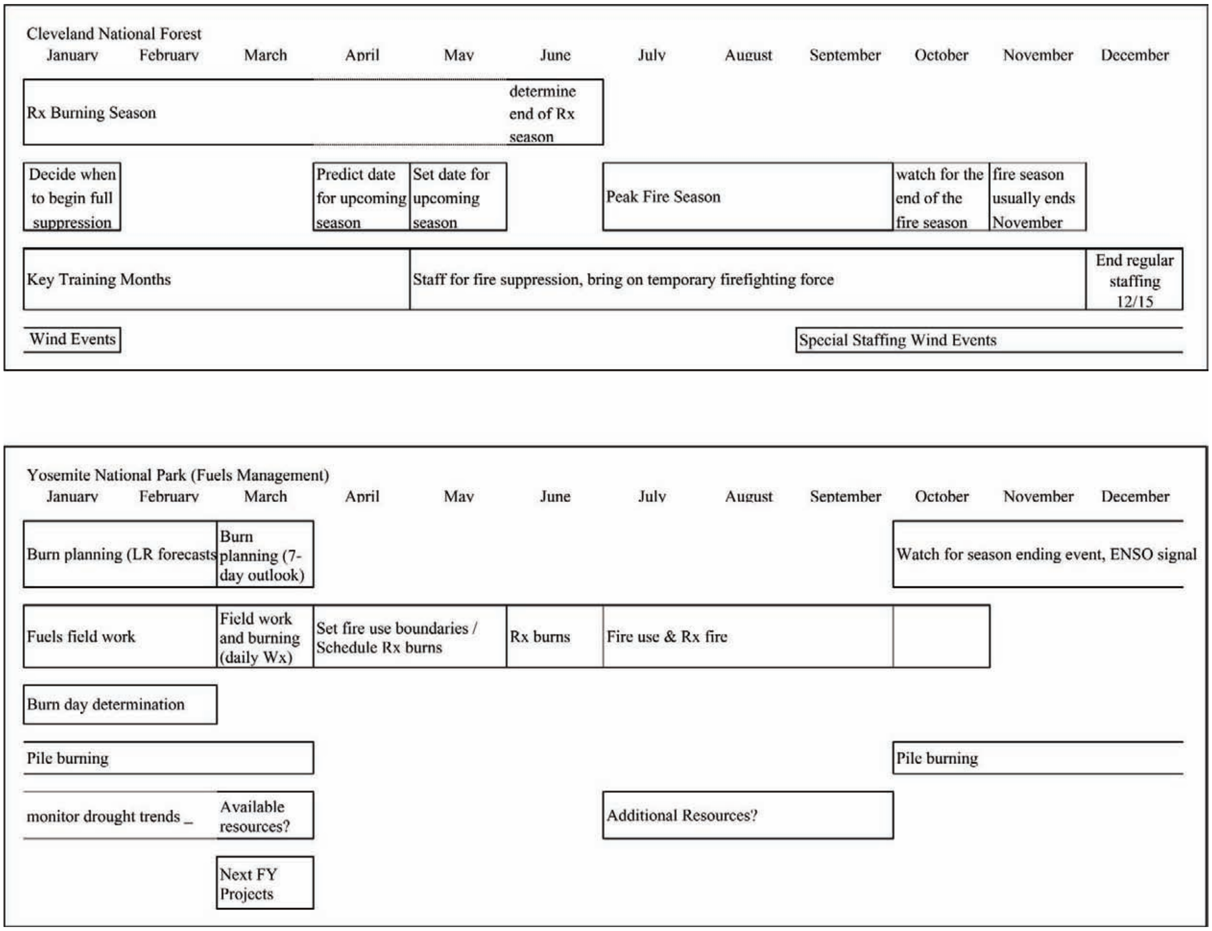

Figure 5c.

which allows little latitude for shifting funds regarding forest treatment activities based on climatic conditions that arise after budgets are submitted and approved. For example, given the high probability of La Nina conditions producing anomalously dry conditions during the winter in the Southwest (Gershunov and Barnett 1998), a reasonably confident La Nina prediction the winter before a fire season should prompt a new analysis of budget allocations to address the emerging fire risk for that season. However, current policies afford little room for such adjustments to allocations of funds to avert or suppress fires in the region.

This institutional constraint is related to another barrier, the lack of flexibility in authorizing legislation, at the federal level, to make regional or local-level modifications in policies that reflect ground-level realities. For example, fire managers argue that it should not be so cumbersome to obtain permission from the USFWS to treat areas protected by the Endangered Species Act. Climate information offers another tool for assisting both fire managers and USFWS specialists in arriving at management strategies that take into account the vicissitudes of environmental variability and change, as well as the strong mandate to protect threatened and endangered species.

A third area of institutional disjuncture between availability and effective use of climate information involves the lack of flexibility in the fire planning process itself. Organizational inertia is partly to blame. As Lach and Ingram (2003) have shown for water managers, changes only tend to be made when extraordinary conditions result in the inability of existing practices and policies to address the problems. Understanding how and when innovation can occur (such as the use of climate information and forecasts to make fire management decisions) is crucial for devising ways to communicate appropriate information, and to providing the information at the appropriate time, to the appropriate people. Understanding the decision calendars of fire managers provides a means of beginning this task.

The fourth area of constraints involves the mismatch between decision calendars and forecast time horizons. One solution is to adjust the timing and content of forecasts to fit the temporal and spatial patterns of decision making. Recent efforts to establish annual fire-climate-fuels assessment processes for the US West and the US Southeast, for example, have included the development of specific consensus climate forecasts for the time periods of most concern to fire and fuels managers, particularly those associated with pre-season planning for resource allocation (Garfin and others 2003).

A more challenging solution would be to alter the timing of funding decisions, and planning horizons to recognize and respond to the spatial and temporal vicissitudes of environmental variability and change. If congressionally allocated funds could be spent for prescribed burns and other treatments over inter-annual or decadal time horizons, or if tradeoffs in funding could be made over larger regions, it would be easier for managers to adjust their fire management plans to reflect forecasts and impacts of ENSO conditions, including multi-year combinations of wet and dry conditions.

Conclusions and Recommendations

Climate information is currently widely used by fire managers, but there is potential for greater and more effective use of available information. The results presented here could be readily extended to other land management agencies, and to State and local fire agencies. In some cases the science and technology is available to integrate climate information into decision making, although organizational changes may be required to fully realize the value and increased efficiency of climate forecasts and information. In other cases, forecast accuracy will have to be increased before decision makers in the fire management sector will be willing to change their management strategies in a manner that integrates such information.

On the basis of our survey results, we recommend a review of management procedures to make various decision processes more flexible, and to allow forward-looking use of climate information and climate forecasts. For example, climate forecasts could be used to set more realistic fuels management goals at the unit level, and to strategically set priorities for fuels management and prescribed fire treatments. We also recommend a review of wildland fire budgeting procedures at the local, regional, and national levels, again taking climate considerations into account.

The National Fire Plan notes that "Critical to fire science program success are mechanisms to ensure that the information is transferred to land and fire managers in a usable form." (USDA/USDOI, 2001). The National Wildfire Coordinating Group (NWCG) Fire Weather Working Team has been charged with assessing current and projected requirements for fire weather products as part of its ongoing efforts to address fire weather issues. In this task, collaboration with Regionally Integrated Science Assessment groups (RISAs) could be highly productive. Training in the use of climate information could be provided at the Fire Management Leadership course at the National Advanced Resource Technology Center (NARTC).

Considering the wide variation in the use of climate information and forecasts, and in the climate-related expertise of wildland fire and fuels managers, we recommend that one clearing house for information be established, to allow the sharing of information and analysis across all agencies and at all institutional levels. Further, to ensure a high standard of use of climate information and forecasts we suggest that climate forecasts be explicitly considered in the National Interagency Mobilization Guide, in Geographic Area Mobilization Guides, in the interagency Wildland Fire Situation Analysis (WFSA), and in interagency Allocation of Resources protocols.

Realizing the full potential of climate information and forecasts will require the collaborative effort of several agencies and the climate science community. The potential gains from such an effort would be significant, however, and can be facilitated by a detailed understanding of the decision making processes involved in wildland fire agencies, the timing of such decision processes, and the kinds of information requested by fire managers across the United States.

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Monitoring Ecological Resources within U.S. National Parks: Developing "Vital Signs" of Ecological Integrity for the Northeast Temperate Network

Don Faber-Langendoen, Senior Ecologist, NatureServe and Adjunct Associate Professor, State University of New York College of Environmental Science and Forestry (SUNY ESF), Syracuse, NY
Geraldine Tierney, Post-doctoral Associate and James Gibbs, Associate Professor at SUNY ESF, Syracuse, NY
Greg Shriver, Network Coordinator and Fred Dieffenbach, biologist/data manager, Northeast Temperate Network, National Park Service, Woodstock, VT
Pam Lombard, hydrologist, U.S. Geological Survey, Augusta, ME

Abstract—*The National Park Service (NPS) initiated a new "Vital Signs" program in 1998 to develop comprehensive, long-term monitoring of ecological resources within U.S. national parks. Vital signs (VS) are indicators, and are defined as key elements, processes or features of the environment that can be measured or estimated and that indicate the ecological integrity of an ecosystem. A core science team is working with the 11 parks of the Northeast Temperate Network (NETN) to identify appropriate regional and park-specific indicators of ecological integrity, and to develop criteria for assessing changes. The team identified VS representing the diversity of ecological systems and anthropogenic stressors within NETN parks at a range of ecological scales. In Phase 1, baseline inventories and analysis of threats provided information to build conceptual ecological models for four ecosystem groups – terrestrial, wetland, aquatic, and intertidal systems. In Phase 2, the core science team developed a list of more than 100 potential VS. This preliminary list was peer-reviewed through workshops, from which a final list of 22 high priority VS, with 104 associated potential measures, was developed. In Phase 3, protocols will be developed for each VS measure. Statistical power analysis and cost assessment will be an integral part of Phase 3 in order that the final set of measured VS produce reliable inference within cost constraints of NETN. Standard summaries of statistical trends in VS measures will be compiled. Importantly, each measure will also have a rating scheme to allow integration of VS into an overall ecological integrity rank (A-D) for particular occurrences of an ecosystem. These ranks, currently used by NatureServe and the Network of Natural Heritage Programs, provide an important communication tool for managers. An example is presented for jack pine woodland in Acadia National Park.*

Introduction

Recognizing the need for comprehensive, long-term monitoring of ecological resources within the U.S. National Park System, the National Park Service (NPS) undertook a major new initiative in 1998 to develop a program for long-term monitoring of "Vital Signs," or indicators, of ecological integrity within the parks. Vital signs (VS) are key elements, processes, or features of the environment that can be measured or estimated and that indicate the ecological integrity of an ecosystem. This Inventory & Monitoring (I&M) program is being implemented within 270 parks, which have been grouped into 32 park networks, using a consistent framework and process (Fancy, this proceedings; Gross, this proceedings). A core science team is working with the 11 parks of the Northeast Temperate Network (NETN) to identify appropriate regional and park-specific indicators and measures of ecological integrity and to establish protocols for their measurement (table 1). As with other NPS Networks, the NETN team has focused on identifying indicators representing the diversity of ecological systems and anthropogenic stressors within NETN parks at a range of ecological scales. The challenge has been to

Table 1. Parks included in the Northeast Temperate Network, showing park name, state, and park size (in acres). NP = National Park, NST = National Scenic Trail, NHP=National Historical Park, NHS=National Historic Site, NPA = National Park Area. Only the northern section of the Appalachian NST (from Maine to Pennsylvania) lies within the NETN. Other networks assess the southern sections.

Park Name	State	Size (acres)
Acadia NP	Maine	47,498
Appalachian NST	Maine-Georgia	85,036
Boston Harbor Islands NPA	Massachusetts	1,465
Marsh-Billings-Rockefeller NHP	Vermont	643
Minute Man NHP	Massachusetts	967
Morristown NHP	New Jersey	1,707
Roosevelt-Vanderbilt NHS	New York	775
Saint-Gaudens NHS	New Hampshire	150
Saratoga NHP	New York	3,392
Saugus Iron Works NHS	Massachusetts	9
Weir Farm NHS	Connecticut	74

identify a coherent set of indicators that cover the range of ecological resources and stressors found in the network within the budgetary constraints of the program, and that can be meaningfully compared to other NPS networks, as well as indicator programs outside the NPS. NETN Vital Signs must also provide information that allows park managers to respond when changes to park ecological integrity are detected.

The need to compile a coherent set of indicators and measures that encompass essential aspects of ecosystem structure and function and contribute to an adaptive management program has led to increasing interest in the development of measures or indices of ecological integrity (Karr and Chu 1995; Harwell and others 1999; Andreasen and others 2001, Young and Sanzone 2002; Parrish and others 2003). At the outset, understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Fancy, this proceeding). Although our current understanding of these dynamics is far from complete, indices of ecological integrity should allow managers to discriminate between changes in indicators and measures that fall within the bounds of normal system dynamics from those that require a management response (Woodley 1993).

The overall process for developing the NPS VS program has been described elsewhere in this proceeding (Fancy, this proceedings, Gross, this proceedings). Briefly, the I&M Vital Signs Program incorporates a three-phase approach: Phase 1) define goals and objectives; begin the process of identifying, evaluating and synthesizing existing data; develop draft conceptual models; and complete other background work; Phase 2) prioritize and select VS and develop specific monitoring objectives for each park and the network; and Phase 3) develop detailed plans to implement monitoring, including the development of sampling protocols, a statistical sampling design, a plan for data management and analysis, and expectations for reports and other presentation of results. Herein we focus primarily on the NETN Phase 2 process – the prioritization and selection of Vital Signs – but we also briefly summarize our efforts in Phase 1 to develop conceptual ecological models, which provide a foundation and summary tool for indicator selection, and preview our next steps in Phase 3.

Phase 1: Conceptual Modeling

During the initial phase of the VS program, baseline data assessments are compiled, including results from 12 baseline inventories that the U.S. Geological Survey (USGS) I&M Program provide for each park. These include species group inventories, such as mammals, birds, herptiles, and exotic species, as well as comprehensive park mapping of ecosystems and communities through the USGS Vegetation Mapping Program (biology.usgs.gov/npsveg/). These maps are based on the federal U.S. National Vegetation Classification standards (FGDC 1997) and NatureServe Ecological System classification (Comer and others 2003). When all 11 parks are completed, these maps will provide a consistent ecosystem inventory across the Network. Park staff also completed a threats assessment 2001 to 2003 to assist in prioritizing VS. These inventory data provided the basic information needed to develop conceptual models that could be used to communicate the primary threats, stressors, natural resource priorities, and ecological condition within Network parks, and ultimately identify indicators of ecological integrity.

Conceptual ecological models are useful tools for summarizing and communicating ecological knowledge. Our intent in building these models is to predict linkages between ecological resources, key stressors, and elements of ecological integrity, and to use this information to select appropriate Vital Signs. These models should facilitate development of indicators that are a useful subset of measurable ecosystem features or processes that are particularly information-rich, in that their values are indicative of the integrity of the larger ecological system to which they belong (Parrish and others 2003).

Within NETN, we employed a conceptual model that includes both stressor (threats) and ecological condition

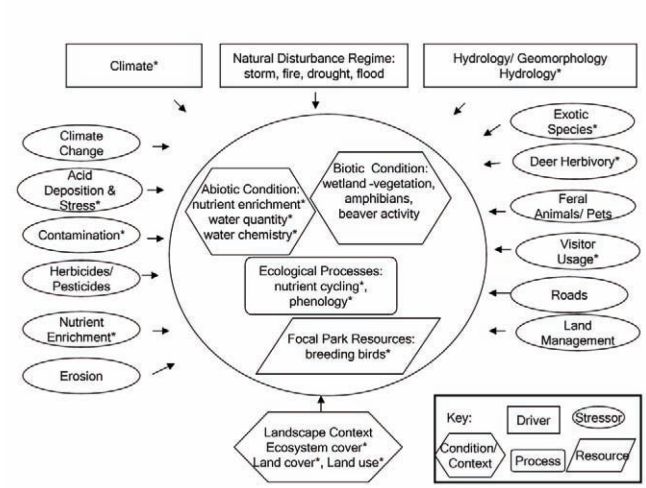

Figure 1. Example of a conceptual model for the wetlands ecosystem group. The key shows the major categories that organize the various vital signs. Similar models exist for terrestrial, aquatic and intertidal, and for each park. Stressors that are asterisked, and all vital signs inside the circle, were selected as part of the final Vital Signs list (see table 3).

components, visually depicting how system components interact. An accompanying narrative provides specific details of our understanding of the systems. We chose a hierarchical approach to model development, beginning with a general model for each of four key NETN ecological system groups --terrestrial, wetland, aquatic and intertidal ecological systems (figure 1). These general models identify key ecosystem drivers, stressors, ecological processes, elements of ecosystem condition and landscape context, and focal park resources within each of these four major system groups. The categories for our model include 1) Drivers, Stressors, and Landscape Features, 2) Ecological Condition, and 3) Focal Park Resources. Ecosystem drivers are major external forces such as disturbance regimes, hydrology, geomorphology, or climate that have large-scale influences on natural systems. Stressors are natural or anthropogenic forces of change acting upon ecosystems. Landscape features include landscape context, which refers to features of the surrounding environment that affect the ecosystem of interest at the "landscape" scale. Ecological condition in these models is comprised of elements biotic and abiotic condition, usually at the "stand" scale, such as population trend of selected species, or air quality. Ecological processes such as nutrient cycling or phenology are also considered as elements of ecological condition. Finally, these models include focal park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of their relevance to ecosystem integrity. These models and associated narrative are continually updated as new information about the systems becomes available.

Phase 2: Selection of Vital Signs

We prioritized and selected potential Vital Signs using a sequential peer review process. A core science team of six staff (representing expertise in forest ecology and vegetation science, aquatic ecology, wetland ecology, amphibians, ornithology, biogeochemistry, conservation biology, and ecological data management) first drafted a list of over 100 potential VS representing the three major categories identified in the conceptual models. This was a comprehensive list -- targeted to ecological systems present within NETN—that spanned spatial, temporal, and biological scales of organization.

We reviewed and prioritized this list with a multi-stage process, comprised of 1) initial review by the NETN core science team, which initiated the list of VS and criteria for selection (table 2); 2) external peer-review by a group of more than 40 scientists and park managers; 3) review by the NETN Technical Steering Committee, composed of both external scientists and NPS staff., 4) additional review by NETN core science team, and 5) National I&M Program Review and Approval (in process).

This review process has, to date, generated a list of 22 VS (table 3). In the process of selecting the VS, we also identified specific measures for quantifying each VS (table 3). Ongoing review will ensure a coherent list of VS that are responsive to park needs, fiscally reasonable, and scientifically sound.

Phase 3: Protocols and Ecological Integrity Assessment

NETN will begin Phase 3 during fall 2004. The primary focus of Phase 3 is to develop specific measures and protocols for each VS. We plan to emphasize four features – 1) consider tiers of VS measures, 2) assess how bundling and considerations of effect size on VS measures affects costs, 3) development of standard summaries of statistical trends in VS measures, and 4) use of an ecological integrity scorecard. First, we will consider a tiered approach to the measures and VS. Not all VS are equally accessible and measurable. A first tier of measures may rely on remote sensing imagery and rapid ground assessments. A second tier may rely on more detailed monitoring, perhaps requiring greater temporal and spatial sampling.

Table 2. Summary of 4 main criteria used to screen potential list of vital signs during the Phase 2 peer review process.

1. Management Significance & Utility	2. Ecological	3. Feasibility of Relevance	4. Response Implementation Variability
Relevant to assessment questions	Clear linkage to ecological function or integrity or specific resource	Availability of standard, well-documented methods	Low or controllable measurement error, high repeatability of measurement, quantitative & objective
Sensitive to and/or indicative of stress	Anticipatory	Lack of sampling impacts on indicator	Temporal variability (both within and between seasons) predictable and/or described
Not redundant unless improves performance	Indicative of status of other resources	Rapid, cost-efficient and/or can be bundled with other indicators for measurement	Spatial variability understood or controllable
Relative to determining quantitative thresholds for condition		Baseline data available	Sufficient discriminatory ability, both along a long-term condition gradient and in terms of statistical power
Linked to management actions		Easily measured with little equipment or specialized knowledge, and large sampling window	
Widely applicable (geographic, across ecosystems, and for multiple purposes)		Long-term data management feasibility	

Second, we will consider a bundled approach to protocol development. Rather than developing protocols and estimating costs for each VS independently, we plan to approach the problem conceptually as it will eventually be tackled in the field, that is, by field crews measuring multiple VS on co-located plots to the full extent possible. Thus we are proceeding into Phase II as follows: (1) all VS will be represented by one or more measure, (2) multiple measures at co-located sites will represent "bundles" (which may cross multiple vital signs) that will be recorded by field crews trained to measure the particular bundle of VS (for example, forest mensuration, soil chemistry, amphibians, and invasive understory plants could be the focus of the "forest health bundle," (3) the first measure selected for a given bundle includes all base costs for travel to the plot; measures subsequently added to a bundle assume only incremental cost associated with adding them to bundle (in many cases no or little additional cost), (4) overall costs are calculated based on cost of an individual measurement * number of measurements needed to detect change (assuming statistical errors type I = type II = 0.10) * number of parks where measured X number of ecosystems with each park for which inference is to be made, and (5) sampling designs represented by repeat measurements of permanent plots. Some VS measures will be essentially censuses (for example, land cover change analysis) and thus will involve a single "up front" cost. Significant decisions have yet to be made on effect size sought for detection for each VS measure, as these dramatically affect sample size and hence overall cost. By proceeding with an assessment of potential VS measures in the manner described about we will track the accrual of monitoring costs and terminate the VS measure selection process once available financial resources for conducting the monitoring are allocated.

Third, we will address how to perform standard synthesis of VS trends. Because VS data will consist of repeated measures of continuous metrics, we will perform standard summaries of statistical trends in VS measures. These will include aggregate trends among related indicators and aggregate trends among indicators within particular ecosystem types. Because many VS will be measures at co-located sites, correlations among them will also permit general inferences to be made about potential causes of ongoing trends observed in the VS.

Fourth, we will develop the use of ecological integrity ranks. These tools are needed to take a program from collection of field data for indicators and measures to interpretation of those values that allow managers to determine whether or not ecological integrity is changing in the parks. This interpretation does not supersede the precise analysis of the field data themselves, but does inform the intensity of their sampling and the response of managers to changes in those data. In other words, a good monitoring program needs to set objectives for measuring indicators based on the best current understanding of how ecological systems work, baselines that include reference conditions from known high quality sites, and

Table 3. Northeast Temperate Network VS list, August 2004. Vital Signs (VS) are presented within the NPS Vital Signs Program national framework to create reporting consistency among networks. Potential measures in italics will be investigated for inclusion during Phase 3 but require further evaluation. No. of Parks indicates the number of NETN parks within which each VS will be monitored.

Level 1	Level 2	Network Vial Sign Name	Potential Measures	No of Parks
Air and Climate	Air Quality	1. Ozone	Atmospheric ozone concentration (synthesize existing data), (foliar injury to indicator species)	7
		2. Acidic deposition & stress	Wet and dry deposition rates (synthesize existing data), soil nitrification, soil base cation availability, soil Ca:Al ratio, streamwater ANC, streamwater nitrate concentration (Total deposition rates including occult)	7
		3. Contaminants	Heavy metal deposition (synthesize existing data)	11
	Weather and Climate	4. Climate	Air temperature, precipitation by type, relative humidity, total solar radiation, wind speed, wind direction, snow water equivalent, snow depth	11
		5. Phenology	First flowering of sensitive plant species, first amphibian call dates, length of growing season, ice out/in dates for lakes and ponds	5
Geology and Soils	Geomorphology	6. Shoreline geomorphology	Relative surface elevation, shoreline change	2
Water	Hydrology	7. Water quantity	Water depth, water duration, lake levels, streamflow, groundwater levels/inputs, spring/seep volume, sea level rise	11
	Water Quality	8. Water chemistry	Stream water nitrate, stream alkalinity/ANC, water temperature, % dissolved oxygen, specific conductance, pH, turbidity, Secchi disk, color	11
		9. Nutrient enrichment	Turbidity, #septic systems in and near park, algal biomass, total and dissolved phosphorus, amount fertilizer used within park, residential density near park	11
		10. Streams - macroinvertebrates	Diversity of selected communities and subcommunities	9
Biological Integrity	Invasive Species	11. Exotic Species- early detection	Presence/absence, extent, distribution	11
	Focal Species or Communities	12. Intertidal – vegetation	Diversity of salt marsh and rocky intertidal community and subcommunities, exotic species extent	2
		13. Wetland – vegetation	Diversity of community and subcommunities, exotic species extent, beaver activity	11
		14. Forest - vegetation	Community diversity (all layers), tree species, rates of mortality and regeneration, stand structural dynamics, tree basal area by species, canopy condition, snag density, coarse woody debris volume; percent exotic species	9
		15. High elevation - vegetation	Diversity of community and subcommunities; percent exotic species	1
		16. Fish – lakes and streams	Diversity of community and subcommunities; percent exotic species.	6
		17. Breeding birds	Diversity of forest, high elevation, grassland/scrub, old-field, and coastal communities and subcommunities	10
		18. Reptiles and amphibians	Diversity of wetland/vernal pool communities and subcommunities (red-backed salamander abundance in forests)	10
		19. White-tailed Deer herbivory	Browse intensity in forests	9
Human use	Visitor and Recreation Pressure	20. Visitor usage	Number of visitors by location and activity, trampling impacts, soil erosion	11
Ecosystem Pattern and Processes	Land Cover Land Use	21. Land cover / Ecosystem cover	Change in area and distribution of ecological systems (including intertidal communities) within park and adjacent landscape, patch size distribution, patch connectivity, patch fragmentation, extent of major disturbance, ecological integrity index by ecological system	11
		22. Land use	Road network extent, nearby housing development permits, proportion of nearby lands in various categories of human uses, % impervious surface in watershed, nearby human population density, landscape buffers	10

the historic range of variability expected or permissible in the measures. Indeed, if restoration of sites in parks is being considered, this kind of information is especially critical. Information of this kind can lead to indicator thresholds based on "normal' or "natural" benchmarks with clearly identified thresholds, along with developing protocols for those measures to ensure consistent field measurements and documentation. A subsequent step is to then provide a scorecard matrix by which the measures are rated and integrated into an overall assessment of the ecological integrity of the system(s) in a park or across the network.

In order to synthesize and summarize VS in a meaningful fashion that can be communicated to a diverse audience, VS and Measures will require ratings for levels of overall ecological condition. These ratings can be integrated into an overall ecological integrity rank, similar to the "element occurrence ranking procedure" developed by NatureServe and the Network of Natural Heritage Programs (NatureServe 2002, Parrish and others 2003). A series of steps to generate an Ecological Integrity Rank will be taken, as shown in figure 2. After the VS and measures are prioritized (fig. 2, steps 1 and 2) and a final list is generated (as in table 3), they can be linked to specific ecosystem targets (fig. 2, step 3). In this way, measures are tailored to the systems being assessed. By compiling information from baseline studies in the park, reference sites outside the park, and understanding the historic range of variability of VS and measures for each system, it may be possible to rate the field values that are collected using these protocols during the monitoring program (fig. 2, step 4). Ratings range from Very Good to Poor, and are a judgment about the expected range of values that define better or worse conditions of ecological integrity. The intensity of sampling and expectation for detecting trends may be derived from our understanding of these sources (fig. 2, step 5). Note that for each sample period, the field values are recorded and stored independently of the ratings. The roll-up of these ratings provides the basis for the overall Ecological Integrity Rank (fig. 2, step 6) for specific occurrences (or sites) and across the park or network.

An illustration of this process is shown for the rare Jack Pine Woodland type at Acadia NP. This community is a rare NVC association found within the Laurentian-Acadian Acidic Rock Outcrop system. An ecological integrity rank is developed by first linking the VS and measures from table 3 to this Ecosystem (table 4), as illustrated in figure 2, step 3. Mapped occurrences of this jack pine woodland association are visited, and measures associated with all applicable vital signs will be collected. Field values of each measure will be assigned a rating. Ratings can then be "rolled-up" into an overall Ecological

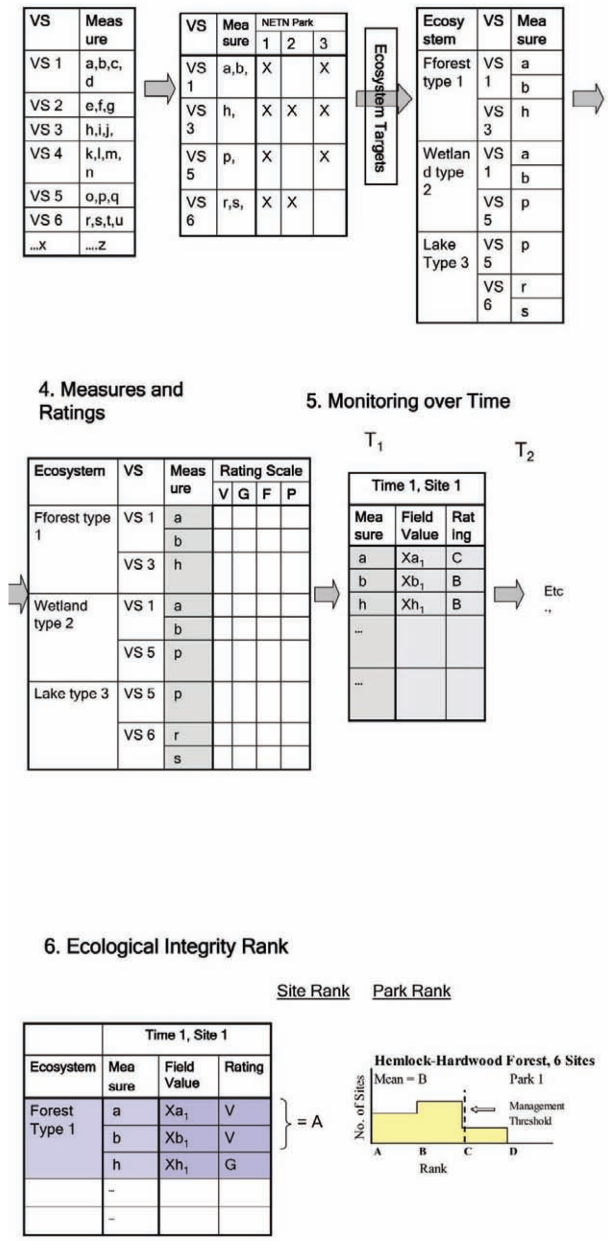

Figure 2. Illustration of ecological integrity rank methods based on vital signs and measures. Steps 1 – 2 show development of vital signs and measures, step 3 links a subset of them to specific ecosystem targets, step 4 develops rating for each measure specific to the ecosystem, and step 5 shows how field values for each measure are stored independent of the rating for that measure. For example, VS 1 = Forest -- vegetation. Measure a = exotic species percent cover. Forest Type 1 = Hemlock-Hardwood Forest. Ratings for measure a = Very Good < 1 % cover exotic species; Good= 1-4 % cover; Fair = 5-20%; Poor = >20%. Thus, a field value for a stand of Hemlock-hardwoods forest with 3% exotic species cover generates a rating of Good. In Step 6, combining all ratings for measures of a system through a rule-based approach generates the Ecological Integrity Rank for the occurrence (A=Excellent, B=Good, C=Fair, D=Poor). Ranks across a park can be averaged into an overall park rank, or displayed as a histogram, with management thresholds established; if individual stands fell below this threshold, management action would be taken.

Table 4. Jack Pine Woodland Ecological Integrity Rank table. Table displays the vital signs and measures applicable to assessing the ecological integrity of the Jack Pine woodland. Field Values are collected based on standard protocols. A rating is assigned to the Field Value based on the Rating Scale, which summarizes the range of values expected for a measure. Ratings for only a few measures are shown, for reason of brevity.

Category	Vital Sign	Measure	Field Value, T1	Rating, T1	Rating Scale Very Good	Good	Fair	Fair Fair
Condition	Ecosystem Cover	Patch size in acres			>50 acres	20-50 acres	5-20 acres	3-5 acre
	Consumptive Use	Degree of anthropogenic disturbance (e.g. logging, recreation)	5%	Good	Minimal; affecting < 1% of community	Minor; affecting < 10% of community	Significant, affecting 10-50% of community, severe impacts may be evident, but recovery possible	Extensive; affecting > 50% of community, poor potential for recovery, if at all
	Extreme Disturbance Events	Natural disturbance regime (fire and/or blowdown)			Not shown	Not shown	Not shown	Not shown
	Forest—Vegetation	Basal area / canopy cover by species			Not shown	Not shown	Not shown	Not shown
		Cover of exotic species	2%	Very Good	Absent	Present, but in low numbers (1-5%)	In abundance (5-20% cover)	Abundant (> 20%)
Land-scape Context	Land Cover / Ecosystem Cover	Patch size distribution - Edge to interior ratio			Not shown	Not shown	Not shown	Not shown
		Patch connectivity			Not shown	Not shown	Not shown	Not shown
		Patch fragmentation			Not shown	Not shown	Not shown	Not shown
	Land Use	Proportion of nearby lands in various categories of human use (e.g., develop-ment, roads, logging, fire suppression)			Not shown	Not shown	Not shown	Not shown

Integrity Rank, using a Scorecard value (A-D), allowing the rank to be displayed on the map (for roll-up methods see NatureServe 2002). Only two sets of polygons have been visited at this time to allow a rank to be assigned (fig. 3). Future fieldwork will focus on remaining occurrences, once the protocols for the measures are in place.

Conclusions

Selection of Vital Signs by NETN during Phase 2 of the NPS I&M program was dependant upon conceptual ecological models developed during Phase 1 of this program. These conceptual models help demonstrate linkages among ecological resources, stressors, and potential VS across the four major ecological system groups (terrestrial, wetland, aquatic, intertidal).

NETN found the sequential peer-review process, from core science team to external science partners and internal technical committee review, to be useful in developing a comprehensive set of VS. This process allowed us to test our assumptions, and expand scientific and technical input. The end result is a robust list of VS. Park participation in all stages ensured a good link between VS selection and management goals.

Our next steps, in Phase 3, are to set objectives, develop specific protocols based on bundling of VS measures and standard trend analysis, and develop ecological integrity ranks. These steps will be challenging, requiring careful attention to the role of baselines, reference conditions, and historic range of variability for measures of these dynamic sets of ecosystems. These VS need to be integrated into a process of adaptive management, whereby trends in VS can be communicated to managers, scientists, conservationists, policy-makers, and the public. The development of ecological integrity ranks to summarize VS trends should help provide the needed link between monitoring and management decision-making aimed at maintaining, enhancing, or restoring the ecological integrity of park ecosystems.

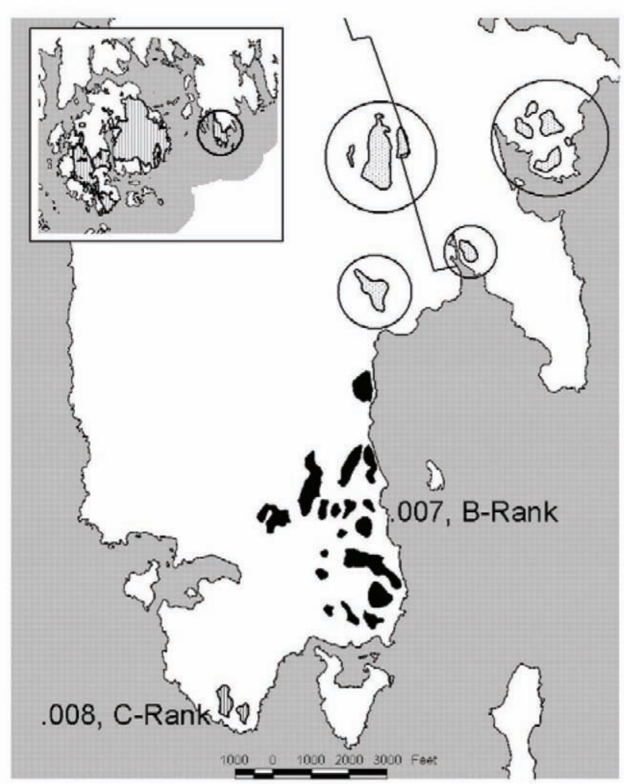

Figure 3. Map of Schoodic Peninsula, Acadia National Park, showing the occurences of Jack Pine Woodland, a part of the Laurentian-Acadian Acidic Rocky Outcrop system. Groups of polygons (in black and in vertical shading) are treated as separate occurrences. Each occurrence has been assigned an ecological integrity rank, based on the ratings for the field values for each measure (see table 4). Clusters of polygons that have been circled represent other occurrences that have not been field-visited, so they have not yet been assigned an overall ecological integrity rank. Inset shows the boundaries of Acadia NP, Maine, with the Schoodic Peninsula area circled.

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Sustainable Forest Management Support Based on the Spatial Distribution of Fuels for Fire Management

José Germán Flores Garnica, Juan de Dios Benavides Solorio, and David Arturo Moreno Gonzalez, Centro de Investigaciones del Pacífico Centro. INIFAP. Parque Los Colomos S/N, Col. Providencia. Guadalajara, Jal.isco. México

Abstract—*Fire behavior simulation is based mainly on the fuel model-concept. However, there are great difficulties to develop the corresponding maps, therefore it is suggested the generation of four fuel maps (1-hour, 10-hours, 100-hours and alive). These maps will allow a better definition of the spatial variation of forest fuels, even within a zone classified as a given fuel model. The used data was acquired under a forest inventory of 554 sample plots, within an are of 1,400 ha approximately, in the ejido El Largo y Anexos (Chihuahua, México). Twelve different interpolation techniques (five deterministic and seven stochastic) were used to generate continuous surface of each fuel class. These surfaces were evaluated and compared. In general, stochastic techniques produce the best results, although individually the technique called inverse distance weighted showed a more constant performance. It is suggested that there is not a single interpolation technique to be used for any variable. The generated information (fuel maps) would help to the decision making process for a sustainable management of a given area, because it would help implement fire management strategies.*

Introduction

Sustainable forest management planning considers the function of many elements, of a forest ecosystem, but also their interrelations. Since it is difficult to evaluate the total number of element, decision makers must define which are the more important elements. In order to do this we must consider an integrated approach that guarantee, basically, forest regeneration. In this way, the elements that represent, of support, disturbance occurrence have a high priority. This hierarchy approach is useful when: a) it is difficult to know all the forest elements; b) it is difficult to measure the influence among elements; and c) there is a limited budget. Disturbance factor, such as pest, hurricanes, and fire, could affect forest sustainability in both a very short time period, and in very large areas. Among them, fire is more common in most of the Mexican forest ecosystem, affecting not only vegetation regeneration, but also trees and other biotic and physic elements. Therefore, any management planning (focused on sustainability) must consider: i) fire occurrence (frequency) and ii) fire intensity. The definition of such aspect can be supported with the use of fuel maps. However, the definition of the spatial distribution of fuel models has represented one of the more complicated challenges facing forest fire scientists (Keane and others1999). As an alternative, the fuel-model concept (numerical characterization of fuels [Rothermel 1972]) has been a practical solution for this problem. However, this concept consider fuels (quality and quantity) distribution homogeneous within an area qualified into a given fuel model. That means that fire behavior variation will be based only on changes of wind, fuel moisture, and slope (Omi 1997). However, the spatial distribution of forest fuels tends to be rather discontinuous and highly variable (Brown and Bevins 1986). Since most of the current fire behavior simulation models are based on the fuel-model concept, the objective of this study is to show an alternative approach in order to develop three dead fuels maps. This information will be useful to support sustainable forest management under Mexican forest ecosystems.

Methods

Study Area

This study was carried out with information on forests of the ejido "El Largo y Anexos", located in the region called Mesa del Huracán, at the NW of Chihuahua State, México (fig. 1). The predominant tree species are *Pinus durangensis, P. arizonica* (Engelmann), *P. Engelmanni* (Carriere) *and Quercus sideroxyla* (Humb. and Bonpl.). A fuels inventory was carried out in 1998 where a total of 554 plots, randomly distributed, were sampled in a

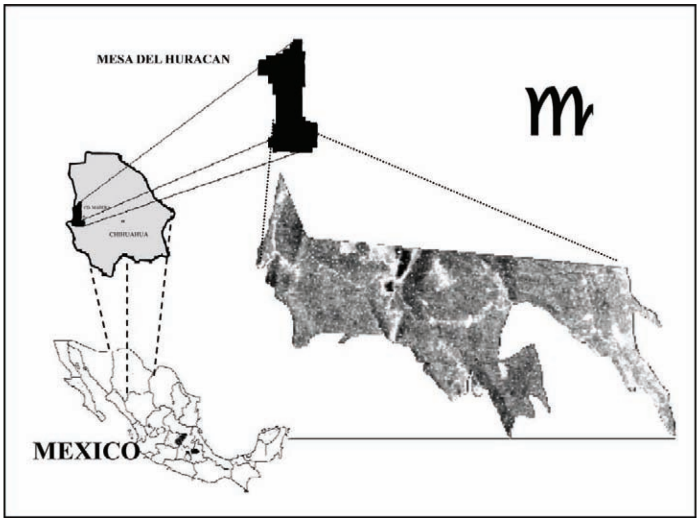

Figure 1. Approximate study area location, close to Cd. Madera (Chihuahua, México).

1400 ha area. Fuels loading (1 hr, 10 hr, 100 hr, shrubs, and saplings) were measured based on the techniques described by Brown and others (1982). Sample plots locations were determined using a global positioning system.

Fuel Map Generation

The three fuel loadings maps used in this study were generated by Flores (2001). Three are based on fuel timelag classes (Deemnig and others 1978), that is, a measure of the rate at which a specified size of dead fuel gains or loses moisture [i.e., 1-HR, 10-HR, and 100-HR fuel classes]. These maps were generated comparing five statistical interpolation methods (spline, polygonal mapping, inverse distance weighting [power 1 and 2]) and five geostatistical options (ordinary kriging [point kriging and block kriging], universal kriging [1st and 2nd degree], and cokriging,) (Flores 2001). Based on these techniques were defined the continuous surfaces that more accurately represent the spatial distribution of four fuel classes (tn/ha). Interpolations were based on field data.

The ancillary data required for cokriging were gathered from a Digital Elevation Model, a Landsat 5 TM and a forest inventory. The four fuel classes showed significant autocorrelation and cross-correlation, thus it was possible to model the spatial continuity of each of the four fuel types. The average spatial dissimilarity between data points defined a structural distribution (variogram), which allowed characterization of spatial continuity patterns (Flores 2001) and definition of weighting factors for both kriging and cokriging (Hunner and others 2000).

Results

Fuels Statistics

Fuel loadings (tn/ha) were related to the forest stand conditions where the evaluations were made. General statistics for the four fuel types are shown in table 1. The fuel class loadings were combined with the secondary variables selected from a stepwise process.

Fuels Interpolation

Using elevation (ELE) as secondary variable, and modeling such relation with an exponential cross-variogram, resulted in the lowest MSE for 1-HR, and 100-HR. However, other combinations resulted in similar results. In the case of 1-HR principal component 3 (PC3) (exponential cross-variogram) was the secondary variable that result in the lowest MSE. Table 2 summarizes the performance of all the 10 interpolation techniques used to estimate each fuel class loading. The evaluation of this performance was based on four measures: Mean square error (MSE). MSE ranges from 0.162 to 0.929, 2.157 to 4.385, and 39.84 to 183.37, for 1-HR, 10-HR, and 100-HR, respectively. These ranges represent a considerable difference among the interpolation techniques. In the cases of 1-HR and 100-HR fuels, the lower MSE was obtained through cokriging (CK) procedure based on elevation (ELE) as a secondary variable. This suggests an increase in precision when modeling the joint spatial continuity of fuel classes and ELE. By contrast, CK was the worst technique in the estimation of 10-HR fuels. In this case the lowest MSE was obtained through the inverse distance weighting (Power 1).

Fuels Continuous Surface

Based on the best interpolation techniques, the corresponding continuous surfaces were generated for each forest fuels (fig. 2). The spatial distribution of 1-HR fuels shows that higher loads are located at the west portion of the study area. The lower loads of this fuels occurred at the east, which could be explained because the minor tree

Table 1. General statistics of the four fuel classes for the study area (Cd. Madera, Chihuahua. México).

Statistic	1-hour	10-hours	100-hours
Minimum	0.08	0.00	0.00
1st Quantile	5.26	0.66	0.00
Mean	11.32	2.08	10.09
Median	10.34	1.31	7.22
3rd Quantile	16.30	2.63	14.45
Maximum	35.45	13.79	101.14
Std. Deviation	7.41	2.19	14.33

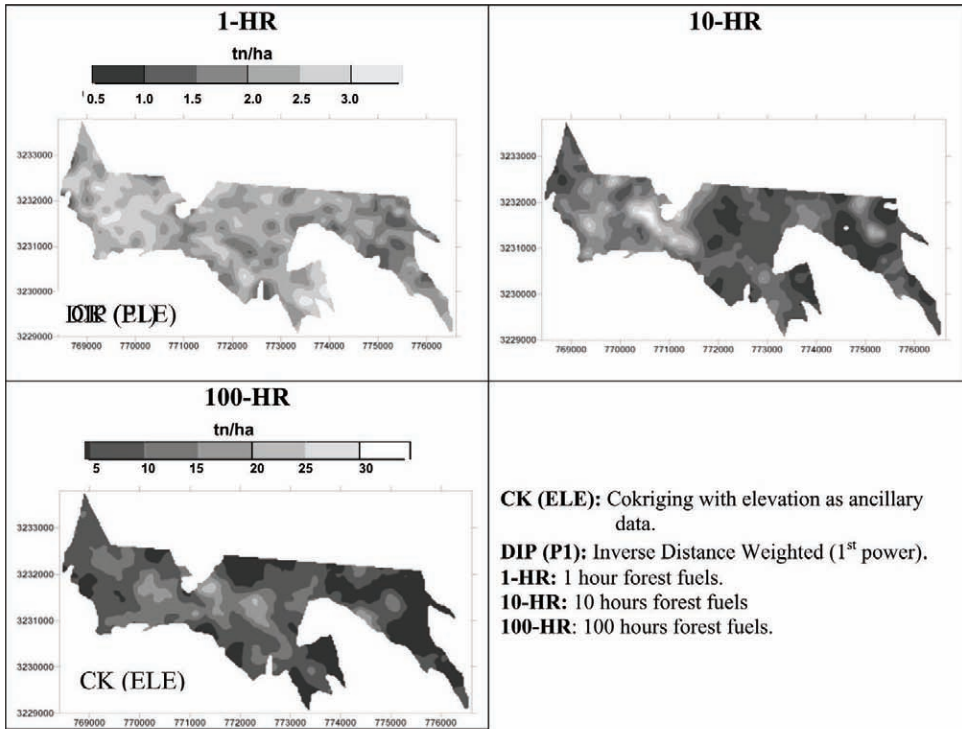

Figure 2. Thematic maps of three dead fuels spatial distribution for the study area located close to Cd. MaderaChihuahua, México (after Flores, 2001).

density. On the other had, 10-HR fuels showed a more variable distribution, however higher loads are located at the east. Lower loads occurred at both central and east portions of the study area. In the case of 100-HR, fuels distribution is less heterogeneous and there is a clear tendency of low loads at the east portion. Higher load values are located at the central part of the studied area. In general, we could say that the reason of the low loads at the east part are because this portion is close to the Cd. Madera town. Since people from this town get firewood from the forest, it sounds logic that they take it from the closest areas. Therefore, any management planning should consider two kind of priorities: a) defining those areas with high risk of fire, which are related to their proximity to urban areas (Flores 2004); and b) considering the potential fire effects, based on fuel loadings. This means that forest managers not only should avoid fire occurrence (mainly in the areas close to the town), but also to implement silvicultural practice to decrease fuel loading (for example prescribed fires [Flores and Benavides 1993]).

Discusion and Conlcusions

Geostatistical interpolation techniques showed a better performance that the traditional interpolation techniques tested (table 2) for the four fuel classes (1-HR, 10-HR, and 100HR fuels), in general. Similar response is reported in other studies (Hohn 1998; cited by Hunner 2000). The results suggested no increases in the precision of our

Table 2. Performance of the interpolation techniques evaluated by four measures, for each fuel class, for the study area (Cd. Madera, Chihuahua. México).

		Statistical					Geostatistical				
Fuel class	criteria	spline	polyg. mapping	thiessen	idw power 1	idw power 2	uk 1st degree	uk 2nd degree	cokriging (ele)	point kriging	block kriging
1-HR	MSE	60.846	33.469	58.058	31.364	32.019	32.822	40.010	9.944	30.759	30.683
10-HR	MSE	4.022	3.048	3.780	2.157	2.259	2.353	2.360	4.385	3.224	3.215
100-HR	MSE	183.37	109.93	168.28	93.536	96.538	94.398	94.933	39.844	95.231	95.016

1-HR= 1 hour fuel (0-0.6 cm diameter)   MSE= mean square error
10-HR= 10 hours fuel (0.6-2.5 m diameter)
100-HR= 100 hours fuel (2.5-7.5 cm diameter)

estimations when modeling spatial continuity (kriging) for 1-HR and 10-HR fuels. Thus, in these cases at least, one traditional technique was better than the simple kriging possibilities. However, the spatial continuity for 100-HR fuels was enough to increase the precision of estimate.

The spatial resolution of the resulted forest fuels maps was implemented at a "point level," in which fuel loadings are estimated at any point in the area of interest. This was implemented under the raster GIS perspective, with the limitation of the raster resolution (in this case 30 x 30 m). This means that using the strategies illustrated in this paper it is possible to define fuel maps at different scales (Yuan 1994). Furthermore, the spatial variation of fire behavior at small scales (heterogeneous conditions) requires levels of resolution that only can be managed under the cell automata (raster) approach (Liu and Chou 1997). Using the vector approach, such as in the fuel-model concept (Finney 1998), fuels distribution is assumed homogeneous within the entire fuel model area. This approach could be useful: (a) at large-scale levels, but with homogeneous landscapes or (b) at small-scale levels with a fine differentiation and classification of fuel models (Campbell and others 1996). However, the latter has been the major problem of the fuel mapping process (Keane and others 1999).

Since the study area is affected frequently by wildfire, it makes sense that any attempt of a sustainable management considers both fire occurrence and fire effects. This information has its higher usefulness when it is considered under a spatial approach. It is not enough to know that we have different fuel loadings along our managed areas, but it is essential it define their spatial variability. The definition of continuous surfaces is a great alternative to understand better the gradual changes of forest fuels. Based on this it will be possible to prioritize which areas have more risk of fire (related mainly in 1-HR distribution), and which areas could produce higher negative effect of the forest ecosystem elements (tree, grasses, soil, water, etc.). The latter is focused mainly on the potential of fire intensity fire, which is related to large dimensions fuels (Albini 1976). Nevertheless, in Mexico this kind of spatial information is not considered, and most of the forest management plans mention the implementation some practical activities as the solution to the fire problem. However, there is not a clear support not only on the implementation of such practices, but in their location and dimension. The methodology illustrated in this paper, could be used to: i) prioritize areas; ii) give dimension to the problem (calculating a given area; and iii) calculate time and cost requirements. Finally, decision makers should consider other ancillary data, such as climate, roads, altitude, wind, vegetation, and human activities. Thinking on fire as a factor that can alter considerably any sustainable management plan, it is important to spend some time and resources to develop the type of maps showed in this paper.

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Geostatistical Evaluation of Natural Tree Regeneration of a Disturbed Forest

José Germán Flores Garnica, David Arturo Moreno Gonzalez, Juan de Dios Benavides Solorio Centro de Investigaciones del Pacífico Centro. INIFAP. Parque Los Colomos S/N, Col. Providencia. Guadalajara, Jal.isco. México

Abstract*—The implementation of silvicultural strategies in a forest management has to guaranty forest sustainability, which is supported by an adequate regeneration. Therefore, quality and intensity of silvicultural practices is based on an accurate knowledge of the current spatial distribution of regeneration. At the same time, this regeneration is determined by the spatial distribution of many disturbing factors, such as fuel loadings, trees density, and grazing. However, regeneration mapping is not considered very often because its evaluation is both time and cost consuming. As a practical alternative, this study shows the results of a spatial evaluation of trees regeneration, where spatial distribution of regeneration is modeled. The data was obtained from 79 sample plots systematically distributed in a watershed of 1000 ha., at the saw of Tapalpa, Jalisco (México). Two interpolation alternatives were tested and compared: a) Inverse Distance Weighting [IDW]; and b) Ordinary Kriging (simple stochastic interpolation). Individuals between 0.30 and 2.5 m of height represented tree natural regeneration. The results showed that geostatistics technique (OK) was better in 50 percent of the cases, and deterministic technique (IDW) was better for the rest 50 percent. This suggest that not single interpolation technique has to be used in all situations. The results would support silvicultural strategies. It is suggested in further studies to use ancillary data, such as tree density, fuels, slope, and species distribution.*

Introduction

Forest sustainability is based in adequate forest management strategies. The implementation of silvicultural practices in a forest management has to guaranty forest sustainability, which is supported by an adequate tree regeneration (Moreno and others 1993). Therefore, quality and intensity of silviculture is based on an accurate knowledge of the current spatial distribution of regeneration. At the same time, this regeneration is determined by the spatial distribution of many disturbing factors, such as fuel loadings (Flores y Benavides, 1993), trees density, and grazing. As a consequence, forest sustainability is affected, costs are increased, and new management program must be developed (or at least adjusted). Therefore, before to implement a silvicultural program, we must develop methodologies that allows to know the spatial distribution. In this way, we will be capable to define which areas have a higher priority (for example, with low regeneration density), and establish a spatially better silvicultural planification. However, regeneration mapping is not considered very often because its evaluation is both time and cost consuming. Therefore, as a practical alternative, this study shows the results of a spatial evaluation of trees regeneration, where spatial distribution of regeneration is modeled. This modeling is based on the evaluating and comparing two interpolation techniques: inverse distance weighted and ordinary kiging. These techniques has been used successfully in other fields, such as mining, meteorology, and soil science (Laslett and others 1987; Webster y Oliver, 1989). However, their use has been limited in forestry (Hunner, 2000).

Methods

Study Area

The study area was a watershed located at 5 km to the west of Tapalpa town (Jalisco state), in the west-central region of Mexico (fig. 1), and it is located within the 19º 56’ and 19º 58’ North latitude; 103º 47’ and 103º 51 West longitude (Benavides, 1987). This watershed has the following general characteristics: Altitude: 2060-2420 m.a.s.l. Mean annual rainfall: 901 mm. Mean temperature: 16.6ºC (Minimum mean annual 9.1ºC, Maximum mean annual 24.3ºC). This region corresponds to a temperate sub-humid climate (Benavides, 1987),

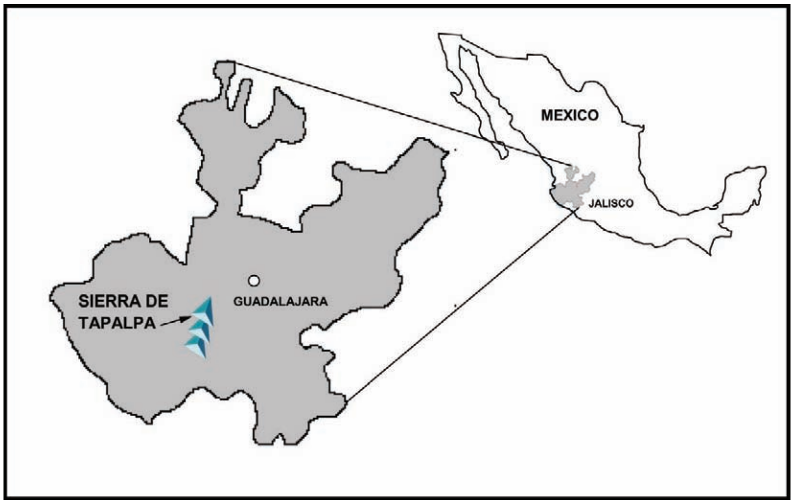

Figure 1. Approximate location of the Tapalpa Saw (Jalisco state, México), where the "El Carrizal" watershed is located.

and is dominated by *Pinus devoniana, Pinus oocarpa, Quercus rugosa; Quercus resinosa* and *Alnus*. The study area is mostly on north-facing slopes, at an altitude of 2110 m.a.s.l. In average, the slope varied between 5 and 65 percent.

Data Collection

The information used in this study was collected based on a specific forest inventory. Since we did not know well the study area, we used a systematic sample design. Sample plots were located every 500 m, within an area of around 1400 ha. Saplings were evaluated in a total of 79 100-m^2 circular sample plots, during a period of 30 days (between May and June, 2003). Plot center locations were determined using a global positioning system (GPS) receiver.

Data Analysis

The analysis of information was divided into two phases: I) Defining of fuel thematic maps: and II) Location of areas according to their potential fire effect. For the former, two spatial interpolation analyses were tested to get five thematic maps: (a) 1-HR fuels; (b) 10-HR fuels; (c) Downed woody; (d) Fine fuels weight; and (e) Fine fuels depth. The used techniques were:

Inverse distance weighting (power 2). This technique assumes that the value of an un-sampled point is a distance-weighted average of the values of observed points occurring nearby (Burrough and McDonnell, 1998). This interpolation technique gives more weight to closer observations than those that are farther away (Hunner, 2000). Such weights are inversely proportional to the distance between the point to be predicted and the data of nearby points computed, and are computed from a linear function (Burrough and McDonnell, 1998; Isaak and Srivastava, 1989):

$$\hat{\beta}*(x_0)=\frac{\sum_{i=1}^{n}\frac{1}{d_i^p}*\beta(x_i)}{\sum_{i=1}^{n}\frac{1}{d_i^p}}$$

where: $\hat{\beta}$ *(x0) = estimated value at un-sampled location x0; $\hat{\beta}$ (xi) = observed value at location xi; di = are the distances from each observed locations to the un-sampled point; p = distance exponent; n = number of sampled points.

Ordinary kriging, OK, is considered as the "best linear unbiased estimator" (Hunner, 2000; Isaaks and Srivastava, 1989): (a) Linear, because its estimates are weighted linear combinations of the available data; (b) Unbiased, because it tends to generate a mean square error equal to zero (E[Estimated(x0)-True(x0)] = 0, and Eλi = 0); and (c) Best, because it aims at minimizing the variance of the errors (E{[Estimated(x0) – True(x0)]2 = minimum). The following formulas are used to calculate the OK estimates (Hunner, 2000; Isaaks and Srivastava, 1989):

$$\hat{\rho}_{OK}(x_0)=\sum_{i=1}^{n}\lambda_i\cdot\rho(x_i)$$

where: $\hat{\rho}_{OK}(x_0)=$ ordinary kriging estimate at location x0; λi= the weight for sample point i at location xi; ρ (xi)= the value of the observed variable ρ at location xi. All the geostatistical estimations were defined under the assumption of an isotropic behavior of the data (omnidirectional approach).

Validation

To evaluate and select the interpolation techniques, cross-validation was applied(Goovaerts, 1997). This technique supported the calculation of prediction errors (differences between estimated and observed values [Hunner, 2000]), which were used to define the corresponding mean square error (MSE). The lower MSE was the criterion to select the best interpolation techniques (Flores, 2001). Mean square error (MSE) is a summary statistics that incorporates both the bias and the spread of the error distribution (MSE= variance + bias2), which is calculated as (Isaaks and Srivastava, 1989):

$$MSE=\frac{1}{n}\sum_{i=1}^{n}r^2$$

where: n= the number of sample points; and r= the residuals

Cross-validation was also applied to find the optimal number of nearest neighbors to include in the kriging processes.

Results and Discussion

Based on tree density and tree distribution, it was expected a high regeneration (individuals lower than 30 cm and saplings [up to 2.5 m]) density. However, there was very little regeneration lower than 30 cm, mostly at the north of the watershed. This distribution agrees with the distribution of higher dimensions (both diameter and height). In this portion we found also the higher densities of pine trees. Due to the low number of individuals lower tan 30 cm, we work with individuals between 0.65 and 2.5. m of height. I this way we define the following classes: (a) Saplings of main dominant species with < 60 cm of height (B-1A); (b) Saplings of main dominant species with 0.6–2.5 m of height (B-1B); (c) All the saplings of main dominant species (B1); (d) All the saplings of main co-dominant species (B2); (e) All the saplings of secondary co-dominant species (B3); and (f) All the saplings individuals (BT). The tree species of saplings were: *Pinus devoniana, P. oocarpa, P. leiophylla, P. lumholtzii, P. douglasiana, Quercus rugosa; Quercus resinosa y Alnus arbuta*. There were no dead saplings.

Following the kriging processes, the corresponding variograms for each class were defined. The resulting graphic is shown in figure 2, where in general a low spatial autocorrelation is observed: This condition is remarked in class B3, where the population variance is constant regardless the lag distance between sample plots. The models that better fit experimental variograms (semivariances distribution) corresponded to classes B-1A y B-1B, which showed a "Nugget effect" (Isaaks y Srivastava, 1989) relatively lower. In general, the maximum lag distance, where it is possible to appreciate a spatial autocorrelation, was 1,300 m. Most variograms fitted to spherical models, while classes B2 and B3 fitted better to an exponential and a lineal models.

In general, we can say that there was not a considerable difference of MSE values when comparing OK and IDW. However, it was OK was better in 50 percent of the classes, in IDW was the better option (table 1). These

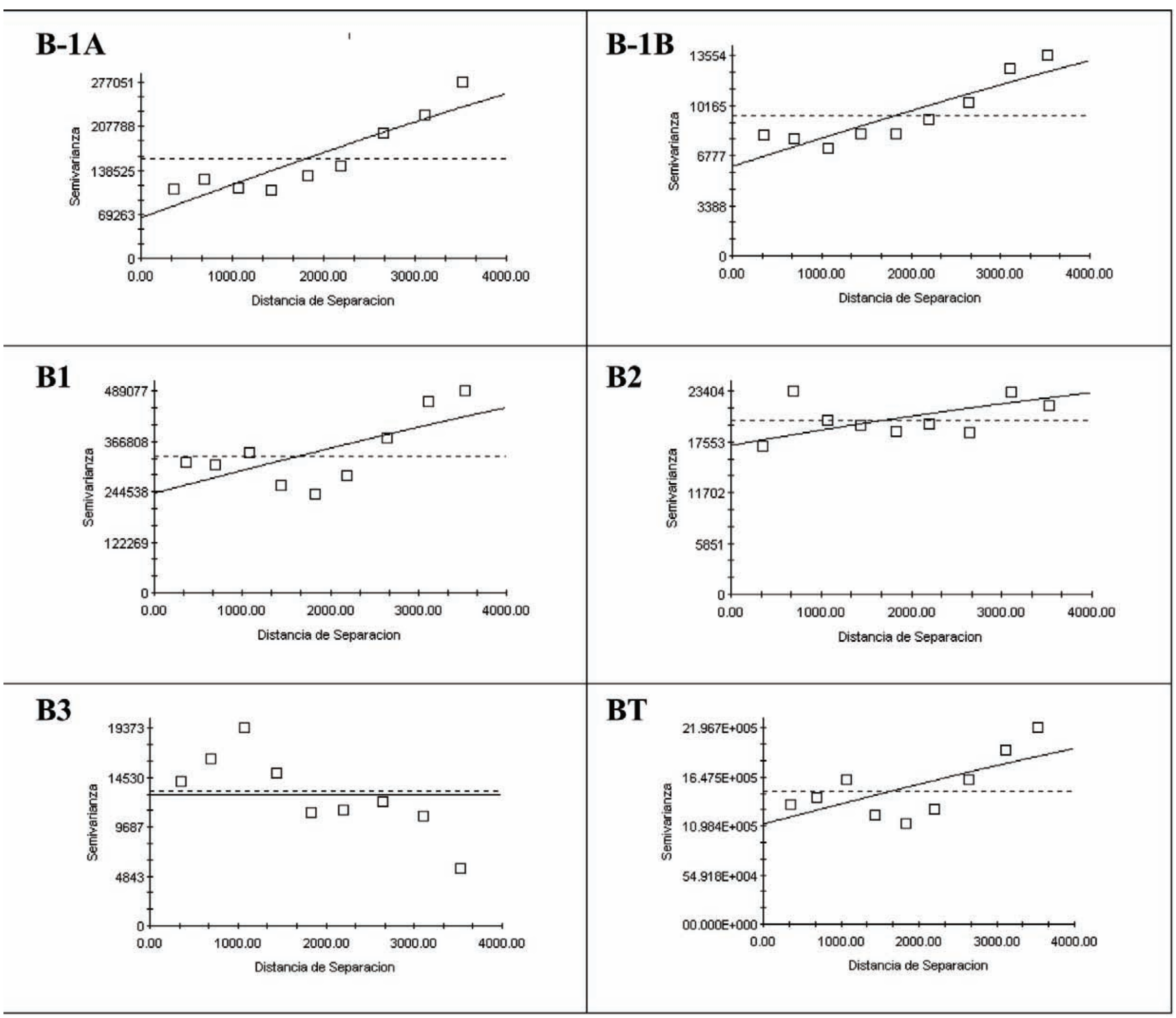

Figure 2. Variograms of spatial autocorrelation of saplings classes. Straight line shows the fitted model, the dot line shows the level of population variance.

Table 1. Mean square error resulted from the process of cross-validation of inverse distance weighted (IDW) and ordinary kriging interpolation techniques.

Sapling class	Idw	Kriging
B1A	135,005.81	125,967.41
B1B	8,858.21	8,869.73
B1	306,262.63	303,842.08
B2	20,676.40	21,259.80
B3	13,667.00	14,100.57
BT	729,924.72	715,040.54

results suggest that not always geostatistics alternatives are better. Nevertheless, variograms definition is a good tool to explore when could be possible to use OK (or other geostatistics technique). For example, in the three cases where OK was better the corresponding variograms defining better the spatial autocorrelation of sapling classes. The nugget effect was a lower, and the slope of the fitted model is higher than in the cases where IDW was better. This differences are more evident in the variogram of class B-1A, which resulted also in the higher MSE difference between OK and IDW (table 1). On the other hand, class B2 generated a variogram with a high nugget effect, and a very low slope. This defined a poor spatial autocorrelation of such class, which resulted in a better performance of IDW. There are two possible reason of such differences: i) a low number of sample plot with saplings in the corresponding class; and ii) geostatistics techniques are highly influenced in both the spatial autocorrelation the variable of interest, and the clustering of sample plots (Hunner, 2000). However, since the sample design was systematic, the latter condition could have a very low influence in the kriging process.

Figure 3 shows the continuous surface for each of the sapling classes generated from the best interpolation class. It is clear the graphical differences between

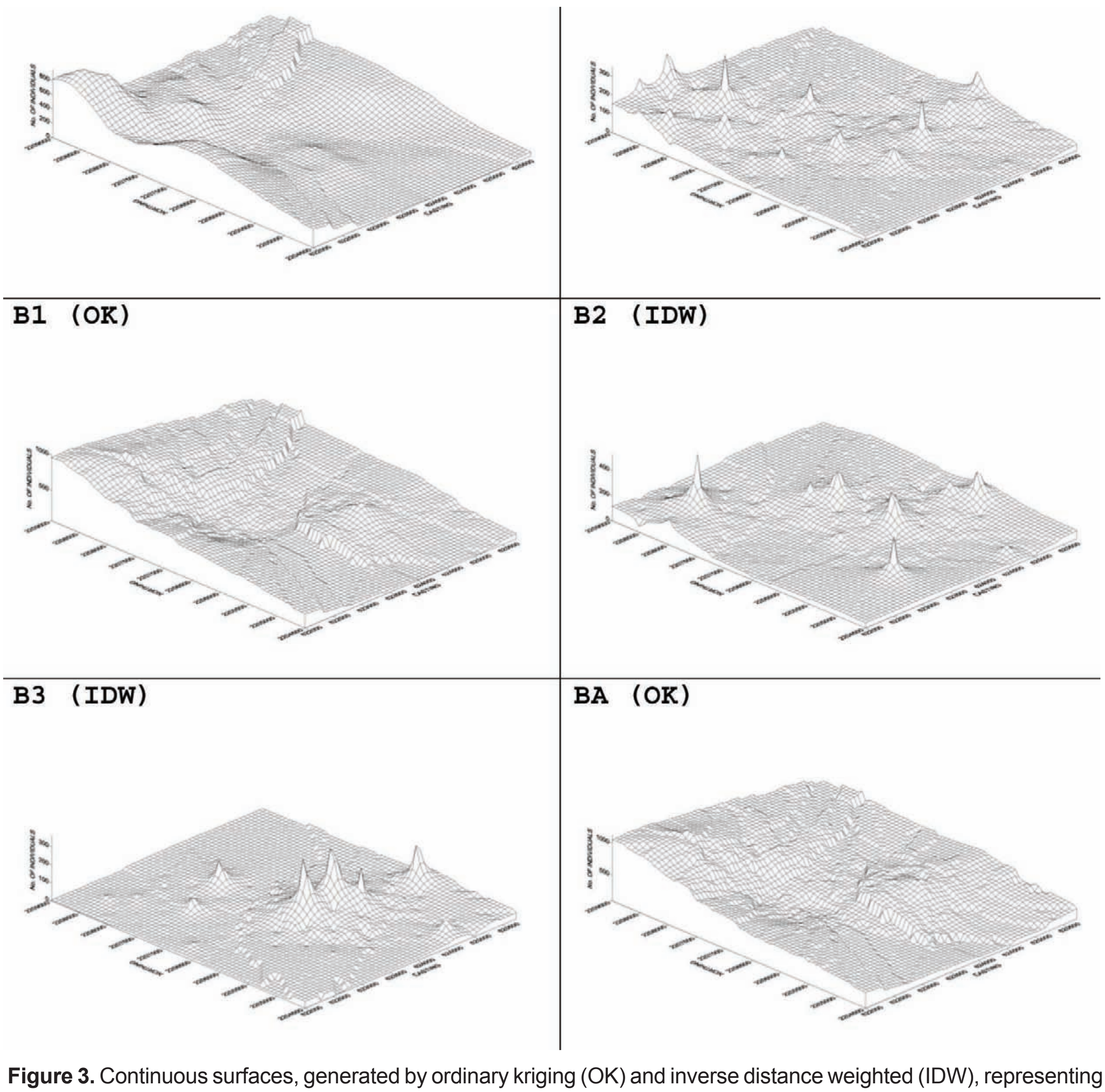

Figure 3. Continuous surfaces, generated by ordinary kriging (OK) and inverse distance weighted (IDW), representing the spatial variation of sapling classes.

continuous surfaces generated by OK and those generated by IDW. As it was mentioned, this difference could be the result of a low number of sample plots with saplings (mainly in the cases of classes B-1B, B2, and B3). This condition is better represented with the continuous surfaces generated by IDW, where it is easy it appreciate the locations of sample plots with a considerable higher number of saplings (relatively with the surrounded plots). When the number of sample plots with sapling was higher, such in the case of B-1A, B1, and BA, OK generate a smoother surface.

In general, natural regeneration is higher at the north of the watershed, which is logic if we consider that in that portion we found the better tree populations (specifically pine species). This spatial behavior was well defined for those dominant species (B-1A class). On the other hand, the spatial behavior of co-dominant species was better represented with the continuous surfaces generated by IDW. Considering all the sampled saplings (class BA) the resulting continuous surfaces is smoother. Which represent a decrease of sapling number going from north to south of the watershed.

Conclusions

To look for the best, or at least the more ad equated, spatial interpolation technique is a iterative process. In this study none of the used techniques generated the best results in all the cases, which agree with the results of other studies (Asli y Marcotte, 1995; Phillips and others 1997). However, it was important to consider the spatial autocorrelation of the studied classes, because it let us to define when OK could be better than IDW. The graphical representation of such autocorrelation, through the corresponding variograms, was a important factor in order to define strong autocorrelation. When OK was used, a spherical model fitted better to the corresponding experimental variograms (generating the lower MSE values). This implies a clear influence the "nugget" effect, with a gradual proximity to the corresponding "sill" and to the variogram range (Burrough y McDonnell, 1998).

The fact that IDW was better in 50 percent of the cases could be attributed to the following conditions: a) When data is abundant, most interpolation techniques produce similar results (Flores, 2001). In this study, because we have low spatial variability, it is considered that data were abundant (79 sample plots within 1400 ha). b) 2) Geostatistics techniques consider the data clustering. Since the used sampling design was systematic, this factor could have a low influence (Stein, 1999); and c) Geostatistic techniques assume that variable to interpolate show a normal distribution (Armostrong, 1998; Weber y Engud, 1994). Although this condition was true in most cases, it was not strong.

The continuous surface resulted in this study will support the generation of thematic maps of regeneration. These maps could be used to establish better spatial strategies to implement silvicultural activities. However, regeneration information has to be related to the spatial distribution of other factors, mainly slope, tree age, tree density, tree species composition. Nevertheless, regeneration maps will help to establish those areas with higher priority. Also we could define where we can establish multiple production systems, such as forestry and cattle, or forestry and eco-tourism. The main goal will be to take care of those areas where natural regeneration is located. On the other hand, based on the regeneration maps, we could define the location and the size of those areas that require artificial regeneration.

Finally, it is suggested to test other interpolation alternatives, mainly those that consider ancillary data. We could have better results if we relate tree regeneration with other factor of the forest environment, such as tree density, tree age, tree diameter, slope, aspect, and altitude.

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Economic Impact of Fire Weather Forecasts

Don Gunasekera, Graham Mills, and Mark Williams, Australian Bureau of Meteorology, Melbourne, Australia

Abstract—*Southeastern Australia, where the State of Victoria is located is regarded as one of the most fire prone areas in the world. The Australian Bureau of Meteorology provides fire weather services in Victoria as part of a national framework for the provision of such services. These services range from fire weather warnings to special forecasts for hazard reduction burns. Fire weather services are important inputs into the decision-making processes of fire management authorities that enable effective decision-making at various stages of fire management. The key beneficiaries of these services are the general community through better information provided to fire management authorities. This paper discusses the fire weather service that is provided by the Bureau of Meteorology and makes an attempt to measure the economic impact of such services for bushfires in Victoria focusing on both costs and benefits. The overall costs will relate to the direct and indirect cost of supplying the fire weather services, the cost of the fire mitigation and management efforts implemented as a consequence of these fire weather services and the cost of fire fighting and relief/recovery initiatives. The benefits will relate to minimization or avoidance of damage to timber assets, private property and public infrastructure, of agricultural production losses, of disruption to other economic activities, of human injury and fatalities; of damage to recreational sites and public amenities, of adverse ecological and environmental impacts, and of adverse effect on public health and general visibility due to smoke dispersion. Some of these benefits will have market values and the others non-market values. The benefit-cost comparisons can provide useful information for improvement of existing fire weather programs and also assist in making decisions on future investments in specific activities.*

Introduction

Since mid 1960's Australia has experienced 20 to 25 major bushfire events. According to the Center for International Economics (CIE) (2001), this equates to one major bushfire event in approximately every one and half years. In addition to these large-scale major bushfires, every year many small-scale bushfire incidents occur across Australia, which cause damage to property and in some instances the loss of human life. CIE (2001) analysis based on State agency statistics indicated that average annual area burnt due to bushfires nationally in Australia (excluding Northern Territory) is around 440 000 hectares. (In Northern Australia, large areas burnt due to large-scale grass fires can distort the overall areas burnt and hence fire damages per area burnt.) In the state of Victoria, it is estimated that the average annual area burnt due to bushfires is around 110 000 hectares (CIE 2001). This means that 25 percent of the area burnt in Australia (excluding Northern Territory) due to bushfires generally takes place in Victoria.

Under the Meteorology Act 1955 among the functions of the Australian Bureau of Meteorology (Bureau) is "the issue of warnings of gales, storms and other weather conditions likely to endanger life or property, including weather conditions likely to give rise to floods or bush fires." These functions are to be carried out in the public interest generally and in particular for the purpose of assisting persons and authorities engaged in primary production, industry, trade, and commerce".

The provision of fire weather services to the fire agencies and the community is mainly through the Bureau's distributed service delivery structure. The Bureau operates a Regional Office in the capital city of each State and Territory in Australia, except in the case of the ACT, where a smaller satellite office is operated under the guidance of the NSW Regional Office in Sydney. Within the structure of each Regional Office, there is a Regional Forecasting Centre (RFC), which carries overall responsibility for forecast production and dissemination. Day to day operational output from each Region is the responsibility of the Senior Meteorologist who works under the general direction of a senior line manager. Each Regional Office is operated under the guidance and direction of the Regional Director.

Fire Weather Services

The Bureau provides two broad categories of fire weather services. The first category is the services provided to the general public. These services include:

- Routine forecasts of fire danger during the fire season by way of public weather forecasts.
- Public fire weather warnings when the fire danger is expected to exceed a certain critical level.

The second category is the services provided to fire management authorities, civil defense organizations, police and other emergency services. These services include:

- Detailed routine forecasts during the fire season.
- Warnings when the fire danger is expected to exceed a certain critical level.
- Operational forecasts to assist in combating ongoing fires.
- Special forecasts for prescribed burns.
- Advice regarding the installation and operation of special meteorological stations operated by fire authorities.
- Consultative advice and climatological information to assist with assessment of risk, development of fire prevention strategy and other aspects of fire management.

In addition to the routine services provided each day during the fire season (November to May), the Bureau provides the following services when extreme fire danger is expected and/or when fires are burning. These include:

- Fire weather warnings issued on a District basis when the fire danger is expected to reach extreme. These are issued publicly and are used by the Country Fire Authority (CFA) as a key input into decisions about the declaration of a total fire ban.
- Wind change charts. These are issued to the fire agencies on days of significant fire risk when a wind change is expected to affect the State. These charts show the current and expected future position of the wind change and are used by fire agencies when developing operational fire management strategies and tactics.
- Spot fire forecasts. These are highly detailed fire weather forecasts that are issued for specific locations in which a fire is burning or where a controlled burn is planned. They include information on the expected wind, temperature, relative humidity and other meteorological factors such as the timing of any wind changes. They are provided to the Incident Controller of the fire agency that is dealing with the specific fire and are also sent to the central fire control centres of both the CFA and the Department of Sustainability and Environment (DSE), in the case of Victoria. The spot fire forecast is broken up into three sections: the first section contains the general weather scenario and weather conditions for a specific location at +3 hours, +6 hours, +9 hours, +12 hours, and +24 hours. The second section contains a possible alternative weather scenario, to allow the fire agencies to undertake contingency planning. The third section is utilized by fire agency staff for the provision to the Bureau of observations of actual fire site weather conditions – this is valuable information that greatly assists the forecasters in making accurate predictions.
- On request, the Bureau can provide a forecaster at CFA Headquarters on critical days and, for large on going fires, a forecaster may be "outposted" to a fire incident control centre.
- Regular consultation is maintained between Bureau forecasters and the fire agencies. Bureau staff provides detailed briefing to fire chiefs, senior operational personnel and participate in operational briefings, both in person and by teleconference.

Direct Cost of Fire Weather Services

The provision of the meteorological information including fire weather forecasts is based on three essential processes: first, observing and monitoring the current state of the atmosphere and ocean; second, understanding the physical mechanisms of weather and climate forming processes in order to formulate numerical models of the atmosphere and ocean; and third, feeding the observed 'initial' data into these models, in real time, to predict the future evolution of the atmosphere as a basis for providing a wide range of forecast, warning and advisory services (Zillman 2002). Generally speaking, in many countries including Australia, these three processes are funded by the national governments. In other words, the basic meteorological infrastructure, data collection and basic research are taxpayer funded. Furthermore, their overall costs spread across a wide range of forecasts, warnings, and advisory services, given the economies of scale, scope and size of meteorological service provision. In this paper these costs are not considered and are assumed to be sunk costs for the provision of routine fire weather services by the Bureau.

The key focus here is on the direct costs of the additional fire weather services made available to fire and emergency authorities above and beyond what is available to the general public by the Victorian Regional Office of the Bureau. The following is an annual average estimate of these various direct costs that are incurred by the Victorian Regional Office. These estimates are based on standard accounting procedures and charging rules adopted by the Bureau. These estimated direct costs add up to around $0.40 m per year.

- Three fire weather forecasters provide operational support to the fire agencies on a daily basis during the fire season (November to May) ($ 0.2 m).
- One to two forecasters are outposted as onsite weather forecasters during major bush fires in specified locations or two forecasters are outposted as on site weather forecasters during major bush fires in specified locations (on average this would happen about 2 weeks per year although there is variation from year to year). Training is a significant component, probably about 4 weeks per year for one person ($ 0.009 m).
- Cost of providing computing and administrative support ($0.007 m).
- Cost of telecommunication services. This covers the cost of receiving extra observations from Automatic Weather Stations (AWSs) at high frequency during the fire season, and in particular during high risk fire weather days ($0.008 m).
- Cost of research support into smoke plume modeling ($ 0.05 m).
- Other related costs including balloons ($0.001m).
- Cost of operating additional AWSs and other equipment (including depreciation costs). The CFA has in the past operated its own AWS network of 8 across the State of Victoria ($0.064m).
- Cost of operating eight portable AWSs on behalf of the CFA and three AWSs on behalf of the DSE (including depreciation costs) ($0.031m).

The Bureau is currently using additional resources allocated as part of the extra funding from the newly established Cooperative Research Center (CRC) for Bushfires to finance the efforts to improve the fire weather services in Australia. Those additional funds amount to around $0.4 million per year for 7 years, which commenced in 2003-04 (that is, $2.8 million over 7 years). These additional funds are treated as the additional cost of improving the accuracy, timeliness and the nature of the enhanced fire weather services provided by the Bureau. It is expected that these improvements will enable the Victorian Regional Office to enhance the fire weather services that it currently provides to the fire management authorities, civil defense organizations, police and other emergency services, and hence to the general community.

Benefits for the Users

Assessing the benefits of fire weather information to the users is not an easy task. It is not appropriate to start from a situation where no fire weather information is available (see Sol 1994) because there is routine information on fire weather available to the general public in an ongoing basis. Hence, the purpose here is to focus on the benefits of additional information made available to fire and emergency authorities over and above what is available to the general public.

The benefits to the users of fire weather information can be assessed in the form of reduced losses from better use of fire weather services provided by the Victorian Regional Office of the Bureau. The potential benefits or reduced losses could be wide ranging depending on the location and circumstances of the specific bushfires cases. The potential benefits of reduced impact of bushfires can be viewed from the perspective of economic/commercial, social and environmental outcomes. The economic and/or commercial outcomes may involve reduced damage to timber assets, property and infrastructure, buildings, fences and vehicles, farm production, activities of businesses, personal belongings, etc. The social outcomes could range from reduced human fatalities, injuries and illnesses, psychological trauma, and destruction of personal memorabilia. The environmental outcomes may include reduced damage to native flora and fauna, water quality, amenity values, and reduced greenhouse gas emissions (see CIE 2001). Failure to reduce the impact of bushfires means a range of costs on the community and the economy. Some of these costs have market values (tangible) and can be easily quantifiable while others have non-market values (intangible) and may not be easily quantifiable.

Using the analysis presented by CIE (2001) based on data and information from Emergency Management Australia and various electronic records held by State land management agencies in Australia, Gunasekera and others (2004) have calculated the damage costs due to minor and major bushfires (table 1). As described earlier, it is estimated that the average annual area burnt in Victoria due to bushfires is around 110 000 hectares. Assuming a damage cost per area burnt of $133 000 for every 1000 hectares burnt (table 1), this amounts to $14.6 m per year. Furthermore, the damage cost due to major bushfires in Australia is estimated to be around $90 m per year based on the analysis of CIE (2001) and Bureau of Transport Economics (BTE) (2001) (table 1). On the

Table 1. Summary of estimated damage costs due to minor and major bushfires in Australia.

Type of cost	Estimated cost
Minor bushfires	
Damage costs per area burnt	$133 000 for every 1000 hectares burnt by bushfires
Major bushfires	
Insured losses (e.g. to property, assets and agricultural production)	$70 million per year
Damage to timber assets	$7.3 million per year
Cost of human fatalities	$8.3 million per year
Cost of serious human injury	$3.5million per year

Source: Based on CIE (2001), BTE (2001), and Gunasekera and others (2004).

basis that 25 percent of the area burnt in Australia due to bush fires generally takes place in Victoria, it could be inferred that 25 per cent of overall damage cost per year due to major bush fires in Australia of $90 m per year, that is $22.5 m per year, will also occur in the state of Victoria. Although the extent of bushfire damage impact discussed here is an approximation, it provides a broad indication of the likely average damage costs over time based on the best available information and plausible assumptions.

Hence, the bushfire damage costs in Victoria based on historical estimates imply an estimated $14.6 m of damage cost due to the area burnt and an additional damage cost of around $22.5 m due to insured losses, damage to timber assets, and losses due to human fatalities and serious injuries. Overall, this amounts to an estimated $37 million per year.

There are several key areas of savings (or benefits) that have not been taken into account explicitly here. These relate to potential savings to fire and emergency agencies as a result of efficient use of fire weather information that will enable them to better pre-position their resources including the relocation/deployment and mobilization of staff and equipment. For example, fire agencies deploy their resources including ground systems and airborne fire fighting operations based on the nature and intensity of various bushfires. Aircraft used in fire fighting operations are stored in locations least likely to be affected by smoke, thus maximizing the likelihood that they can take off safely early each morning near large fires. These are the costs that have to be borne as part of fire management. If specialized meteorological information provided by the Bureau help save the use of some of these resources or assist in better using those resources, that may lead to a reduction in the cost of operation of fire and emergency management in certain circumstances.

Another area of potential savings is due to prevention of fires through effective prescribed burning which could result in improved fuel reduction and reduced incidence of high intensity fires with extensive spread. Prescribed burning can be regarded as an important method by which the impact of bushfires can be reduced (Victorian Government 2003). There is a renewed emphasis on fuel reduction programs including prescribed burning, following the major bushfires in the recent past. If the fire prevention measures help avoid at least a single fire of 1000 hectares each year, the savings or reduced losses could be considerable. There is also the possibility of a prescribed burn escaping and becoming a large bushfire negating any accrued benefits of the program, and possibly increasing the costs.

Concluding Remarks

One of the primary objectives of providing and using fire weather information in prevention and mitigation of bushfires is to ensure that the potential and actual threats to human life, property and other assets due to bushfires are reduced or, to the extent possible, avoided. There is widespread recognition of the importance of fire weather services in understanding and dealing with the effect of weather and climatic conditions on the impact of bushfires.

Based on the information provide in this paper, the cost of providing fire weather information to fire agencies in Victoria is around $0.8 m per year. This includes the direct cost of operations with respect to the provision of fire weather services in the Victorian Regional Office of around $ 0.4 m and the additional cost of $ 0.4 m of improved fire weather services as a result of research sponsored through the Bushfire CRC. This compares with an estimated damage cost per year due to major bush fires in Victoria of $37 m.

It is assumed here that the improved fire weather services by the Bureau will lead to a modest reduction in the impact of bushfires and the related damages and losses culminating in, for example, a 5 to 10 percent reduction in overall damages that can be expected, over a medium term time period (5 to 10 years), (for example, over a 7 year period). As discussed earlier, the estimated overall damage cost due to bushfires in Victoria is around $37 m per year on average, which is around $260 m over a 7-year period. An assumed 5 to 10 percent reduction in overall damages due to the better use of improved fire weather services is expected to lead to a $13 m to 26 m reduction in overall damage costs over a 7-year period.

Comparing the costs of providing the additional enhanced information ($5.6 m over a 7-year period) to the potential savings illustrated here ($13 m to $26 m over a 7-year period) would allow us to determine if the cost of additional information is worth incurring. The results here show the investment on additional enhanced information is worth making as it results in savings 2 to 5 times larger than the investment over a 7-year period. We have neither annualized nor discounted to the present the cost and benefits associated with this additional fire weather services program. This benefit – cost comparison is based on a key assumption that the provision and use of improved fire weather services is likely to lead to a reduction in the impact of bushfires and the related damages and losses culminating in, for example over a 7 year period, a 5 to 10 percent reduction in overall damages that can be estimated. An important area of future research that is noteworthy here is a detailed examination of the applicability of this assumption.

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Inventorying and Monitoring of Tropical Dry Forests Tree Diversity in Jalisco, Mexico Using a Geographical Information System

Efren Hernandez-Alvarez, Ph. Dr. Candidate, Department of Forest Biometrics, University of Freiburg, Germany
Dr. Dieter R. Pelz, Professor and head of Department of Forest Biometrics, University of Freiburg, Germany
Dr. Carlos Rodriguez Franco, International Affairs Specialist, USDA-ARS Office of International Research Programs, Beltsville, MD

Abstract—*Tropical dry forests in Mexico are an outstanding natural resource, due to the large surface area they cover. This ecosystem can be found from Baja California Norte to Chiapas on the eastern coast of the country. On the Gulf of Mexico side it grows from Tamaulipas to Yucatan. This is an ecosystem that is home to a wide diversity of plants, which include 114 tree species. These species lose their leaves for long periods of time during the year. This plant community prospers at altitudes varying from sea level up to 1700 meters, in a wide range of soil conditions. Studies regarding land attributes with full identification of tree species are scarce in Mexico. However, documenting the tree species composition of this ecosystem, and the environment conditions where it develops is good beginning to assess the diversity that can be found there. A geographical information system overlapping 4 layers of information was applied to define ecological units as a basic element that combines a series of homogeneous biotic and environmental factors that define specific growing conditions for several plant species. These ecological units were sampled to document tree species diversity in a land track of 4662 ha, known as "Arroyo Cuenca la Quebrada" located at Tomatlan, Jalisco. This paper will describe and discuss the methodology used for the study, the results obtained for three plant strata, the number of families found, the number of genera per family, and the number of species per family by Ecological Unit, and it will describe a follow up plan for monitoring this vegetation. This research was supported by Consejo Nacional de Ciencia y Tecnología (CONACYT), México, Project: 31808-B.*

Introduction

Mexico's biological diversity is one of its main natural resources for economic development, however, this biological potential has not been adequately assessed, and its use and conservation have not been addressed in a sustainable manner. Mexico is a very important country regarding its biodiversity use and conservation, because it is one of the twelve countries covering, as a group, between 60 to 70 percent of total planet's biodiversity; therefore, Mexico is considered a megadiverse country.

Although Mexico covers 1.3 percent of the planet's total area surface, it holds 10 percent of the world's biodiversity; it holds the first place in number of reptile species; fourth place in amphibious species; second place in mammals, eleventh place in birds, and fourth place in vascular plants. Similarly, Mexico has a great rate of endemism, with more than 800 endemic vertebrate species. Regarding the Mexican flora, its temperate forests are the most diverse on earth with 55 pine tree species and 138 oak species, with 85 percent of endemic pine tree species and 70 percent of endemic oak tree species.

Tropical dry forests in Mexico are an outstanding natural resource, due to the large surface area they cover. This ecosystem can be found from Baja California Norte to Chiapas on the eastern coast of the country. On the Gulf of Mexico side it grows from Tamaulipas to Yucatan. This is an ecosystem that is home to a wide diversity of plants, which include 114 tree species. These species lose their leaves for long periods of time during the year. This plant community prospers at altitudes varying from sea level up to 1700 meters, in a wide range of soil conditions. The most diverse dry forests in the world occur in southern Mexico and in the Bolivian lowlands (Bullock, Monney, and Medina, 1996; Gentry, 1993; and Parker and others, 1993).

Mexican inhabitants of tropical dry forest regions in Mexico benefit from this plant biodiversity using several species for medicinal purposes (*Crecentia alata*, *Guazuma ulmifolia*, *Tecoma stans*, and *Amphiterigium adstringens* among others), as a raw material for local construction, for firewood, fruit, raw material for handcrafts, honeybee production, raw material for fencing, forage, and religious purposes. However, not so much attention has been given to this magnificent natural resource, which currently faces the threat of the expansion of agricultural border for crops, grasslands and animal husbandry, overexploitation through illegal cutting, urban expansion, and the periodic occurrence of natural and human caused disturbances such as fires.

Despite this richness in natural resources, studies regarding land attributes with full identification of tree species for this ecosystem are scarce in Mexico. By this reason the general objective of this study was to develop a work methodology for the application of a geographical information system for a track of land located at "*Arroyo Cuenca la Quebrada*," Tomatlan, Jalisco. The specific objectives were a) To determine tree species composition of this ecosystem, b) To determine ecological units that define specific growing conditions for several plant species, and the number of families, the number of genera per family, and the number of species per family found, and c) To propose a follow up plan for monitoring this vegetation.

Review of Literature

Tropical Sub-deciduous Forests

According to Lamprecht (1986) these are dense forests with tall trees, deciduous in the dry season, which lasts from two to 7 months. These are transitional forests between tropical rain forests and tropical dry forests, by this reason they are highly variable in species composition, structure, physiognomy, and phenology. Their distribution occurs in Africa in regions at the mid equatorial rain forests, mostly at the south and east; in Asia in Hindustan and Indochina; Latin America, in the Amazon region, Colombia, Venezuela, Central America and Mexico; and Australia at the north and east coasts.

In Mexico, this forest is a dense community and the height of its trees varies from 20 to 30 m, with a homogeneous canopy, and diameters from 30 to 80 cm. This forest are located in tropical areas where half and some times until three quarters of the species lost their leaves for a 6 month period during the dry season of the year (Rzedowsky 1983). This forest grows in areas with annual average temperature higher than 20º C and less than 28º C, annual rainfall between 1000 and 1600 mm as a maximum, although in some areas like Jalisco could be 800 mm, a dry season between 5 or 7 months were almost all the species lost their leaves during some period of the year. These forest ecosystems are located from the sea level up to 800 m. Common species are: *Brosimum alicastrum, Aphananthe monoica*, in Jalisco, Colima and some part of Nayarit and Michoacán the most frequent species are the following: *Astronium, graveolens*, *Bernoullia flammea*, *Sideroxylon cartilagineum*, *Bursera arbórea*, *Calophyllum brasiliense*, *Cordia alliodora*, *Cordia elaeagnoides*, *Tabebuia donnell-smithii*, *Dendropanax arboreus*, *Enterolobium cyclocarpum*, *Ficus cotinifolia*, *Ficus involuta*, *Ficus mexicana*, *Hura polyandra*, *Luehea candida*, *Hymenaea courbaril*, *Lysiloma divaricatum*, *Sideroxylon capiri*, *Attalea cohune*, *Swietenia humilis*, *Tabebuia impetiginosa y Tabebuia rosea*. In the intermediate stratum the following species are outstanding: *Acacia langlassei*, *Apoplanesia paniculata*, *Trichospermum mexicanum*, *Bursera excelsa*, *Bursera simaruba*, *Jacaratia mexicana*, *Ceiba aesculifolia, Coccoloba barbadensis*, *Cordia seleriana*, *Croton draco*, *Cupania glabra*, *Esenbeckia berlandieri*, *Eugeniamichoacanensis*, *Euphorbia fulva*, *Exothea copalillo*, *Forchhammeria pallida*, *Inga laurina*, *Jatropha peltata*, *Plumeria rubra, Psidium sartorianum*, *Swartzia simplex*, among others. This type of vegetation can be found from Central Sinaloa up to Chiapas along the coastal line up to 1,200 m above sea level and in small areas in central Veracruz, central Chiapas and central and north Yucatan (Rzedowski y McVaugh, 1966, Pennington y Sarukhán, 1998).

Tropical Dry Forests

According to Lamprecht (1986) tropical dry forests vary from dense to very poor stand density, mostly xerophytic or deciduous in the dry season, which lasts from 5 to 7.5 months. They have a rainfall varying from 700 to 1000 mm/year, and sometimes more; they can have two strata, with poor floristic composition. This type of forest grows mostly in Africa: south of Sahara, the Eastern part including Kenya, Tanzania, and Zimbabwe. In North America and Central America: in the mountain range from Mexico to Costa Rica; in South America in the Chaco region, in the Pacific ocean side close to Guayaquil, Equator up to Northern Peru, and on the Atlantic ocean side in Venezuela, Colombia and Brazil. In Asia it can be found at the occidental monsoonal zone close to India, at the dry watershed in High Burman, Thailand, the Khorat watershed, and the dry monsoon region of the Sunda Islands.

In Mexico, these forests are located in tropical areas where the dominat species loose their leaves for a 6 month period during the dry season of the year (Rzedowsky, 1983). This type of forest grows in areas with an annual average temperature higher than 20º C, annual rainfall between 800 and 1200 mm as a maximum, a dry season between 7 or 8 months during, which almost all the species loose their leaves during some period of the year. These forest ecosystems are located from the sea level up to 1700 meters above sea level.

Tree height varies from 4 to 10 meters, although can reach 15 m. Frequently, the trunks of the trees are short, twisted and with branches starting close to the soil, tree crowns are sparse and extended, and a great number of species can sprout. The understory is very scarce and it can be seen only during the rain season. Lianas are abundant and epiphytes are limited to those from the bromeliaceae family such as the genus *Tillandsia*. Succulent plants are common and are represented by the genus *Agave*, *Opuntia*, *Lemaireocereus*, and *Cephalocereus*. Species with spines are not abundant. This plant community grows on hillsides, stony ground, and in sandy or clay shallow soils with good superficial drain. It has a wide geographical distribution on the Pacific coastline, especially in the Balsas river watershed and on hillsides of the Occidental mountain range from Colima to Sonora states in ravines. It extends from Baja California to Chiapas. At the side of the Gulf of Mexico it can be found in the region known as the Huasteca, and a large portion of Yucatan.

Frequent tree species on the Pacific coastline (Michoacan, Jalisco, Colima and Nayarit states) are: *Lysiloma divaricatum*, *Bursera excelsa*, *Bursera fagaroides*, *Ceiba aesculifolia*, *Comocladia engleriana*, *Cyrtocarpa procera*, *Lonchocarpus eriocarinalis*, *Lysiloma acapulcensis*, *Pseudosmodingium perniciosum*, *Spondias purpurea*, and *Trichilia americana* (Rzedowsky and McVaugh, 1996; Pennington and Sarukhan, 1998).

Land Classification Systems

Most land classification systems are based on the study of the physical and biological attributes of the land surface. These systems only differ in the classification unit concept in which the generation of maps is used for planning the different human activities carried out in a specific region.

In Australia, the Division of Land Research and Regional Survey of The Commonwealth Scientific and Industrial Research Organization (CSIRO) developed a system of geomorphological mapping for resource survey based on a concept of land units and land systems. The concept was designed to provide a basic and functional subdivision of landscape (Christian and Stewart, 1968). A land unit was defined as an area dominated by a land surface with similar genesis and with similar topography, soils, vegetation, and climate. A land system was assembled of land units, which are geographically and genetically related (Christian, 1958). This system was well adapted to rapid reconnaissance surveys of large areas based on information derived from aerial photographs, and it was widely used to map large areas of Australia and New Guinea (Mabbutt and Stewart, 1963).

Another land classification system is the one based on the landscape or geomorphological and edaphic criteria; the phisiographical survey is represented by CSIRO, the Military Engineering Experimental Establishment in England and the National Institute for Road Research in South Africa.

One more system is known as ecological typology represented by the French group "Centre D'Etudes Phytosociologiques et Ecologiques" based on regions made up of climatic, phisiographic, geological, and edaphic criteria, and vegetation types (Boyas, 1992). The basic unit in this system is the site or station, which defines a homogeneous unit based on climate, topography, geology, soil, and vegetation. In this system vegetation has more weight for territorial regionalization, because it is considered is the most exact expression of the interaction of environmental factors. According to Boyas (1992), this is the closest definition to the term called ecological unit in which the study to determine productivity, composition and structure of arboreal communities in Morelos state in Mexico was based.

Currently these kinds of land classification systems are widely used to support studies that to work with ecosystem and landscape ecology, which focuses on structure, the spatial patterns of landscape elements, and ecological objects (such as animals, biomass, and mineral nutrients); function, the flow of objects between landscape elements; and change, alterations in the mosaic through time (Forman and Godron, 1986).

In Mexico, several studies have been done using the phisiographical system (Ortiz and Cuanalo, 1984). Most of them were done to estimate land productivity for agricultural activities as a basis for the elaboration of management and conservation plans (Peña, 1974; Ponce and Cuanalo, 1977; Ortiz y Cuanalo, 1977; Rodriguez y Ortiz, 1982; Basurto and others, 1984; Soria and Ortiz, 1987; Salazar y Ortiz, 1987; and Terrazas, Ortiz and Vargas, 2002).

The use of the ecological typology methodology in Mexico has been applied to develop several studies to estimate the productivity capacity of the land for planning animal husbandry, agricultural, and forestry activities. The concept of ecological units has been used as the basic study unit to assess the best use aptitude of the land according to its productive potential. The National Institute for Statistics, Geography, and Informatics based on the French School has developed charts of potential use of the land for that entire country.

Studies to obtain ecological units charts for specific regions of some states such as Huitzilac, Morelos (Reyes and Boyas, 1983), Morones mountain range in Zacatecas (Vela y Boyas, 1984), and the region known as la Montaña in Guerrero (Toledo, 1984; Carabias and others 1987) have been developed for planning of agricultural and conservation activities.

The most important effort in applying this methodology was done by Boyas (1992) to define the ecological regionalization of Morelos state through the definition of ecological units for the most important arboreal communities and to assess the composition, structure, and wood productivity of the most important ecological units for tropical dry forests in the whole state. Climatic, phisiographic, geologic, soil, and current use of the soils 1: 250,000 scale charts were stratified and overlapped to define 130 ecological units; those with the biggest size were considered as more representative of the environmental conditions in the state; 22 covered 76 percent of the state surface area.

The composition, structure, and wood productivity of the tropical dry forest was studied through a systematic forest inventory with a sample intensity of 0.01 percent of the total area surface. The taxonomic studies showed the presence of 100 tree species, and the most important plant families were leguminosae and burseraceae; for each ecological unit the vertical stratification of the average stand was obtained according to their diametric structure; three arboreal strata were identified. Total volume and commercial volume were estimated for the 100 species and by ecological unit as an indicator of productivity. This study shows demonstrates that the ecological typology methodology constitutes a very good framework to assess forest potential for a region, and that productivity varies for each ecological unit, providing the basis to design and plan specific management plans for each one.

Materials and Methods

Area of Study

This study was carried out on a forested track of land known as "Arroyo Cuenca Quebrada," in Tomatlan, Jalisco. This track of land has a total surface area of 4,462 hectares. It is located between the coordinates 105º 05' West longitude and 19º 55 North latitude. It is located 70 km from Puerto Vallarta. The weather is considered as A w 1 (w). (I') sub-humid tropical with rainfall in summer. The average total annual amount of rainfall is 1408 mm; the average temperature is 25.8º C, with an oscillation between 5º to 7º C (Garcia, 1988). Tropical deciduous and dry forests occupy 97 percent of the area; the remaining amount of land is mainly covered with grassland, a small amount of oak forest (5.7 ha), and of agriculture 5 ha. The intrusive igneous rocks are derived from the cretaceous period, and are mostly granite. According to the FAO/UNESCO soil classification system (2001) modified by the National Institute for Statistics, Geography and Informatics of Mexico (1989), this area has regosol eutric (unconsolidated mineral material of some depth, excluding coarse textured materials and materials with *fluvic properties,* with no diagnostic horizons other than an *ochric horizon*); Cambisol eutric, and cambisol chromic (soils with incipient soil formation. Beginning transformation of soil material is evident from weak, mostly brownish discoloration and/or structure formation below the surface horizon); Phaeozems haplic are more intensively leached in wet seasons. Consequently, they have dark, humus surface soils that are less rich in bases than surface soils of Chernozems and Kastanozems and Phaeozems, and have no signs of secondary carbonates in the upper meter of soil; and litosols (soils with less of 10 cm of depth to the bedrock). The area has an accidental topography with slopes from 5 to 20 percent. The average altitude above sea level varies from 128 to 760 m. The aspect in general in the study area is Southwest.

Methods

Ecological classification of the study area

Digital cartographic material of the GIS database created by Kruger (2000) at a scale 1:50,000 was used. The digital layers with vectorial data to define the ecological units were: Area.shp, Contours.shp, Presammpl.shp, Sample.shp, Geology.shp, Soils.shp, and Landuse.shp, and the layers with raster data used were DMH.grid, Exposition.grid and Hangneigung.grid. The stratification of the ecological units was done according to French methodology pointed out by Boyas (1992), overlapping maps. The GIS Arc View© with the geoprocessing wizard tool was used to overlay different layers of information and the generation of new ones. The specific functions used were dissolve features based on an attribute, merge themes together, clip one theme based on another, intersect two themes, union two themes, and assign data by location or spatial joint.

The main layer used was geology to overlap the different layers of information such as soils, digital altitude pattern, aspect, slope, and vegetation. Strata were defined according to their limits and combination of physical types and vegetation types. In this way each stratum was defined by 4 factors (geology, soils, vegetation, and altitude) giving origin to ecologic units.

Tree species composition assessment

A systematic sampling design was carried out. Distance between sampling lines was 500 m and between plots was 250 m. A pilot sample with 20 plots was used to estimate the coefficient of variation for diameter at breast height and compute the final sample size. A final sample size of 357 plots was taken with a 95 percent of confidence and sampling intensity of 0.4 percent. Each plot was located with a preprogrammed GPS with the data of the sampling grid; at the plot center a metallic rod was buried to allow the future plot relocation. Circular plots of three sizes were used. Circular 500 m^2 plots for recording data of adult trees, 100 m^2 circular subplots for intermediate size trees and 12.57 m^2 circular subplots for tree regeneration. At each plot the following information was recorded:

Control data. Plot number, UTM geographical coordinates, name of the responsible person for the information, date of the sampling, additional plot information such as erosion presence (no erosion, sheet erosion, channel erosion, and gully erosion), disturbance type (none, illegal cuttings, grazing, insect attack, other), and tree damage (high, medium, and low), use of the soil (forest, animal husbandry, agriculture).

Tree data. For all the trees over 5 cm of dbh, plot number, individual number, species name, dbh, total height, distance from the center of the plot to the tree, azimuth (from cero to 360 degrees), health status of the tree (good, regular, sick), damage (hollow up, bunch of stems, bifurcated, curve, decrepit, blunted, branchless, injured, sided, none, infested, half-alive) were recorded. For the 500 m^2 plot additional information was recorded such as commercial height, and average crown diameter.

Analysis of data. Digital cartographic material of the GIS database created by Kruger (2000) at scale 1:50,000 was used as starting point to create a wider database and expand the existing information, as well as to generate new information layers. The information from the forest inventory was cleansed, and stored in excel format for processing. This format allowed management of the files to be used with the Statistical Analysis System to estimate the central tendency parameters for the variables recorded at the forest inventory, in general for all the population, for each ecological unit.

Results and Discussion

Ecological Units (EU)

The map of EU for the track of land Arroyo Cuenca Quebrada, in Tomatlan, Jalisco was obtained. The main layer used was geology to overlap the different layers of information of soil, digital altitude pattern, aspect, slope, and vegetation. The bigger weight was given to vegetation, because it is the most exact expression of all the interaction of environmental factors, in the definition of the boundaries between EU (fig. 1). According to this map the study area has 19 EU (table 1), but only 14 covered with forest were considered relevant to this study. The most representative EU were those with the bigger coverage of surface area, pointed out at table 1 with numbers 6,7 and 8, which are covering 4,087.7 ha (91.5 percent) of the total area. Their altitude range only differentiates them.

Vegetation

The vegetation types found at the area correspond with those described by Rzedowski (1983) as tropical sub-deciduous forest and tropical dry forest. Ten EU with 4,255.1 ha (95.3 percent of the total area) were covered by tropical sub-deciduous forest; the remaining four EU are covered with tropical dry forest. The dominant vegetation families at the area are (table 2) leguminosae with 16 genera and 22 species, the euphorbiaceae family with 5 genera and 7 species, the moraceae family with 4 genera and 6 species followed by the myrtaceae family with 2 genera and 4 species. Dominant genera per family were for the leguminosae *Acacia* with 4 species, *Lonchocarpus* with 3 species, and *Lysiloma* with 2 species; euphorbiaceae with the genera *Croton* with 2 species, and *Cnidoscolus* with 3 species; moraceae with the genus *Ficus* with 3 species; myrtaceae with the genus *Psidium* with 3 species; burceraceae with the genus *Bursera* with 3 species; and the bignonaceae family with the genus *Tabebuia* with 4 species (table 2). These results coincided with those reported by Rzedowski y McVaugh, 1966, Rzedowski, 1983, Pennington y Sarukhán, 1998, and Boyas, 1992.

The total number of families found at the area was 39 families with 75 genera and 136 species. It is important to mention that 40 species were identified at the field only with common names, when the forest inventory was carried out, and further taxonomic identification work is

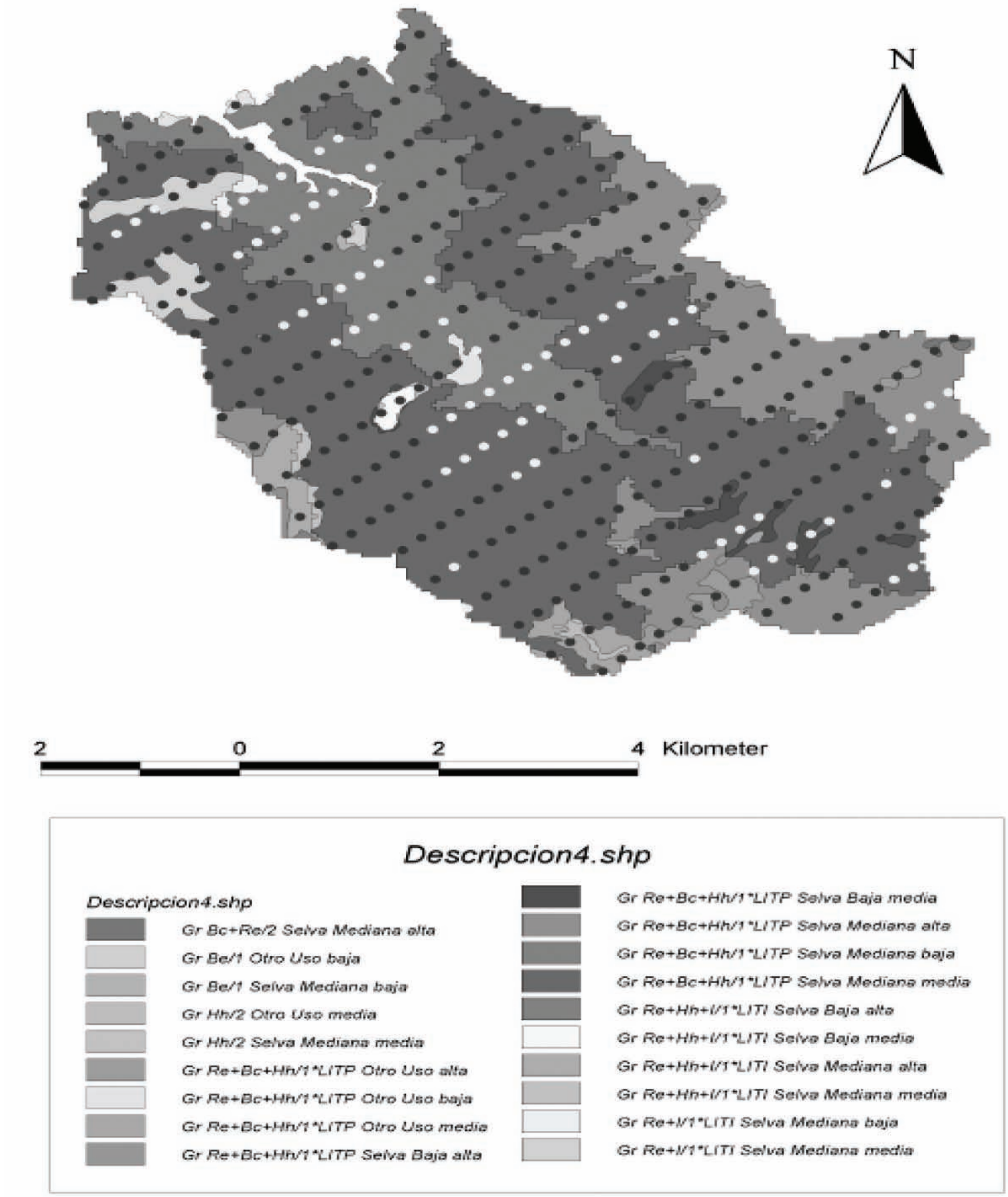

Figure 1. Ecological units at Arroyo Cuenca Quebrada, in Tomatlan, Jalisco, Mexico.

required; the list of species found in this study, together with other of their main characteristics are presented at the table 2.

Regarding plant families distribution by EU, the Ecological Unit with representation of the 39 families found in this study was the one identified as Gr Re+Hh+I/1*LITI Selva Baja media, with a surface area of 12.8 ha, indicating that there is high species diversity per unit of land, and this result also shows that tropical dry forest in this environmental conditions in Jalisco state is more diverse than tropical sub-deciduous forest (table 3). The subsequent EU with more families represented were Gr Re+Bc+Hh/1*LITP Selva Mediana media with 30 families, followed by the EU Gr Re+Bc+Hh/1*LITP Selva Mediana alta with 28 families, these last two EU cover a total surface area of 3,191.59 ha. the EU with the less number of families was Gr Be/1 Selva Mediana baja with 1 family (palmae) covering 4.52 ha,this situation could be a result of a disturbance occurrence such as intensive grazing or a fire, but more detailed studies are needed about stand dynamics in the long term to know the successional dynamics of this type of

Table 1. Ecological units at Arroyo Cuenca Quebrada, in Tomatlan, Jalisco.

Number	Ecological unit	Surface area (ha)	Surface area (%)
1	Gr Bc+Re/2 Selva Mediana alta	5.16	0.12
	Gr Be/1 Otro Uso baja	4.41	0.16
2	Gr Be/1 Selva Mediana baja	4.52	0.33
	Gr Hh/2 Otro Uso media	7.90	0.33
3	Gr Hh/2 Selva Mediana media	0.49	0.03
	Gr Re+Bc+Hh/1*LITP Otro Uso alta	52.98	2.13
	Gr Re+Bc+Hh/1*LITP Otro Uso baja	21.66	0.66
	Gr Re+Bc+Hh/1*LITP Otro Uso media	45.08	1.18
4	Gr Re+Bc+Hh/1*LITP Selva Baja alta	2.84	0.28
5	Gr Re+Bc+Hh/1*LITP Selva Baja media	58.78	2.66
6	Gr Re+Bc+Hh/1*LITP Selva Mediana alta	780.29	24.21
7	Gr Re+Bc+Hh/1*LITP Selva Mediana baja	896.11	13.78
8	Gr Re+Bc+Hh/1*LITP Selva Mediana media	2411.30	48.19
9	Gr Re+Hh+I/1*LITI Selva Baja alta	1.31	0.12
10	Gr Re+Hh+I/1*LITI Selva Baja media	12.80	0.35
11	Gr Re+Hh+I/1*LITI Selva Mediana alta	44.65	1.44
12	Gr Re+Hh+I/1*LITI Selva Mediana media	16.49	0.67
13	Gr Re+I/1*LITI Selva Mediana baja	8.21	0.28
14	Gr Re+I/1*LITI Selva Mediana media	87.88	3.10
	Total	**4,462.91**	**100%**

Gr= Granite, Bc= Cambisol cromico, Re= Regosol eutrico, Be= Cambisol cromico, Hh= Fezem haplico, /1 = thick texture, /2 = medium texture, LITI = soil fase litic cover with rocks from 10 to 50 cm, LITP= soil fase deep ltic with rocks from 50 to 100 cm, baja= 0-250 m, media= 251-500 m alta=501-760 m above sea level.

Table 2. List of species found at the Arroyo Cuenca Quebrada, in Tomatlan, Jalisco.

Species number	Species common name	Scientific name	Botanic family	Plant use	Wood clasification
001	Achiote	*Bixa orellana*	Bixaceae	The fruit is used as a coloring for chewing gum	
002	Aguacatillo, laurelillo	*Nectandra ambigens*	Lauraceae	Firewood	Soft wood
003	Ahuilote	*Vitex mollis*	Verbenaceae	The fruit is edible and together with the leaves are medicinal	
004	Algodoncillo	*Luehea speciosa*	Tiliaceae	Post and firewood	Low quality
005	Amolillo, jaboncillo	*Sapindus saponaria*	Sapindaceae		
006	Anona	*Annona purpurea*	Anonaceae	Edible fruit	
007	Árbol María	*Calophyllum brasilense*	Gutiferaceae	Sawmilling, furnitures and construction	Precious wood
008	Arrayán	*Psidium sartorianum*	Myrtaceae	Edible fruit,	Saw mill
009	Arrayancillo	*Eugenia fragans*	Myrtaceae	Postes, furnitures and construction	Common tropical
010	Arrayancillo negro				
011	Bejuco				
012	Bonete	*Jacaratia mexicana*	Caricaceae	Fruit edible and medicinal use	
013	Botoncillo, aucelote	*Cordia alliodora*	Boraginaceae	Posts, beams, and furniture	Saw mill
014	Brasil	*Haematoxylon brasiletto*	Leguminosae	Furnitures and construction and natural colorant	
015	Cabra	*Aphananthe monoica*	Ulmaceae	Posts.	Saw mill
016	Camotillo	*Dalbergia* sp.	Asteraceae		
017	Canelilla	*Croton* sp.	Euphorbiaceae	Sticks for crops.	Saw mill
018	Caoba, cobano	*Swietenia humilis*	Meliaceae	Sawmilling, furnitures	Precious wood
019	Capiri	*Masthicodendron capiri*	Sapotaceae		
020	Capomillo	*Trophis racemosa*	Moraceae		
021	Capomo	*Brosimum alicastrum*	Moraceae	Sawmilling, construction, and leaves and fruit for forage	Precious wood
022	Capulín	*Tremula micrantha*	Ulmaceae		
023	Caramuza				hardwood
024	Cedoso				
025	Cedro blanco	*Gyrocarpus jatrophifolius*	Hernandiaceae		High quality wood
026	Cedro rojo	*Cedrela odorata*	Meliaceae	Sawmilling, furnitures.	Precious wood
027	Ceiba, pochote	*Ceiba aesculifolia*	Bombacaceae	The fiber of the fruit is used for stuffing pillows	
028	Chachalaco				
029	Chicozapote	*Pouteria* sp.	Sapotaceae		
030	Chilte	*Cnidoscolus elasticus*	Euphorbiaceae	Chewing gum	
031	Chorunbo garruñolo				
032	Cinión, cinlón				

Table 2. *Continued*.

Species number	Species common name	Scientific name	Botanic family	Plant use	Wood clasification
033	Ciruelo	*Spondias purpurea*	Anacardiaceae	Edible fruit	
034	Clavellina	*Pseudobombax ellipticum*	Bombacaceae		
035	Cola de vaca				
036	Coloradillo				
037	Concha	*Pithecellobium lanceolatum*	Leguminosae	posts, fruit for forage	Saw mill
038	Copal	*Bursera heteresthes*	Burceraceae	Fruit use for inciense	
039	Copalillo	*Bursera excelsa*	Burceraceae	Construction	Saw mill
040	Cruzillo	*Randia laevigata*			
041	Cuamecate	*Anredera vesicaria*	Basellaceae	Hornamental and medicinal	
042	Cuata	*Vitex piramidata*	Verbenaceae	Se wood use for doors	Saw mill
043	Cuata laca	*Caesaria dolichophylla*	Flacurtiaceae		
044	Cuate	*Eysenhartia polystachya*	Leguminosae	Posts and constuction	High quality wood
045	Cuernillo			Posts	Long lasting wood
046	Cuerno de toro			Posts	
047	Cuero de Indio	*Lonchocarpus longopedicellatus*	Leguminosae	Porous wood	
048	Cuil				
049	Cuirí				
050	Culebro, amargoso	*Astronium graveolens*	Anacardiaceae	Sawmilling, furnitures and construction	High quality wood
051	Embele			Wood use for handcrafts	
052	Encino	*Quercus glaucescens*	Fagaceae	Industrial use	
053	Frutilla				
054	Gallinilla				
055	Garrapato	*Lonchocarpus constrictus*	Leguminosae	Posts	High quality wood
056	Garruño negro				
057	Gavilancillo				
058	Gobonero				
059	Granadillo	*Platymiscium lasiocarpum*	Leguminosae	Posts and construction	High quality wood
060	Guaiparín				
061	Guajillo	*Leucaena glauca*	Leguminosae	Posts	High quality wood
062	Guasima	*Guazuma ulmifolia*	Sterculiaceae	Sawmilling, furnitures and construction, fruit for forage	High quality wood
063	Guayabilla	*Psidium guineense*	Myrtaceae		
064	Guayabo	*Psidium guajava*	Myrtaceae		
065	Habillo	*Hura polyandra*	Euphorbiaceae	Sawmilling, furnitures	High quality wood
066	Hediondillo	*Cassia atomaria*			
067	Higuera	*Ficus obtusifolia*	Moraceae	Fruit and foliage use for forage	
068	Hincha huevos	*Comocladia engleriana*	Anacardiaceae	Posts and construction	harwood
069	Hormiguillo, guarumbo, trompeta, cuitapilli	*Cecropia obtusifolia*	Cecropiaceae	Construction	High quality wood
070	Huevo de gato	*Thevetia ovata*	Apocynaceae	Construction.	sawmill
071	Huizache	*Acacia farnesiana*	Leguminosae	Posts and fruit for forage	sawmill
072	Huizapol				
073	Huizcolote	*Acacia cymbispina*	Leguminosae	Posts	sawmill
074	Jarretadera	*Acacia hindsii*	Leguminosae		
075	Juan Pérez	*Pseudosmodingium perniciosum*			
076	Juanita	*Halimium glomeratum*	Cistaceae	Firewood	firewood
077	Juaquinicuil	*Inga jinicuil*	Leguminosae	Edible fruit and for forage.	
078	Lechoso				
079	Llora sangre, sangre de grado	*Croton draco*	Euphorbiaceae	Packingboxes, coloring, and bark for medicinal purposes	
080	Majahua	*Heliocarpus pallidus*	Tiliaceae	Construction	sawmill
081	Mameycillo				
082	Mano de león	*Oreopanax xalapensis*	Araliaceae		
083	Maravilla				
084	Margarita	*Karwinskia latifolia*	Rhamnaceae	Construction	sawmill
085	Mataiza	*Sapium pedicellatum*	Euphorbiaceae	Sin uso	
086	Mora	*Chlorophora tinctoria*	Moraceae	Posts and construction	sawmill
087	Murciélago			Wood for tool handles	sawmill
088	Nance	*Byrsonima crassifolia*	Malpigiaceae	Edible fruit	edible
089	Naranjillo			Posts, and tool handles	sawmill
090	Naranzuchil				
091	Obo, ravelero	*Sciadodendron excelsum*	Araliaceae		
092	Órgano	*Pachycereus pecten-aboriginum*	Cactaceae	Edible fruit	edible
093	Otras				
094	Palma coyul	*Acrocomia aculeata*	Palmae	Edible fruit, wood for beams	
095	Palma real	*Sabal mexicana*	Palmae	Leaves used as a house roof	sawmill
096	Palo blanco	*Tabebuia* sp.	Bignoniaceae	Construction	sawmill
097	Palo bobo	*Ipomea arborescens*	Convolvulaceae		
098	Palojiote				
099	Pan pan	*Cnidoscolus tubulosos*	Euphorbiaceae		

Table 2. *Continued*.

Species number	Species common name	Scientific name	Botanic family	Plant use	Wood clasification
100	Papelillo	*Bursera simaruba*	Burceraceae	Sawmilling, furnitures and construction	sawmill
101	Parota	*Entherolobium cyclocarpum*	Leguminosae	Sawmilling, furnitures and construction, edible fruit and for forage	Precious wood
102	Parotilla	*Poeppigia procera*	Leguminosae		
103	Pata de res				
104	Pata de venado	*Bahuinia cungulata*	Leguminosae	Posts	hardwood
105	Pinolillo, tzinacacao	*Andira inermis*	Leguminosae	Furniture and doors	sawmill
106	Polvillo	*Lonchocarpus* sp.	Leguminosae		
107	Pozolillo				
108	Primavera	*Tabebuia donnell-smithii*	Bignoniaceae	Sawmilling and furniture	precious wood
109	Quebramuelas	*Cupania dentata*	Sapindaceae	Wood for tool handles	sawmill
110	Quemador	*Cnidoscolus* sp.	Euphorbiaceae		
111	Raspa vieja	*Curatella americana*	Dilleniaceae		
112	Roble	*Quercus* sp.	Fagaceae		
113	Rosa morada, amapa	*Tabebuia rosea*	Bignoniaceae	Sawmilling and furnitures	precious wood
114	Saladillo				
115	San Antonio				
116	Suelda	*Agonandra racemosa*		Posts	sawmill
117	Tacote				
118	Tacotillo				
119	Tahuitole	*Pterocarpus orbiculatus*	Leguminosae	Posts	sawmill
120	Tampiziran	*Dalbergia congestiflora*	Leguminosae	Sawmilling and furnitures	High quality wood
121	Tancua				
122	Tempuche				
123	Tepame	*Acacia pennatula*	Leguminosae		
124	Tepeguaje	*Lysiloma acapulcensis*	Leguminosae	Posts and construction	sawmill
125	Tepemezquite	*Lysiloma microphylla*	Leguminosae	Posts and construction	sawmill
126	Tezcalame	*Ficus cotinifolia*	Moraceae	Fruit for forage	
127	Tintilagua				
128	Trementinillo				
129	Uña de gato	*Mimosa benthami*	Leguminosae	Posts for construction	
130	Vainero				
131	Verdecillo, palo fierro, amapilla, amapa prieta	*Tabebuia chrysantha*	Bignoniaceae	Posts and tool handles	sawmill
132	Xilomecate, panicua, rosa amarilla, huevo de burro	*Cochlospermum vitifolium*	Cochlosperm-aceae	Fiber used to make ropes	
133	Zacalozuchilt, corpo, flor de mayo, palo de oído	*Plumeria rubra*	Apocynaceae	Posts	
134	Zalate	*Ficus petiolaris*	Moraceae	Fruit for forage	forage
135	Zapotillo	*Couepia polyandra*	Rosaceae	Sawmilling, furnitures and beams	hardwood
136	Zorrillo	*Zanthoxylon* sp.	Rutaceae	Wood for tool handles	sawmill

vegetation at the study area. Regarding this kind of studies the plots established in this research has been planned as a permanent plots, and a series of different studies will be carried out in the long term. This study constitutes the first approach to the processing of part of the total database of this research.

Conclusions

The ecological typology methodology with the use of GIS constitutes a very good tool to assess the environmental conditions and the forest potential for a region. The definition of ecological units provides the basis to design and plan specific management, and monitoring plans for each one in particular and the whole region.

The ecological regionalization done in this research allows the identification of specific growing conditions and the definition of ecological requirements for different plant species to develop through an ecological range.

One hundred thirty six species were recorded in all the ecological units. The most diverse ecological unit was Gr Re+Hh+I/1*LITI Selva Baja media with 39 plant families.

The dominant vegetation families at the area were leguminosae, euphorbiaceae, moraceae, and myrtaceae.

Dominant genera were *Acacia*, *Lonchocarpus*, *Lysiloma, Croton, Cnidoscolus*, *Ficus, Psidium, Bursera* and *Tabebuia*.

This technique has potential application to a wide spectrum of ecological problems and to the management and conservation of biodiversity. However, its most potential application could be in inventorying and monitoring natural resources, because the effective application of ecological knowledge to problems of ecosystem management requires the utilization of a variety

Table 3. Plant families distribution for EU at Arroyo Cuenca Quebrada, in Tomatlan, Jalisco.

Family/EU	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Anacardiadeae				X	X	X	X	X	X	X	X	X	X	
Anonaceae	X			X	X	X		X		X			X	X
Apocynaceae						X		X		X				
Araliaceae						X		X		X		X		
Asteraceae										X				
Basellaceae								X		X				
Bignoniaceae	X		X	X	X	X		X		X		X	X	X
Bixaceae								X		X				
Bombacaceae						X		X	X	X			X	
Boraginaceae						X		X		X			X	X
Burceraceae	X		X		X	X	X	X	X	X	X	X	X	X
Cactaceae									X	X				
Caricaceae				X	X	X		X		X		X	X	X
Cecropiaceae						X		X		X		X	X	
Cistaceae						X		X		X			X	X
Cochlospermaceae						X		X	X	X	X		X	
Convolvulaceae								X	X	X				
Dilleniaceae								X		X			X	
Euphorbiaceae	X		X	X	X	X	X	X	X	X	X	X	X	X
Fagaceae				X		X				X				
Flacurtiaceae										X			X	X
Gutiferaceae						X		X		X				
Hernandiaceae			X			X	X	X	X	X				
Lauraceae						X		X		X				
Leguminosae				X	X	X	X	X	X	X	X	X	X	X
Malpighiaceae								X	X					
Meliaceae						X		X		X			X	
Moraceae					X	X		X	X	X		X	X	X
Myrtaceae	X		X			X		X		X			X	
Palmae	X	X		X	X	X		X		X				X
Rhamnaceae										X		X	X	
Rosaceae						X		X		X			X	
Rutaceae						X		X		X			X	
Sapindaceae						X		X	X	X	X		X	X
Sapotaceae						X		X		X			X	
Sterculiaceae	X			X	X	X	X	X		X	X		X	X
Tiliaceae					X	X		X	X	X	X	X	X	X
Ulmaceae						X		X		X	X		X	X
Verbenaceae						X		X		X			X	
Total	**7**	**1**	**4**	**9**	**11**	**28**	**8**	**30**	**13**	**39**	**12**	**12**	**24**	**18**

of information (from historical records, the research data, to observations obtained by direct management and disturbances effect) at different aggregations levels that this methodology can provide.

It is recommended to develop further taxonomic identification work and further studies on ecological succession to provide an understanding of successional dynamics, and the interrelationship between successional processes and other community attributes associated with stability, diversity, and dominance.

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Tree Crown Structure Indicators in a Natural Uneven-Aged Mixed Coniferous Forest in Northeastern Mexico

Javier Jiménez-Pérez, Oscar Aguirre-Calderón, and Horst Kramer

Abstract*—Characterization of tree crown structure provides critical information to assess a variety of ecological conditions for multiple purposes and applications. For biomass growth, for example, tree crowns have basic physiological functions: assimilation, respiration, and transpiration. How tree crowns spatially interact and grow can bring about a seamless landscape of unique features and microclimatic conditions that are highly relevant to biological diversity, soil processes, productivity, wildlife habitats, ecosystem health and sustainability. Approaches to measuring tree crown structure and variability within multiple diameter distributions are particularly important in uneven-aged, multi-species natural stands. Results of using the "Weibull bimodal probability distribution function" to model diameter distributions of multi-storied stands and various crown index measurements to describe their respective tree crown attributes and properties are presented and discussed. Specific patterns of values of these indices were found which suggest they have potential for use as indicators of crown structure complexity and variability across a wide spectrum of forest conditions and types. In light of these results, we also address the relevance of these results for forest inventory and monitoring programs. Funding for this research was provided by Mexico's National Council of Science and Technology (Consejo Nacional de Ciencia y Tecnologia (CONACYT; Project 333919-B) and Universidad Autónoma de Nuevo León.*

Introduction

The main functions of a tree crown are assimilation, respiration and transpiration. Assimilation, which is known as photosynthesis in green plants, can be described as the process by which light energy is trapped by chlorophyll and used to produce sugar from carbon dioxide and water. Respiration refers to the process by which the energy stored in reduced carbon compounds during photosynthesis is released by oxidation in a form that can be used in assimilation and growth, and in maintenance of cell structure and function. Transpiration is the process of taking water from the soil through plant roots and the loss of this water into the atmosphere as water steam through the leaves (Kozlowski and others 1991).

The tree crown is one complement of net primary production and its dimensions reflect general tree health. Dense and large crowns are associated with potential growth rates. Sparse and small crowns can prove responsive to unfavorable site conditions (competition, moisture, diseases). Tree crowns are highly variable. Their general shape varies from relatively dense conoid crown-shapes for conifers of an excurrent habitat to wide open shapes for many broad-leaved trees of a deliquescent habitat (Husch and others 2003). Tree crown research contributes to several key forest ecosystem attributes: biodiversity, productivity, forest management, forest environment, and wildlife. Crown characteristics are useful in predicting growth responses in spacing and thinning, and in relating growth to soil moisture availability. These studies emphasize the close relationship between the crown size and the amount of the photosynthetically active foliage (Laar and Akca 1997).

The surface area of forest trees is a useful measurement for the study of precipitation interception, light transmission through forest canopies, forest litter accumulation, soil moisture loss, and transpiration rates (Husch and others 2003). The size of a tree crown is strongly correlated to tree growth. The crown displays the leaves to allow the capture of radiant energy for photosynthesis. Thus, measurement of a tree crown is often used to assist in the quantification of tree-growth. The crown biomass and the quantity and quality of branch material, however, are also of direct interest to ecological studies and research into the effects of trees on pollution. Nowadays, the knowledge concerning to the tree crown structure is important, in the sense that trees use this tree component as a source of absorption of carbon dioxide.

Now, the length of the live crown is determined as the height of the first branch or the first live branches (Bachmann, 1998; Nagel and Biging, 1996; Kramer and others 1999). Taking into consideration the crown as a primary element in the vegetation development, several scientific studies relating to tree crown confirmation and growth have been undertaken to determine tree growth through models for tree crown profiles (Kellomäki and Kurttio, 1991; Biging and Gill, 1997; Gadow, 1999; Gill and others 2000).

Objective

The objective of this research is to develop a method to characterize tree crown structure in uneven-aged, mixed coniferous forests, through the application of tree dimensions (dbh, total height, basal area), diameter distribution (bimodal Weibull distribution) and crown indexes (crown width, crown thickness index, crown spread ratio, crown projection area and crown surface area).

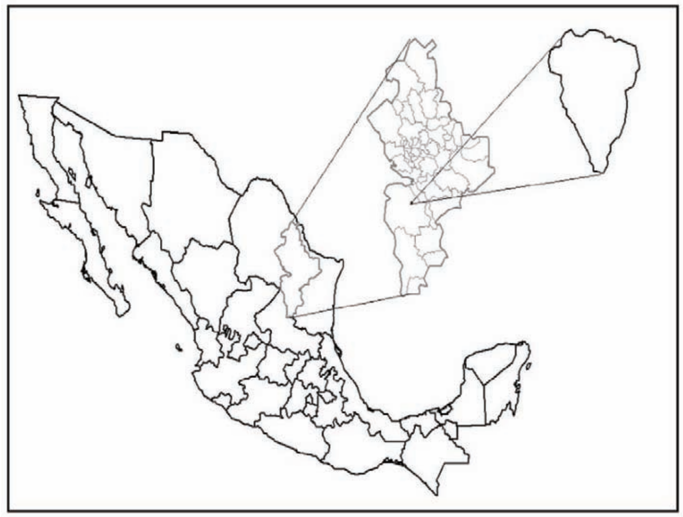

Figure 1. Location of the study area.

Study Site and Methods

In recent decades, Mexico has promoted the protection of natural forests through the creation of protected areas and national parks (Jiménez and Kramer 1991, Aguirre and others 2001). Accordingly, in 1998 the Cerro El Potosí was decreed as protected area, containing natural forests of high biological value and being located in the highest peaks (3,675 masl) of Northeastern Mexico. This mountainous area is located in the Sierra Madre Oriental.

The study area is located in Cerro El Potosí, in a mixed coniferous forest composed by *Abies vejari, Pseudotsuga menziesii, Pinus hartwegii* and *Pinus ayacahuite*. This uneven-aged stand contains 504 trees, with a mixture of species in a marked differentiation of strata. For each tree the diameter (dbh), height (h), age (t), and basal area (g), as well as its spatial distribution, were measured. The area is located at an altitude of 3,100 meters above the sea level (figure 1).

To obtain the diametric distributions per species, the Weibull distribution was employed, being one of the most used in the forest area because of its relative flexibility, as well as being better adapted to uneven-aged and mixed forest (Zarnoch and Dell, 1985; Killki and others 1989; Maltamo and others).

$$f(x)=\frac{c}{b}*\left(\frac{x-a}{b}\right)^{c-1}*e\left(\frac{x-a}{b}\right)^{c}$$

Where:
x=dbh, a=Location parameter, b=Scale parameter, and c=Shape parameter.

Crown radius is needed in certain kinds of competition measurements (Gill and others 2000) and is defined in this study as the distance between the center of the bole and the four cardinal points. Crown diameter or crown width assessment is based on the measurement of two or four radii, and is usually defined as twice the radius. Crown length or live crown length (Biging and others 1990) is defined as the distance between the apex of the tree and the base of the live crown (CL = tree height – crown base). Live crown length is the distance between the apex and the light crown.

After tree crown parameters were measured, the following crown indexes were calculated: Crown percentage (CR%), Light crown percentage (LCP%), Crown thickness index (CTI), Crown spread ratio (CSR), Crown projection area (CPA), and Crown surface area (CSA).

Crown percentage is the length of the light crown length calculated as a percentage of the total tree height ($CR\%=100*CL/h$). Light crown percentage is the percentage of light crown length and crown length ($LCP\%=100*LCL/CL$). Crown thickness index is the ratio of the crown diameter and crown length ($CTI=CD/CL$). Crown spread ratio is the ratio between the crown diameter and the tree height and it is used when attempting to determine the shape of the crown ($CSR=CD/h$). The crown projection area is the surface occupied by the crown and is usually used as a measurement of stand density ($CPA=\pi/4*CD$). The crown surface area is defined as the external surface area of the live crown. Normally it is assumed that the conifer crown can be represented either as a cone or as a paraboloid (Kramer, 1998; Laar and Akca, 1997; Jiménez and others 2002)

Results and Discussion

Size Structure

From the table 1 we found that the numbers of individuals, as well as the basal area per hectare are very different. There is a similarity between the individual number of most species: *Pinus ayacahuite* (124 stems/hectare), *Abies vejari* (120 stems/hectare) and *Pseudotsuga menziesii* (102 stems/hectare), most of them except *Pinus hartwegii* (60 stems/hectare). However, an affinity was discovered in the values of the basal area for *Pinus ayacahuite, P. hartwegii* and *Pseudotsuga menziesii*. Despite the fact that *Abies vejari* showed a higher tree number, its basal area only represents a total of 12 percent of the total basal area percentage per hectare. In general, there is a high variability between all the species with respect to age (14-126 years), diameter (5-65.4 cm) and height (2.2-22.4 m). This high variability in age, height, and diameter of the species is due to the fact of the mixed and uneven-aged stand.

Diameter Distribution

In order to determine the diametric distribution applicable to all species we used the Weibull distribution, which is frequently observed in young even-aged stands before the first thinning, and in age-varied forests (Laar and Akca1997), but it was observed that in its natural state, the forest showed a bimodal type distribution, resulting in a typical structure with two subpopulations. In table 2 it is demonstrated that *Abies vejari, Pseudotsuga menziesii* and *Pinus hartwegii* present a higher number of individuals in the minor categories. However, *Pinus hartwegii* shows a similar bimodal distribution, as much in the minor as well as in the major diametric categories. It is important to note that at the site level, 73 percent of the trees are located in the lower strata and only 27 percent of them in the higher strata. This demonstrates a clear bimodal distribution.

This study employed a method for describing bimodal diametric distributions using estimates of a maximum and minimum stand diameter (Hessenmöller and Gadow 2000). Thus, for the mixed conifer forest the following bimodal Weibull distribution ensues:

$$f(x)=g*f_u(x)+(1-g)*f_0(x)$$

Where $f_u(x)$ and $f_0(x)$ describe the respective diametric functions regarding the higher and lower forest strata and g is the linking parameter between both functions.

Figure 2 shows the Weibull distribution of the four species found in the study area. It is observed that there exists a good adjustment of the bimodal Weibull distribution in the diametric categories.

It was observed that the method employed by Hessenmöller and Gadow (2000) showed a greater precision when the parameters of distribution were calculated separately, equally for the upper as well as the lower strata. By using the diametric bimodal Weibull distribution method, we concluded that the forest proved to be uneven-aged and mixed, presenting two strata in vertical structure.

Crown Analysis

Following the diametric analysis, it proceeded to separate the trees into Height Zones. The study site was divided into two strata: Height Zone I and Height Zone II. Table 4 shows the trees by species and by Height Zones, 75 percent

Table 1. Size structure of the uneven-aged stand per hectare.

Tree species	Age (years)	N stems	Basal Area (m^2)	Diameter (cm)	Height (m)
Abies vejari	32	120	1.86	12.5	7.9
Pseudotsuga menziesii	38	102	3.65	17.1	8.9
Pinus ayacahuite	40	124	5.10	18.8	8.1
Pinus hartwegii	51	60	4.62	26.5	10.6
Stand	38	406	15.10	17.6	8.6

Table 2. Tree distribution in relation to two diametric categories.

Tree species	Diametric Category 5- 20 cm	Diametric Category >21 cm	Total
Abies vejari	133	16	149
Pseudotsuga menziesii	97	29	126
Pinus ayacahuite	107	47	154
Pinus hartwegii	33	42	75
Total	**370**	**134**	**504**

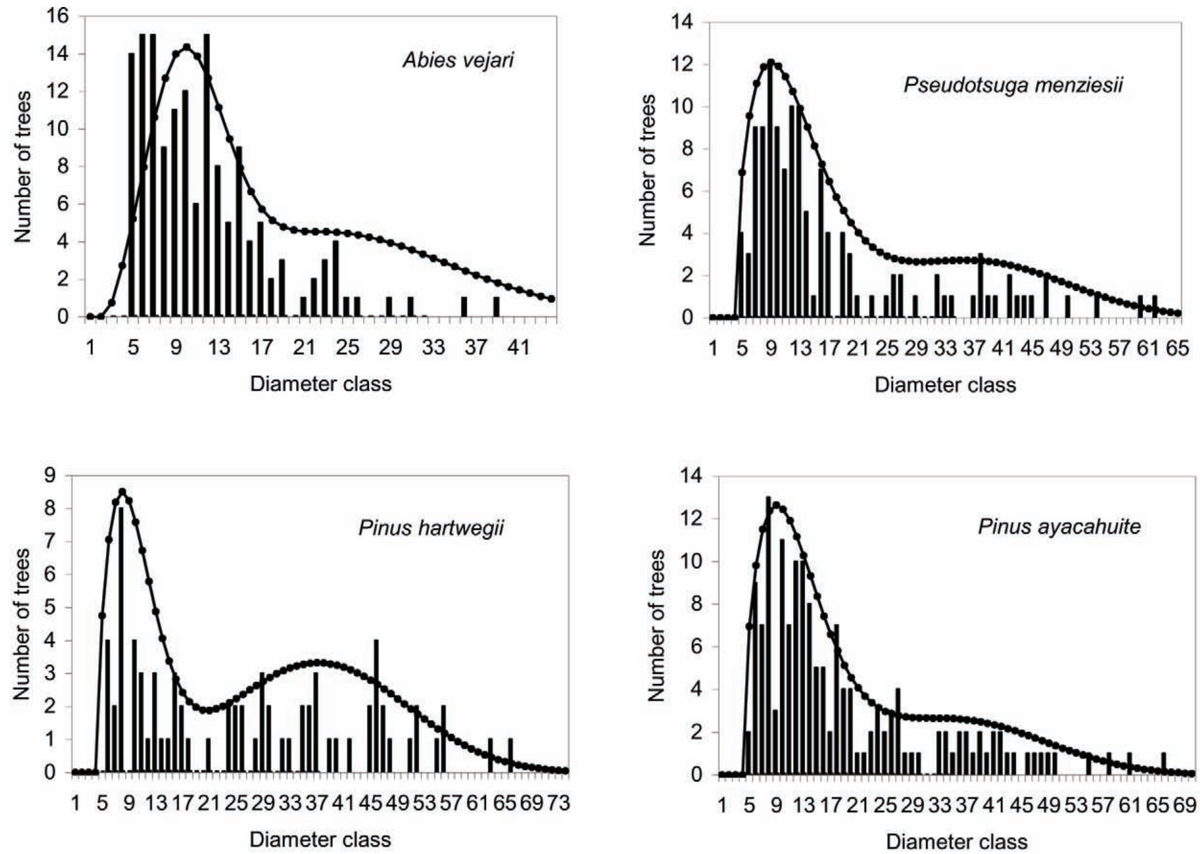

Figure 2. Bimodal Weibull distribution for *Abies vejari, Pseudostuga menziesii, Pinus hartwegii,* and *Pinus ayacahuite*.

(376) corresponding to the individuals in Height Zone II, and only 25 percent (128) in Height Zone I.

In the predominant and dominant trees stratum (Height Zone I), *Pinus ayacahuite* and *Pinus hartwegii* show a remarkable similarity in their stem dimensions (*d, h, t*). With respect to the relation $^{dbh}/_{h}$, we observed that they present a lower value (41-42), which is evidence of the stability of the species in this site. *Abies vejari* and *Pseudotsuga menziesii* show a greater variability in their dendrometrical parameters, as well as an increase in their stabilizing values (51-61). This is due to the fact that they are shade-tolerant species, and for this reason their development is slower in their primary phases and with greater competition, which is why a positive stable relationship does not exist. However, in Height Zone II, the shade-tolerant species show a greater similarity in diameter, height, and age values, thus observing a greater stability.

The definition of the base of the live crown is important to calculate the crown length, crown percentage, crown thickness index and crown surface area. In this case, the base of the live crown was defined as the height of the last live branch. Table 3 shows in a global way that, in the upper stratum, the crown percentage covers 53 percent of the tree, while in the lower stratum it covers 73 percent. At a species level, it was observed in Height Zone I that crown percentage decreases while the age increases (*Pinus hartwegii* t = 73; *CR%* = 45 percent, *Abies vejari* t = 47; *CR%* = 62). This is due to the fact that crown percentage decreases while the tree keeps growing. However, in Height Zone II there exists a great similarity between the age (28-31 years) and CR% (71-78 percent) values, presenting no difference between the species because they are located underneath the canopy of Height Zone I.

In order to characterize the light crown length (*LCL*) the height of the widest part of the crown was measured, and to calculate the light crown percentage (*LCP%*) a relation between the light crown length and the crown length ($LCP\%=100{*}^{LCL}/_{CL}$) was performed. In general, there is no differentiation of the *LCP%* (75 percent) between the two Height Zones. At the species level, *Abies vejari* presents the highest *LCP%* (I = 96 percent; II = 90 percent), meaning, practically, that a high percentage of the light crown belongs to the complete crown. *Pseudotsuga menziesii* also presents a high percentage of light crown (87 percent). This is explained if we consider that both species are tolerant to light. However, in both pine species, there exists a lesser percentage of *LCP%* (I = 60-67 percent; II = 61-65 percent).

Table 3. Stand crown characteristics according to the height zone.

Species	n (ítem)	dbh (cm)	h (m)	t (year)	dbh/h	CL (m)	CR%	LCP (m)	LCP%
Height Zone I (predominant and dominant trees)									
Abies vejari	21	23.9	13.	47	61	8.4	62	8.2	96
Pseudotsuga menziesii	35	33.6	15.2	63	51	8.9	58	7.9	87
Pinus ayacahuite	33	39.3	15.5	72	42	8.2	53	4.9	60
Pinus hartwegii	39	39.6	15.3	73	41	6.7	45	4.4	67
Strata	128	35.3	15.2	66	47	8.0	53	6.1	75
Abies vejari	128	10.7	6.9	29	68	4.9	72	4.3	90
Height Zone II (suppressed trees)									
Pseudotsuga menziesii	91	10.8	6.5	28	67	4.8	76	3.6	75
Pinus ayacahuite	121	13.2	6.1	31	50	4.2	71	2.8	65
Pinus hartwegii	36	12.2	5.6	28	50	4.2	78	2.6	61
Strata	376	11.7	6.4	29	58	4.6	73	3.5	75

CL= Crown length, CR%= Crown percent, LCP= Light crown length, LCP%= Light crown percent.

Conclusions

In accordance with the heterogeneous structure of this mixed and uneven-aged stand, it was observed that there is a great variability in stem dimensions and crown parameters, not only at a site level, but also in the species that are found in the ecosystem. *Abies vejari* is the species showing the lowest average age (32 years) and *Pinus hartwegii* is the one presenting the highest average age (51 years). Despite this, *Pinus ayacahuite* shows a wider dispersion range (15-126), which indicates that the ecosystem is uneven-aged. In turn, *Pinus hartwegii* is considered the one having the widest average diameter (55 cm), but *Pseudotsuga menziesii* has the widest range of variability (CV%=77.2 percent). Regarding the greatest height, *Pinus hartwegii* holds 10.6 m on average, and a range that varies between 2.3-22.4 m.

A large discrepancy was observed in tree distribution per species. The shade-tolerant species - *Abies vejari* and *Pseudotsuga menziesii* - respectively 74 percent and 66 percent of their individuals in the 10 cm diametric categories; while the light-tolerant species – *Pinus ayacahuite* and *Pinus hartwegii* – have only a 55 percent and 47 percent of their trees in this diametrical category.

There is a bimodal type Weibull distribution for the tree species of the ecosystem. *Abies vejari*, *Pseudotsuga menziesii* and *Pinus ayacahuite* show a higher slope in the curve in the first diametric categories, due to a greater amount of trees, while *Pinus hartwegii* shows a similar tendency among the higher and lower diametric categories, which results in a similar curve slope. In general, it is observed that there is a good adjustment in the bimodal Weibull distribution for all species.

One of the important objectives in this investigation was the analysis of the crown parameters. Towards this end, the crown diameter, light crown length, and the base of the crown defined as the height of the last live branch, were used. With these variables, the crown indexes were defined: crown length, crown percentage, light crown length, and light crown percentage. It was concluded from tables 4 and 5 that there exists a great heterogeneity in the values corresponding to the crown indexes in Height Zone I and Height Zone II; the discrepancy among the species within each of Height Zones is even greater.

The final conclusion of this study is that uneven-aged, mixed forests present a specific structure, in accordance with its stem parameters, diameter distribution, and crown parameters and indexes, proving that this evaluation methodology can be reliably used. These tree crown structure indicators have a high value in forest ecosystem management, where the forest structure is considered a high priority.

Acknowledgments

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Development of a Transition Pathway Model Using Three Traditional Variables to Describe the Main Structural Characteristics of a Forest Stand Type, Size, and Density

Chad Larson

Introduction

The Central Hardwood Region is a unique forest region in the United States, encompassing 340 million acres of land, of which 100 million acres are forested (Parker 1993). The region contains one-fourth of the U.S. population, with approximately 90 percent of the land in private ownership (Parker 1993). In general, private forested lands in the Central Hardwood Region tend to be small, non-industrial forests with little forest management (Nyland 1992). The tendency of non-industrial private forest (NIPF) landowners to eschew professional guidance when managing their forests is cause for concern. The sustainability of Central Hardwood Region forests with regards to economic, environmental, and social benefits may depend on educating and encouraging NIPF landowners to seek professional forest management advice.

The most difficult part of the decision making process often lies in identifying and choosing goals. Since the purpose of modern forest management is to achieve diverse landowner goals, reasoned management cannot be practiced without those goals (Wang and others 2002). Private landowners have many interests pertaining to their lands; they may be interested in increasing the value of timber production, producing better wildlife habitat or creating aesthetically pleasing forests. In all cases, management options are available to the landowner to increase or decrease the inherent value of the forest relative to a particular goal. We created a decision support tool designed to assist private landowners in identifying management goals based upon probable outcomes and impacts associated with forest management decisions.

As a general rule, existing forest management tools are technical and complex. In designing a new tool for NIPF landowners, we wanted to keep the tool relatively simple while ensuring compatibility with existing tools. To this end, a transition pathway model was developed using three traditional variables to describe the main structural characteristics of a forest stand: type, size, and density. The transition pathway model predicts the probability of the current stand transitioning to a new Type-Size-Density class given various forest management treatments. Most NIPF landowners are not aware how Type-Size-Density variables relate to their management interests. Thus, several forest attributes were assigned qualitative values for each Type-Size-Density class describing the suitability of that class for specific commodity and non-commodity resource uses. The assigned qualitative attributes were designed to give the NIPF landowner a greater appreciation for different attribute potentials while describing likely structural changes from different management decisions. An option-based decision support tool was then developed based on the transition pathway model and forest resource attributes. A complete description of the project can be found in Larson (2004).

Option-based decision tools provide a series of options given the initial conditions, describe the options, and provide a number of metrics to rate the options against each other. However, there is a dearth of simple option-based forest decision tools (but see Marquis and Ernst 1992, Twery and others 2000). Our underlying premise is that many landowners may have trouble stating specific goals for their land; but, if presented with a number of options, landowners would have little trouble choosing between them. The attributes assigned to each Type-Size-Density class provide the landowner with the means to

Table 1. The Type, Size, and Density variables defined by the categories for each variable and a brief description of each category.

Variable	Category	Description
Type[a]	White Oak	White oak species group is dominant
	Red Oak	Red oak species group is dominant
	Pine	Pine species group is dominant
	Other Hardwood	All other species group is dominant
	Mixed	No species group is dominant
Size	Sapling	Less than 6 inches DBH
	Pole	6 to 10 inches DBH
	Sawlog	Greater than 10 inches DBH
Density	High	Greater than 750 trees per acre
	Medium	250 to 750 trees per acre
	Low	Less than 250 trees per acre

[a] Species group dominance is defined as >40% relative dominance by basal area.

evaluate management options using the criteria deemed most important by the landowner. Landowners may then proceed to existing forest growth models and decision tools with a clear understanding of their own desires and goals, as well as knowledge of the effect professional management may have on their forest.

Methods

Transition Pathway Model

Study area

The study area consisted of the St. Francis River and Black River Watersheds, located in southeastern Missouri. Both watersheds were chosen because over 90 percent of the land area is forested. Combined, the watersheds encompass ~1.75 million acres and include portions of St. Francois, Madison, Iron, Reynolds, Wayne, Carter, Ripley and Butler counties (fig. 1).

Data sources

The primary presupposition made in designing the decision support tool was that a simple model with easily defined variables was the best method for fulfilling the purpose of the study. However, in order to prevent placing unnecessary limits on the possible applications of the tool, the underlying model was based on simulations run on the Forest Vegetation Simulator (FVS), a standard forest growth and yield model of the U.S. Forest Service (Stage 1973, Wykoff and others 1982).

Forest Inventory and Analysis (FIA) data (Miles and others 2001) from 1987 and 1988 (582 plots) were input into FVS. FIA data and FVS simulation output were summarized into three variables: Type, Size, and Density. Within a stand, Type refers to the dominant tree species group, Size refers to the average tree diameter at breast height (DBH), and Density refers to the number of trees per acre (TPA). The species groups for Type were based on oak dominance in the study area and the economic importance of oak and pine species in Missouri. Categories for the Type variable species groups were White Oak, Red Oak, Pine, Other Hardwood, and Mixed species. A species group was considered dominant if the relative dominance by basal area was >40 percent. Quadratic mean diameter was used to create three Size categories: Sapling (<6" DBH), Pole (6"-10" DBH), and Sawlog (>10" DBH). Size categories were based on industry standards and professional expertise. Density was also classified into three categories: Low (<250 TPA), Medium (250-750 TPA), and High (>750 TPA). The Density categories were chosen after initial analysis of the FIA data and were based on professional expertise.

The FIA plots were grown in FVS using the Suppose graphical user interface (Crookston 1997, Dixon 2003). Plots were grown using the following management options: no treatment, thinning from below, and diameter limit cut. Predictions were limited to 20 years, which is long enough for potential forest change and short enough

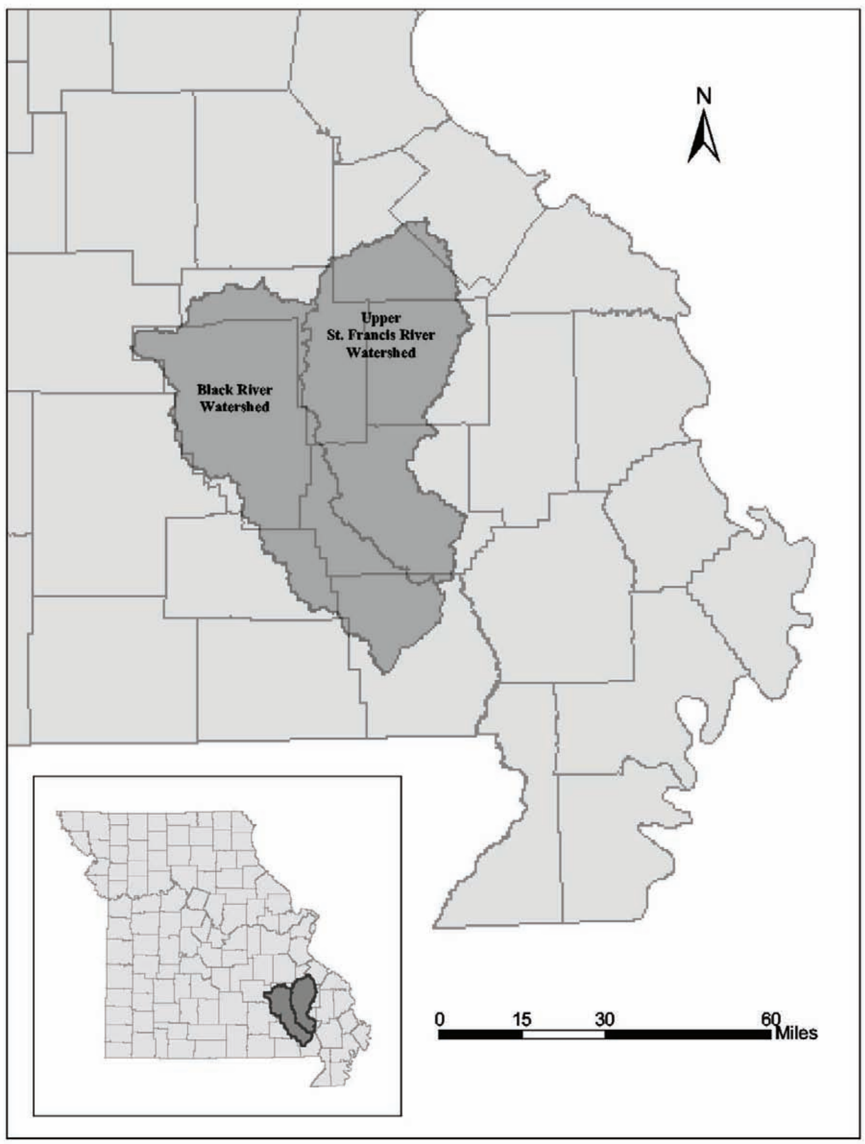

Figure 1. The study area in southeastern Missouri as defined using USGS 8-digit hydrologic units (Seaber 1984).

for landowners to retain a vested interest in the land. For the No Treatment option, FIA plots were grown in FVS with no management treatment. The Thinning From Below and Diameter Limit Cut management options used FVS predefined management treatments: "thinning from below" to a basal area target of 55 ft^2/acre (Thinning From Below) and "thinning from above" to a desired diameter of 10 inches DBH with 100 percent removal (Diameter Limit Cut). All management options conducted the management prescription at year zero and then grew the sample plot for 20 years with no further management activity.

Transition pathways

The transition pathway model was built to predict the probability of an initial Type-Size-Density class transitioning to a new Type-Size-Density class. Based on categories defining the Type-Size-Density variables, all possible combinations of variables were developed (table 2); however, the large number of Type-Size-Density classes created an overly complex model with insufficient data to support the development of a full transition matrix. Therefore, transition pathways were designed based on two assumptions for the No Treatment option. First, it was assumed that the dominant species group (Type) at year zero would have a low probability of changing in 20 years, thus all transitions to a different Type were combined into the same probability class of "other." Second, it was assumed that Size and Density were negatively correlated; thus, over 20 years, the plots would tend to grow larger in diameter (Size increases) while becoming smaller in density (Density decreases).

A matrix was created for each management option with the initial classes (year 0) in rows and counts of the transition classes (year 20) in columns. Transition probabilities were calculated by dividing the count for each transition class by the total number of plots in the initial class. The transition pathways were then created by collating the initial classes by Type category, keeping intact all transition class probabilities of the initial Type, and combining all transition class probabilities for new Type categories into a new probability class called "other."

Model testing

Model testing consisted of verifying that the transition pathway model predictions were consistent with the FVS model being summarized. Test plots were selected from FIA plots outside the study area but within the same FIA survey unit. Ten test plots were chosen for each Type-Size-Density class using a random number generator (even distribution from 0 to 1), except in those classes with ≤10 samples. Data were grown in FVS, Type-Size-Density classes of initial test data and resulting FVS output were calculated, and results were compared to predictions of the transition pathway model. The chi-square goodness of fit test (Zar 1999) was used to determine if a significant difference existed between the actual FVS output classes and the predicted transition classes (all $\alpha = 0.05$). Two methods were used to determine if a significant difference existed between the FVS test results and the transition pathway model predictions. First, the chi-square value was compared to the appropriate critical value. Second, the test plots used to calculate the chi-square value were analyzed to determine if any plots transitioned to a class that was not predicted by the model.

Table 2. Combined Type-Size-Density classes. Blue font indicates classes not used in the building of the transition pathway model.

Class	Type	Size	Density	n
1	White Oak	Sapling	High	37
2	White Oak	Sapling	Med	94
3	White Oak	Sapling	Low	3
4	White Oak	Pole	High	0
5	White Oak	Pole	Med	20
6	White Oak	Pole	Low	15
7	White Oak	Sawlog	High	0
8	White Oak	Sawlog	Med	0
9	White Oak	Sawlog	Low	5
10	Red Oak	Sapling	High	31
11	Red Oak	Sapling	Med	99
12	Red Oak	Sapling	Low	1
13	Red Oak	Pole	High	0
14	Red Oak	Pole	Med	31
15	Red Oak	Pole	Low	8
16	Red Oak	Sawlog	High	0
17	Red Oak	Sawlog	Med	0
18	Red Oak	Sawlog	Low	5
19	Pine	Sapling	High	11
20	Pine	Sapling	Med	9
21	Pine	Sapling	Low	1
22	Pine	Pole	High	0
23	Pine	Pole	Med	3
24	Pine	Pole	Low	3
25	Pine	Sawlog	High	0
26	Pine	Sawlog	Med	0
27	Pine	Sawlog	Low	1
28	Other Hardwood	Sapling	High	35
29	Other Hardwood	Sapling	Med	69
30	Other Hardwood	Sapling	Low	5
31	Other Hardwood	Pole	High	0
32	Other Hardwood	Pole	Med	8
33	Other Hardwood	Pole	Low	4
34	Other Hardwood	Sawlog	High	0
35	Other Hardwood	Sawlog	Med	0
36	Other Hardwood	Sawlog	Low	2
37	Mixed	Sapling	High	21
38	Mixed	Sapling	Med	36
39	Mixed	Sapling	Low	1
40	Mixed	Pole	High	0
41	Mixed	Pole	Med	7
42	Mixed	Pole	Low	5
43	Mixed	Sawlog	High	0
44	Mixed	Sawlog	Med	0
45	Mixed	Sawlog	Low	0

Forest Resource Attributes

A forest resource attribute describes an inherent characteristic of a forest. The complexity of analysis was limited by the simple model design and simple variables; however, we wanted to provide landowners with general impressions of forest potential, and for that purpose qualitative attribute values were defined as a function of Type-Size-Density.

Attributes were developed for income potential (e.g., sawtimber), wildlife habitat suitability (e.g., gray squirrel), and risk susceptibility (e.g., insect/disease). The sawtimber attribute was assigned qualitative values based on professional expertise and Missouri logging sale charts, with tree species and tree diameter influencing the attribute values. Gray squirrel (Sciurus carolinensis) habitat attributes were assigned qualitative values based on a habitat suitability index (HSI) model (Larson and others 2003), with forage and nesting cover influencing the attribute values. The insect/disease risk attribute was assigned qualitative values based on professional opinion and the work of Wargo, Houston and LaMadeleine (1983), with stress from competition for resources influencing the attribute values.

The first step in assigning a qualitative attribute value to a Type-Size-Density class was to determine which variable(s) was the most influential for that attribute and then ranking all classes on a relative scale of 1 to 9. The second step was to indicate the degree of confidence in the assigned ranking for each class. The degree of confidence (high, medium, low) was a measure of the importance of outside factors not captured by Type-Size-Density in determining the suitability and potential of a particular forest for the attribute in question.

Decision Support Tool

The predictions and attributes developed in the transition pathway model were organized in a Microsoft Access database. A transition table was created for each management option containing the two largest transition probabilities for each initial class along with the probability of that class staying the same. The attribute tables in the database consisted of the relative ranking and degree of confidence for all classes. A table with representative photographs of each class was added to the database for additional landowner edification. A user interface was built in the same Microsoft Access database using a series of forms, command buttons, and macros, and was designed to provide landowners with a series of screens giving them the ability to choose the Type-Size-Density class of their forest from drop down menus, select management options, view attributes, and maneuver back and forth through the screens (fig. 2).

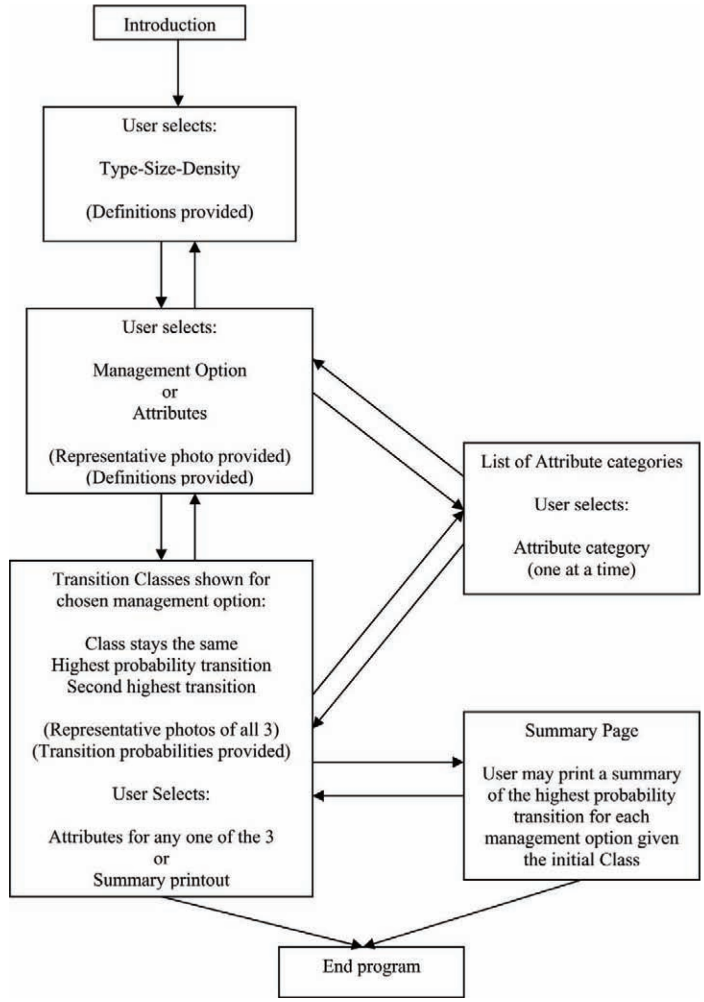

Figure 2. Design logic of the user interface for the decision support tool.

Results

Transition Pathway Model

Initial classes were calculated for the 582 FIA data plots. Analysis of initial sample counts (n) prompted the removal of all Size-Density combinations of Sapling-Low and Pole-High classes from the database due to low n (table 2). In addition, Sawlog classes and plots containing no live trees were removed. The 546 remaining FIA data plots were used to build the transition pathway model predictions.

The White Oak category included 166 sample plots. The transition pathway probabilities (table 3) affirmed the assumptions made for the No Treatment management option; the White Oak, No Treatment management option demonstrated that Size and Density were negatively correlated and Type at year zero had a low probability of changing in 20 years. The largest sample size for White Oak, White Oak-Sapling-Medium (class 2), was 94 plots and only 7.4 percent of the plots changed Type, while

Table 3. Transition pathway probabilities (in percent) for the White Oak category.

Management Treatment	Initial Class[a]	Transition Class[a] (percent) 1	2	3	5	6	9	Other
No Treatment	1	10.8	29.7	0.0	51.4	0.0	0.0	8.1
	2	0.0	8.5	1.1	78.7	4.3	0.0	7.4
	5	0.0	0.0	0.0	50.0	35.0	15.0	0.0
	6	0.0	0.0	0.0	0.0	33.3	46.7	20.0
Thinning From Below	1	0.0	13.5	0.0	10.8	5.4	40.5	29.7
	2	0.0	7.4	1.1	17.0	14.9	48.9	10.6
	5	0.0	0.0	0.0	0.0	10.0	65.0	25.0
	6	0.0	0.0	0.0	0.0	13.3	66.7	20.0
Diameter Limit Cut	1	8.1	45.9	0.0	21.6	0.0	0.0	24.3
	2	0.0	26.6	2.1	44.7	3.2	0.0	23.4
	5	0.0	0.0	5.0	20.0	30.0	0.0	45.0
	6	0.0	0.0	0.0	0.0	40.0	6.7	53.3

[a] The Type-Size-Density classes are: 1-White Oak-Sapling-High, 2-White Oak-Sapling-Medium, 3-White Oak-Sapling-Low, 5-White Oak-Pole-Medium, 6-White Oak-Pole-Low, 9-White Oak-Sawlog-Low.

78.7 percent changed Size to White Oak-Pole-Medium (class 5). The No Treatment transition pathway for White Oak is illustrated in figure 3.

The No Treatment management options for Red Oak, Pine, and Other Hardwood followed similar patterns as White Oak and further affirmed the assumptions made in the design of the transition pathways; the Sapling classes in particular showed strong probabilities to increase in Size, Density, or both, while showing low probabilities of changing Type. However, the Mixed category averaged >30 percent probability of changing Type. This tendency was expected due to the lack of a dominant species group in the Mixed category and is consistent with forest stand dynamics theory, as competition for resources allows tree species with a competitive edge to achieve dominance over time.

The Thinning From Below management option showed a stronger tendency for classes to change Type than the No Treatment option (White Oak example, table 3), with the exception of the Red Oak category. Thinning proscriptions were carried out in FVS with no regard to tree species; thus, the dominance of tree species groups (Type) was potentially shifted at year zero. Any shifts were then exaggerated over the 20 year simulation, resulting in the stronger tendency to change Type.

The Diameter Limit Cut management option generally showed an even stronger tendency for classes to change Type than the Thinning From Below option (White Oak example, table 3), with the exception of the Other Hardwood category. Harvesting the largest trees in a stand at year zero had an even greater potential to shift tree species group dominance than thinning.

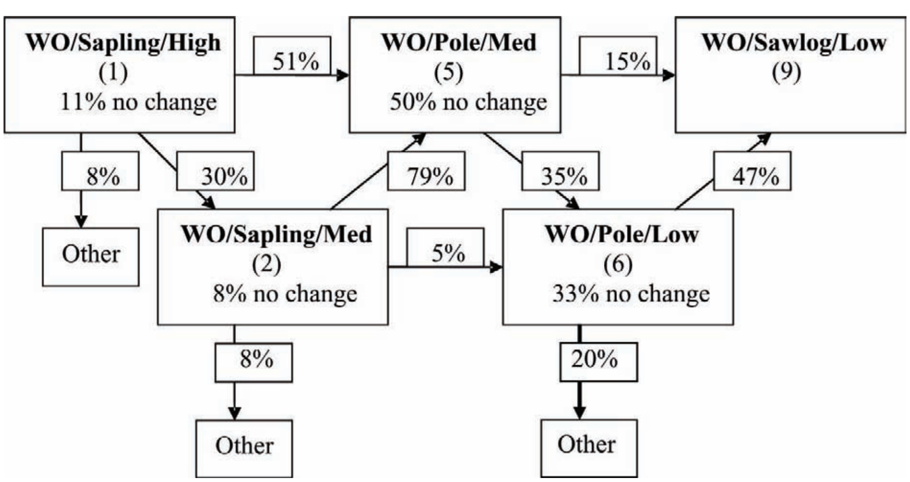

Figure 3. Transition pathway for the White Oak Type category.

Model Validation

The chi-square goodness of fit test was conducted 84 times and used 255 test plots. The White Oak and Red Oak classes were tested twice each with replacement. In total, 31 of the 84 tests (37 percent) were significantly different from the transition pathway model predictions (White Oak results, table 4). Each management option had 28 tests, with all three options showing <40 percent significant difference. Of the 31 tests that showed a significant difference, 23 were significantly different due to one or more test plot transitions having a predicted transition probability of zero, while only 8 (10 percent of total) were significantly different due to the chi-square value being greater than the critical value. Analyzing the chi-square tests by Type shows that

Table 4. Results of the predicted White Oak transition pathway model chi-square tests.

Management Treatment	Class[a]	n	χ^2 Test 1	χ^2 Test 2	Critical Value
No Treatment	1	10	2.721	0.061	7.815
	2	10	1.503	0.601	7.815
	5	10	*	*	5.991
	6	10	0.046	3.153	5.991
Thinning From Below	1	10	2.297	4.232	9.488
	2	10	1.276	3.440	11.07
	5	10	1.138	1.138	5.991
	6	10	0.450	2.796	5.991
Diameter Limit Cut	1	10	1.003	8.207	7.815
	2	10	0.950	1.994	9.488
	5	10	1.500	4.222	7.815
	6	10	*	2.019	5.991

[a] The Type-Size-Density classes are: 1-White Oak-Sapling-High, 2-White Oak-Sapling-Medium, 5-White Oak-Pole-Medium, 6-White Oak-Pole-Low.
* - Indicates one or more observed test plots transitioned to a Class that was not predicted in the study area.

Pine and Red Oak transition pathways were the weakest with 58 percent and 54 percent significantly different, respectively. The Other Hardwood transition pathway had 42 percent significantly different. The White Oak and Mixed transition pathways were the best with both having only 17 percent significantly different.

Forest Resource Attributes

The most influential variable for sawtimber was Size, with the Sawlog category receiving the highest ranking (table 5). The highest value sawtimber species in Missouri are oaks and pines, and thus the Sawlog classes for White Oak, Red Oak, and Pine received the highest ranking of 9. However, the confidence for the ranking of 9 was assigned as Low due to the Type-Size-Density variables being unable to take into account the quality and grade of lumber. The classes for Other Hardwood and Mixed were ranked slightly lower than the White Oak, Red Oak, and Pine across all classes.

The most influential variable for gray squirrel species was Size, as related to forage and nesting (table 4). Hard mast production and nesting habitat were considered highest in the Sawlog classes, particularly for White Oak and Red Oak. The confidence values for the best gray squirrel habitats were high due to forage and nesting requirements being met by the same classes of forest.

Insect/disease risk was most influenced by Density combined with Size (table 4). Competition for moisture and nutrients was the main factor increasing tree susceptibility to insect/disease. The confidence levels assigned were Low to Medium due to the importance of landscape position, frost injury, and drought.

Conclusion

The decision support tool was based on the idea of producing a simple forest growth model capable of predicting forest change while providing descriptive forest resource attributes to assist forest landowners in developing management goals. The additional goal, to maintain compatibility between the developed simple forest growth model and existing models, was a major design consideration. A transition pathway model utilizing the three traditional variables, Type, Size, and Density, was designed and tested for compatibility against the FVS model on which it was based.

The management treatments used (No Treatment, Thinning From Below, and Diameter Limit Cut) all produced differing transition pathways showing that the model design is capable of capturing select effects of forest management. The No Treatment scenario showed that as trees grow larger in size, stand density goes down, and the dominant tree species group (Type), once established, is unlikely to change in 20 years. The Thinning From Below scenario demonstrated that trees grow larger more rapidly when competition for resources is eased. The Diameter Limit Cut scenario demonstrated that the forest stand will continue to grow and transition after management actions have been taken; however, the Diameter Limit Cut scenario also demonstrated that removing the largest trees in a forest stand does not guarantee replacement by similar species.

The transition pathway model was reasonably compatible with the FVS model. Over 60 percent of all

Table 5. Qualitative values assigned to forest resource attributes.

	Sawtimber		Gray Squirrel		Insect/Disease[a]	
Class	Rank	Confidence	Rank	Confidence	Rank	Confidence
1	1	High	1	High	1	High
2	1	High	1	High	1	High
5	4	Med	6	Med	4	Low
6	4	Med	6	Med	3	Med
9	9	Low	9	High	4	Med
10	1	High	1	High	2	High
11	1	High	1	High	2	High
14	4	Med	6	Med	5	Low
15	4	Med	6	Med	4	Med
18	9	Low	9	High	6	Low
19	1	High	1	High	1	High
20	1	High	1	High	1	High
23	4	Med	4	Med	4	High
24	4	Med	4	Med	3	High
27	9	Low	6	Med	5	Med
28	1	High	1	High	1	Med
29	1	High	1	High	1	Med
32	3	Med	4	Low	5	Low
33	3	Med	4	Low	4	Low
36	8	Low	6	Low	5	Low
37	1	High	1	High	1	High
38	1	High	1	High	1	High
41	3	Med	3	Low	3	Med
42	3	Med	4	Low	3	Med
45	7	Low	6	Low	4	Med

[a]Higher rankings for Insect/Disease indicate the class is at greater risk.

chi-square tests showed no significant difference from the model predictions. Of the 31 tests showing a significant difference, 23 were due to one or more test plots transitioning to a Type-Size-Density class that was not predicted by the transition pathway model (prediction = 0.0 percent). However, no model can predict all transitions for every possible forest combination, and the number of significantly different results is acceptable for this type of model.

The forest resource attributes captured the general aspects of forest potential. The simple model design limited the amount of information that could be shown using attributes; however, when taken with the descriptive explanations in the decision tool, landowners have access to knowledge of forest potential that is capable of aiding in the development of management goals.

The decision support tool software, as currently developed, will provide landowners with the means to predict forest change, analyze forest resource potential, and aid in the development of management goals. Overall, the decision support tool is designed largely for NIPF landowner education and information. Future developments will seek to expand management options and forest attributes, produce an internet based version, apply the methodology to data sets from different geographical regions, and distribute the software to federal and state agencies for use with landowner consultations.

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Biodiversity Conservation, Sustainable Development, and the U.S. Man and the Biosphere Program: Past Contributions and Future Directions

P. N. Manley, Research Wildlife Biologist and Technical Assistant to U.S. MAB Coordinator, U.S. Forest Service, Pacific Southwest Research Station, Davis, CA
D. C. Hayes is the National Program Leader for Watershed Research and U.S. MAB Coordinator, USDA Forest Service, Washington D.C.

***Abstract*—*U.S. Man and the Biosphere (MAB) Program is part of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) MAB program, and is one of six regional MAB programs that span the globe. The MAB Program was created in 1971 with the goal to explore, demonstrate, promote, and encourage harmonious relationships between people and their environments. Biosphere reserve networks are a primary vehicle for accomplishing MAB goals and serve four basic functions: 1) conserve biodiversity, 2) demonstrate sustainable development approaches, 3) support research and monitoring related to local, national, and global issues of conservation and sustainable development, and 4) build social capacity for sustainable development through education and training. The U.S. network, established in 1976, consists of 47 biosphere reserves that represent a diversity of ecosystems. The U.S. MAB program is in a period of reflection and revitalization as it nears 30 years of commitment and contribution to biological diversity conservation and sustainable development. Major accomplishments of the U.S. MAB program have been through many different institutions, such as the Information Center for the Environment's (ICE) development of a biodiversity database that serves to document species occurrences for protected areas around the world (www.ice.ucdavis.edu), the development of the monitoring and assessment of biodiversity program research and education activities by the Smithsonian Institution (www.nationalzoo.si.edu/conservationandscience/MAB), and Southern Appalachian MAB program's exemplary achievements in promoting environmental health and stewardship in natural and cultural ecosystems in the Southern Appalachian mountains. Future emphasis areas for the U.S. MAB program include refreshed operating principles based on a model of integrated human and natural ecosystems, enhanced networking capabilities among reserves within the U.S. and around the world, innovative advances in global change monitoring, sustainability research, and education at U.S. biosphere reserves, and accelerated development of solutions to key challenges to sustainability.*

Introduction

Sustainability is increasingly a focus of national and international attention in terms of dialogue, monitoring, research, development, and policy (Sayer and Campbell 2003). However, recognition of the importance of sustainability is not new—indeed, it is as old as human societies themselves (Diamond 1999). Over the past 50 years, many advances have been made in our understanding of the limitations and sensitivities of the biosphere, and in our use of technology to minimize detrimental effects of human activities on the environment. The United Nations Educational, Scientific, and Cultural Organization's (UNESCO) Man and the Biosphere (MAB) program, founded over 30 years ago, is an example of a significant international effort to enhance and promote sustainability, and it has made significant contributions toward this goal, both in the U.S. and throughout many countries around the world. Much has changed since the 1970s, most significantly being that human populations have increased by approximately 50 percent, from 4 billion to 6 billon people globally, and similarly from 200 million to 300 million in the United States (U.S. Census Bureau 2004). As we begin a new millennium, it seems prudent to take stock of U.S. MAB's past accomplishments, operational short-comings, current and future opportunities, and pressing priorities to sharpen its focus and continue its insightful offerings to tomorrow's sustainability challenges.

MAB Program Fundamentals

The MAB Program was launched in 1971 to facilitate intergovernmental cooperation in promoting harmonious relationships between people and their environments. As such, MAB was the first deliberate international initiative to work toward sustainable development. Specifically, the goals of the MAB program are to: (1) foster the rational use and conservation of the resources of the biosphere and the improvement of the global relationship between man and the environment; and (2) to predict the consequences of today's actions on tomorrow's world and thereby increase man's ability to manage efficiently the natural resources of the biosphere. U.S. MAB Program is one of six regional MAB programs in 97 countries that span the globe (UNESCO 2003). The United States was one of the first countries to establish a national MAB organization and begin establishing biosphere reserves as part of a national network. The United States is a member of the regional EuroMAB program, along with 30 other countries in Europe and North America. The objective of the U.S. MAB program mirrors those of the international MAB program with an added emphasis on a balance between social and ecological systems, "To demonstrate and advance a sustainable balance between conserving biological diversity and promoting human development while maintaining associated cultural values" [www.euromab.org/general_information/geninfo.html].

The U.S. MAB program consists of three primary components: a National Committee, Research Directorates, and a Biosphere Reserve Network. The National Committee is comprised of a diversity of entities, including federal agencies, academic institutions, and non-governmental institutions. The National Committee provides national direction for all aspects of the program, such as the establishment of research directorates, allocation of funds and resources to biosphere reserves, international relations, and fund raising. Research directorates are pivotal positions designated to promote focused research and education to further our understanding of ecosystem sustainability and speed the development, availability, and application of key information, useful tools, and effective practices. Five research directorates were established: temperate ecosystems, high latitude ecosystems, marine and coastal ecosystems, tropical ecosystems, and human-dominated ecosystems.

Biosphere reserve networks are the primary land-based vehicle for accomplishing MAB objectives and serve three basic functions: 1) conservation - contribute to the conservation of landscapes, ecosystems, species, and genetic variation; 2) development – foster economic and human development which is socio-culturally and ecologically sustainable; and 3) logistic support - support for demonstration projects, environmental education and training, research and monitoring related to local, regional and global issues of conservation and sustainable development (UNESCO 1995). UNESCO criteria for establishing a biosphere reserve are as follows: (1) contain a mosaic of ecological systems representative of a major biogeographic region, including a gradation of human influences; (2) contain areas significant for biodiversity conservation; (3) offer opportunities to explore and demonstrate approaches to sustainable development on a regional scale; 4) extend over an appropriately sized area to serve the first three functions; 5) identify appropriate zones (core, buffer and transition) to accomplish functions; 6) establish an organizational structure that provides for the involvement and participation of a range of authorities, communities, and interests; and 7) plans, programs, and policies that support the functions and activities of the biosphere reserve (UNESCO 1995). Biosphere reserves are intended to have three zones delineated: (1) one or more core areas, consisting of legally protected area(s) managed to sustain indigenous biota and natural processes; (2) a buffer zone, consisting of a legally or administratively established area that typically adjoins or surrounds the core area; and (3) a transition area, which surrounds the core area and buffer zone and supports a variety of resource uses and human activities characteristic of the larger region (fig. 1).

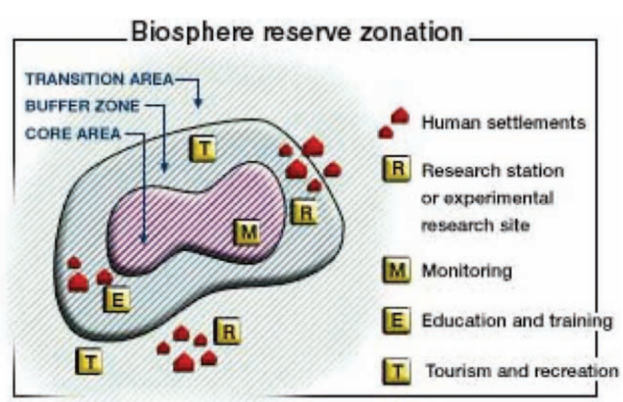

Figure 1. Three management zones associated with biosphere reserves (from UNESCO).

Highlights of U.S. MAB Contributions

Overall, UNESCO views MAB as instrumental in helping to reconciling conflicts between conservation and resource use by contributing to a more in-depth understanding of social-ecological interactions, and developing tools and techniques that can be used to implement ecosystem approaches promoted by Convention on Biological Diversity [www.biodiv.org]. The U.S. MAB program has made significant contributions to these ends in conserving biological diversity and promoting sustainable development in the U.S. and around the globe. Its contributions have taken a multitude of forms and have been accomplished through many different institutions.

Throughout the tenure of the U.S. MAB program, individual biosphere reserves have made a plethora of research, inventory, monitoring, and education contributions to local, regional, and international communities. In 1995, stellar contributions of 12 biosphere reserves were highlighted in U.S. MAB publication (Anonymous 1995). The cornucopia of activities included: a symposium on bioregional biodiversity sustainability; coordinated research between a U.S. and French coastal biosphere reserve on ecological sustainability issues; a regional workshop to introduce local educators to the objectives and activities of biosphere reserve programs; a cooperative research program to accomplish data compilation, analysis, and modeling for an ecoregion; and a multi-agency assessment of water quality within a large-scale community watershed.

In the 1980s, the Smithsonian Institution, as a partner in the U.S. MAB program, developed their Monitoring and Assessment of Biodiversity program (www.nationalzoo.si.edu/conservationandscience/MAB). The mission of the program is to enable the implementation of biodiversity monitoring projects and to inform adaptive management planning around the world. Over its nearly 20 years of operation, this program has made substantial advances in research, development, and education in the arenas of biodiversity inventory and monitoring. For example, they offer formal educational opportunities in the form of intensive courses in biodiversity assessment and monitoring, and environmental leadership. They also have an active research program in over 10 locations around the world that strives to accomplish four main objectives: 1) test and implement protocols for long-term, multi-taxa monitoring of forests; 2) establish biodiversity assessment and monitoring projects to further regional conservation needs; 3) provide data management and analytical procedures that allow rapid assessment and dissemination of information, and 4) coordinate the interactive biodiversity monitoring network to facilitate information exchange and dissemination, and the formation of data quality standards.

In the late 1980s, the Southern Appalachian Biosphere Reserve was designated, along with establishment of the associated Southern Appalachian Man and the Biosphere (SAMAB) program and cooperative agreement codifying the collaborative intentions of several agencies (ultimately 14 federal and state agencies) (Van Sickle and Turner 2001). SAMAB's vision is to foster a harmonious relationship between people and the Southern Appalachian environment. Over the course of its existence, SAMAB it has garnered exemplary achievements in promoting environmental health and stewardship in natural and cultural ecosystems in the Southern Appalachian Mountains, and has demonstrated the remarkable potential that biosphere reserves have to bring people and resources together to achieve shared sustainability goals and objectives. Southern Appalachian Biosphere Reserve consists of six core areas including one national park (Great Smoky Mountains), two research areas, a state park, and two nature preserves. One of its greatest single contributions to date has been to lead the acclaimed Southern Appalachian Assessment, which provided a detailed accounting of the status of the Appalachian ecosystems and identified key areas of concern and opportunity to meet sustainability objectives throughout the ecoregion (SAMAB 1996).

In the early 1990s, the Biosphere Reserve Inventory and Monitoring database was created to house and disseminate information on the biodiversity of biosphere reserves around the world. The utility and scope of the database eclipsed its original goal during the first decade of its existence to become a world-class resource as the Biological Inventory of the World's Protected Areas. The database is currently managed by the Information Center for the Environment's (ICE) at the University of California at Davis, and is readily accessed through the world wide web from any where in the world (www.ice.ucdavis.edu).

Throughout the 1990s, research directorates administered research that addressed one or two priority topics areas with respect to their ecosystem types, and together they completed seven major research projects addressing pressing sustainability challenges such as ecosystem management approaches to achieve ecological sustainability south Florida wetland ecosystems, caribou population and management dynamics in the arctic, ecological and socio-economic impacts of management strategies for marine protected areas in three different oceanic areas, and the development of a land use change analysis system for modeling landscape-scale change at the ecoregional scale. In addition to large research projects, research directorates also distributed small grants to support student research projects on biosphere reserves.

The new millennium brought about many changes in the U.S. MAB program. In 2000, administration of the U.S. MAB program was transferred from the State Department to the U.S. Forest Service, and the U.S. MAB Secretariat and chair of the National Committee was conveyed to the Associate Deputy Chief for Research and Development in the U.S. Forest Service. The Forest Service has been engaged in updating the U.S. MAB program since 2000. In 2003, the United States rejoined UNESCO after a 19 year hiatus. Rejoining UNESCO brought with it renewed interest and optimism about the potential of the U.S. MAB program to continue to make significant contribution to sustainability challenges in the 21st century. The first U.S. Biosphere Reserve Association was also formed in 2003 (www.samab.org/about/usbra/usbra.html). The U.S. Biosphere Reserve Association is a non-profit organization dedicated to three primary aims: 1) provide leadership and support for the biosphere reserves; 2) convey factual information about the purposes and activities of biosphere reserves; and 3) develop cooperation among biosphere reserves in North America.

The U.S. Biosphere Reserve Network

UNESCO regards the world network of biosphere reserves as MAB's most visible asset and operation tool in the 21st century, and a key mechanism by which priority work on sustainability issues will be accomplished. Similarly in the U.S., the biosphere reserve network is viewed as a collection of landscape for learning that uniquely positions MAB to provide leadership and deliver substantive contributions toward sustainability in the U.S. At the global scale, external recognition for the unique value of the world network of biosphere reserves has come in the form of the prestigious Concord Award in 2001 from the Prince of Asturias Foundation. The award acknowledges its 30 years of contributions to the conservation of unique natural areas and associated species that are the heritage of mankind, and to opening new horizons of knowledge about how to protect and preserve ecological and cultural treasures (www.fps.es/ing/premios/galardones/galardonconcordia2001.html).

The U.S. biosphere reserve network consists of 47 biosphere reserves (fig. 2); about 60 percent were established

Figure 2. U.S. MAB biosphere reserve network (from UNSECO).

Table 1. Biosphere reserves in the U.S. MAB network.

Biosphere Reserve Name	Administrative Offices	Number of Units
Aleutian Islands	Adak, AK	1
Beaver Creek	Flagstaff, AZ	1
Big Bend	Big Bend, TX	1
Big Thicket	Beaumont	1
California Coast Ranges	Northern coast, CA	8
Carolinian-South Atlantic	Coast, SC	11
Cascade Head Biosphere	Corvalis, OR	1
Central Coast Biosphere	Stanford, San Francisco, Stinson Beach, Corte Madera, Burlingame, Glen Ellen, Bodega Bay, Neward, Novato, and Point Reyes, CA	14
Central Gulf Coast Plain	Eastpoint, FL	1
Central Plains	Ft. Collins and Nunn, CO	1
Champlain-Adirondak	Ray Brook, NY and Waterbury and Rutland, VT	3
Channel Islands	Santa Barbara and Ventura, CA	2
Coram	Missoula, MT	1
Denali	Denali, AK	1
Desert	Provo, UT	1
Everglades & Dry Tortugas	Homestead, FL	1
Fraser	Ft. Collins, CO	1
Glacier Bay-Admiralty Island	Juneau and Gustavus, AK	2
Glacier	West Glacier, MT	1
Guanica	Guanica, Puerto Rico	1
H.J. Andrews	Corvalis, OR	1
Hawaiian Islands	Hawaii and Maui, HI	2
Hubbard Brook	Campton, NH	1
Isle Royale	Houghton, MI	1
Jornada	Las Cruces, NM	1
Konza Prairie	Manhatten, KS	1
Land Between the Lakes	Golden Pond, KY	1
Luquillo	Rio Piedras, Puerto Rico	1
Mammath Cave Area	Bowling Green, KY	1
Mojave and Colorado Deserts	Palm Desert, Borrego Springs, Death Valley, San Bernardino, and Twentynine Palms, CA	5
New Jersey Pinelands	New Lisbon, NJ	1
Niwot Ridge	Nederland, CO	1
Noatak	Fairbanks and Kotzebue, AK	2
Olympic	Port Angeles, WA	1
Organ Pipe Cactus	Flagstaff and Ajo, AZ	1
Rocky Mountain	Estes Park, CO	1
San Dimas	Riverside, CA	1
San Joaquin	Fresno, CA	1
Sequioa-Kings Canyon	Three Rivers, CA	1
South Atlantic Coastal Plain	Hopkins and Georgetown, SC	1
Southern Appalachian	Knoxville, TN	6
Stanislaus-Tuolumne	Sonora, CA	1
Three Sisters	McKenzie Bridge, OR	1
Univ. of Michigan Biological Station	Ann Arbor, MI	1
Virgin Islands	St. John, Virgin Islands	1
Virginia Coast	Nassawadox, VA	1
Yellowstone	Jackson Hole, WY	1

in 1976 and the remaining ones established over the following 15 years. Thirty-nine of the reserves are located across the contiguous U.S., with an additional four in Alaska, one in Hawaii, two in Puerto Rico, and one in the Virgin Islands. The 47 reserves span a diversity of ecosystem types, including terrestrial and marine ecosystems. The U.S. biosphere reserve network is unique relative to networks in most other countries in a number of features. First, unlike most of the 393 reserves in other countries, almost all of the reserves in the U.S. were established in areas that were already designated for conservation or research purposes (table 1). Specifically, the majority (> 60 percent) of the biosphere reserves in the U.S. are associated National Parks. USDA Experimental Forests are the next most prevalent association (17 percent), with the remainder located on a smattering of different lands, such as state forests, U.S. Fish and Wildlife National Wildlife Refuges, Bureau of Land Management lands, University properties, and Nature Conservancy properties. Thus, biosphere reserve designations did not increase the amount of land set aside for conservation in the U.S., but rather served to strengthen and broaden the emphasis of unit management to encompass research, monitoring, development, education, and demonstration of sustainability practices. Second, a large proportion (> 30 percent) of reserves consists of multiple core areas (in other words, individual administrative units). Reserves with multiple units serve an important function in the US. MAB network because they present a complex administrative scenario where multiple and potentially conflicting mandates of various units need to be considered and management options are negotiated to best meet the shared objectives and individual needs of each unit. Thus, multiple unit reserves have some of the same management challenges as buffer and transition areas. Finally, most U.S. biosphere reserves do not have buffer or transition areas designated. This is largely a function of the reserves being based on previously designated areas that only consisted of core reserve areas with a single set of objectives. A few of the reserves (for example, Mammoth Cave Area Biosphere Reserve) have proposed zones of cooperation, which are intended to serve a similar function as buffer and transition areas.

In some respects, reserves without designated buffer and transition areas serve as ecological and social experiments in the value and necessity of buffer and transition areas in meeting the objective of maintaining biological diversity of core areas. The evolution of boundary designations and land management in and around Yellowstone National Park is a prime example. Yellowstone National Park was the first national park in the U.S., established in 1872 (USDI 2004), and it was designated as a biosphere reserve in 1976 with only the core area of the park designated (no buffer or transition areas). The park itself extends over a 900,000 ha area. The concept of a Greater Yellowstone Ecosystem came into being in the mid 1980s, driven by the recognition that many of the values for which the park was established were dependent upon the management of lands outside the park. As such, the Greater Yellowstone Ecosystem was established to maintain the important ecological and social linkages across the headwaters of three major river systems – Yellowstone, Snake, and Green rivers – and thereby maintain ecosystem integrity, including populations of wide ranging species that require large landscapes to persist, such as grizzly bear, wolverine, lynx, and gray wolf. The Greater Yellowstone Ecosystem currently occupies a 7 million ha area centered on Yellowstone National Park, including two National Parks, portions of six national forests, three national wildlife refuges, BLM lands, state lands, and private and tribal lands (Clark and Minta 1994; Shullery 1995). A future review of the Yellowstone Biosphere Reserve is likely to conclude that the boundaries of the Greater Yellowstone Ecosystem function as a zone of cooperation and should be designated as such within the MAB program.

UNESCO states that biosphere reserves are to be reviewed every 10 years to evaluate their effectiveness and needs. Toward this end, a survey of biosphere reserves in the U.S. was conducted in 1995, and repeated in 2003, to determine their functional strengths and needs (Gilbert 2004). The survey asked each reserve to provide their perspective on the state and future of U.S. biosphere reserves. Five primary questions were asked of managers: 1) what are the management benefits to your biosphere reserve, 2) who is participating, 3) what resources are needed, 4) who identifies with the biosphere reserve concept, and 5) who is concerned about or opposed to the biosphere reserve. A number of substantive conclusions came from the most recent survey. Biosphere reserve status conferred management benefits for most reserves, and benefits were greatest in the areas of promoting an ethic of sustainability, research, public consultation and participation, environmental awareness, ecosystem management, and improved cultural resource protection. Academic research institutions were the most prevalent participants in the biosphere reserve activities, followed by federal agencies. Few units experienced expressions of concern by local communities and organizations. Perhaps most importantly but not surprising is that funding was the most limiting factor, followed by limited local involvement and infrequent communication among biosphere reserve managers. Without funding from the MAB program, the mission of units tends to shrink back to the core mission of the unit's original designation, and most frequently that means that programs directed toward sustainable development atrophy. Finally, responses were quite similar in 1995, with some changes in the focus of programs. Since 1995, areas of emphasis for biosphere reserves have shifted from conservation and ecosystem management to research and education.

The ecological status of U.S. biosphere reserves has never been evaluated as a network. Given that most biosphere reserves are co-located with national parks, we consulted the results of the National Parks Conservation Association's (NPCA) annual evaluation of national parks (www.npca.org) as a small window into their status. Every year the NPCA identified the 10 most endangered National Parks out of the 387 units designated in the National Park system. In 2003, 5 of the 10 most endangered National Parks are also biosphere reserves (Big Thicket National Preserve, Everglades National Park, Great Smokey Mountains National Park, Organ pipe cactus National Monument, and Yellowstone National

Park). Predictably, biosphere reserves co-located with National Parks will suffer from the same set of stressors that affect the parks, namely air and water pollution and recreation impacts. A more thorough evaluation of the status of the ecological status of biosphere reserves would be a valuable tool to guide future investments in biosphere reserve management and considerations for additions to the network.

Future Directions

The U.S. MAB program is in a period of reflection and revitalization as it contemplates its future commitment and contributions to biological diversity conservation and sustainable development. Much has transpired over the last three decades, including advancement of our understanding of ecology, ecosystem dynamics, and sustainability thresholds and threats. Similarly, many national and international programs have been created with the intent of achieving a variety of biodiversity conservation and sustainability objectives (for example, the Long-Term Ecological Research Network and the National Center for Ecological Analysis and Synthesis). At the same time, it is clear that sustainability challenges continue to mount. At the Johannesburg World Summit on Sustainable Development in 2002, it was determined through exchange and discussion by thousands of participants, including over 100 heads of state, that growing poverty and increasing environmental degradation are threatening sustainability at local to global scales. The Summit intended to focus the world's attention toward meeting the challenge of improving people's lives and conserving natural resources in the face of growing human populations and association demands for resources. Given the limited progress that has been made since the Rio de Janeiro Summit in 1992, there is now an urgency to take substantive action, and the U.S. MAB program could play a pivotal role.

It is incumbent upon the U.S. MAB program to take a multitude of factors into consideration in charting its course for the future. Certainly, the draft recommendations from the Johannesburg World Summit will outline keystone steps in the pursuit of sustainability. Similarly, the 2002 Convention on Biological Diversity generated broad objectives for 2010 that mirror those of the 2002 World Summit on Sustainable Development – poverty reduction and slowing the current rate of biodiversity loss at the global, national, and regional levels (www.biodiv.org). Specific approaches and actions have been generated by the MAB program through two seminal conferences. MAB program representatives from over 40 countries convened in Seville, Spain in 1995 to examine past experience in implementing the innovative concept of biosphere reserves, and to look to the future to identify what emphases should now be given to their three functions of conservation, development and logistical support. The result was Seville Strategy, which contains 11 objectives and associated recommendations for improving the national and bioregional effectiveness of the MAB program (table 2) (UNESCO 1996). A subsequent meeting in 2000 resulted in another document that provides further refinement to the original strategy in the form of a checklist for priority actions referred to as Seville+5 (UNESCO 2000). These recommendations are tailored specifically to the MAB program and provide a clear set of actions that will assist in directing and energizing the U.S. Program.

In summary, retooling the U.S. MAB program for success over the next few decades to will undoubtedly updating many of its elements. A refreshed set of objectives and operating principles based on a model of integrated human and natural ecosystems is needed. An increased emphasis on the interface between

Table 2. Four goals and 11 objectives articulated in the Seville Strategy (recommendations for action are available).

Goal I: Use of biosphere reserves to conserve natural and cultural diversity
- Improve the coverage of natural and cultural biodiversity by means of the World Network of Biosphere Reserves.
- Integrate biosphere reserves into conservation planning.

Goal II: Utilize biosphere reserves as models of land management and of approaches to sustainable development
- Secure the support and involvement of local people.
- Ensure better harmonization and interaction among the different biosphere reserve zones.
- Integrate biosphere reserves into regional planning.

Goal III: Use biosphere reserves for research, monitoring, education, and training
- Improve knowledge of the interactions between humans and the biosphere.
- Improve monitoring activities.
- Improve education, public awareness, and involvement.
- Improve training for specialists and managers.

Goal IV: Implement the biosphere reserve concept
- Integrate the functions of biosphere reserves.
- Improve the strength of the World Biosphere Reserve Network.

human-dominated and wildland ecosystems will guide revisions and additions to the reserve network (for example, urban biosphere reserves), as well as within-reserve activities. Enhanced networking capabilities among reserves within the U.S. and with other countries is critical to speed the exchange of ideas and the application of innovations. Global climate change has been identified as a sustainability challenge that biosphere reserves can make a unique contribution, as evidence by the recent MAB Global Change Monitoring Initiative (UNESCO 2004). The U.S. biosphere reserve network contains a number of high elevation and island ecosystems, and has the opportunity to contribute to global change challenges. Finally, national direction and support is essential to promote and advance much needed education and capacity building activities at multiple scales. The U.S. MAB program is poised at the event horizon of a new century of promise and challenges, and holds great potential to contribute substantially to the goals, objectives, and challenges in the pursuit of sustainability in the decades ahead.

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The Multiple Species Inventory and Monitoring Protocol: A Population, Community, and Biodiversity Monitoring Solution for National Forest System Lands

P. N. Manley, Research Wildlife Biologist, U.S. Forest Service, Pacific Southwest Research Station, Davis, CA

B. Van Horne, National Wildlife Research Program Leader, U.S. Forest Service, Arlington, VA

Abstract—*The U.S. Forest Service manages approximately 76 million ha (191 million acres) of National Forest System (NFS) lands. The National Forest Management Act (1976) recognizes the importance of maintaining species and ecosystem diversity on NFS lands as a critical component of our ecological and cultural heritage. Information on the condition of populations and habitats of plants and animals is a primary tool for determining desired conditions, understanding potential conflicts in multiple use objectives in the context of sustainability, and formulating management direction to achieve these objectives. To date, no consistent, nationally standardized monitoring program exists to obtain status and trend data on multiple species on NFS lands. Inconsistencies in the development and implementation of multiple species monitoring programs have resulted in inadequate or unreliable monitoring data on most species. Over the past five years, Forest Service research and management have collaborated to develop a nationally standardized protocol, the Multiple Species Inventory and Monitoring (MSIM) protocol. The MSIM protocol is designed to provide a minimum of presence/absence and habitat data for a broad suite of vertebrate and plant species. Primary survey methods are identified for each taxonomic group, including terrestrial and aquatic birds, mammals, amphibians, reptiles, and plants. The protocol is uses the Forest Inventory and Analysis systematic grid to structure sampling, thus enabling a variety of options for post-stratifying the data to address various management questions. Ancillary information includes habitat relationships of many species, identification of potential causal factors associated with observed trends, and data to evaluate the validity and strength of indicators. The protocol is designed for implementation on both NFS and non-NFS lands to provide data on population and habitat conditions at multiple scales for a variety of applications.*

Introduction

The U.S. Forest Service manages approximately 76 million ha (191 million acres) of National Forest System (NFS) lands. Information on the condition of populations and habitats of plants and animals is a primary tool for determining desired conditions, understanding potential conflicts in multiple use objectives in the context of sustainability, and formulating management direction to achieve these objectives. The National Forest Management Act (1976) highlights the need to maintain species and ecosystem diversity on NFS lands as essential elements of our ecological and cultural heritage, and specifies the inclusion of a monitoring strategy in each Forest's Land and Resource Management Plan. Further, the U.S. Forest Service has a lead role in assessing the extent, condition, and sustainability of the nation's forests and grasslands under the guidance of legislation (for example, Forest and Rangeland Renewable Resources Planning Act 1974) and international agreements (for example, Criteria and Indicators for Sustainable Forestry – the Montreal Process) (Anonymous 1995).

Development and implementation of monitoring at Forest and Regional scales has been slow. A report by the General Accounting Office (GAO 1997) documented inadequacies in the agency's monitoring, stating "the Forest Service (1) has historically given low priority to monitoring during the annual competition for scarce resources, (2) continues to approve projects without an adequate monitoring component, and (3) generally does not monitor the implementation of its plans as its regulations require." Reasons for inadequate monitoring have not been evaluated as thoroughly, but undoubtedly include lack of clear monitoring objectives in land management plans that can be readily translated into sampling design specifications, lack of capacity or commitment to fund data collection, management, and analysis, and lack of standardized monitoring protocols. Consistent, nationally standardized monitoring protocols have not been available to Forests and Regions to obtain reliable status and trend data on animal populations and habitats on NFS lands. Inconsistencies in the development and implementation of integrated species monitoring programs result in the development of various of designs and approaches that are inadequate to address population and habitat trends with sufficient rigor to support land management decisions and meet NFMA monitoring requirements (for example, GAO 1991). The need for effective monitoring programs is mounting because over the next five years most Forest Land and Resource Management Plans which guide management for the second 10 to 20 year planning period as per NFMA will be revised. Lack of credible monitoring plans is likely to create a barrier to successful plan revision.

An increased emphasis on monitoring on NFS lands is being generated not only by NFMA, but also by growing concerns about declines in biological diversity in the United States (Flather and others 1999) and around the world (United Nations 2002). Recent ecoregional assessments conducted in various locations around the country suggest that a consistently large proportion of all vertebrate and plant species are of concern and interest (SAMAB 1996; Stephenson and Calcorone 1999; Wisdom and others 2000; USDA 2001). For example, in a recent assessment of the Columbia River Basin, 173 of 468 vertebrate species (37 percent) were considered species of focus based on concerns for their persistence (Wisdom and others 2000). A similar scenario existed in California, where an assessment of vertebrates in the Sierra Nevada indicated that 213 of 465 species (46 percent) were considered vulnerable to population losses (USDA 2001), and the Southern California assessment found 184 of 482 vertebrates (38 percent) were considered focal species based on special interest or concern (Stephenson and Calcorone 1999). Across the country in the southern Appalachian Mountains, a comparable situation existed, where an assessment determined that 92 of their 320 vertebrate species (29 percent) were considered special interest or concern (SAMAB 1996). Similar trends existed for vascular plant species in these assessments, with proportions of species that are of concern generally ranging from 10 to 20 percent, but the absolute numbers of plant species of concern were over twice those of vertebrates of concern. Clearly, single species approaches to conservation, management, and monitoring are not feasible or effective means of dealing with the significant ecological and social consequences associated with the potential loss of 20 to 50 percent of the flora and fauna, equating to hundreds of species of plants and animals at ecoregional scales. Multiple-species, ecosystem-based monitoring strategies that provide reliable, timely, and informative measures of change are desperately needed.

Investments in monitoring by land management agencies are on the rise, particularly in the development and implementation of regionally and nationally consistent protocols for the inventory and monitoring of natural resources and land uses (for example Amphibian Research and Monitoring Initiative, Partners in Amphibian and Reptile Conservation, National Park Vital Signs Monitoring, Aldo Leopold Wilderness Research Institute Monitoring Initiative, Environmental Protection Agency's Environmental Monitoring Assessment Program, Forest Inventory and Analysis). Over the past few years, the U.S. Forest Service has launched multiple efforts to develop nationally consistent inventory and monitoring protocols for a variety of resources (e.g., wildlife, vegetation, streams, recreation use) (www.fs.fed.us/emc/rig). Within the Forest Service, most wildlife monitoring approaches being developed are restricted to one species or narrow taxonomic groups, with one exception. The U.S. Forest Service has developed the Multiple Species Inventory and Monitoring (MSIM) protocol. Through collaboration between research and management, this nationally standardized protocol for monitoring a large number of plant and animal species was designed to meet the basic requirements of NFMA and provide an effective, efficient, and reliable source of information on the status and trends of populations, habitats, and biological diversity on NFS lands. The MSIM protocol was developed in response to the large and growing number of species of concern and interest (for example, Management Indicator Species, Forest Service Sensitive species, and state and federally listed species) on NFS lands and throughout the country. This paper provides an introduction to the MSIM protocol and its potential to meet a variety of information needs at a range of scales for National Forest System lands and across land ownerships throughout ecoregions.

Objectives

The MSIM protocol was designed to provide a cost effective means of generating reliable status and trend (sensu Busch and Trexler 2003) estimates based on presence/absence data that are spatially and temporally coincindent across multiple species and taxonomic groups. The MSIM protocol yields status and trend data for a breadth of levels of ecological organization (genetic, species, community, and landscape), thus enabling a more comprehensive evaluation of biological diversity and ecosystem condition (Noss 1990; Gaines and others 2003). Primary survey methods provide data on species occurrence and composition, and contribute data on habitat condition at multiple scales. The acquisition of genetic data is not part of the primary survey method, but could be readily accomplished with collection of hair or tissue from lured or captured animals (Mills and others 2000).

The MSIM protocol is designed to answer the following inventory (status) questions (1) within an administratively defined area (for example, National Forest or Region), (2) within an ecologically defined area (for example, ecoregion or biome), and (3) throughout a species range, including diverse landscapes:

1. What is the status of populations of individual species adequately detected?
- Proportion of occupied monitoring sites
- Spatial distribution of occupancy
2. What is the status of habitat for species for which predictable habitat relationships have been determined?
- Habitat characteristics (at all FIA points)
3. What is the relationship between the status of species and environmental conditions?
- Predictive models of species presence based on environmental conditions (for example, vegetation composition and structure, logs and snags, elevation)
- Develop or validate habitat relationships
4. What is the pattern of co-occurrence between species adequately detected?

The MSIM protocol is designed to answer the following change (trend) questions (1) within an administratively defined area, (2) within an ecologically defined area, and (3) throughout a species range, including diverse land ownerships:

1. What is the direction and magnitude of change in the proportion of sites occupied by individual species that have been adequately detected?
- Change in the proportion of occupied points
- Change in the spatial distribution of probability of occupancy
- Change in site occupancy rates and patterns (in other words, sequence of occupancy for individual sites summarized over all points)
2. What is the change in community composition and structure?
- Change in species composition
3. What is direction and magnitude of change of habitat?
- Change in habitat characteristics (at all FIA points)
4. What is the relationship between changes in species and their habitats?
- Coincident change in species presence and habitat conditions

The MSIM protocol is a retrospective approach to monitoring (NRC 1995; Noon and others 1999; Noon 2003), meaning that it seeks to reflect effects or changes after they have occurred. Unlike predictive or "prospective" monitoring, it is does not presume prior knowledge of key environmental stressors (anthropogenic sources of change) or make predictions about the ecological effects resulting from primary stressors. The principle objective of retrospective monitoring is to estimate parameter values at points in time and over time, and not to test hypotheses (Stewart-Oaten 1996). Alternatively, prospective monitoring targets condition indicators of stressors and ecological responses, and tests hypothesis about cause-effect relationships (Noon and others 1999; Noon 2003). It is likely that MSIM will provide status and trend data on a number of species that are considered indicators and their associated environmental conditions. Thus, the MSIM protocol may enable hypothesis testing by providing data to address one or more assumptions associated with prospective monitoring, such as population distribution and response to disturbances.

Sampling Design and Detection Methods

The MSIM protocol consists of a national framework of core design, methodological, and procedural elements (table 1) (see Manley and others in prep for more details). The core design and methodological elements of the protocol are described here: sampling frame, sampling frequency, and survey methods.

Sampling Frame

The sampling frame of the MSIM protocol is the systematic grid of the Forest Inventory and Analysis (FIA) program, which is an on-going nation-wide program that monitors the composition and structure of forested ecosystems (Roesch and Reams 1999). The national FIA design consists of a single point randomly located in each systematic hexagonal 2400 ha (6000 acres) grid cell (fig. 1), resulting in a grid point density of approximately 210 points per 5000 km2 (1.25 million acres). The FIA grid was selected as the foundation of the MSIM sampling

Table 1. Summary of core elements of the National Framework for the MSIM protocol.

Element	Specifications
Sampling frame	• MSIM monitoring points will be established in association with FIA grid points • A minimum of 50 percent of the FIA grid points sampled
Sampling frequency	• A minimum of a five-year resample with at least 10% of sites sampled every year, which equates to 28 percent of sample sites surveyed in a given year
Survey methods	• Primary survey method are identified for each major vertebrate taxonomic group, four of which are recommended to be implemented in all regions: bird point counts, small mammal live trapping, terrestrial visual encounter surveys, and habitat measurements. • Secondary survey methods are additive, complementing primary survey methods for each taxonomic group. • Multiple visits are made to all or a subset of points for each survey method used to maximize probability of observing species that are present.
Data acquisition	• Data collection will be designed at the regional scale and coordinated within and among regions.
Data storage	• Core data (species sighting and habitat conditions) will be stored in the FAUNA module of Natural Resource Information System. • Relevant data copied to a variety of destinations, including FAUNA, TNC, and state heritage programs (via NatureServe).
Data analysis	• Data analysis will follow the minimum standards identified in the national framework, such as estimates of proportion of points occupied, probability of detection, and a quantitative description of habitat condition for each species detected. • A Regional-scale analysis guide should be developed to provide consistency and reliability to results from Regional analyses.
Reporting	• Annual reports will be produced by each Region, and they will comply with reporting standards established as part of the national framework to ensure a minimum quality and detail, as well as facilitate the examination of trends across Regions. • At 5-year intervals, a more detailed analysis will be conducted that analyzes population trends, habitat trends, habitat relationships, and any desired ancillary analyses.
Evaluation and revision	• Annual and 5-year reports will be reviewed by: 1) the Wildlife Fish and Rare Plants and the Ecosystem Management Coordination staffs; and 2) the Region and Station Leadership Teams in each Region and Station for compliance with the national framework and to evaluate the significance of results.

design because the density of the grid is low enough to assume independence between points for the majority of vertebrate species (in other words, different individuals detected at each point). Further, the FIA program offers a temporally and spatially reliable source of vegetation data across all land ownerships, thus it promises to provide the potential for monitoring habitat conditions at the density of the grid on NFS lands, and across all land ownerships in collaboration with other institutions and landowners. To maintain the integrity and anonymity of FIA plot locations, MSIM sampling is slightly off-set from FIA points

Sampling Frequency

Sampling every FIA grid point every year clearly would yield the greatest statistical precision and power. However, fiscal conservancy has led FIA to a serially alternating panel designs because they appear to have a high degree of statistical precision and power per unit effort to describe status and detect trends over time (Lesser and Overton 199;, Thornton and Hyatt 1994; Roesch and Reams 1999). In a serial alternating panel design, a systematic subset of grid points (a panel) is identified for sampling each year, thus if all sites are visited every five years, then there are five panels with 20 percent of the sites in each panel.

Sampling frequency for the MSIM protocol follows a panel design, but differs from FIA in the frequency of sampling to better meet population monitoring information needs. The status and trends of animal and plant populations and habitats need to be described with a 10 to 20 year planning period. Given that animal populations exhibit fluctuations from year to year, the MSIM protocol has added an annual panel that is sampled every year, called an augmented serial alternating panel design, or ASAP, to improve the power to detect trends over the relatively short planning period (Urquhart and others 1993; Fuller 1999). In sum, the MSIM protocol recommends that a minimum of 50 percent of the FIA points be included in the sample, and that at least 10 percent of the selected grid points be sampled every year as part of the annual panel.

Detection Methods

The eight primary survey methods selected for the MSIM protocol consist of commonly employed, stan-

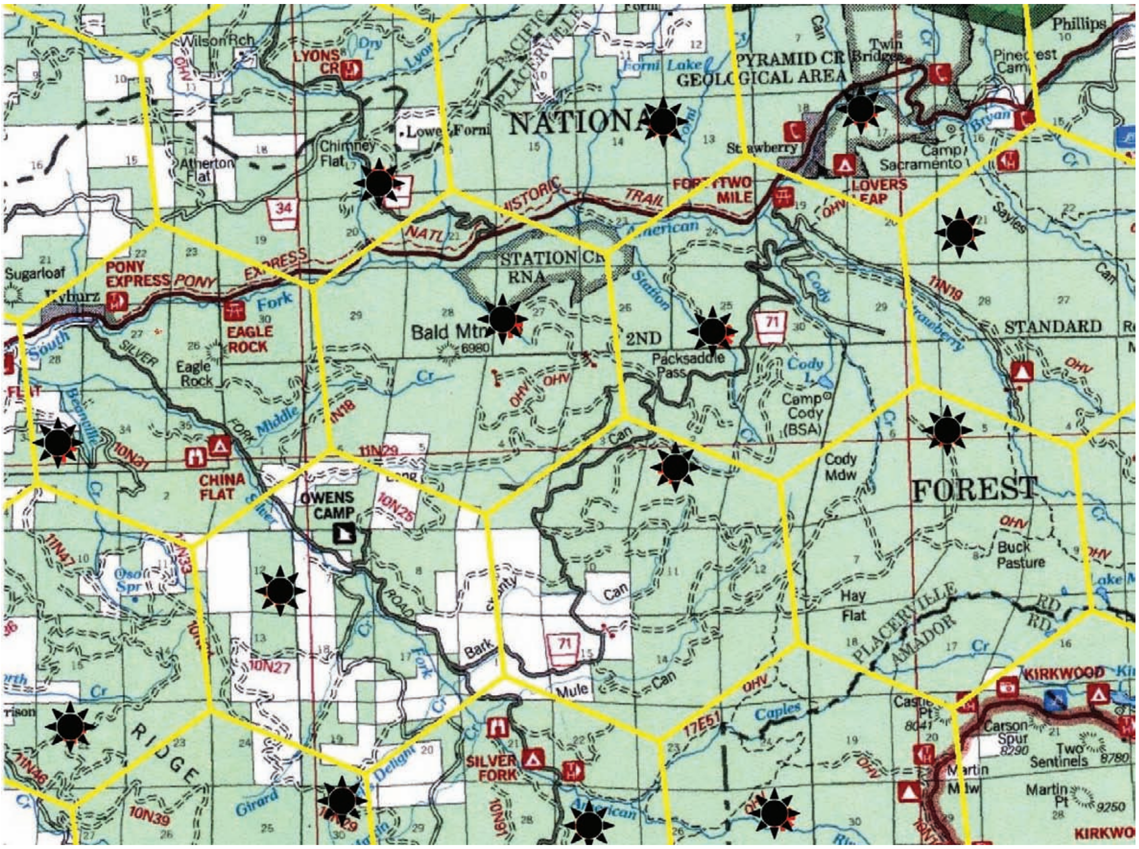

Figure 1. Graphic representation of a Forest Inventory and Analysis hexagonal grid and sample points.

dardized survey methods that detect a large number and breadth of species per unit effort and, in the case of habitat, most efficiently measure habitat variables pertinent to the majority of species detected by survey methods. Primary survey methods include methods to detect species in each of the following major taxonomic groups: songbirds and woodpeckers, owls, aquatic birds, small mammals, medium and large-bodied mammals, amphibians, reptiles, and vascular plants (table 2). Point counts are used to survey songbirds and woodpeckers, and consist of standing at each of four count stations 200 m apart and recording the number of individuals of each species of vertebrate seen or heard during a 10 minute count period. Distance estimates can be added to the protocol to calculate density estimates. Broadcast calling is used to detect nocturnal birds (primarily owls) and consists of a nighttime survey conducted by driving or hiking along roads and trails throughout a 3 km radius area around the sample point and broadcasting calls of local owl species. Sherman live trapping is used to detected small mammals, and consists of quart-sized aluminum trap boxes placed around a 200 m radius hexagon around the point that are baited and checked for occupants over a four night period. Prior to release, captured individuals (primarily rodents) can be marked to estimate abundance and tissue can be collected for genetic analysis. Trackplates and cameras are used to detect medium to large sized mammals (primarily carnivores), and the array consists of six devices placed 250 m apart around the sampling point over a 10 day period. Trackplate stations consist of sooted aluminum plates that are baited with meat, and tracks created by animals walking on the sooted surface are identified to species. Associated camera stations are baited with meat and vegetables, and visitation to the bait triggers the camera to take a picture of the animal. Mistnetting is used to detect bat species, and consists of sampling aquatic sites or forest openings within a 1 km radius area around the sample point. Mistnets are lightweight nets that extend 6 to 18 m across and up to 4 meters in height. Surveys are conducted at night for three to four hours, and captured bats are identified to species. Amphibians and reptiles, as well as a smattering of specialist and larger bodied species, are detected with terrestrial and aquatic visual encounter surveys. During these surveys, observers traverse the sample unit (200 m radius hexagon for terrestrial surveys; littoral and shore zones for aquatic surveys) visually scouring and physically probing suitable habitat for individuals or their sign. Habitat measurements constitute the final primary survey method in the MSIM protocol, which are conducted at the center point, and repeated at some of the more remote survey locations.

Table 2. Primary survey methods in the Multiple Species Inventory and Monitoring protocol.

Protocol	Effort	Reference	Target taxa
Point counts	7 stations, 10 min counts, 3 visits	Ralph and others 1993, 1995	song birds and woodpeckers, some vocal small mammals and amphibians
Broadcast calling (nocturnal)	2 visits	Fuller and Mosher 1981	nocturnal and crepuscular birds
Sherman live trapping	70 traps, 4 nights	Jones and others 1996	small mammals
Trackplate stations with cameras	6 stations, 10 days	Zielinski and Kucera 1995	mid-sized carnivores
Mist netting	3 net sites, 3 visits	Jones and others 1996	bats
Terrestrial visual encounter surveys for vertebrates and their sign	10 ha area, 2 visits	Crump and Scott 1994; Wemmer and others 1996	terrestrial-phase amphibians, reptiles, large mammals, raptors
Aquatic visual encounter surveys for vertebrates	2 visits	Crump and Scott 1994; Fellers and Freel 1995	aquatic amphibians, reptiles, mammals and birds
Environmental measurements	Measurements taken in the same year and season as the species data	Forest Inventory and Analysis manual (USDA 2004a)	Habitat descriptions for all taxa

Design Considerations

Land management agencies are increasingly turning to presence/absence data as an attractive measure of large-scale population trends prompted by recent advances in standardized techniques for obtaining (Ralph and others 1993, Heyer and others 1994, Wilson and others 1996) and analyzing (Azuma and others 1990, MacKenzie and others 2002, MacKenzie and others 2003) presence/absence data. The primary survey methods for the MSIM protocol provide a minimum of presence/absence and habitat data for a broad suite of animal and plant species, but in a number of cases (for example, point counts and Sherman live trapping) they also provide estimates of abundance, typically for species that occur at higher densities such as many small mammal and songbird species (Ralph and others 1993; Wilson and others 1996, respectively). However, obtaining reliable abundance estimates for larger-bodied species with large territories can be very time intensive and infeasible to accomplish for all such species of interest and concern at the ecoregional scale. Thus, occupancy serves as the basic population parameter shared by all species detected in large-scale, multiple-species monitoring efforts.

The proportion of points occupied across a region serves as an index of population abundance (Thompson and others 1998). State Atlas programs (Pearman 1997; Telfer and others 2002) and the National Lynx Survey (McKelvey and others 1999; Ruggerio and others 1999; McDaniels and others 2000) are examples of other population monitoring approaches similarly based on the extent of a species' occurrence. In many cases the areal extent of a population and its size have a positive relationship (for example, Nachman 1981; Geissler and Fuller 1986; Bart and Klosiewski 1989; Robbins and others 1989; Gaston 1994; Syrjala 1996; Thompson and others 1998). However, the proportion of points occupied can be insensitive to certain types of population decline. Specifically, species with higher densities (multiple individuals occupying a given sample unit) could experience significant declines before site occupancy begins to change. In response, standardized multiple species survey methods for higher density species (for example, small mammals and songbirds) typically yield abundance estimates that logically would be generated for these species to better elucidate their individual population trends (for example, Ralph and others 1993; Wilson and others 1996; Buckland and others 2001).

Statistical power to detect a change is lowest for species present at a low proportion of points and/or with low probability of detection (for example, Manley and others 2004). Low densities can result from a variety of life history factors (for example, large home range size, habitat specialization) or from population declines. Generating abundance estimates for low density species would require additional targeted effort across an ecoregion, a level of effort that is outside the model of a broad-scale multiple-species monitoring approach. However, the probability of observation can be optimized within the confines of broad-scale multiple species monitoring approaches such as the MSIM protocol by more intensive sampling per point. Multiple sample stations and/or multiple visits per point can serve not only to increase probability of observation, but also enable estimates of probability of detection and proportion of points occupied (MacKenzie and others 2003). Large-scale monitoring efforts face the challenge of multiple concurrent observers and turnover in observers over time, emphasizing the need to estimate probability of detection each year within each ecoregion.

Empirical Testing

Manley and others (2004) conducted an evaluation of the MSIM protocol to determine its potential effectiveness in meeting agency monitoring needs for vertebrate species. They estimated the number and types of species that would be adequately detected on the approximately 6.5 million ha (16.5 million acres) of federal lands in the Sierra Nevada (SNEP 1996) if all primary survey methods were conducted at FIA points on federal lands at two points in time. They predicted that 76 percent of all vertebrate species would be adequately sampled to detect a 20 percent relative change in the proportion of grid points occupied with 80 percent precision and power. These data were reevaluated for the purposes of this paper based on the subset of points identified for sampling in the national framework for the MSIM protocol: 50 percent of the grid in the sample, 10 percent of those sampled every year, and an additional 18 percent sampled every 5 years for a total of 14 percent of the full grid sampled every year. We found that the proportion of species adequately detected dropped from 76 percent to 42 percent, which still equated to 193 species adequately detected to monitor their populations across federal lands in the Sierra Nevada ecoregion. These results indicate that the MSIM protocol, even implemented at its minimum levels, is capable of providing status and trend data for hundreds of vertebrate species, many of which are likely to be species of concern and interest for which monitoring data are required (Manley and others 2004).

The predicted effectiveness of the MSIM protocol prompted field testing to validate its results. Field testing was conducted at the scale of a National Forest in the Sierra Nevada in 2002, and consisted of 40 sample sites on the Lake Tahoe Basin Management Unit (Manley and Roth 2004). Preliminary analysis of this limited data set (few sites, small geographic area, one sample period) provides some insights into the potential performance of the MSIM protocol. The field test detected approximately 50 percent of the species potentially occurring in the study area, including a wide assortment of species, including a diversity of taxonomic groups, life history characteristics, and many management indicator species and species of concern. The field test also demonstrated that indeed it is logistically feasible and economically efficient to implement multiple primary protocols concurrently at sites over the course of a spring and summer field season. Site integrity was not compromised and survey methods were staggered throughout the season so they did not interfere with one another.

Promising Applications

In addition to MSIM's primary objectives of monitoring the status and trend of a breadth of species and communities, the protocol has the potential to yield many other substantial benefits that meet key land management information needs. In brief, species-related benefits of empirical data generated by the MSIM protocol in the first five years of monitoring could include the following (see Manley and others 2004 for more detail):

1. Identify and evaluate specific conditions of concern and interest, such as habitat thresholds beyond which populations may experience precipitous declines (for example, Fahrig 2002; Flather and Bevers 2002);
2. Provide new scientific information and understanding about community structure and dynamics under a wide variety of environmental conditions and changes over time;
3. Distribution data and models of suitable habitat for some species based on correlative relationships between species presence and environmental characteristics;
4. Provide basic data to empirically derive indicator species based on 1) the co-occurrence pattern among species and 2) the association between species occurrence and environmental features (for example, vegetation, disturbance); and
5. Evaluate and test existing or proposed indicator species or species groups.

Over the course of 10 or more years of implementation of the MSIM protocol, additional species-related benefits could be realized:

1. Improve the design and efficiency of population, habitat, and community monitoring programs over the course of their implementation;
2. Identify potential effects of management actions or natural disturbances on populations and habitat conditions;
3. Provide insights into the potential effects of changes in populations on community structure and dynamics, thus providing a broad-scale context for focusing research to inform management; and
4. Validate trends indicated by other large-scale inventory and monitoring programs, such as GAP (Scott

and others 1993) and Breeding Bird Survey (Droege 1990).

This broad-scale multi-taxonomic monitoring strategy can readily serve as a platform for many topic specific monitoring needs. For example, the U.S. Forest Service has identified four primary threats to the integrity and sustainability of National Forest System lands: fire and fuels, invasive plants, fragmentation, and unmanaged recreation. Implementation of the MSIM protocol across all NFS lands could provide valuable data on the status and trends of these threats and their ecological consequences. Fried and others (2003) demonstrated that FIA data can provide a valuable source of data to assess ecological dynamics, in this case by analyzing pre and post treatment on the effects of fuel treatments on residual biomass. Another example of the utility of FIA-based data is the status and trends of wilderness ecosystems throughout the country. The U.S. Forest Service and others are embarking on a system-wide monitoring effort evaluate compliance with the Wilderness Act (1964) and associated agency policies in terms of the status and trend of wilderness character (Landres and others 1994; USDA 2004b). Threats to wilderness character include exposure to and effects of modern human impacts. Plant and animal populations and communities are a major component of the wilderness experience, and the MSIM protocol could readily provide a sound foundation of biotic data for evaluating wilderness character at bioregion, biome, and national scales.

In conclusion, the MSIM protocol holds a great deal of promise in its ability to meet a wide range of valuable and timely scientific and management-related biodiversity information needs at a range of relevant scales in a cost effective manner. Implementation of the protocol at the ecoregional scale is a logical next step toward refining and optimizing the protocol to best meet the needs of the U.S. Forest Service, other public land stewards, States, and the country in conserving and monitoring plant and animal species, communities, and biological diversity.

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General Direction of the National Center for Environmental Research and Training (Cenica)

A. P. Martínez Bolívar, Director of Research in Air Quality Monitoring and Analytic Characterization of Pollutants
J. Zaragoza Ávila, O. Fentanes Arriaga and S. Hernández Millán, Direction of Research in Air Quality Monitoring and Analytic Characterization of Pollutants, CENICA Tecamachalco/INE/SEMARNAT, Boulevard El Pípila No. 1. Col. Lomas de Tecamachalco, C.P. 53950, Naucalpan de Juárez, Estado de México. MEXICO
V. J. Gutiérrez Avedoy is the General Director of the CENICA, CENICA /INE/SEMARNAT, San Rafael Atlixco No. 186 Col. Vicentina Delegación Iztapalapa, C. P. 09340 UAM-l Edificio de Ciencia y Tecnología Ambiental "W"

Abstract—*The National Atmospheric Monitoring Program (Programa Nacional de Monitoreo Atmosférico - PNMA) is the answer to one of the main priorities of Mexico's Ministry of the Environment and Natural Resources (SEMARNAT) for its linkage to other sectors of the administration. Under a transversal scheme, this program proposes to create links with the various municipalities and Mexican States that currently have air quality monitoring systems, as well as with other branches of the Federal Government, in order to promote programs to inform and create awareness in the population, establish financing schemes and support local monitoring efforts, by strengthening their institutions and providing procedures, among others. Its main objective is to Establish an air quality monitoring program to guarantee adequate diagnostic and surveillance of air quality at the national level; to generate information that is real, valid, and comparable among the different sites and air quality networks in the Country which would serve as a foundation for the design and establishment of environmental policy for the protection of the health of the population and the well-being of ecosystems. This program is divided in three different stages with specific objectives, which upon implementation will serve as basis for the following stage. The first stage is the analysis and development of tools, where PNMA's main task is to produce a diagnosis of the current state of the air quality monitoring networks in the Country, and of the laws, institutions, and financial mechanisms that support them. Also, this stage focuses on the development of tools and/or procedures that will guide air quality monitoring practices at the national level, in order to guarantee quality systems and comparability of data. The second stage is the establishment of strategies for identifying the sites where it is a priority to instrument air quality monitoring programs. These strategies include the identification criteria, the launch of awareness and information campaigns, and the implementation of the various states' monitoring plans. Finally, the third stage, where the tools and strategies are applied to: monitor air quality in priority sites; obtain the homologation of monitoring practices; establish quality assurance and control programs which guarantee the veracity of the data generated by these air monitoring systems; and to set up national surveillance programs through audits. Last, this stage would help create a proposal for a Second National Atmospheric Program that would include countrywide multi-pollutant and toxic pollutants' monitoring networks in areas where the existence of these pollutants is suspected.*

Introduction

During the past three decades of environmental management, several programs have been established to control and diminish the air pollution levels in the main urban centers of Mexico since the 1970's and, more recently, in some medium-sized cities.

As of today, 18 locations in the Country are being monitored by automatic equipment and 24 others are being monitored manually. There is also monitoring by private and state companies, such as CFE and Pemex. The main pollutants are being measured, such as Sulfur Dioxide (SO_2), Carbon Monoxide (CO), Suspended Particles (TSP, PM_{10} and $PM_{2.5}$), Nitrogen Oxides (NO_2 – NO - NO_x), Ozone (O_3), Lead (Pb), Hydrogen Sulfide (H_2S), Heavy Metals, Sulfides, Nitrates, and other parameters such as solar radiation and atmospheric deposits, both dry and wet. Also, there is equipment for the determination of meteorological parameters, mainly wind direction and velocity, ambient temperature and humidity, which, associated to the pollution levels, ease the analysis of inverse trajectories and the prediction of future concentrations of the pollutants at ground level.

There are, nonetheless, within the Mexican Territory, areas that require greater attention, such as towns with a high degree of industrialization, areas at environmental risk, and degraded areas classified as critical, among others. Also, there is a need for local governments and communities to increase their efforts to obtain dependable information regarding the concentration of pollutants, their sources and effects in these places, a must for making decisions regarding the protection of health and ecosystems.

Monitoring the air quality is fundamental to identify and provide the necessary information to evaluate the air quality of each region and its trends, as a tool to develop control and prevention strategies, air quality management plans, and integral environmental policies, among other applications. Because of this, a decision was made to develop a National Program of Atmospheric Monitoring to define the practice of air quality monitoring, to establish monitoring sites of national interest and to guarantee its quality.

Program

Following is a summary of the National Program of Atmospheric Monitoring (PNMA), whose main objective is the institution of a program for air quality monitoring that will guarantee a diagnosis and vigilance of the air quality at the national level which in turn will generate real, valid and comparable information between the different sites and networks in the Country, as a fundamental instrument for the establishment of environmental policies to protect the health of the population and the ecosystems.1

Because of the reach, diversity, and cost of instituting a program such as this, specific objectives were established through a process split in stages with definite time spans. So, the program consists of three stages whose specific objectives and interactions are summarized in figure 1.

Stages

First Stage (Short Term, From 2003 to 2004)

During this first stage the actual state of the air quality networks and monitoring stations of the Country is to be evaluated, as well as their legal support, assistance from institutions and finance sources to establish a diagnostic and national requirement. Also, the procedures that will rule the practices of air monitoring will be established at the national level, setting up a Reference Framework for Air Monitoring Procedures. The main objective of this stage is diagnosing the present situation of the monitoring networks in order to identify the fundamental requirements of the monitoring systems and their strengths and weaknesses, in order to develop strategies to strengthen them.

1. *Diagnosis of the present situation of the air monitoring networks at the national level.*

To carry out this work a questionnaire has been designed that includes technical information of the tools that constitute the monitoring systems, administrative information and information on resources and operation problems for each monitoring system.

State laws and rules will have to be compiled and reviewed, as well as those of a regional or local character if they exist, and also the air quality plans and control programs. With this information, the needs and weaknesses of the legal framework at the federal, state and local level in the subject of air quality monitoring will be identified.

State governments and, if possible, municipal governments, will be asked to provide information on the institutions in charge of environmental management within their territory, in order to establish the needs and required strengthening of the institutions within each region to establish Air Monitoring Programs.

From the information obtained in the questionnaire, in which sources of financing for the existing air monitoring networks will be identified, a review and update of the finance instruments or strategies that have supported the development of these networks will be carried out,

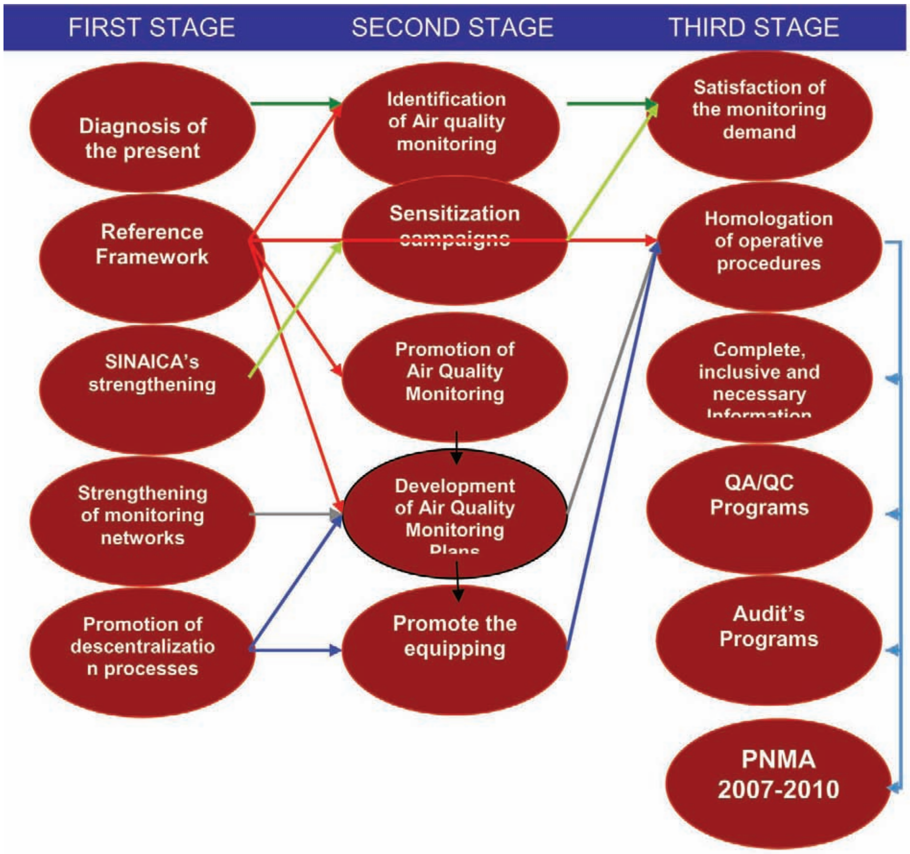

Figure 1. National Program of Atmospheric Monitoring (PNMA) stages.

new possible national or foreign sources of funds will be identified and strategies or financial instruments applied in other countries will be identified, such as funds, taxes, penalties, compensations, emission-exchange mechanisms, permits, credits and others, establishing conceptual designs of financing schemes, in order to organize a range of possibilities for the financing of the institution, operation and maintenance of the monitoring systems.

The feasibility of establishing, in the long run, a market of credits or bonds for the reduction of emissions in which the cities might exchange a reduction of emissions within their territory for additional benefits from the Federal Government will be analyzed. Air quality monitoring would have a leading role in the verification and auditing of these reductions. These emission credits might be commercialized internationally in accordance with strategies and policies established in this regard.

2. *Establishment of the reference Framework for Air Quality Monitoring Procedures.*

In order to establish a reference framework to standardize monitoring practices, data handling and information distribution that will serve as a guide to reach a quality monitoring system at the national level, during this stage the Reference Framework for Air Quality Monitoring Procedures will be developed. This framework will provide, as mentioned before, the basis for the unification of procedures at the national level, supplying the tools required for the establishment of quality standards that will make possible the comparison between air quality monitoring systems. For this purpose, with the aid of the Japanese Agency for International Cooperation, JICA, and based on EPA documents, six manuals are being developed, which include:

- Goals and components of the air quality monitoring systems.
- Design of the installation of air monitoring systems.
- Operating instructions for the air monitoring systems.
- Maintenance and calibration of air monitoring systems.
- Quality control and quality assurance of air monitoring systems.
- Federal procedure for auditing air monitoring systems.

3. *Strengthening of the Air Quality National Information System (SINAICA)*

Also, during this stage, the Air Quality National Information System (SINAICA) is being strengthened, in order to establish an integral management system of the air quality data generated in the Country. The SINAICA is an ongoing project that gathers and distributes through the web page of the National Ecology Institute, http://sinaica.ine.gob.mx/presentacion.html, the data generated by the main automatic air quality monitoring networks of Mexico in order to publicize the current and historic situation of the air quality in different cities in the Country. This information is openly available through the Internet, being useful for specialists in the subject, researchers, employees from the three levels of government, the private sector, and general population interested in finding out the levels of concentration of critical air quality pollutants. Currently, it includes information on air quality from the monitoring networks from the metropolitan areas of the cities of Mexico, Guadalajara, Toluca and Puebla. During 2004, INE's monitoring stations and the air quality monitoring networks from Salamanca, León, Celaya, Irapuato, Monterrey, Ciudad Juárez, Tijuana-Rosarito-Tecate and Mexicali are being included. In the long run, the SINAICA should be the institutional medium that integrates the data from all the air quality monitoring stations in Mexico, including both continuous and manual, and public and private measuring stations from sites of national interest.

4. *Strengthening of air quality monitoring and evaluation of the capacity of the cities currently participating*.

During this stage, the monitoring of the air quality in Mexico will be strengthened, promoting the updating of the networks and their equipment when required, in accordance with the results obtained with the diagnosis. The Federal Government will offer technical support in the design of programs to strengthen the current monitoring systems and will also look for financial mechanisms to support them. It also includes the formalization of transfer agreements and safekeeping of the equipment that several sites have received form the Federal Government.

5. *Promotion of the decentralization processes*

Promoting the formalization of agreements for the transfer of responsibility over the equipment to the state authorities will commit them to take charge of its installation, operation and maintenance. This would promote the observance of the decentralization programs.

The duration of the first stage would be one year. Its activities and tasks are listed in table 1.

Products:

- Diagnosis of the current state of air quality monitoring and its projected future potential. Inventories of monitoring networks and stations and their equipment, current situation of rulings, institutional framework and finance sources.
- Conceptual design of finance schemes
- Reference Framework of Procedures for Air Quality Monitoring for the validation of instruments, networks and systems and the coordination of the efficient handling of data and the distribution of reliable information, such as:
- Criteria for the design of monitoring networks.
- Protocols for operation, maintenance, calibration and data handling.
- Criteria for quality assurance and quality control.
- Criteria for the evaluation of air quality monitoring systems.
- Strengthening of SINAICA
- Training programs
- Agreements for the transfer of measuring equipment to the states or municipalities that have received them.

Second Stage (Medium Term, From 2005 to 2006)

During the second stage of this program the criteria and strategies for the determination of the sites which require air quality monitoring will be defined. Required networks and their equipment will be defined, having in mind items like institutional and legal strengthening in accordance with state and municipal governments, so that plans for the instrumentation of state monitoring programs be developed. The main objective is the determination of those sites that require air quality monitoring in Mexico and the setting of priorities. Needed activities include the following:

6. *Identification and prioritization of the sites which require air quality monitoring in Mexico*

This strategy requires, in the first place, the definition of criteria for the determination of those sites where it is required to establish an Air Quality Monitoring Program. Among these criteria will be the socio-economic characteristics of the site, its climatic and topographic characteristics and the claims from the inhabitants. Also, non-complying and high risk areas will be designated, as well as areas that require special attention, which will be given priority. Once the criteria are defined, an investigation will be made to identify the areas or sites that require air quality monitoring in the Country. From these areas, priorities will be selected based on the impact on the population or the environment.

7. *Support of campaigns for the sensitization and promotion of the importance of establishing Air Quality Monitoring Programs*.

This strategy foresees the design of a model of sensitization and awareness to promote the participation of the population in the solution of environmental problems, with the support of other Government Departments such as the "Secretaría de Educación Pública" and, potentially,

Table 1. Short term activities (First Stage).

Short term objectives	Activity	Task
1. Diagnosis of the present situation of the air monitoring networks at the national level	I. Gather and update the information at the national level	1. - Take inventory of the Country's monitoring networks. 2. - Take inventory of the equipment in the Country's monitoring networks. 3. - Analyze the handling of air quality monitoring data.
	II. Analyze the legal basis and the institutional development	1.- Review the legal framework 2. - Define legal requirements 3. - Review the institutional framework
	III. Identify finance sources and mechanisms	1.- Identify finance sources and mechanisms 2. - Find new finance sources and mechanisms 3. - Establish alternatives sources of financing
2. Establishment of the reference Framework for Air Quality Monitoring Procedures	IV. Establish the reference Framework for Air Quality Monitoring Procedures	1. - Define protocols for the design, operation, maintenance, and calibration of networks and data handling. 2. - Establish criteria for quality control and assurance. 3. - Define procedures for the evaluation of air quality monitoring systems. 4. - Define requirements for data handling and information distribution at the national level. 5. - Establish the National Reference Framework for Air Quality Monitoring Procedures 6. - Establish norms and regulations. 7.-Evaluate the main monitoring networks in the Country.
3. Strengthening of the Air Quality National Information System (SINAICA).	V. Strengthen the Air Quality National Information System (SINAICA).	1. - Define the basis for strengthening the SINAICA 2. - Consolidate the SINAICA
4. Strengthening of air quality monitoring and evaluation of the capacity of the cities currently participating	VI. Strengthen and evaluate the capacity of existing monitoring networks	1. - Design programs to strengthen existing monitoring networks 2. - Offer technical support.
5. Promotion of the decentralization processes	VII. Foster the compliance with decentralization processes.	1. - Formalize transfer agreements for measuring equipment with those states or cities that have received them.

of international organizations. The goal is to promote collective actions for the improvement of daily life conditions of those involved.

The establishment of the model would be followed by the implementation of campaigns by the state governments, which may consist of workshops, talks and propaganda, among others. It will probably be required to design didactic material to support the development of community workshops. An increase in the awareness of the populace in environmental problems will translate into public pressure for the generation and dissemination of air quality data as a first step towards the development of environmental policies in accordance with the particular problems of each location.

8. *Promotion of the establishment of local, state or regional air quality monitoring programs through government, academic or private organizations.*

Together with the divulgation of information and the sensitization of the populace, it will be necessary to promote among the authorities and the academic and private organizations the development of monitoring programs to determine the actual state of the air quality in their localities. Both the decision makers and the pertinent organizations should be conscious of the environmental problems and particular risks of their districts.

The design and establishment of the monitoring program will vary from site to site, leaving the responsibility in the hands of either the department of ecology, urban development, health care or other government agency or to industrial, scientific or higher education organizations. Whichever is the case, it is a real necessity to involve those organizations interested in the planning, design and operation of the system. Because of this, there is a need for campaigns so that the different participants exchange information and reach a consensus and understanding of the environmental problems. These campaigns will be made through congresses, forums or interdisciplinary workshops.

9. *Support to the states in the development of their program of instrumentation of air quality monitoring in those regions that require it.*

This strategy foresees the strengthening and/or establishment of the legal framework that will commit each state to develop a State Plan of Air Quality Monitoring in the regions that require it. The review of the legal framework referred to in the first stage of this program will produce guidelines for the legal requirements in need of being strengthened or implemented. It is recommended that, together with the establishment of the required legal framework, criteria be defined to allow each state to determine and include in its plan or program the kind of environmental parameters that should be measured, the number of stations required, their location and their time and area coverage.

Likewise, measures will be taken to obtain and provide technical support from SEMARNAT to each state in the development of its State Air Quality Monitoring Plan in the regions that require it. The establishment of procedures in accordance with the Reference Framework of Air Quality Monitoring Procedures will be promoted.

10. *Promote the equipping of the air quality monitoring networks at the national level.*

Within this strategy, it is foreseen to develop and institute alternative methodologies for air quality monitoring, proven and validated by national and international organizations, in those regions where conditions do not permit the use of automatic instruments, to facilitate the adoption of monitoring programs.

Likewise, with alternative methodologies for air quality monitoring it will be possible to develop programs to promote the equipping of monitoring networks set to accomplish the particular goals of each region. The steps needed to design the programs will be included in the program model in which all details for their orchestration will be specified. Once again, the goal of these programs will be the guidance of air quality monitoring so it will fulfill the local needs of each community at a reasonable cost. These programs will be added to those for strengthening the established networks that were initiated during the fist stage and will continue throughout the three stages of this plan.

The duration of the second stage would be two years. Its activities and tasks are listed in table 2.

Products:

- National criteria for the identification of sites that require air quality monitoring.
- Location of the regions that require air quality monitoring in Mexico
- Selection of prior sites.
- Model of diffusion and sensitization
- Campaigns of diffusion and sensitization
- State programs for setting up air quality monitoring
- Programs to promote the equipping of monitoring networks

Third Stage (Long Term, From 2007 to 2008)

After having produced during the first stage the Reference Framework of Procedures for Air Quality Monitoring to standardize, evaluate and strengthen the air quality monitoring systems and to coordinate the efficient handling of data and the diffusion of reliable information in the Country, and having spread the information contained within this reference framework in the second stage, in order to develop strategies for setting up new systems of air quality monitoring it will be necessary the production of a program to coordinate the homologation of procedures and to support the different locations in the development of quality assurance and control programs that comply with the criteria established in the aforementioned reference framework. To verify the compliance of the established procedures, a program of vigilance and environmental audits will be defined which will evaluate the networks using local groups of regional accredited inspectors.

The main goal of this stage is to satisfy the demand for air quality monitoring from the sites identified as priorities. Likewise, to give continuity to the National Atmospheric Monitoring Program, during this stage a new National Program 2007 – 2010 will be designed in order to develop and establish regional networks for multiple pollutants.

11. *Satisfaction of the demand for air quality monitoring from the sites identified as priorities.*

Once the selection criteria for the sites which require air quality monitoring in the Country have been defined, and after selecting those sites which are classified as priorities, strategies to fulfill the demand for air quality monitoring of these will be applied, in accordance with the states' plans for setting up air quality monitoring which were defined during stage 2 of this plan. For this purpose, technical support and advice will be given to identify finance sources for the states in which these sites are located.

Also, in order to strengthen training and technical updating, the establishment of regional training centers

Table 2. Medium term activities (Second Stage).

Medium term objectives	Activity	Task
6. Identification and prioritization of the sites which require air quality monitoring in Mexico.	VIII. Identify and prioritize the sites which require air quality monitoring in Mexico.	1. - Establish criteria for the identification of locations that require an air quality monitoring program. 2. - Identify and prioritize sites
7. Support of campaigns for the sensitization and promotion of the importance of establishing Air Quality Monitoring Programs.	IX. Foster campaigns for the sensitization and promotion of the importance of establishing Air Quality Monitoring Programs.	1. - Design campaigns 2. - Implement sensitization and promotion campaigns.
8. Promotion of the establishment of local, state, or regional air quality monitoring programs through government, academic or private organizations.	X. Promote the establishment of local, state, or regional air quality monitoring programs through government, academic or private organizations.	1. - Organize congresses, forums, and workshops.
9. Support to the states in the development of their program of instrumentation of air quality monitoring in those regions that require it.	XI. Back the states in the development of their program of instrumentation of air quality monitoring in those regions that require it.	1. - Strengthen and/or establish the framework of rules that commit each state to develop a State Air Quality Monitoring Plan in those regions that require it. 2. - Define the procedure to support those regions that require it in the development of their State Air Quality Monitoring Plan.
10. Promote the equipping of the air quality monitoring networks at the national level.	XII. Foster the equipping of the air quality monitoring networks at the national level.	1. - Develop and institute methodologies adapted to the specific monitoring needs of the participating locations. 2. - Design programs to foster equipping.

will be promoted in those locations around which monitoring activities be concentrated which show a quality performance in agreement with the standards established in the reference framework, making use of the strengths and capacities of certain locations. Three regional centers might be established: Northern Border, Pacific Region and Southeast Region.

The regional centers will also offer guidance in the definition of strategies for the financing of equipping, installing and operating these networks, as well as alternative finance sources that will be established in agreement with the Federal Government and with national and international organizations. The regional center will serve as guide and facilitator in the negotiations that need to take place during the design, installation and operation of a monitoring system.

Likewise, the Federal Government might support the establishment of programs for equipping the air quality monitoring networks and stations, in accordance with the states' programs or plans for setting up air quality monitoring so that its demand will be satisfied in the locations identified as priorities.

12. Homologation of operative procedures at the national level.

The establishment of the Reference Framework of Air Quality Monitoring Procedures will allow the instrumentation of a program to coordinate the homologation of procedures at the national level and to support the different locations in setting up whichever measures are required.

The homologation of procedures at the national level will promote the compatibility and comparability of data and the validation of procedures between the different monitoring networks, will increase the quality and will permit the evaluation of monitoring practices, data handling and information spread, making the technical review programs and the nationwide audits more efficient.

13. Supply of complete, inclusive and necessary information for the rational management of air quality.

The supply of complete, inclusive and necessary information for the rational management of air quality will depend strictly upon the compliance with the monitoring goals set when the network or the system were designed.

The Data Quality Objectives derive from the monitoring objectives. The former are defined as the criteria that clarify the study objectives, define the appropriate types of data acquisition and specify the allowed error levels of potential decisions. The procedure to establish the DQO is one of systematic planning to generate enough air quality data to guarantee the use for which they were designed and, at the same time, improve the effectiveness of planning, the efficacy of design and the safekeeping of results (EPA 1998; EPA 2002).

One of the main tasks will be fostering the establishment of systematic planning procedures, like the procedure to establish DQO, to generate criteria with which can be evaluated if the data are of the correct type, quantity and quality to sustain the DQO (EPA 1994).

Once the criteria are defined, they will be spread through the regional centers, requesting an evaluation or estimate of the quality of the data obtained through the various monitoring systems, in order to verify the data's compliance with the DQO.

The review of the DQO, the design of the sampling process and the review of the monitoring system will show if the data obtained complies with the established goals. The validation of the monitoring systems and the data obtained will provide the guidance to review and establish the quality control and assurance programs for the data that will guarantee that these are of sufficient quality for the goals set.

The Federal Government will ask the main urban centers in Mexico and those networks whose data are included in the SINAICA to validate their monitoring systems providing them with the technical support they require. Guaranteeing that the information contained in the data transmitted by the SINAICA is complete, inclusive, and necessary for the rational management of the air quality will be a priority.

Distributing data that ensure high quality will allow more precise estimates of the levels and trends of urban pollutants and their potential effects in the ecosystems and in the population's health, which will provide better options for their reduction.

14. Supporting the Country's air quality monitoring networks in the review, or definition and institution of quality assurance and control programs.

Due to the fact that the measurement of the air pollution is carried out by different government agencies, groups and organizations with different equipment, number of stations and laboratories and with different monitoring objectives, the Quality Assurance and Control component is essential to guarantee any monitoring program, since it provides the certainty that the data produced comply with the requisites of the established standards, such as the data quality criteria set in the DQO.

Because of this, every organization or state involved in air quality monitoring must review and/or develop its Quality Assurance and Control program, describing the monitoring project, measurement requirements and defining the specific Quality Assurance and Control activities that must be applied to the project with the purpose of complying with its objective and the specified DQO. The Air Quality Monitoring Procedures Reference Framework, developed during the first stage, will guide the production and review of these programs.

Likewise, the regional centers will offer training courses and technical support for the development and inception of the quality assurance and control programs, and the Federal Government will support these regional centers. Those cities that do not have an air quality monitoring program, but would like to institute one, will also receive technical assistance.

15. Establishment of audit programs.

An audit is defined as the systematic and independent review and evaluation of the systems and activities that constitute a procedure to determine if the end products reach the specified objectives (EPA 1998). The Environmental Protection Agency defines several kinds of audits for established monitoring systems.

Based on national and international experience, the kind of audits that will have to be performed by every monitoring system in Mexico and their frequency will be determined.

The evaluation and characterization of the main monitoring networks in the Country started during this program's first stage will be an important information input for the establishment of the audit programs. It is suggested that the following audits be established (EPA 2000):

- Program of local and regional technical audits: Their purpose would be to verify the fulfillment of the quality control and assurance programs of the local and regional monitoring systems.
- Network review or inspection audits: Dedicated to verifying the observance of the established recommendations for the local monitoring systems.
- Performance audits: Through the application of this kind of audits an evaluation system of the performance of the measurement instruments of the monitoring systems would be established.

Once the audits to be performed throughout the monitoring systems in the Country and their frequency are defined, the authorities responsible for these will be designated at the state, regional and federal level.

A program will be established that will divide the Country in regions within which the audits will be developed and supervised. CENICA, with the support of the regional centers, will coordinate these audits. Also, through accreditation schemes, interested citizens will be able to participate in the process, being first accredited as private auditors to increase the efficiency of these procedures.

The compliance of the audit activity will have to be backed by highly qualified personnel. CENICA will offer excellent training supported by international environmental agencies.

The Federal Government will ensure the fulfillment of the regional audit programs and will verify compliance among regional centers and local monitoring systems.

Establishment of the National Atmospheric Monitoring Program, PNMA 2007 – 2010

Having diagnosed the current situation including the legal, institutional and financial requirements, and having established the tools to fulfill these requirements and strategies, the next phase of the National Atmospheric Monitoring Program, PNMA, will be designed to support the state plans for the institution of air quality monitoring and to provide the equipment that these plans will require.

Additionally, this program should introduce a model of technical support to include the tools, products, and strategies developed during stages 1 and 2 of this program, in order to continue providing guidance and technical assistance to the other monitoring networks already established in the Country.

This second phase of the PNMA 2007 –2010, should also foresee the design and institution of a national/regional network to monitor multiple pollutant conditions in the main metropolitan areas and in the rural or suburban areas that require it, as well as pollutants classified as dangerous or toxic in the areas of the Country where their existence is suspected or proved.

All of this effort will only make sense if it is possible to commit all participants in the institution and long term preservation of this program.

The duration of the third stage would be two years. Its activities and tasks are listed in table 3.

Products:

- National operative program
- Quality assurance and control programs.
- Audits' program
- National Atmospheric Monitoring Program, PNMA 2007 – 2010

Every specific objective of each stage results in activities and tasks required to reach the established goals. These activities and tasks, as aforementioned, are listed in tables 1, 2, and 3.

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Table 3. Long term activities (Third stage).

Long term objectives	Activity	Task
11. Satisfaction of the demand for air quality monitoring from the sites identified as priorities.	XIII. Satisfy the demand for air quality monitoring from the sites identified as priorities.	1. - Strengthen the programs for training and technical updating. 2. - Offer assistance in the identification of finance sources. 3. - Promote equipping programs
12. Homologation of operative procedures at the national level.	XIV. Homologate operative procedures at the national level.	1. - Establish a strategy for compliance with the Reference Framework. 2. - Develop standard procedures per monitoring type. 3. - Establish a single operation program.
13. Supply of complete, inclusive, and necessary information for the rational management of air quality.	XV. Supply complete, inclusive, and necessary information for the rational management of air quality.	1. - Establish criteria to evaluate compliance with DQO data. 2. - Spread evaluation criteria. 3. - Validate the main monitoring systems in the Country, especially those included in the SINAICA.
14. Supporting the Country's air quality monitoring networks in the review, or definition and institution of quality assurance and control programs.	XVI. Support the Country's air quality monitoring networks in the review, definition and institution of quality assurance and control programs.	1. - Review and/or define quality assurance and control programs. 2. - Start quality assurance and control programs.
15. Establishment of audit programs. audits at the national level.	XVII. Establish audit programs.	1. - Define the type and frequency of 2. - Design a national audit program.
16. Establishment of the National Atmospheric Monitoring Program, PNMA 2007 – 2010.	XVIII. Design the PNMA 2007 – 2010.	1. - Design the PNMA 2007 – 2010.

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Simulation Tools for Forest Health Analysis: An Application in the Red River Watershed, Idaho

Andrew J McMahan, Ecological Modeler, INTECS International, Inc., Ft. Collins, CO
Eric L Smith, Quantitative Analysis Program Manager, Forest Health Technology Enterprise Team, USDA Forest Service, Ft. Collins, CO

Abstract*—Software tools for landscape analyses—including FVS model extensions, and a number of FVS-related pre- and post-processing "tools"—are presented, using an analysis in the Red River Watershed, Nez Perce National Forest as an example. We present (1) a discussion of pre-simulation data analysis; (2) the Physiographic Information Extraction System (PIES), a tool that can improve the quality of stand level input-data prior to its use in FVS simulations; and (3) tools for output-data spatial analysis, including the Event Monitor ArcView Project (FVS-EMAP), the Westwide Pine Beetle Model mapping tools, and EnVision.*

Introduction

The focus of public lands forest management has recently shifted from emphasizing stand management to protecting and restoring ecosystems. Landscape level analysis is now an integral part of forest management. Coincident with this shifting focus has been a surge of computing and geographic information system (GIS) technology. Numerous computational tools—simulation models, such as the Forest Vegetation Simulator (Dixon 2003); GIS software, such as ArcView and ARCGIS; data recorders; database and spreadsheet software—are now readily available to land managers and their staffs. These technological tools can assist managers by providing realistic projections about what future conditions might be like under different management alternatives. They can also provide powerful and efficient interfaces that vastly improve our ability to understand natural processes and conditions.

Early development of landscape-scale modeling tools within the Forest Vegetation Simulator (FVS) "family" of models began with the Parallel Processing Extension (PPE; Crookston and Stage 1991). The PPE permits the simulation of stands altogether (in parallel) through simulated time—instead of serially (one stand after another). In FVS, parallel processing facilitates not only the simulation of landscape-scale managerial decision-making (for example, the scheduling of thinning treatments), but also the modeling of landscape-scale ecological processes, such as pest contagion and fire behavior. The Westwide Pine Beetle Model (FHTET, in press) is an FVS extension that takes advantage of the parallel processing capabilities of FVS by simulating, on an annual time step, between- and within-stand bark beetle contagion and bark beetle-induced tree mortality.

Though landscape-scale analyses of forest management projects are important and often necessary, applications of FVS to landscape analyses are often hindered by incomplete inventory coverage of the landscape. Statistical imputation programs and procedures are available to facilitate the "populating" of landscapes with tree list data that can then be processed by simulation models. One example is the Most Similar Neighbor (MSN) imputation program of Crookston and others (2002). Such statistical imputations greatly improve our ability to meaningfully simulate whole landscapes into the future. Although we did not use the MSN program, per se, in the Red River watershed analysis, we mention it here because (1) imputing tree data to polygons for landscape analyses can be a very worthwhile undertaking, (2) MSN is a good tool to do such imputations, and (3) it provides context for our description of the Physiographic Information Extraction Tool, a software program we developed as part of this landscape analysis project.

This paper describes processes involved and tools used in a landscape-scale analysis of forest conditions in the Red River Watershed (Nez Perce National Forest, Idaho; fig. 1). The project arose from local observations of increased tree mortality from mountain pine beetle (*Dendroctonus ponderosae*) and western root disease (*Phellinus weirii*), and associated increased fire risk in the Red River watershed. In April 2002, the Red River Ecosystem Analysis at the Watershed Scale (EAWS) Team, the Regional Forest Health Protection office, and the Forest Health Technology Enterprise Team developed a strategy to use simulation modeling to assist with the evaluation of current and potential future watershed conditions. The strategy was refined over the next few months, and completed within the year. This paper describes some of the procedures we used in the Red River analysis, and outlines, in more general terms, types of landscape-level ecological questions to which these tools can be applied.

The Red River project utilized a number of software tools. All of these tools are readily available through the internet. Proprietary software—ESRI's ArcView and ARCGIS software packages, and Microsoft's Access database and Excel spreadsheet software—while available at a cost to the general public, are available to all USDA Forest Service personnel as part of their standard computing environment.

Some software tools used in the Red River Analysis include:

- The Physiographic Information Extraction System (PIES)
- The base model Forest Vegetation Simulator (FVS)
- The Parallel Processing Extension to FVS
- The FVS Event Monitor
- The Structural Stage Model (an FVS extension)
- The WWPB Model (an FVS extension)
- The Western Root Disease Model (an FVS extension)
- The FVS Event Monitor ArcView Project (FVS-EMAP)
- Two WWPB Model ArcView-based mapping tools

Overview of the Red River Analysis Area

The Red River watershed is located in the Red River Ranger District of the Nez Perce National Forest, Idaho (fig. 1). It consists of all or part of thirteen management compartments, comprising approximately 103,000 acres (41,722 hectares). The biophysical classification of stands is represented predominantly by five habitat type groups (Applegate and others 1993; table 1). Tree species are predominantly lodgepole pine, grand fir, subalpine fir, Douglas-fir, and Engelmann spruce, with smaller amounts of western larch, western redcedar, and ponderosa pine. Several stands have had management actions performed on them since inventory. For the FVS simulations, no management was simulated because quantitative data (about removal or residual amounts) were not readily available.

Lodgepole pine stands in the watershed experienced significant mountain pine beetle (MPB, *Dendroctonus ponderosae*) activity in the decade leading up to this analysis. The most recent MPB outbreak commenced in the late 1990s, though significant MPB-induced mortality occurred at smaller spatial scales within the watershed during early 1990s (Randall and Wulff 2002). An earlier outbreak occurred in the mid 1980s, giving rise to much of the 1980s-era management and inventory activity. Additionally, laminated root disease (*Phellinus weirii*) is prevalent in the landscape. A primary objective of the study was to estimate potential future effects of these two disturbance agents on tree mortality, stand structure, and fuel loading.

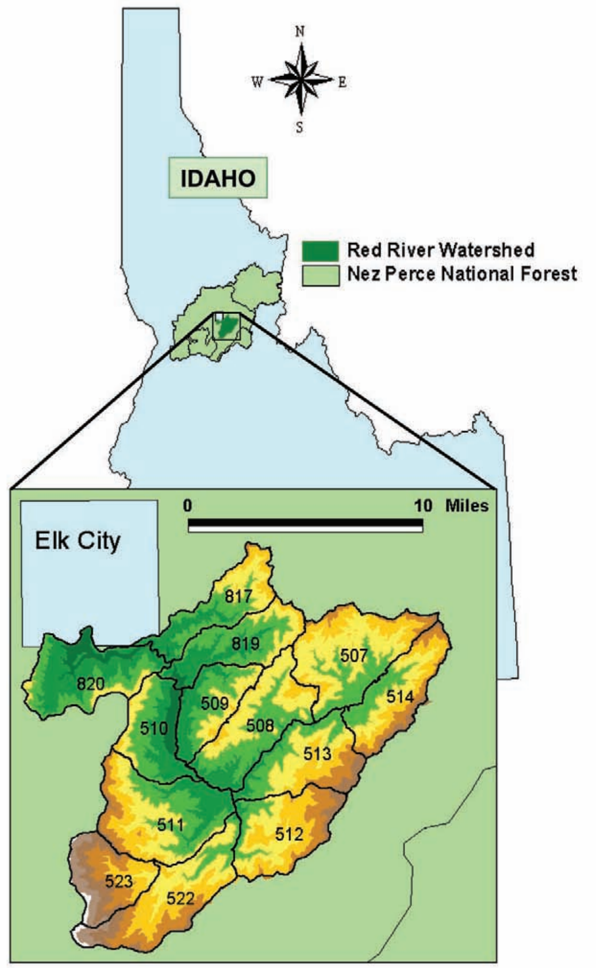

Figure 1. The management compartments of the Red River watershed. At the south end is compartment 522, depicted in subsequent figures.

Pre-simulation Processes

Gathering Data/Analyzing Current Conditions

We assembled numerous forms of data to help us characterize the landscape, including: stand exams, aerial photo-interpretation (PI) data, aerial detection surveys (for MPB), and tabular data characterizing stand-level

Table 1. Red River watershed stratification criteria. A stratum is a unique combination of one class from each of the four categories: habitat type group, forest type, size class, and percent canopy cover. Classes are defined by the Red River Ranger District's 1986 photo-interpreted GIS data-layer.

HTG number	Habitat Type Group (HTG) Definition
1	Warm and Dry PIPO or PSME/grass types
2	Moderately warm and dry PSME and dry ABGR types
3	Moderately warm and moderately dry PSME or ABGR types
4	Moderately warm and moist ABGR, Asaria, and Clintonia types
7	Cool and Moist Clintonia and Menziesia types
8	Cool and wet *Calamagrostis canadensis*, Equisetum, Galium, and Streptopus
9	Cool and moderately dry cooler ABLA and PICO types
	Forest Type
Class	**Definition: Plurality of overstory is composed of:**
1	*Pinus ponderosa* and/or *Pseudotsuga menziesii*
2	*Pinus contorta*
3	*Picea engelmannii* and/or *Abies lasiocarpa*
4	Mixed species
	Size Class
Class	**Definition: Stand QMD is:**
1	0-5”
2	5-9”
3	9-14”
4	>14”
	Percent Canopy Cover Class
Class	**Definition: Total Stand %Canopy Cover is:**
0	0-10%
1	10-40%
2	40-70%
3	70-100%

disturbance and management histories. Satellite data (heavily relied upon by MSN) were not readily available. Of the 3955 stands in the watershed, 1723 were inventoried at least once between 1981 and 1996. Essentially all of the stands were photo-interpreted in 1986 and again in 1996.

Using the 1986 PI data layer as a basis, we stratified the landscape by habitat type group, forest type, size class, and percent canopy cover. Within each of these four categories are PI-defined classes (table 1). Each unique combination of the classes, one from each of the four categories, represents a stratum; every stand falls into a stratum. For example, one stratum represents stands classed into HTG 3; forest type: lodgepole pine; size class: small sawtimber; percent canopy cover: 70-100 percent. The Red River watershed, as PId in 1986, comprised 216 strata.

The classification of the stands in the landscape into strata served two purposes. First, it guided our populating of stands with stand exam (tree data) for the modeling exercise (discussed in next section). Additionally, it provided a means by which to analyze current and historical conditions. For example, comparisons among 1986 and 1996 PI data layers, yearly aerial detection surveys (throughout the 1990s), and stand exam data (throughout the 1980s and 90s) can provide insight as to where conditions have recently changed, where future data collection might need to be concentrated, what portions of a landscape might be susceptible to MPB (or fire, or other agents), and where potential managerial problems might exist. Although our pre-simulation analysis did not specifically probe into these types of "current conditions" analyses, these types of geo-processing techniques can be extremely useful to address questions such as these. For our purposes, these pre-simulation analyses served primarily to guide our simulation model-building.

Imputing Tree Data to Non-inventoried Stands

To predict future landscape conditions using FVS, we needed to (1) establish a point in time to begin the simulations, and (2) describe the landscape at that point in time (that is, provide the model with appropriate tree data). We used 1986 as our simulation start year for a number of reasons, two of which are: (1) it is year around which most of the stand inventories were conducted, and (2) it is a year for which there exists a complete photo-interpreted vegetation classification data layer, spatially resolved at the stand-level.

After the stands were stratified (as described above), a representative stand exam from each stratum was chosen as a surrogate for the remaining un-inventoried stands in that stratum. (Methodologies behind how we chose a representative stand exam will not be presented here.) In cases where a stratum contained no inventoried stand, tree data from an inventoried stand in a similar stratum was used. We acknowledge that there are numerous methods available to populate the landscape. The MSN is one example of a (potentially) more rigorous approach. The method we implemented, although simple, is effective. Our imputation procedure resulted in a landscape fully "populated" with tree data. An extensive sensitivity analysis showed that the level of "accuracy" achieved by our imputation was sufficient to address the types of landscape scale questions that this project was attempting to answer.

Improving Imputations with PIES

Input data used by FVS typically consists of two "types" of data: individual tree measurements ("tree records", "tree data"), and stand-level physiographic information (slope, elevation, aspect, etc). Tree records represent the tree data that will be projected by the model. Stand level data consist of variables used in various ways by FVS. For example, tree diameter-growth rates in FVS utilize slope, aspect, elevation, and (in many variants) habitat type. Fire intensity in the Fire and Fuels Extension to FVS (Reinhardt and Crookston 2003) is strongly influenced by slope. Elevation can be a strong controlling variable on simulated beetle dynamics in the WWPB Model.

Typical imputation procedures (including MSN) often result in an imputed stand inheriting stand level data along with its surrogate tree data. In some cases, the inheritance of site data from a surrogate stand will contribute significant errors to model predictions because the inherited site factors are significantly different from those of the imputed stand. As GIS applications are becoming more sophisticated, imputing accurate physiographic data into simulations is becoming easier.

The Physiographic Information Extraction System (PIES) is a simple program that greatly improves the quality of physiographic data made available to FVS. The PIES utility writes GIS-extracted physiographic data into FVS-ready stand list files. (A stand list file is the data structure used by FVS to read in stand-level data.).

The PIES utility consists of two programs, one operating within a customized ArcView 3.x project (FVS-EMAP, discussed later); the other a simple FORTRAN-based program operating in Windows DOS. The utility requires both a polygonal layer delineating stand boundaries, and a raster-based elevation data layer (for example, a DEM). The PIES utility allows FVS users to extract up to five different physiographic data elements from their GIS: slope, aspect, elevation, habitat type, and area. The extracted stand-level physiographic data are then appropriately inserted into a stand list file (SLF). For imputed stands—heretofore non-existent in the SLF—PIES will create new SLF records. This new record will contain appropriate "pointers" to the imputed stand's surrogate tree data, as well as containing the imputed stand's GIS-extracted physiographic data. The PIES utility thus accomplishes two important functions for landscape analyses. It facilitates the creation of a complete-landscape stand list file. Secondly, it inserts into a stand list file physiographic information that is potentially more accurate than what would otherwise be available to FVS. The end result of our imputation procedures was an FVS-ready stand list file composed of records representing all 3955 stands of the Red River watershed.

Simulation Set-up

The Forest Vegetation Simulator (Dixon 2003; Van Dyck 2001) is a keyword driven model. Keywords are the means by which users provide instructions to the model. The keyword sets we developed for this landscape analysis involved many of FVS' numerous extensions. We present here a very cursory overview of the procedures we employed and extensions used. Further details about these simulations are provided in McMahan and Smith 2003.

The WWPB Model was used to simulate the effects of MPB in the landscape. We used aerial detection survey (ADS) data to guide our initialization of beginning-of-simulation beetle "population" levels. Specifically, the 1986 ADS provided estimates of trees per acre beetle killed, acres beetle-infested, and numbers of stands infested. We constructed the model's "beetle history" file—used to initialize beginning-of-simulation beetle conditions—to reflect the ADS-estimated conditions. Construction of keywords simulating environmental "stress events", used to initiate simulated outbreaks, was guided by historical climate data (using a Palmer Drought Severity Index) and expert opinion about typical temporal trajectories of MPB outbreaks. Lodgepole pine is the most abundant host to MPB in the landscape, with smaller amounts of ponderosa pine.

The Western Root Disease Model (Frankel 1998) was used to simulate the effects of laminated root disease (LRD, *Phellinus weirii*) in the landscape. Keyword sets parameterizing its behavior were developed by local pathologists. All tree species were modeled as potential hosts to LRD. Keyword sets were habitat type-group specific.

The Structural Stage Model (Crookston and Stage 1999)—an FVS extension—was invoked in order to calculate variables needed by a mountain pine beetle hazard rating (Randall and Tensmeyer 2000). The hazard rating was translated into FVS Event Monitor (Crookston 1990) "code" and included in the simulation. By having FVS calculate stand-level MPB hazard over simulated time, we provide a means by which to evaluate (1) the imputation procedure, (2) current conditions, (3) model behavior, and (4) the hazard rating system itself. These evaluations are accomplished via comparing the hazard rating estimates with aerial detection survey data, PI data, and model predictions of beetle-induced tree mortality.

We conducted a number of simulations ("runs"), including a "no pest" run, runs including both pest models simultaneously, and runs simulating each pest by itself. Because the focus of this paper is to demonstrate spatial analysis software, we present only a very brief description of numerical results.

Simulation Results

All simulations, including the base-model "no pest" run, predicted high levels of tree mortality. Tree mortality in the no-pest run represents density-dependent and/or "background" mortality, occurring mostly in small trees. Runs simulating LRD predicted high tree mortality rates throughout most forest types, in all but the smallest size-classed stands, and occurred predominantly in the first decade of the simulation. Runs simulating effects of MPB predicted high rates of mortality in the largest pine trees, concentrated in the larger size-classed stands, in the two pine forest types. Runs simulating both MPB and LRD experienced only slightly more mortality than did either of the single-agent runs alone (because there is much overlap in the trees killed by the two models.

Simulated MPB-induced mortality (in terms of basal area per acre) was highest in the pole-size-classed stands of the lodgepole pine forest type. At the landscape scale, MPB-induced mortality rates remained relatively low for the first decade of the simulation (1986-1996). A landscape-wide "outbreak" occurred during the simulation in the late 1990's continuing to about 2006. Some stands, however, experienced high rates of MPB-induced mortality early in the simulation.

The Red River watershed, as projected into the future by FVS, is a mosaic of stand conditions. Spatial analysis of this mosaic can lead us to a better understanding of the conditions. In the images presented in the following discussion, we focus attention on one compartment—522—to simplify the presentation.

Spatial Analysis of Simulation Output

Standard base-model FVS output data consists of tabular data representing stand-level estimates of tree growth and mortality, stand density, wood production, etc. Concatenating output from multiple stand runs provides landscape-level estimates of these metrics. Although such analysis provides useful information regarding means and ranges of output variables across the landscape, it is lacking in spatial evaluation.

Numerous software tools are now available to assist FVS users to spatially analyze simulation output. These include the FVS Event Monitor ArcView Project (FVS-EMAP, McMahan and others 2002), the WWPB Model Annual and Cycle Mapping Tools (AMT and CMT; FHTET), and EnVision (USDA Forest Service, Pacific Northwest Research Station).

The FVS Event Monitor ArcView Project (FVS-EMAP)

The Event Monitor (Crookston 1990) is part of FVS that allows users to schedule "activities" during a simulation. One type of activity that a user can schedule is the computation of various user-defined output variables over simulated time. For example, a user could enter into the simulation mathematical expressions, using stand-level metrics, to calculate a stand-level hazard rating. After processing, FVS makes available these output variables in a separate comma-delimited text file (indexed by stand number and simulation year).

The FVS-EMAP (McMahan and others 2002) facilitates the "joining" of these user-defined stand-level output variables to maps in ArcView. Figure 2 presents an example FVS-EMAP-generated map portraying a MPB stand hazard rating for compartment 522 in simulated-year 2001. The hazard rating was calculated within FVS by supplying the Event Monitor mathematical expressions representing the hazard rating algorithms of Randall and Tensmeyer (2000). Results show large contiguous areas of "moderate" hazard, and scattered areas of high hazard. Evaluation of the specific location of these high hazard areas, in context of the surrounding landscape, can provide a land manager with useful information—for example where control measures might be more effective or more important.

The use of FVS-EMAP requires that a user has an ArcView-based shapefile containing a polygonal layer defining stand boundaries, along with polygonal identifiers corresponding to the FVS stand identifiers. Using FVS-EMAP, one can efficiently produce time-series map

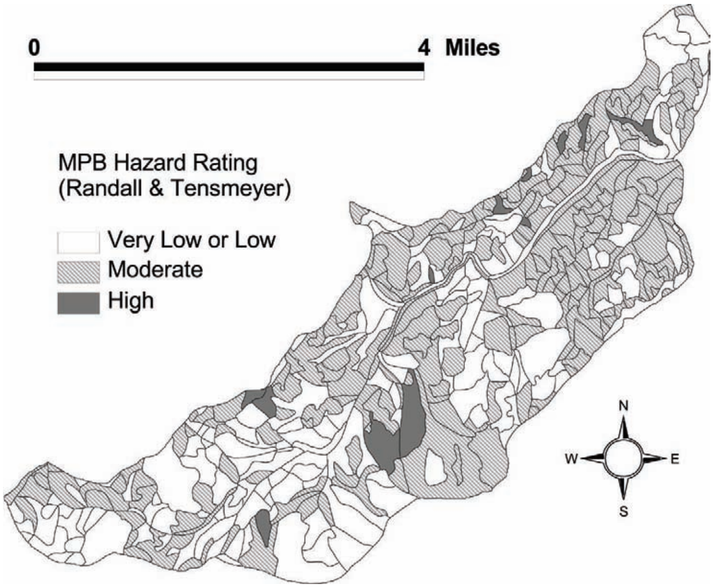

Figure 2. MBP hazard rating in simulation-year 1996. Map was produced using FVS-EMAP, using the Randall and Tensmeyer (2000) hazard rating system calculated within FVS via the Event Monitor. Results are from the run that simulated effects of MPB.

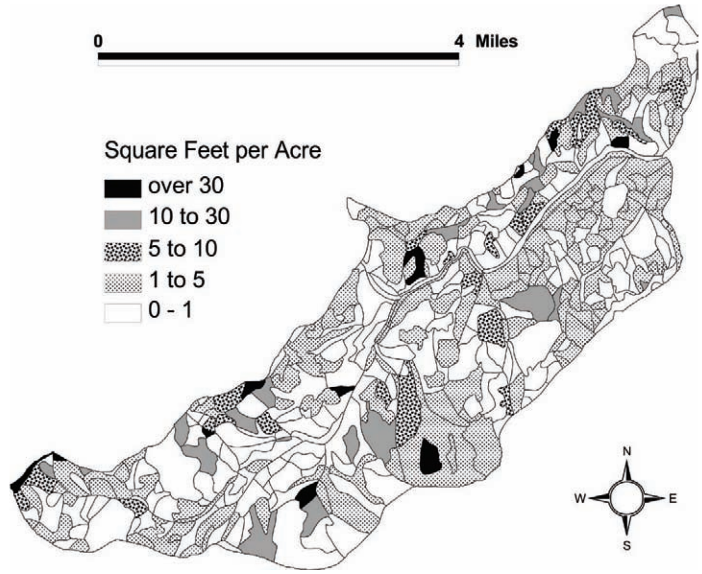

Figure 3. Simulated MPB-induced basal area mortality during the pre-epidemic period 1991-1995. Map was produced using the Westwide Pine Beetle Model Cycle Mapping Tool, using model results from the run invoking the WWPB Model (without the WRD Model).

displays of FVS model projections of any of the user-defined output variables. Once these data are joined to a GIS, numerous spatial statistical analyses can be performed. For example, habitat scores could be calculated via the Event Monitor, brought into ArcView via FVS-EMAP, and then spatial metrics such as habitat edge, connectivity, or fragmentation could be elucidated. Moreover, numerous other ArcView-based extensions—such as the Spatial Analyst, and the (freeware) Patch Analyst (Elke and others 1999)—could be used in conjunction with this application to help evaluate spatial data.

The WWPB Model Mapping Tools

The WWPB Model produces number of different output files containing data characterizing the simulated landscape. The WWPB Model mapping tools—the annual mapping tool (AMT) and the cycle mapping tool (CMT)—work very much like FVS-EMAP. The CMT reads FVS/WWPB Model output data from two WWPB Model output files written at FVS cycle boundaries and joins those data to an ArcView-based shapefile. ("Cycles" are FVS's time-units of projection, typically five or ten years.) The AMT reads and joins data from a WWPB Model output file that is written every projection year (within cycles). Maps produced using these tools can be useful for analyzing potential bark beetle behavior and effects across a landscape.

Figure 3, produced using the CMT, depicts simulated MPB-induced basal area mortality over the period 1991-1995, prior to the simulated landscape-wide epidemic. It shows that while most of the area is experiencing low "endemic" levels of simulated MPB, a number of stands (in black) have experienced high rates of mortality. Thus we see that what constitutes an "outbreak" is, to a large degree, scale-dependent. That is, the simulated landscape as a whole has not yet experienced an epidemic, but some individual stands have experienced epidemic levels of mortality. With these WWPB Model mapping tools, one can quickly produce time-series maps of simulated landscapes, facilitating the analysis of spatial trajectories of simulated outbreaks. Note that some of stands experiencing the highest rates of mortality during 1991-1995 have a relatively low MPB hazard rating in 1996 (fig. 2) because, by then, a large proportion of the host basal area in those stands has already been consumed by MPB.

EnVision

EnVision (USDA Forest Service, Pacific Northwest Research Station) is a landscape visualization tool that can produce realistic images of landscapes from grid-based elevational GIS data (used to build topographic terrain) and FVS output data (used to render vegetation) (fig. 4). This powerful program enables portrayals of viewsheds from virtually any defined point in space, and at different time steps. Further, because of its ability to utilize FVS-simulated tree data output, it enables rapid viewshed assessments of hypothetical management scenarios, or other simulation scenarios—for example,

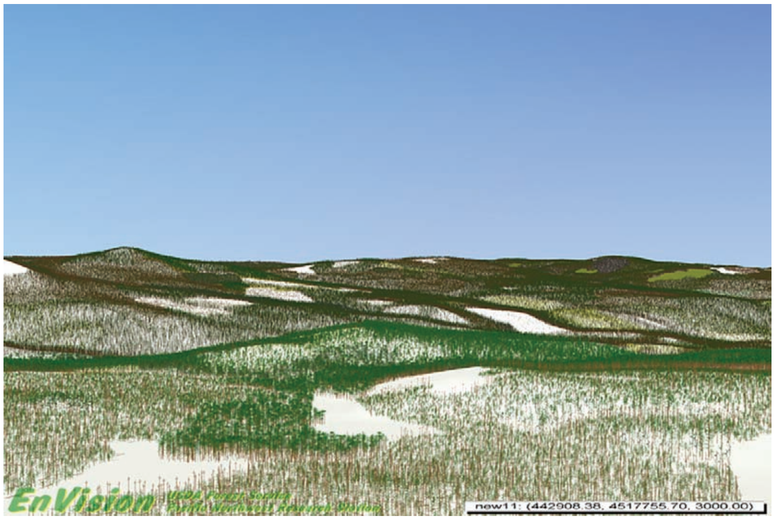

Figure 4. Landscape image produced using EnVision. Rendered tree data are from FVS-produced output tree data. Terrain data are from a raster-based elevational GIS. (Note: This image is not from the Red River watershed.).

post-wildfire. Such demonstrations are extremely useful for communicating scenarios to the public.

Discussion

Landscape analyses can be conducted at different levels of complexity (Smith and others 2002). For public lands managers, landscape analyses often need to be more complex than a mere accounting of landscape-level means or ranges (of condition classes, for example). Indeed, land managers are often interested in spatial distribution patterns across a landscape, including various "emergent properties" of such patterns, such as connectivity, fragmentation, and configuration (of condition classes, for example).

The Forest Vegetation Simulator is a powerful and continually evolving set of tools able to simulate a variety of ecological processes. While historically it was developed as a stand level analysis tool, the FVS—together with various pre-and post-processing tools and extension—is increasingly becoming a tool for landscape-scale analyses.

The tools presented here—PIES, the WWPB Model and associated mapping tools, FVS-EMAP, and EnVision—facilitate the process of "landscape analysis" by providing interfaces between geographic databases and the simulation model FVS. Such interfacing can vastly improve the efficiency with which managers and analysts can examine current and projected data.

In addition to the tools presented here, there exist other FVS extensions that further improve the capabilities of FVS as a landscape analysis tool. The Database (DB) extension to FVS (Crookston and Gammell 2004) greatly facilitates data handling at both the input and output "ends" of processing. The DB extension is now fully integrated into all FVS variants. Also, the linkage between the Parallel Processing Extension (PPE) and the Fire and Fuels Extension (FFE) has been recently completed. Although this linkage does not yet—by itself—permit the simulation of stand-to-stand fire contagion, the PPE-FFE linkage will certainly lead to vast progress in the realm of landscape-scale fire and fuels analyses.

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Integrating Fire, Climate, and Societal Factors into Decision Support for Strategic Planning in Wildland Fire Management

Barbara J. Morehouse and Gregg Garfin, Institute for the Study of Planet Earth, University of Arizona
Timothy Brown, Desert Research Institute, Reno, NV
Thomas W. Swetnam, Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ

Abstract—*An El Niño winter in 1998-99, followed by a strong La Niña winter in 1999-2000, set the stage for potentially large wildfires in the southwestern, southeastern, and northwestern forests of the United States. Researchers at the University of Arizona organized a three-day workshop to discuss the relationship between synoptic scale climate conditions and wildland fire probability. Over the three days, fire managers, fuels managers, fire ecologists, climatologists, and other experts began the task of not only learning from each other, but also figuring out how to talk to each other. The workshop exceeded the organizers' expectations and has led to the institutionalization of annual fire-climate workshops. The initial workshop also provided the foundations for a subsequent project, completed in July 2004, to build a GIS model that integrates fire, climate, and societal values in a manner that specifically supports strategic planning in wildland fire management. This paper describes the two parallel paths that emerged from the 2000 fire-climate workshop and discusses the benefits and challenges of interdisciplinary, collaborative research projects for building regional and local-scale sustainability in the face of multiple societal and natural stressors.*

Introduction

Millions of acres are at risk of wildland fire in the United States. The General Accounting Office has noted that, "Primarily as a result of human activities, ecological conditions on 211 million acres – or almost one-third of all federal lands and about 10 percent of the nation's total surface area – continue to deteriorate. According to a 2001 update of federal wildland fire management policy, these ecological conditions have increased 'the probability of large, intense fires beyond any scale yet witnessed'" (GAO 2002, p.8; for source of embedded quotation, Interagency Federal Wildland Fire Policy Review Working Group 2001). Statistics compiled by the National Interagency Fire Center (NIFC) indicate a sharp rise in acres burned and in suppression costs over the past decade (table 1) (see http://www.nifc.gov).

While over-zealous suppression is cited as one of the primary reasons for the problem, many other factors play a role. Climate can be influential in periodic, regional-scale fire regimes, and can be an important factor in fire use as well as fire suppression planning. Development of lands adjacent to and within wildland areas presents increasing challenges not only with regard to fire suppression and fuels management strategies, but also with regard to the nature and level of interactions with residents and interest groups who seek to influence wildland and fire management policy. Scientific advances in understanding the patterns, drivers, and impacts of wildland fire and its management offer opportunities for addressing the dilemmas facing managers, decision makers and the public alike. This paper chronicles two related initiatives, one to introduce climate into wildland fire decision-making processes, and the other to develop an integrated Geographic Information Science (GIS) model for use in strategic planning. Both projects

Table 1. Acres Burned and Suppression Costs 2000-2004 and 10-Year Average.

Year	Acres Burned	Cost
2004 (to date)	7,381,166	Not yet available
2003	2,695,156	$1,326,138,000
2003	6,334,283	$1,661,314,000
2001	2,904,868	$917,800,000
2000	6,482,016	$1,362,367,000
10-year average	3,193,463	

Source: National Interagency Fire Center, http://www.nifc.gov; accessed 9/1/04.

are based on an integrated, iterative conceptual model, described below.

Integrated, Collaborative, and Iterative Science for Decision Support

The research activities described in this paper draw on concepts of integrated assessment as a model for investigating questions, through scientific synthesis, that cannot be answered from a singular disciplinary perspective. Such research involves explicit efforts to deliver the resulting knowledge in ways that are useful to society for thinking about issues and making more informed decisions (CIESIN 1995, Parson 2995, Rotmans and vanAsselt 1996, Cohen and others 1998).

The Regional Integrated Science and Assessment (RISA) program within the National Oceanic and Atmospheric Administration's Office of Global Programs (NOAA-OGP), is an example of a program that supports regional integrated climate impacts assessment projects in several regions of the United States. RISA specifically supports experimentation in alternative structures and methods for carrying out integrated assessments and is one example of the types of funding programs that are explicitly interested in bridging the science-society gap. RISA focuses on determination of the impacts of climate variability and change and identification of ways in which climate information may reduce vulnerability and increase resilience and adaptation capacity. The program recognizes that "a variety of climatological, social, economic and ecological circumstances that interact over different spatial and temporal scales…" and details RISA research components as involving (1) interdisciplinarity, including syntheses of related scientific knowledge, (2) bridging the gap between climate and societal interactions on different temporal and spatial scales, and (3) development of decision support and services" (Pulwarty 2002).

More broadly, integrated assessment today constitutes an important mechanism for addressing compelling societal dilemmas, such as management of wildland fire, that occur in complex biophysical and societal contexts. Many of the assessments underway accord bridging the science-society divide a high priority, in recognition that significant benefits can accrue from close and sustained collaboration with entities ("stakeholders") who have a stake in the questions being addressed. In particular, iterative research models that encourage ongoing exchanges and interactions between stakeholders and researchers in the co-development of science and policy (see Jasanoff and Wynne 1998) provide a promising avenue for assuring not only that the science remains focused on pragmatic questions, but also that the products emanating from the research activity are relevant, useful, and usable (Baldwin 2000, Gibbons 2000). Indeed, high levels of iterativity have been seen as offering potential for greater innovation and, ultimately, greater societal utility and impact (Lemos and Morehouse forthcoming).

The research activities described in this paper were based on these types of iterative integrated research endeavors. The climate-fire-fuels forecasting effort was carried out under the auspices of the Climate Assessment for the Southwest (CLIMAS) project, funded through the NOAA-OGP RISA program described above (the current cooperative agreement number for CLIMAS is NA 16GP2578). Development of the Fire-Climate-Society GIS model was funded through a grant from the US Environmental Protection Agency's Science to Achieve Results (STAR) program (grant number GR-828732-01-0).

The following sections provide a brief background on climate and wildland fire in the US Southwest, and a discussion of how integrated, iterative assessment was directed toward accomplishing knowledge exchange and decision support through a series of fire-climate workshops, as well as through the Fire-Climate-Society GIS model project, which grew out of the first fire-climate workshop. The paper concludes with reflections on future initiatives that build on the synergies established through these endeavors.

Climate and Wildland Fire In The US Southwest

As noted above, wildland fuel conditions across the United States remain problematical. This is certainly the case for the Southwest: fuel loads in many areas are extremely high, forests are densely packed with small-diameter trees, and dead fuels litter the landscape. The wildlands of the region tend to be fire-adapted, reflecting centuries of recurrent fire patterns at local to regional scales. Today, forest managers and scientists explicitly recognize the positive role fire plays in promoting forest health (Brown 1985, Baker 1992, Covington and Moore 1994, Pyne and others 1996), though fire suppression remains a dominant factor in fire management operations. Far less well adapted are societal policies and practices, including many decades (50-100 years) of fire suppression policy, continued and accelerating land-use encroachments on wildlands, and public intolerance of risk and reluctance to allow any fire – and especially smoke – to affect their geographical areas of habitation, recreation, and work. Forested lands dot the landscape in

Arizona and New Mexico; all attract heavy recreational usage and livestock grazing occurs in many areas. Some logging also occurs but is generally not a major land or resource use at the present time.

In managing fire risk and assessing conditions for fire use in the Southwest, as elsewhere, managers routinely take fire weather into account. However, they have tended not to pay much attention to predictions made for monthly to seasonal and interannual time scales. By contrast, over the past decade, climatologists have improved their forecasting ability in some areas, including prediction of El Niños and La Niñas, and other scientists have determined that climate exerts an important influence on fire regimes in some areas of the United States. The El Niño-Southern Oscillation (ENSO) plays a particularly important role in modulating wildland fire risk in the US Southwest (fig. 1), as well as in the Pacific Northwest and the US Southeast (Swetnam and Betancourt 1998, Swetnam and others 1999).

Improvements in ENSO forecast accuracy and skill has opened the door to possibilities for introducing climate forecasts into strategic planning for management of wildland fire and for fire use (including timing and location of prescribed burns). ENSO-related climate conditions that began in the winter of 1997-1998 provided an unusually good opportunity to bring climate forecasters and fire/fuels managers together to initiate a dialogue on how climate information might be integrated into fire management decision processes. Researchers associated with the CLIMAS project partnered with fire ecology and climate specialists to organize a workshop aimed at facilitating this dialogue.

The Climate-Fire Workshops

El Niño brought unusually wet winters in the Southwest and Southeast in 1997-1998; the Southwest also experienced a very wet summer in 1999. These conditions produced regional abundances of fine fuels. The winter of 1998-1999 in the two regions, was, by contrast, unusually dry, due the effects of La Niña in those regions. By late summer 1999 it became apparent that the two regions would be likely to experience a second dry La Niña-spawned winter. Research indicates that such combinations of conditions have, in the past spawned regionally extensive fire seasons. Indeed, over the past 400 years, the sequence of a wet El Niño winter followed by dry La Niña winter conditions is closely correlated with extensive wildfire occurrences (fig. 2) (Swetnam and Betancourt 1998).

NOAA's Climate Prediction Center (CPC) issued a La Niña forecast for the winter of 1999-2000 with a high degree of confidence, prompting a decision to hold a workshop, under the auspices of CLIMAS, that would bring fire managers and researchers together with climatologists, meteorologists, and climate impacts researchers to discuss the implications of the forecast for fire management and more broadly to explore interactions between climate (defined as processes and observations occurring over time scales from a month to millennia; "weather" encompasses processes and observations occurring over time scales from immediate to about 3-4 weeks) and wildfire regimes.

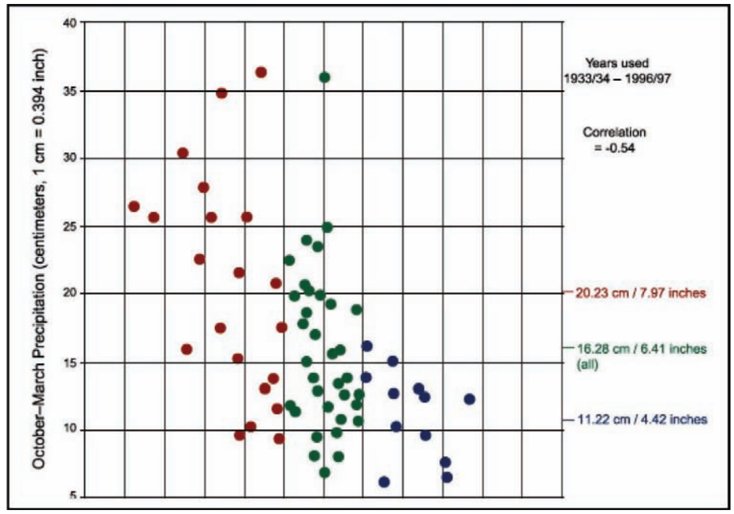

Figure 1. ENSO Patterns in the US Southwest. Source: Climate Assessment for the Southwest.

The initial climate-fire workshop took place in late February 2000, and included climatologists, fire managers, and fuel managers from the Southwest, Southeast, and Northwest, all areas that could potentially benefit from ENSO forecasts and other climate information products (see Morehouse 2000). The workshop afforded opportunities for climatologists to educate fire/fuels managers about what sorts of forecasts and other information were available, and what the climate forecasts for the coming fire season were, as well as some basics about the science behind the forecasts. In turn, the fire and fuels managers provided insights into their areas of expertise and activity to the climatologists. Fire profes-

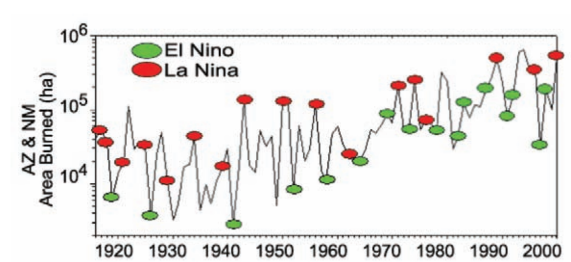

Figure 2. ENSO and Fire in the US Southwest.

sionals learned about the difference between "weather" and "climate," what climate parameters can and cannot be predicted, and which parameters have not yet been explored, and uncertainties associated with the science of forecasting, regional differences in forecasts. They also learned about issues associated with downscaling, particularly the point at which downscaling degrades data quality to an unacceptable level in terms of both time and space; and about what types of climate information can be usefully be applied at local scales. Climatologists learned from fire experts about topics such as the nature and practice of fire management, what types of climate information products fire managers want, what types of information are needed, and what research topics might be most productively pursued.

Information needs identified at the workshop included a call for "one-stop shopping" rather than having to thread one's way through a thicket of web pages; keeping a focus on commonly used products requested by the fire management community as well as new products; providing basic climate information at the regional level to allow assessment of climate norms and extremes; product and information guides pitched at the appropriate technical level; and more opportunities for interaction/feedback. Final recommendations included, among others, development of tools that integrate climate into environmental impact statement (EIS) processes and into large-scale National Environmental Protection Act (NEPA) planning efforts; development of tools for use in planning and decision making, including climate-fire regime modeling tools; and assignment of climatologists to teams revising land management plans. These latter recommendations inspired a group of UA researchers to write of a proposal to the EPA-STAR program to fund a three year project to develop an integrated fire-climate society GIS model (described later in this paper). Establishment of an ongoing, dynamic assessment process and holding another meeting of the workshop group were also suggested. These latter recommendations were addressed through two more years of workshops, followed by efforts to operationalize an annual fire-climate assessment process.

During the following year, 2000-2001, the organizers convened two workshops, with the goal of building on the success of the first year's endeavors (see Garfin and Morehouse 2001). While the climate forecasts for the winter season were not as compelling as those that had prompted the previous workshop, the devastating 2000 fire season, at that time the worst in 75 years, provided a strong impetus to reconvene for the purposes of further exploring the potential links between climatology and fire/fuels management. In addition, the higher level of uncertainty associated with the 2000-2001 winter forecasts provided an opportunity to explore the implications of inherent variabilities in climate forecasting skill and accuracy, topics of potentially critical interest to decision makers poised to integrate such information into their decision processes.

The first of the two workshops was held in mid-February 2001. Based on the previous year's experience, the organizers recognized a critical need to also inform individuals higher up in fire management organizational structures about the potential utility of climate information for fire management and the value of the interactions generated through the workshop process. For this workshop, regional-level representatives were invited from the fire management, fire research, integrated assessment, and climate science communities, covering much of the United States and Alaska. Members of the Joint Fire Science Program also participated. A second workshop, held in mid-March 2001, focused specifically on climate-fire linkages in the Southwest and adjacent area of Mexico, and on building relationships between southwestern fire and fuels managers and key climatologists.

The workshops occurred in a climatological context of persistently drier and warmer-than-normal weather prevailing over many of the nation's forested areas, leading in turn to record dryness of fuel loads in some areas. Reductions in spring rainfall, including a failure of May-June rains in the Northwest and northern Rockies, poor recovery of relative humidity and a general moisture deficit provided an unprecedented opportunity to continue the fire-climate dialogue. Workshop topics included examination of links between fire and long and short-term climate variations, communication and interpretation of forecasts and the uncertainties associated with those forecasts, and stakeholder-driven integrated assessment initiatives having a bearing on fire management. A retrospective look at the 2000 fire season, including the spring 2000 Cerro Grande fire in Los Alamos, New Mexico provided a focal point for discussion of the challenges facing fire managers and of potential uses of climate information for reducing vulnerability to damages caused by large wildland fires.

Presentations were also made regarding initiatives being supported by the Joint Fire Science Program and about integrated assessment activities, including a first introduction to the Fire-Climate-Society GIS modeling project, newly funded by EPA-STAR and formally initiated in February 2001. As with the previous year's meeting, recommendations for research and climate information development were proposed, including (among others) improvement in knowledge transfer processes and rationalization in delivery of information from disparate sources to make locating information easier; improvements in observation networks, data collection; data and database access at scales from local to global; more scientific analysis of key variables, such as wind and its association with synoptic climatology; better access to fire data (e.g., fire starts); research into linkages between climate and the Fire Danger Rating System; inclusion of climate into existing fire model software; and development of a climatology primer for fire managers and decision makers. While not all of these recommendations have been acted upon, the list remains an important source for identifying and supporting additional research and development efforts.

A third workshop was held in the winter of 2001-2002. This time topics included, in addition to climate forecasting, presentations on smoke modeling, improvements in long-range predictions for land management, a talk by a representative of a city fire department, and a special session on social science perspectives on fire. One output of the meeting was the first-ever climate-fire consensus forecast, developed in a side meeting by the group of climatologists who participated in the meeting. The meeting was important for cementing synergies within and among the climatology and fire management communities, and for reinforcing the links between fire scientists and managers more broadly.

The winter of 2003 saw a transition from the original workshop format to a national process collaboratively organized by the Predictive Services Office of the National Interagency Fire Center (NIFC) and CLIMAS. Persistent drought conditions throughout much of the US West provided a pivotal theme for the meeting (Brown 2003). The meeting, held in late winter 2003, brought together climatologists, fuels specialists, and fire meteorologists from the Geographical Area Coordination Centers (GACCs) to develop national and regional maps representing fire-climate forecasts for the coming fire season. The effort resulted in the first-ever integrated fire-climate-fuels forecast map, as well as forecast maps for each of the GACCs (Garfin and others 2003). The exercise was repeated in 2004, again resulting in production of special forecasts for fire management (fig. 3). The effort is now transitioning from an experimental effort under CLIMAS auspices to an operational effort under the headed up by NIFC's Predictive Services Office.

The workshop process and the operationalization of the fire-climate forecasting effort exemplify a successful employment of an iterative, integrated, and collaborative research process to address some of the multiple stresses decision makers regularly confront. The fire-climate forecasting process, which began as a process of exploration of potential common interests and synergies, has evolved into a process by which researchers, climate forecasters, and decision makers continue to meet to co-develop and co-produce forecasts specifically tailored for wildland fire management.

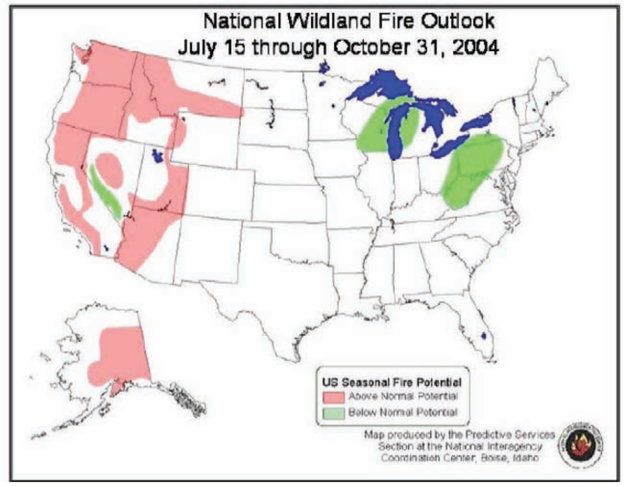

Figure 3. Example of National Wildland Fire Outlook. Source: National Interagency Fire Center, http://www.nifc.gov, accessed 9/1/04.

The Fire-Climate-Society Integrated GIS Model for Decision Support

As noted above, an outcome of the first fire-climate workshop was the writing of a research proposal to the EPA-STAR program to develop an integrated fire-climate-society GIS model to be used for decision support (Morehouse and others 2000). The project, funded for three years, involved an interdisciplinary team of researchers from the University of Arizona who represented fuels, climate, remote sensing, fire history, GIS, social science, and public outreach expertise. Over the course of the research and development process, Fire-Climate-Society, Version 1 (FCS-1) took shape as a GIS-based tool that could be used not only by fire experts but also by community members to explore fire risk conditions under different climate scenarios and component weighting schemes.

The model, which is supported on the University of Arizona's Wildfire Alternatives (WALTER) web site, allows users to construct maps at a scale of one kilometer (the lowest level to which climate data could be downscaled) for four specific study areas: the Catalina-Rincon Mountains adjacent to Tucson, Arizona; the Huachuca Mountains adjacent to Sierra Vista, Arizona and Fort Huachuca Army Base; the Chiricahua Mountains in rural southeastern Arizona, and the Jemez Mountains adjacent to Los Alamos, New Mexico.

The model includes two submodels, one representing fire hazard components, and the other representing values at risk components. The user selects a climate scenario from a special climate scenario selector, then proceeds to assign weights to the models components through pair-wise comparisons of the components within each submodel, then of the two submodels. Based on these inputs, the model produces maps of each component and each submodel, and a fire risk map that combines all components.

The WALTER web site also features options whereby stakeholders can organize group-level as well as individual participation in the modeling exercise. This feature is designed to foster communications about fire management issues not only across expert communities but also between expert and community groups. Development of FCS-1 involved highly interdisciplinary interactions among the project researchers and a series of iterative meetings with potential users of the model. These meetings were especially important for obtaining feedback early enough in the development process to allow adjustments and for identifying sources of information and insight not otherwise available to the team.

FCS-1 includes nine components, divided between two submodels. The fire hazard submodel includes five components: fire return interval departure, fuel moisture stress index, large fire ignition probability, lightning probability, and human factors of fire ignitions. The values-at-risk submodel includes four components: recreation value, species habitat richness, property value, and personal landscape values. A schematic of the model and details about each of the components are available on the WALTER web site (http://walter.arizona.edu). With this array of variables, FCS-1 goes beyond existing fire models that incorporate weather and in some cases basic economic variables to provide options based on climate scenarios relevant to the four study areas and to include a richer array of societally important values at risk from wildland fire.

Based on user input, FCS-1 produces fire risk maps that may be analyzed at multiple scales, ranging from the entire mountain range to a 1 kilometer^2 pixel. Users may experiment by running the model using different climate scenarios and/or different weightings in the pair-wise comparison of the model components, and they have the option of saving the maps they have produced so that they can refer to them later for purposes such as making detailed comparisons of the similarities and differences shown on the maps or for sharing results in group settings.

FCS-1 is accompanied by additional information on the WALTER web site, including an interactive explanation of key legal policies, dynamic vegetation maps, fire history maps, and a wildfire-climate regression tool. The WALTER web site itself is designed with usability very much in mind: navigation is easy, and strong effort was directed toward ensuring that the content is easily understood. Importantly, the model allows use of the kinds of climate forecasts developed through the fire-climate workshop process: the user consults the forecast for the coming fire season, and selects one or more closely analogous scenarios available for the model.

In explicitly seeking to draw ordinary citizens as well as experts into exploration of wildfire alternatives, the WALTER web site and FCS-1 represent an innovative approach to co-development and use of fire models through interdisciplinary research and development, and through collaborative iteration between scientists, decision makers, and community members in the four study areas. Both the web site and the model encourage exploration of how different factors influence fire risk, and provide a framework for participatory decision making processes. In providing a means, through climate scenario analogues, for reflecting climate forecasts in the running of the model, FCS-1 provides a direct connection with the ongoing fire-climate forecast initiative described above.

Conclusions and Looking to the Future

The fire-climate workshops and the FCS-1 modeling effort represent parallel but interconnected paths for linking science and society in a common effort to improve strategic planning for wildland fire management. In part, the success of these efforts derives from a confluence of events: climatic conditions posing high threat of fire risk, increased public awareness of the unsustainable conditions of the nation's forests, and heightened interest among governmental funding agencies in supporting efforts to bring science to bear on these problems. Success also derives from the willingness of scientists, fire managers, and other decision makers to commit to an ongoing, multi-year effort of collaboration and iteration to make sure that the multi-directional knowledge transfer process was maximally productive in terms of development of useful, relevant, and usable decision tools.

Good foundations have been set, but much remains to be done. Research needs range from improvements in knowledge about paleo, historical, and future climate variability and change to improvements in climate and fuels forecasting, vegetation modeling, fire emissions, fire-climate relationships, and understanding of ecological variability and change. Also needed are research efforts that explicitly take into account land use and land use changes, focus on continued development of state-of-the-art decision support tools, examine of decision processes associated with use (or non-use) of these tools, and assess the roles of human values, behaviors, and philosophies in heightening or diminishing wildland fire risk and vulnerability to fire impacts. In fire-climate-society integrated modeling, advances that need to be made include being able to integrate dynamical capabilities such as bringing real-time climate forecasts into the model and developing capabilities to integrate dynamical change in variables such as vegetation cover and fire perimeters. Expansion of the model to other sites, particularly within the Southwest is also a crucial future step.

Those who have participated in the fire-climate workshop and FCS-1 development activities are committed to continuing to build upon the existing iterative model of integrated research in support of decision making, and to sustaining the synergies that have been developed. Given the prospect of continued high fire hazard over the foreseeable future (GAO 2004, Westerling and Swetnam 2003, Dale and others 2001), the effort is an important one.

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Wildfire Mitigation and Private Lands: Managing Long-Term Vulnerabilities

Brian Muller, Assistant Professor, and Stacey Schulte, Doctoral Student, University of Colorado at Denver, College of Architecture and Planning, Environmental Design Building, Boulder, CO

Abstract—*Long-term management of wildfire vulnerability requires strategies that address complex interactions between fire ecology and human settlement. In this paper, we examine the integration of wildfire mitigation and land use planning in county governments in the western U.S. This research relies on data from two sources. First, we conducted a survey of land use mitigations in over 300 forested counties in the Western United States. Planning directors in each county were asked to identify and assess land use planning tools adopted in their county for the purpose of reducing wildfire risk. Second, we interviewed wildfire mitigation staff from 10 Colorado counties to better understand problems in implementation of land use mitigations. We find that many forested counties across the Western U.S. have adopted land use mitigation programs focusing on regulation of new subdivisions and public education. Many fewer counties have adopted regulatory programs focusing on existing structures or development of individual parcels outside subdivisions. Rapid rates of development outside subdivisions may pose substantial, continuing wildfire risks in Western U.S. counties that are not addressed in many land use mitigation programs.*

Introduction

During the past five years the western United States has incurred increased economic and social costs due to wildfire. In this period billions of dollars have been spent on fire suppression, hundreds of structures have burned and many firefighters have lost their lives (NIFC 2004). One of the primary reasons for the increased costs of wildfire is development in the wildland-urban interface (WUI). With high rates of development over the past three decades many WUI communities in the Western United States are increasingly at risk for loss of property, life, and scenic value. In response to increased exposure to wildfire, hundreds of communities have developed strategies to alleviate wildfire danger through planning and public education. This paper examines the impact of wildfire mitigation planning based on interviews in 10 Colorado counties and survey data from 300 counties in the western U.S.

Background

As fire-prone areas become more populated an increasing number of individual and social assets are exposed to wildfire. In addition to firefighting, the social costs of wildfire include other emergency response expenses, mitigation, property loss by individuals, loss of natural resources and loss of human lives. In 2000 alone, over eight million acres of public land burned; suppression costs were over $1.3 billion; 731 structures were destroyed; and sixteen firefighters died (National Interagency Fire Center 2004). The arid Intermountain West lives under persistent threat from wildfire and is also the fastest growing region in the country.

Communities address wildfire vulnerability through emergency response and mitigation. Mechanisms for emergency response are well established but increasingly expensive as more and more homes in mountain communities need to be protected. Mitigation programs are less well established but are the focus of discussion in many communities as they look for ways to diminish the danger and cost of wildfire. Mitigations are often promoted by fire chiefs who see that the danger posed by development in high-risk areas may exceed their capacity to respond. Federal Emergency Management Agency (FEMA) regulations encourage communities to adopt plans for hazards that include land use mitigations. The Hazard Mitigation Grant Program and the Pre-Disaster Mitigation Programs call for communities to have locally adopted, all-hazard mitigation plans by November 1, 2004 in order to be eligible for mitigation grant money (FEMA 2004). While these regulations are expected to generate a considerable number of new plans, many land use-related wildfire mitigation programs are already in place.

Prior research offers conflicting perspectives on the value of land use strategies in wildfire hazard mitigation. A study of wildfires in California found that no homes were lost in communities with comprehensive wildfire planning; a number of structures were lost in communities that had not adopted land use planning or regulation designed to reduce wildfire impact (Rice and Davis 1991). Other research suggests that site and building codes are more effective than land use controls in reducing damage from wildfire (Scott 1995). Studies of building site and construction show that defensible space (Manning 1990, Ramsey and Dawkins 1993, Wilson and Ferguson 1986) and roof material (Foote 1994, Rice and Martin 1996, Wilson 1988, Wilson 1962) are effective means of reducing structure loss from wildfire.

Study Method

This paper is part of a larger effort to evaluate the influence of wildfire mitigation on land use planning practices in county governments. In this paper, we review the types of land use mitigation programs adopted at a county level over the past decade and their implications for reducing risk. This research is based on two data sources. In the spring of 2004 surveys were sent to over 300 county planning directors and wildfire mitigation coordinators in California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Washington and Wyoming. In order to target those counties with highest wildfire risk the survey was limited to counties containing U.S. Forest Service land. Respondents were asked to identify and evaluate land use planning tools that are used to reduce wildfire risk. They were also asked to describe risk assessment, the structure and financing of their programs, implementation and effectiveness. The statistics below are based on a 57 percent response rate. The second data source is a series of interviews conducted with officials from county planning departments, building departments and fire districts in 10 Colorado counties (tables 1 and 2). In Colorado, the catastrophic fire season of 2002 motivated many communities across the state to develop wildfire mitigation programs. The objective of the interviews was to find out how counties are responding to increased

Table 1. Subdivision Regulations by County in Ten Colorado Counties.

County	Emergency Access	Defensible Space	Building Standards	Building Site Location	Firefighting Water Supply
Archuleta	x	x		x	x
Clear Creek	x	x		x	x
Delta	x		x		
Eagle	x	x	x	x	x
Gunnison	x*	x*			
La Plata	x	x			x
Ouray***	x	x	x	x	x
Routt	x	x	x*	x	x
San Miguel					
Summit	x	x	x		

Table 2. Individual Property Regulations by County in Ten Colorado Counties.**

County	Emergency Access	Defensible Space	Building Standards	Building Site Location	Firefighting Water Supply
Archuleta					
Clear Creek		x	x*		
Delta					
Eagle	x	x	x	x	x
Gunnison					
La Plata					
Ouray***	x	x	x	x	x
Routt	x		x*		
San Miguel					
Summit		x	x		

*only in overlay zone
**does not include regulations for renovations
***regulations based on point system

wildfire hazard, how effectively land use measures are working from the perspective of mitigation planners, and what county officials think are the obstacles to use of land use planning as a wildfire mitigation tool. Respondents were asked to identify and evaluate land use planning tools that are used to reduce wildfire risk and describe the role of perceived risk, risk assessment, and structure and financing of their programs.

Findings

According to our survey results, land use mitigations have been adopted widely among county governments in the Western U.S. 72 percent of respondents have plans, policies, or regulations that address wildfire mitigation through land use planning. Twenty-one percent have a staff person dedicated to wildfire mitigation. Thirty-eight percent have received funding from federal or state sources. Sixty-seven percent of responding counties have undertaken hazards mapping to identify high hazard areas. Thirty percent of responding counties indicated they have public facilities policies that mitigate wildfire hazard, for example requiring proximity to water supply or fire station. These programs are of two types. (1) Mitigation of Existing Development. Hazard can be mitigated on existing development through education, assistance and other encouragement for mitigation of homes and neighborhoods through fuels management and other site-specific investments. (2) Mitigation of New Development. Future development can be mitigated through regulations that require defensible space, fire-resistant construction and "firewise" designs. Mitigation of new development occurs through regulation of subdivisions or individual properties.

Mitigation of Existing Development

Survey respondents indicate that mitigation of existing structures is more difficult to implement than mitigation of new development. Requiring mitigation on existing properties is "politically unpopular." As a result, many counties have turned to voluntary education and assistance programs. Fifty percent of survey respondents said they have public education programs and 39 percent have fuel management assistance for private property owners.

Respondents had varying assessments of the value of education and voluntary mitigation assistance. "Making them [county residents] understand the long-term risk is difficult" according to one emergency management director. He estimates that only 25 percent of homeowners in his county are mitigating voluntarily. After the catastrophic fire season of 2002, a wildfire mitigation officer in another county put an advertisement in the local newspaper offering free mitigation assessments. "My phone rang off the hook" she commented, adding that people understand the benefits of mitigation after even a little education. Without mitigation education, "Everyone thinks they have their own private engine." What many homeowners do not understand is that firefighters are more willing to defend houses that have already been mitigated.

Officials in most counties feel that insurance companies could have a significant impact on homeowner mitigation by making mitigation a requirement for coverage. A site development inspector commented, "What would help is if all the insurance companies would get on the same page. That would make my job a lot easier." At least one insurance company, State Farm, has started to create a market incentive for mitigation by telling policy holders that they need to be "Firewise." The company has initiated a pilot program of assessing policyholders' properties for wildfire risk.

Mitigation of New Development

Mitigation for new development is the focus of most county programs. These mitigation requirements are implemented through subdivision review, site review or building permits. Most survey respondents from Western U.S. counties have adopted some subdivision regulations related to wildfire risk; individual lot development appears to be regulated more loosely from a wildfire perspective. For example, more than half of the respondents regulate water supply and emergency access on subdivisions; less than a third have adopted regulations in these areas for individual lots. The exception to this regulatory distinction between subdivisions and individual lots concerns building codes. About one-third of the respondent counties use building codes to regulate wildfire risk for subdivisions, and about the same percentage on individual lots.

In Tables 1 and 2, we present types of regulations adopted in Colorado case study counties. These regulations have been generalized for comparative purposes. For example, we have aggregated defensible space requirements, which in different counties can be anywhere from 30 feet of cleared area around a home to over 100 feet depending on the nature of the building site. These tables suggest again that the regulatory apparatus for individual lots is less well-developed than for subdivisions.

In our interviews, county officials expressed significant concern about wildfire risk from individual lot development, which dominates growth patterns in many areas of Colorado. They discussed four primary obstacles to wildfire regulation for individual lot development.

1. State law exempts large parcels from subdivision review. County planners argue that they have limited powers of development review on larger lots (which comprise the majority of new wildland-urban interface development in many counties). In these counties, mitigation planners feel that building codes are the only legal mechanism available to them for enforcing mitigation on larger lots, and that building codes have limited effectiveness.
2. Counties do not have the staff time to implement regulations on individual properties. Although many county mitigation planners would like to adopt regulations that affect individual parcels they would also need new staff to implement the regulations. Creating new staff positions is not feasible for most counties in a time of fiscal austerity.
3. Political culture in many counties is "anti-regulation." Although the demographic makeup of western counties is changing rapidly, there continues to be considerable resistance to government regulation. Wildfire mitigation regulations are often seen as an infringement on private property rights.
4. There is little public demand for more wildfire regulation. County officials indicate that residents of the wildland-urban interface were responsive to educational programs after the dramatic fire season of 2002. They had forgotten about wildfire risk by the next season, however. Officials say that over the past two years they have a hard time getting residents to come to public meetings or read educational material. As a result there is little pressure on public officials to create or strengthen regulations.

Conclusion

A substantial percentage of new development across the West is now occurring within the framework of wildfire land use regulations. In this respect, land use planning tools are an important and growing dimension of overall wildfire mitigation practice. However, use of these tools continues to be restrained by the political culture of many rural areas. Existing development is weakly regulated. New development outside subdivisions also receives less attention in the mitigation planning process. Rapid rates of development outside subdivisions may pose substantial, continuing wildfire risks that are not addressed in many land use mitigation programs.

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Temporal Tendencies of River Discharge of Five Watersheds of Northern Mexico

José Návar, Professor of Watershed Management and Forest Hydrology, Facultad de Ciencias Forestales-UANL. Carr. Nacional km 145. Linares, N.L., México
Humberto Hernández and Julio Ríos, M.Sc. For. Studentes. Facultad de Ciencias Forestales-UANL. Carr. Nacional km 145. Linares, N.L., México

Abstract—*The watersheds of northern Mexico that encompasses the Rio San Pedro, Sinaloa, Nazas, Aguanaval, San Juan, and San Fernando-Soto La Marina are located within the main mountain ranges of northern Mexico and within the zone of large deserts of the boreal hemisphere. The hydro-climate variations, the management of forest soils and land use changes are shaping the supply and management of water resources. This research project aims to understand whether changes in discharge variables are present in time series data of 172 gauging stations of five watershed of northern Mexico. The Mann-Kendall test and the Sen's method were used to test for statistical changes in trends or tendencies and the magnitude of change of annual, monthly, monthly standard deviation, daily minimum (baseflow), and daily maximum (peakflow) discharge of the hydrometric stations mentioned above. Results showed that over 40 percent of the gauging stations had statistical significant tendencies in each of the five discharge variables analyzed. Most tendencies had a negative sign indicating a steady reduction of discharge in time. The reduction was, on the average over 5,000 m3 year-1 for annual discharge. Although further research is required to understand the potential sources of variation that explains the negative tendencies of discharge, it can be preliminary attributed to subtle climate changes, and management practices of water and other natural resources.*

Introduction

Conventional management of water resources cannot meet water supply for future development in arid, semi-arid, and subtropical countries (UNCED, 1992; Postel, 2000). Northern Mexico is placed within the arid, semi-arid zone belt of the northern hemisphere. In addition to highly erratic and variable water supply given by hydro-climate variations (Návar, 2001; Návar, 2004; Schmandt and others 2001); unsustainable practices of hydrologic resources are shaping new approaches to meet future demands. Unsustainable practices of water resources include high per capita water use, with a little over 300 l per day per person in several regions, and a high ratio of volume of irrigation to productivity, a common feature in several irrigation districts (Návar, 2004). High losses of water in the distribution systems of most cities (30-40 percent) (CNA, 2000), contamination of streams, reservoirs, and aquifers (De León Gomez y Medina Barrera, 2000; Flores-Laureano y Navar, 2002; Lizárraga, 2003), and abatement of reservoirs and river fragmentation (CONAFOR, 2004) are also indicators of unsustainable management practices of water resources. Other biological indicators are losses of species diversity in streams (Contreras and Lozano, 1994; Edwards and Contreras, 1997) and changes in species structure of plants in streams (Guerra, 1998). These are partially the result from several unsustainable management practices such as river contamination, drawdown of reservoirs, and river fragmentation.

Future conventional water supplies in the region are not warranted because of demographic growth and the presence of drought spells. In addition, Mulholand and others (1997) and the IPCC (2001) predicted using general circulation models that northern Mexico may receive 10 percent less rainfall and generate between 5-10 percent less streamflow with increasing temperatures by global warming. Návar (2001) observed that in the presence of worst drought episodes on record, several regions of northern Mexico receive 12 percent less rainfall and 27 percent less streamflow. Therefore, climate change is already or may magnify drought spells and reduce water supply in the region.

In this part of the Conafor project, we aim to address whether statistical changes in river discharge are taking place in several streams that drains northern Mexico.

A total of 172 hydrometric stations were statistically analyzed by trends and trend magnitude in five variables of river discharge in the hydrologic regions of Sinaloa (RH10), Presidio-San Pedro (RH 11), Nazas-Aguanaval (RH 36), San Juan (RH 37), and San Fernando-Soto La Marina (RH 25). The working hypothesis was that there is no change in any of the variables of river discharge in time and therefore the change in magnitude is equal to zero.

Materials and Methods

Location of the Study Area

The region under study comprises the hydrologic regions of Sinaloa, Presidio-San Pedro, Nazas-Aguanaval, and San Fernando-Soto La Marina and the Rio San Juan watershed located within the Mexican States of Sinaloa, Nayarit, Durango, Chihuahua, Zacatecas, Coahuila, Nuevo Leon, and Tamaulipas.

Population

Demographic information on each watershed is reported in table 1.

Climate

A diversity of climates is present in the studied watersheds (CAN, 1994; 2000). Cold climates are observed in the highest peaks of the mountain ranges; cold-temperate climates in the central valleys, at the piedmont of the Sierras; subtropical, and tropical climates in the low ranges of the Pacific Ocean and Gulf of Mexico piedmonts; to dry climates in the central Chihuahuan Desert.

Plant Cover

Extensive areas are covered by Pine, Oak, mixed Pine-oak forests in the eastern and western Sierras Madre mountain ranges. At the piedmont of the mountain ranges, submontane forests are characterized by thorny shrubs and broadleaved, low trees. In several places of the piedmont, tropical and subtropical flora dominates the landscape. Chaparral, dry, xerophitic plant cover is typical at the central Chihuahuan Desert. Tamaulipan thornscrub, acacia and mesquite forests extend in the lowlands of the Pacific Ocean, Gulf of Mexico, and Great Plains of North America.

Table 1. Population in five watersheds of northern Mexico.

Watershed	Inhabitants
1. Sinaloa (RH 10)	2,279975
2. Presidio – San Pedro (RH 11)	1,465720
3. Nazas-Aguanaval (RH 36)	1,655910
4. Cuenca Rio San Juan (RH 37)	4,216607
5. San Fernando – Soto La Marina (RH 25)	682033
Total	10,300245

Sources: CONAPO, INEGI (2000).

Soils

Soils are characterized mainly by Litosols in the uplands of the major mountain ranges. Regosols and Xerosols dominate the landscape of the central Chihuahuan Desert. Vertisols are characteristic in the lowlands of the Pacific Ocean and Gulf of México.

Methods

A total of 172 gauging stations placed in five watersheds were selected for discharge analysis. The number of hydrometric stations analyzed is reported in table 2.

The Mann-Kendall nonparametric test was used for detecting statistical trends in discharge time-series data. The test reveals the presence or absence of monotonic increasing or decreasing trends. The mathematical formulation of the Mann-Kendall test is described in equations [1] - [3].

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & if \quad S>0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & if \quad S<0 \end{cases} \qquad [1]$$

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right)$$

$$\operatorname{sgn}\left(s_j - x_k\right) \begin{cases} 1 \quad if \left(x_j - x_k\right) > 0 \\ -1 \quad if \left(x_j - x_k\right) < 0 \\ 0 \quad if \left(x_j - x_k\right) = 0 \end{cases} \qquad [2]$$

$$VAR(S) = \frac{1}{18}\left[n\left(n-1\right)\left(2n+5\right) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right]$$

[3]

where xj and xk are the annual values in j and k years, q= number of tied groups and tp= is the number of data values in the pth group. The presence-absence of a statistically significant trend is evaluated using the Z value, which is normally distributed.

Table 2. The number of hydrometric stations analyzed for trends and trend magnitude in five watersheds of northern Mexico.

Watershed	Hydrometric Stations	Average Discharge ($M\ m^3y^{-1}$)	Average Period
1. Sinaloa (RH 10)	58	7,970	1960-1999
2. Presidio – San Pedro (RH 11)	15	4,154	1970-1998
3. Nazas-Aguanaval (RH 36)	33	328	1940-1999
4. Cuenca Rio San Juan (RH 37)	30	1,260	1955-1999
5. San Fernando – Soto La Marina (RH 25)	36		1970-1999

Data source: CNA (2003).

A total of five discharge variables were tested by the sign test. Discharge variables are: (i) annual discharge, (ii) monthly discharge, (iii) the standard deviation of monthly discharge, (iv) minimum daily discharge, and (v) maximum daily discharge.

The non-parametric Sen's method was used to detect the magnitude of slope change in all five discharge variables. The slope is described as a change of the variable per unit time. The Sen's method was used assuming a linear trend in the short time series. Equation [4] describes the Sen's method.

$$Qi = \frac{x_j - x_k}{j - k} \quad [4]$$

where j>k.

Equation [4] is the median slope of N=n(n-1)/2 slope estimates Qi.

Results and Discussion

Discharge is being modified in the five studied watersheds. Table 3 shows the number and percentage of gauging stations which had a statistically significant trend, with negative slope (-), and positive slope (+).

M.Std.Dev. = Standard deviation of monthly discharge. The ratio of last row was estimated from the number of gauging stations with statistical significance to the total number of gauging stations analyzed.

In general, over 40 percent of the gauging stations analyzed showed a statistical significant trend. Of these, on the average, 26 percent had a negative trend and the remaining 16 percent had a positive tendency. Annual and monthly discharge are steadily decreasing at the watersheds San Pedro, Nazas, San Juan, and San Fernando but increasing at the watershed Sinaloa. The former watersheds are characterized by having an important area within the interior valleys and the Chihuahuan Desert of northern Mexico, where erratic and infrequent rainfall and high evapo-transpiration losses control the hydrologic cycle. In the Sinaloa watershed, most gauging stations with positive trends in annual and monthly discharge are located in the lower parts of the watershed, below most irrigation districts, dams, and urban areas. Therefore, the increasing tendency is partially due to management of water resources, rather than to the steady changes in hydroclimate.

The monthly discharge variation is being reduced at all watersheds, partially indicating the influence of reservoirs, over-utilization of streamflow, and steady inputs of municipal and irrigation excess into streams.

Minimum daily discharge, which is a measurement of baseflow, is increasing at most gauging stations at the watersheds Sinaloa and San Pedro, but it is reducing at most gauging stations in the remaining watersheds (Nazas, San Juan, and San Fernando). Irrigation –excess and urban discharge partially explains baseflow increments and water withdrawals in excess from aquifers of the interior watersheds. Subtle changes in rainfall

Table 3. Number of gauging stations with statistical significance in discharge trend.

	Discharge				
	Annual	Monthly	M.Std.Dev.	Minimum	Maximum
Sinaloa	25(-4,+21)	26(-5,+21)	28(-17,+11)	28(-3,+25)	27(-16,+11)
San Pedro	6(-4,+2)	5(-3,+2)	6(-6,+0)	2(-0,+2)	6(-6,+0)
Nazas	18 (-15,+3)	18 (-15,+3)	19 (-16,+3)	11 (-7,+4)	18 (-15,+3)
San Juan	13(-11,+2)	14(-12,+2)	12(-9,+3)	12(-8,+4)	12(-8,+4)
San Fernando	12(-9,+3)	12(-9,+3)	8(-7,+1)	18(-14,+4)	8(-7,+1)
Total	74(-43,+31)	75(-44,+31)	73(-55,+18)	71(-32,+39)	71(-52,+19)
Ratio (%)	43(25,18)	44(26,18)	42(32,10)	41(19,22)	41(30,11)

Table 4. The median slope (and confidence intervals) for five variables of discharge with negative tendency of 172 gauging stations in five watersheds of northern Mexico.

	Discharge				
	Annual	**Monthly**	**M.Std.Dev.**	**Minimum**	**Maximum**
Sinaloa	-3.66(2.19)	-0.82(1.06)	-0.32(0.41)	-1.91(0.51)	-9.69(6.25)
San Pedro	-0.11(0.12)	-2.05(0.94)	-2.52(4.89)	-1.02(0.77)	0(0)
Nazas	-4.74(3.98)	-0.40(0.31)	-0.50(0.28)	-1.31(0.92)	-1.28(0.80)
San Juan	-0.84(1.11)	-2.10(0.92)	-0.01(0.01)	-1.58(0.61)	-2.73(3.30)
San Fernando	-16.47(8.17)	-2.56(2.03)	-2.53(1.02)	-0.12(0.10)	-10.01(2.61)
Average	-5.16(3.11)	-1.59(1.05)	-1.18(1.32)	-1.19(0.58)	-4.74(2.59)

M.Std.Dev. = Standard deviation of monthly discharge.

frequency, depth, and intensity may also be contributing to changes in baseflow.

Maximum daily discharge is being reduced at most gauging stations in all watersheds. Increasing storage in arid, semi-arid, and subtropical reservoirs is reducing peakflows in most gauging stations.

The rate of change of discharge is reported in table 4.

Reductions in annual discharge are noticed in the San Fernando – Soto La Marina, Nazas, and Sinaloa watersheds. The San Juan and San Pedro watersheds have annual discharge reduced in less than 10,000 m3 y-1 and appear to be independent of management practices of water resources. For monthly discharge, the variation between watersheds diminishes.

Peakflows are most dramatically modified than baseflows. Sinaloa and San Fernando watersheds appear to have largest control on streamflow and therefore on peakflows. Baseflow is least modified in the San Fernando watershed.

Causes of shifts in river discharge are management practices of water and natural resources and subtle climatic changes. Conventional management practices must address new approaches to sustainable manage water resources, with special emphasis on critical times. River discharge must partially supply the domestic, agricultural, and industrial sectors (Doorenbos and Kassam, 1979; UNCED, 1992; Soley and others 1998). River discharge must also be protected with the aim to conserve landscapes, riparian ecosystems, species, and genes; as well as the goods and services they provide to society (UNCED, 1992; Postel, 2000). In arid, semi arid, and subtropical regions, prone to erratic, infrequent, and scarce rainfall and streamflow; with steady growing population searching for development, the conservation of streams with running water becomes a difficult task (Kleeberg and Weissberger, 1996; Schmitt, 1997). Therefore, every drop of water withdraw from reservoirs and rivers must double productivity in order to conserve water resources with the aim to sustainable manage water (Postel, 2000). The present and likely future scenarios suggest the need of: (a) reducing per capita water use, (b) increasing the efficiency of water use in the municipal, industrial, and above all in the agricultural sector, (c) treating all water diverted to streams and reservoirs, etc. These practices require the promotion of interactive, iterative, and multisectorial approaches; the planning for the rational utilization, protection, conservation, and management of water resources; the design, implementation, and evaluation of programs and projects that are economically efficient, socially acceptable, and environmentally compatible; and the identification and strengthening of appropriate institutional, legal, and financial mechanisms (UNCED, 1992; Schmandt and others (1998; 2000).

Conclusions

Discharge is being temporally and spatially modified in northern Mexico. A little over 40 percent of gauging stations analyzed showed changes of five discharge variables in time. Most gauging stations showed a negative tendency for most discharge variables for most watersheds indicating a reduction of annual, monthly, monthly deviation, daily minimum, and daily maximum flows. These changes appear to be the result of subtle climatic shifts, management practices of water and natural resources, the presence of reservoirs, irrigation districts, and metropolis within the watersheds. Further research is required for understanding the sources of variation of discharge within each watershed.

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Mitigating Wildfire Risk in the Wildland Urban Interface: The Role of Regulations

Cheryl R. Renner, Research Associate, Department of Environmental Studies, Louisiana State University, Mandeville, LA
Dr. Margaret Reams, Associate Professor, Department of Environmental Studies, Louisiana State University, Baton Rouge, LA
Terry Haines, Research Forester, USDA Forest Service, Southern Research Station, New Orleans, LA

Abstract—*The growth of residential communities within forest areas throughout the country, and particularly in the West, has increased the danger to life and property from uncontrolled wildfire. The conflict of permanent residential settlements built next to a fire-adapted ecosystem has been further exacerbated by 100 years of fire suppression and an extended drought in the West. Under the police powers granted by the Constitution, state and local governments have the power to pass laws to protect the health, safety, and welfare of their citizens. As this relates to land use, the states have delegated this power to cities and counties. As a result, most laws for creating and maintaining defensible space around structures have been enacted at the local level. Research of state and local wildfire mitigation efforts found that many areas adopt regulations for defensible space as only one element of multi-faceted programs for wildfire mitigation. This paper will compare four model ordinances designed for adoption by state and local governments to protect communities from wildfire. In addition, results from a survey of wildfire program managers provide insight into the obstacles faced in administering defensible space regulations. In evaluating program options, managers must assess/balance wildfire risk and safety issues with public acceptance of regulations and the potential effectiveness of the regulation in mitigating wildfire hazard.*

Introduction

As communities have grown into forested areas, homeowners and forest managers have become aware of the threat posed by wildland fire to the safety of those communities. With the help of the National Fire Plan, many communities have taken steps to protect themselves by educating homeowners about the danger of hazardous fuels around homes, developing fuels reduction projects to create defensible space, and conducting disposal or chipping programs.

The State of California and many local areas require the reduction of vegetative fuels around structures through laws and ordinances. These ordinances are based on the police powers granted to states by the constitution, to protect the health, safety, and welfare of its citizens. States delegate this power as it relates to land use to local government entities. The unit of government closest to the people is thereby empowered to adopt, administer, and enforce regulations designed to control private behavior for the public good. Florida's Department of Community Affairs states, "because wildfire protection and mitigation activities must occur at a local level and in concert with local land use and development decisions, regulations for wildfire protections are most effective at the local level" (FDCA 2004).

In this paper we will look at research on public attitudes toward vegetation management regulations, the efforts of at-risk communities to encourage vegetation management, four model ordinances for wildfire risk reduction, and the experience of program managers in administering regulations for vegetation management.

Public Attitudes and Wildfire Risk Mitigation

One of the major challenges facing policy-makers as they formulate state and local risk mitigation programs is how to influence the behaviors of private property owners regarding vegetation management. Public risk perceptions concerning wildfire appear to affect residents' support for regulations to mitigate the risk. For example, Bradshaw (1987) and Loeher (1985) reported that many residents within wildland-urban interface (WUI) communities had had no direct experience with the devastating effects of wildfire and, as a result, tended to underestimate the risk. A decade later, Winter and Fried (2000) found that focus groups in Michigan perceived wildfire to be inherently uncontrollable, with random patterns of damage, a perception that tended to discourage individual property owners from engaging in unilateral removal of vegetation. Further, they found that zoning and safety ordinances are viewed as unacceptable infringements on the rights of property owners to use their property as they see fit.

Similarly, Loeher (1985) cited a belief by residents that it is simply not their responsibility to protect themselves from wildfire risk. Further, some residents may not support vegetation management because they fear that removal of trees and shrubs will negatively affect the aesthetics and ecological functions of a natural landscape (Alan Bible Center for Applied Research 1998, Hodgson 1995, Davis 1990). On the other hand, support for more restrictive government regulations seems to increase after a community has experienced a wildfire (Abt and others 1990).

Vegetation Management Regulations

Research for the National Wildfire Mitigation Programs Database website, www.wildfireprograms.usda.gov, a clearinghouse of information on state and local programs for wildfire mitigation through vegetation management, shows that municipalities and counties adopting regulations to protect wildland urban interface areas use many different regulatory tools (wildfireprograms.usda.gov 2004). Wildland-Urban Interface regulatory mechanisms for vegetation management exist in the form of fire codes, building codes, subdivision regulations, zoning regulations, growth management, or comprehensive plans, and fire plans.

Out of 108 defensible space regulations found in 74 jurisdictions, 23 were in fire codes, 26 were in subdivision regulations or development standards, 19 were in fire plans, 11 were in general plans, 9 were in zoning overlay districts, and 9 were in state guidelines. Smaller numbers were in burn regulations, insurance guidelines, real estate disclosure laws, building codes and land use codes. This shows that there is no one right answer in regulating vegetation management. Jurisdictions are dealing with wildfire risk in ways that best suit their needs and the administrative structure of their fire codes and land use regulations.

Jurisdictions are not relying solely on the regulations to motivate citizens to reduce fuels. Most jurisdictions with regulations also have other aspects of a program to reduce fuel hazards within the community. These other program elements may include defensible space prescriptions, free or cost-share clearing programs, chipping and disposal services, demonstration projects, community fuelbreaks, and public education campaigns. Of the 74 jurisdictions with regulations, 54 of those jurisdictions supplemented the regulations with more than one other program element.

Ordinance Structure

Comprehensive regulations to protect communities from wildfire must include road, bridge and driveway specifications, requirements for fire resistant construction materials, adequate water supplies for fire fighting, multiple ingress and egress roads, visible addresses, and fuel breaks for defensible space. This paper will focus specifically on the defensible space regulations, one part of a comprehensive Wildfire Urban Interface ordinance.

The paper will examine four different model codes and will discuss the elements of vegetation management regulations included in each. Two of the codes are designed to be adopted by any community at risk in the nation; one of which is an international standard. The other two are state model codes for California and Florida, which are representative of the needs of their state's particular terrain and vegetative risk, and represent different areas of the country. It is hoped that this examination of four different ordinances will assist communities considering adopting a model code in finding one that best fits their needs. The model codes to be discussed are:

1. NFPA 1144: Standard for Protection of Life and Property from Wildfire (NFPA 2002);
2. International Urban-Wildland Interface Code (UWI) (International Code Council 2003);
3. Model Ordinance for the Defensibility of Space and Structures, (California Department of Forestry and Fire Protection 2000);
4. Model Wildfire Mitigation Ordinance (Florida Department of Community Affairs 2004).

While all of these ordinances contain the basic elements necessary for a comprehensive wildfire protection ordinance, each is unique in some way. This paper will look first at the similarities within the ordinance elements pertaining to vegetation management, and then the specific elements that make each stand out from the rest.

Findings of Fact and Risk Assessments

Most regulations begin with findings of fact which give reasons why the regulations that follow are necessary to protect to health, safety, and welfare of the citizens of the jurisdiction. The UWI Code includes an appendix which guides the jurisdiction in writing findings of fact which relate directly to the climate, topography and fuels situation of the local environment. The findings of fact form the basis for the designation of the WUI area within the jurisdiction. This area must be mapped, and the criteria and map must be reviewed every three years.

NFPA 1144 does not include an introductory findings-of-fact. Instead it requires the jurisdiction to do a hazard risk assessment based on the following factors:

1. Climate;
2. Vegetative fuels;
3. Rating of existing structures;
4. Slope and aspect;
5. Fire history;
6. Firesafe routes and egress;
7. Other factors determined by the local jurisdiction.

This risk assessment is to be reviewed by the jurisdiction annually.

The model ordinances put forth by Florida and California are structured differently. Both states have conducted hazard risk assessments on a statewide level, and make the information available to communities in map form. The communities may follow up at the local level with more detailed assessments, or they may impose restrictions based on the information provided by the state. In Florida, the entire state was mapped using Landsat imagery at 30 meter resolution and Ikonos imagery at 4 meter resolution. Fire protection service response time was included in addition to the factors listed above. The state plans to review its Florida Risk Assessment (FRA) every three years. However, the jurisdiction may select a different frequency for local review of risk.

California's Very High Fire Hazard Severity Zone (VHFHSZ) is mapped at one square mile resolution, and information is reviewed by the state every five years. Localities containing VHFHSZ areas are asked to adopt two ordinances. The first is the Model Ordinance for Very High Fire Hazard Severity Zone Adoption, which gives the Fire Chief the power to conduct a local hazard risk assessment to define the VHFHSZ based on findings of substantial evidence. The second is the Model Ordinance for the Defensibility of Space and Structures, which the locality must adopt unless it already has regulations in place that are equal to or more restrictive than those outlined in the Model Ordinance.

Table 1 shows the elements included in assessments to determine limits of the area where WUI regulations will apply for each model ordinance, i.e., the Wildland-Urban Interface Zone.

Table 1. Determining the WUI Zone – Findings of Fact / Risk Assessment.

	NFPA 1144	UWI Code	CA LRA Model	FL Model
Climate	X	X	X	X
Vegetation	X	X	X	X
Structure	X	X	X	
Slope/aspect	X	X	X	X
Density/lot size	X		X	
Access	X	X	X	X
Fire history	X			
Fire protection services			X	X
Review	1 yr.	3 yr.	5 yr.	3 yr.
Risk form	X	X	X	X

Hazard Risk Rating Guides

All four ordinances are supplemented with a fire hazard rating guide that allows inspectors to evaluate the fire hazard risk of proposed developments and existing structures. These hazard rating scales differ in complexity and in the weight given to the various factors. Many states have developed their own hazard rating forms which may be based on earlier versions of NFPA 299, but tailored to the environment found in their state. The new standard NFPA 1144 features a revision of the 299 Wildland Fire Risk and Hazard Severity Assessment system. The severity values for non-rated roofs, inadequate separation of vegetation from structures and separation of structures from each other have been increased (NFPA 2002). When choosing a model ordinance for a locality, the choices of hazard risk rating forms should also be considered, and the weightings of the various factors should be tested in the district.

Vegetation Management Plans

All four ordinances include oversight and review by the jurisdiction of new construction. The model codes all contain language requiring the submittal of a plan with a map showing the intended development, existing conditions, and proposed changes, including existing fuels and fuels modifications. All four ordinances hinge the issuance of a building permit and/or grading permit upon acceptance of the proposed plan.

Defensible Space Requirements

The four ordinances all require fuels modification to create defensible space around structures. Defensible

Table 2. Defensible Space Plan Requirements.

	Defensible Space Minimums					
	30'	**Varying**	**Setback/ lot size**	**Greenbelt/ Fuelbreak**	**Fuel modification plan**	**Building permit issued**
NFPA 1144	X				X	X
UWI Code	X	X			X	X
CA LRA Model	X	X	X	X	X	X
FL Model	X			X	X	X

space clearing and pruning requirements are comparable, but the mandated distances are different. A comparison of the defensible space requirements is shown in table 2.

NFPA 1144 and the Florida Model Ordinance require a minimum of 30 feet of defensible space around structures. UWI Code requires a minimum of 30 feet for moderate hazard areas, 50 feet for high hazard areas, and 100 feet for extreme hazard areas. The California Model Ordinance requires a minimum of 30 feet, which can be extended to 100 feet at the determination of the Fire Chief. The California Model Ordinance also requires a minimum setback of 30 feet on parcels over one acre, and for parcels less than one acre the jurisdiction shall provide for the "same practical effect." The other ordinances do not specify setback requirements.

Greenbelts or Fuelbreaks on Common Areas

A fuelbreak is a strip of land surrounding a subdivision or community which provides a barrier to adjacent wildlands by modifying the fuels in this area. Greenbelts act as fuelbreaks, but are lands used for purposes other than fire control such as golf courses, swimming pools, parking lots, parks, playgrounds, and orchards. The Florida Model Ordinance requires 12 foot fuelbreaks around the perimeter of new subdivisions. The California Model Ordinance recommends greenbelts, but does not specify a width for the greenbelt. The ordinance requires the greenbelt to be strategically located as a separation between wildland fuels and structures, and to be approved by the jurisdiction.

Maintenance of Defensible Space and Enforcement

All four model ordinances require the maintenance of defensible space as an element of the fuel modification plan described above. However, since vegetation can grow back quickly, the challenge lies in enforcement of this requirement.

NFPA 1144 states that the fuel modification plan shall include a maintenance element with the responsibility for maintenance defined. No enforcement or penalty language is included in the ordinance.

UWI Code contains language which requires a plan to maintain the defensible space included in the approved Vegetation Management Plan. The UWI Code gives the code official the authority to inspect, the right of entry, and the authority to issue corrective action orders. Persons failing to take immediate action to abate a hazard when notified to do so by the code official are guilty of a misdemeanor.

The California Model Ordinance for the Defensibility of Space and Structures does not include penalty language in the ordinance. Since the model provides for the insertion of component statements into the Uniform Fire Code (UFC), penalties are cited in the UFC. Penalties for failure to maintain fire breaks exist in the California Government Code. Fines may be levied for first, second and third offenses. Or, if a landowner fails to correct the conditions, then the local agency may have the work performed, and the charges become a lien on the property.

The Florida Model Ordinance also includes a procedure should the landowner fail to perform the necessary wildfire mitigation, charging the costs as a lien against the property. As in the UWI Code, the Florida Model Ordinance gives the code official the authority to inspect, the right of entry, and the authority to issue corrective action orders. Persons failing to take immediate action to mitigate a hazard are guilty of a misdemeanor.

Table 3 shows the enforcement penalties for defensible space violations in the four model ordinances.

Public Awareness and Disclosure of Wildfire Hazard

To make the residents of high wildfire risk areas aware of the dangers that surround them, the NFPA 1144 and the Florida Model Ordinance require the jurisdiction to create public education programs. The NFPA 1144 program emphasizes wildland urban interface and intermix issues including: wildland fire hazards, life and property risks, fire causes, prevention and safety programs, directed to target audiences. The Florida Ordinance recognizes that many homeowners are unaware that they live in an area

Table 3. Maintenance of Defensible Space and Enforcement.

	Maintenance	Fines	Misdemeanor	Liens
NFPA 1144	X			
UWI Code	X		X	
CA LRA Model	X	X	X	X
Florida Model	X	X		X

susceptible to wildfire. The ordinance requires buyers of buildings or undeveloped property in wildfire hazard areas to be informed in writing of the wildfire risk and potential nuisance posed by fuel management activities such as prescribed burning. And it requires the Wildfire Mitigation Official to hold a series of public workshops, and distribute informational brochures to homeowners, builders, developers, and realtors. The state of California requires the disclosure of wildfire hazards to purchasers of property in the VHFHSZ.

Unique Characteristics of the Ordinances

NFPA 1144

Unique to NFPA 1144 are regulations dealing with fire protection during construction. NFPA 1144 provides for the control of combustible materials and requires the presence of extinguishing equipment on the job site. Among other requirements, an approved hose with nozzle must be available, and have enough length and water supply that water can reach 20 feet into the vegetative fuels adjacent to the construction site.

Another innovation in NFPA 1144 is the section on Community Planning for Protection of Life and Property from Wildland Fire. This requires the jurisdiction to create an operational plan for command, training, community notification and involvement, public safety and evacuation and mutual assistance elements. The public education component is an important element of the operational plan. In addition to being prepared for evacuation and mobilization of attack, the operational plan will help the community prepare to be recognized through the Firewise Communities USA program. The community planning element may also prove valuable under the Healthy Forests Restoration Act. By having local leadership in place, and working relationships built, the community is well prepared to develop the required Community Wildfire Protection Plans.

UWI Code

The UWI Code, like NFPA 1144, sets out minimum standards for protection from wildland fire. It differs in that it provides for increased defensible space around structures in areas deemed high and extreme hazard, increasing the distance up to 100 feet. The distances may also be increased by the code official based on his determination of site-specific conditions. This makes defensible space less of a one-size-fits-all formula. The UWI Code includes a section on vegetation control around roadways and electrical transmission and distribution lines. In addition, the language on enforcement and penalties strengthens the regulations.

California Model Ordinance for the Defensibility of Space and Structures

California's Model Ordinance is unique because it is mandated by the state, setting out minimum standards for jurisdictions with high and very high hazard zones to enforce. It is the only ordinance of the four in which the defensible space regulations also apply to existing structures. However, localities have the option to dispute the VHFHSZ designations, and communities with pre-existing ordinances are exempt. As a result, adoption of the model ordinance has not been universal.

The model ordinance is just one piece of California's complex set of laws for administration of wildfire hazards statewide. For fire-protection purposes, the state is divided into the State Responsibility Area (SRA) and the Local Responsibility Area (LRA). State Responsibility Areas are "areas in which the financial responsibility of preventing and suppressing fires is primarily the responsibility of the state. The prevention and suppression of fires in all areas that are not so classified is primarily the responsibility of local or federal agencies, as the case may be (PRC 4125[a]). Local Responsibility Areas are places where a local fire district is responsible for preventing and suppressing fires.

California first enacted regulations for fire hazard zoning in the State Responsibility Areas in 1982. Over the years, California added regulations setting out vegetative clearance and roof and structural requirements for the SRA. In 1992, with the adoption of the "Bates Bill", fire hazard assessment and zoning were mandated in the LRA. Minimum fire safety standards were set for local governments to adopt. The regulations are comparable to those that existed in the SRA since 1985, and brought fire hazard reduction regulations to all high wildfire risk areas throughout the state.

Even with state mandated regulations, a Blue Ribbon Commission which studied the 2003 Southern

California wildfires found that "Currently, appropriate minimum building standards and fire safety requirements are neither mandated nor consistently enforced in all communities in High and Very High Hazard Severity Zones." Additionally they found that "Most structural losses occurred where homes had little or no vegetation clearance or were built using combustible building materials, and were thus vulnerable to wildfire" (Schell 2004).

Florida Model Ordinance

The Florida Model Ordinance was created to be a resource for local governments considering wildfire mitigation regulations. It was not intended to be adopted verbatim. It includes a wide range of elements which local governments can choose from in creating their own regulations.

For example, a section on tree protection reconciles defensible space regulations with pre-existing tree protection ordinances. This section provides language which exempts highly flammable trees within 30 feet of a structure from the tree protection ordinance, and allows the planting of replacement trees of a less flammable nature. The jurisdiction should attach a list of flammable exempt trees and less flammable replacement trees.

The Florida Model Ordinance also includes language providing incentives to homeowners in the overlay district to create defensible space. One incentive is an ad valorem tax break. The ad valorem tax exemption is a one-time exemption of the amount paid by the homeowner for improvements made for the purpose of wildfire mitigation.

Another incentive is recognition of homeowners who have demonstrated results and commitment to accomplish the goals of wildfire mitigation. These individuals will be recognized with Landowner Awards that are publicly displayed in the City or County Hall.

The Florida Model Ordinance is meant to be adopted by local governments as one piece of their land use regulations. All Florida counties and municipalities are required to adopt a comprehensive plan to guide their physical development and growth, and all local land use decisions must be consistent with the adopted comprehensive plan. Therefore, the wildfire mitigation goals should be included in the comprehensive plan, and should be integrated into other land development regulations, including subdivision regulations, zoning ordinances, and building and development standards. Florida also recommends that wildfire mitigation standards be included in deed restrictions or subdivision covenants, and be required in a homeowners' associations plan for management of common areas.

Experience of Program Managers with Wildfire Mitigation Regulations

Although model ordinances are excellent tools for providing guidance to local governments in planning for wildfire protection, our research looks beyond these blueprints to examine the policies and programs currently employed in high-risk communities. A survey of 100 wildfire mitigation program managers, conducted in 2003 examined the broad spectrum of mitigation strategies being implemented. Managers were asked to characterize their programs in terms of the types of activities implemented, obstacles to achieving program goals, and the effectiveness of program strategies. Of particular interest to the study at hand, are the responses of managers concerning regulatory programs. Of the 56 survey responses, 25 managers indicated that regulation of some type was a component of their wildfire risk management program whether through ordinances, zoning and/or planning requirements. In all but three responses, managers indicated that regulatory strategies were a component of broader, comprehensive programs that also included education and public outreach efforts, homeowner assistance, and wildfire hazard assessment and mapping. Managers reported that the focus of their regulatory programs included mandatory standards and/or review processes for new developments in all 25 jurisdictions. In addition, thirteen managers reported that prescribed treatments for fire hazards around existing homes through defined defensible space standards were required in their jurisdictions.

Program Barriers

The effectiveness of wildfire risk reduction efforts may be constrained by socio-political, economic, and technical obstacles. The questionnaire asked managers to rank the importance of 12 potential obstacles to achieving program goals on a scale of 0-5, with 0 being of no importance. "Budgetary limitations" were considered major barriers by all the respondents; closely related was "lack of qualified personnel" reported by nineteen managers. Other important obstacles included "public apathy" and "homeowner resistance to conducting fire-wise improvements on their properties" with 17 of the 25 program managers indicating that these social and political factors were impediments to achieving program goals. Perhaps most important to the analysis of regulatory strategies was that the barrier "inadequate enforcement of regulations" was reported as a major obstacle for only eight of the twenty-five managers. Linkages among barriers may create complex challenges for managers. For example, effective regulatory programs require adequate funding and personnel to review planning documents, conduct inspections, administer permit systems, and enforce standards. Public acceptance may also affect the effectiveness of regulatory strategies. Program managers may be averse to enforcing unpopular regulatory policies when the success of other components of their programs, such as education and homeowner assistance depend upon a good rapport with the public and cooperative homeowners.

Effective Strategies

Managers were asked in an open-ended question to identify their most effective program element for creating defensible space. Interestingly, thirteen of the twenty-five managers of programs with a regulatory element, indicated that homeowner services, strategies involving one-on-one assistance to homeowners – such as fire-wise prescriptions, cost-share assistance for reducing hazards around homes, or chipping and fuels disposal - was their most effective program element. Only eight of the 25 managers felt that the regulatory component of their program was the most effective strategy.

Conclusion

Regulations for wildfire mitigation are an important tool which communities can use to prepare the built environment for the eventuality of wildfire. In most communities the enacted regulations apply only to new construction and substantial remodels, so the sooner regulations take affect the better. Communities should compare the provisions of the model ordinances to their needs. They may find that by adding language from one ordinance to another, or by supplementing the ordinance with a more sensitive hazard rating form or increased defensible space standards, it well serve them better. For example, The Village of Ruidoso, New Mexico adopted the UWI 2000 Code, but substituted its own fuels management standard which brings defensible space requirements out to 120 feet in some areas, and a hazard rating form which factors in the indigenous vegetation identified on each property.

Minimum standards to reduce structural losses from wildfire are built into the model ordinances. For a community at risk, each ordinance would put in place an administrative structure and regulations to improve the safety of the built environment as it grows into forested areas. The unique features of each model ordinance should be considered when drafting an ordinance for local adoption. In areas of extreme risk an ordinance with greater distances for defensible space and stronger enforcement options may be appropriate. In areas where existing tree ordinances conflict with the goals of wildfire mitigation, exceptions, as provided in the Florida ordinance can solve the problem.

Wildfire hazard mitigation is a planning goal that should be included in comprehensive plans and growth plans and considered on a par with transportation, open space, housing density, and other land use issues, as recommended in the Florida Model Ordinance. A study by the American Planning Association (American Planning Association 2002) found that in many states, enabling legislation for local planning dates back to the 1920's. The smart growth initiative to modernize planning legislation is an important step toward giving localities zoning and subdivision review powers to effectively deal with contemporary growth issues, but it does not list wildfire mitigation as a goal. Wildfire mitigation needs to be balanced with all growth and development issues, and included in the smart growth planning process.

Regulations are not a quick fix to wildfire susceptibility, and they need the support of the community. They should be part of a broader program of risk awareness and fuels reduction, which demonstrates a commitment by the local government to safeguarding the public. Emphasis should be placed on establishing fuelbreaks between the community and forested land. In developed areas, cost-share clearing, demonstration projects and slash disposal programs will be needed to create defensible space around existing structures and in common areas. Many states and high risk communities are already doing this. Homeowners need to see that the responsibility for wildfire risk reduction is shared between themselves and the larger community, and that wildfire mitigation is an ongoing process. They cannot wait until wildfire threatens their homes to take action.

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Szendrő - type Integrated Vegetation Fire Management—Wildfire Management Program from Hungary

Ágoston Restás. Fire Chief, Szendrő Fire Department, 3752 Szendrő, Hungary

Abstract—*Szendrő Fire Department is located in the northeastern part of Hungary. The main task is to fight against wildfire and mitigate the impact of fire at the Aggtelek National Park – which belongs to the UNESCO World Heritage list. Because of greater effectiveness, in 2004 the Fire Department started a project named Integrated Vegetation Fire Management (IVFM). The IVFM consist of two main parts: Peripheries and Modules. The land use planning, finance, public relations, education, media connections, protective equipment belongs to Peripheries. The Modules are: Tower based environment monitoring and fire detection system, Mobile command control unit and Static and dynamic decision support system. The tower based environment and fire detection system address the Fire Department by hot information. The signal to the Fire Department is not depends on subjectivity; the alarm sign is in fire fighters hand. It means the start of intervention can be as soon as possible. The project develops a static and dynamic decision support system. It is based on robot reconnaissance aircraft (UAV)– dynamic parts; and the GIS – static parts. The data supplied by the robot reconnaissance aircraft is combined with the GIS based fuel model and other information to predict the fire activity. The system provides fire fighters accurate information to increase efficiency of fire fighting.*

Introduction

Geographically, Hungary lies in the Carpathian Basin at the centre of Europe. Politically and economically, it is among the Eastern European countries that joined the European Union on 1 May 2004. Hungary has an uneven division of forest cover. Statistical data (HCSO) shows that there are approximately 1712 thousand hectares of forested territory, which is about 18.5 percent of the country's territory. After the change of the political system in 1989 nearly 40 percent of the total area of domestic forest went into private ownership.

In common with numerous other countries over the past decade, vast forested regions were destroyed by fire in Hungary, too. Having experienced the sluggish and ineffectual central response, a number of local initiatives were started to increase effectiveness in forest fire situations, among these the Integrated Vegetation Fire Management Program of the Professional Municipal Fire Department of the Town of Szendrő is the most comprehensive. The program was also driven by the Department's responsibility for the fire protection in the area of the Aggtelek National Park with its cave-systems that form a part of the UNESCO World Heritage Sites scheme. The program began in early 2004 and is currently in the initial stage of its realization. The date of its accomplishment will largely depend on the schedule of financial opportunities, but at the earliest, it will be in 2007. The first step is the processing of recent fire events and, based on that, the sketching up of a concept.

Study

The Diary of Events of Borsod Abaúj Zemplén County's Catastrophy Prevention Directorate was used for the analysis; this contains data on nine fire departments including Szendrő's. The survey embraces the period of 1 January 1999 through 31 December 2003. Its aim is to offer factual confirmation, based on the Diary, concerning problems that arise and are known through experience in fighting vegetation fires. About 4300 pages of hand-written material were processed. Conclusions springing from the results of the study and from other data resources:

1. We accept the phenomenon of global warming as a fact. A plethora of literature underpins the conclusion that it has resulted in an increase in the number and duration of periods of drought (Heizler 2002). The annual precipitation in the Carpathian Basin is not expected to change, but its distribution will alter (Hargitai 2003). Declining precipitation will appear within shorter periods but with greater frequency or with increased local concentration. Dry periods will become longer, which leads to a higher degree

of plant desiccation, thus will offer more favourable conditions for ignition, combustion and spread of fire (Mika 1988). Overall, the border of fires characteristic to the mediterranian region can be expected to push northwards (Vidal and others 1994).

2. The "fire seasons" are relatively easy to predict on the bases of meteorological conditions and experience (Bussay 1995), despite of which the effectiveness of preventive measures (for example, fire-lighting ban) is, strongly questionable.
3. Experience shows that humans contribute around 80 to 90 percent of the causes for the emergence of fire (Leone and others 2003). An improvement in civil discipline could lower this proportion hugely.
4. In intentional fires or those resulting from negligence the person causing the fire has little motivation to rapidly inform fire fighters. The time within which a fire is reported can be influenced by several factors, such as the interest of the person in reporting it, or the possibility for doing so. Land-line telephones are available only in inhabited areas, while the use of mobile telephones is atypical of those characteristically causing fires. In certain areas the lack of signal strength is also an obstacle in using mobile phones.
5. In the current system the fire department becomes aware of an emerging fire after the indicating person's report. No civil report means no fire. This is defined as passive cognisance. Signalling systems, applied in closed spaces, signal the emergence of a fire to the centres without human contribution and eliminate subjective judgment. This principle is termed active cognizance.
6. In the fire seasons interventions should in effect be carried out simultaneously at all locations. Units rush from one fire to the next, thus often the unit reaches the plot with a considerable loss of time following the report. This results in more widely-spread fire that requires more time and resources to extinguish.
7. A significant number of vegetation fires are categorized as without financial loss although substantial resources had to be employed. The sustainability of the current system needs to be reconsidered in an economic perspective and along the value – cost principle. The objective definition of "causing damage" and the stock-taking of the cost of resources employed are essential. The area of the territory protected should also be determined with at least an estimate.
8. The current system ties up resources for fighting fires that do not cause financial loss in a way that needlessly increases the potential risk for citizens resulting from an absence of fire-hoses. For as long as hoses, that are designed for effectively fighting fire and damage with an urban character, are tied up in the extinguishing of fires without financial loss, the rescue of those in directly life-threatening situations resulting from a different type of damage (accident, escape of dangerous substance into the open, etc.) may incur a time-loss that causes a substantial tactical handicap and a serious and unacceptable delay due to the absence of hoses.
9. To fight vegetation fires we respond with fire engines that, calculated on current prices, are worth approximately 300 thousand euros and are not designed for fighting forest or vegetation fires. This, on the one hand, exposes our equipment to unnecessary wear and tear, while on the other hand the level of effectiveness of their application is also unacceptable. Tackling dirt-tracks and forest paths increases wear and tear on the fire engine hoses, while the danger of possibly getting stuck has also to be considered.
10. In order to look after the hoses, the otherwise logical choice of an occasionally several kilometer-long walk represents substantial time-loss, which helps fires to spread and grow. Meanwhile the time of the walk there and back potentially increases the risk to citizens. Approaching the location by vehicle would be fully justified by fire-fighting beginning sooner, thus reducing the need for higher degrees of alarm and demand on the staff's physical resources.
11. The large numbers of fires emerging in unison often necessitates the simultaneous use of all fire engine hoses available in a given territory. At times hoses for fires cannot be requested at all, or only from distances that the long haul considerably lowers their productive and effective use. This may induce the raising of the degree of alarm. In such cases the defined order of help cannot be complied with and the otherwise logically structured Alarm and Help Plan breaks down.
12. The leader of the unit in need of help does not order the otherwise justifiable higher degree of alarm because there is no hope of any help arriving. It is also possible that smaller units occasionally fight fires in a "planned" way with the aim of protecting their own territory, thus keeping units within their own area. In the event that no free unit can be called upon when a fire is reported or, in a given situation, it is not practical to do so, the burning fires "queue" for a freed-up unit.

Integrated Vegetation Fire Management

Peripheries

The effective operation of and the conditions for IVF Management are ensured by the so-called peripheries. These include sufficient public education, PR activity, special training for firemen, the issue of area-use, media information, the opportunity for necessary international co-operation (Goldammer 2004, Jurvélius 2004) and, unavoidably, financing! The peripheries are established parallel to the modules. The most critical point is the issue of financing the system. With the application of the cost – profit principle financing cannot be divided from the perspective of effectiveness. The system can be considered more effective than that currently employed if there is cost-saving at the state-economy level. When examining the issue of effectiveness, returns from investments and the timing of returns are usually accounted. There is sense in discussing the effectiveness of fire-fighting in this way as well, however, the explanation differs from the classical interpretation. In fire-fighting and other interventions the measures of effectiveness include the preserved value, which is often difficult to express as an objective figures, or the smallest possible scale of damage. An intervention or fire-fighting can be termed effective if the largest possible proportion of the saved value is achieved with the resources and equipment available, or if the damage is of the smallest possible proportion (Restás 2004).

Investigations into the economic effectiveness of IVFM lie in an analyses of the economic loss – time function (Bleszity and others 1989) and of the fire-fighting procedure. The study of the economic loss – time function is usually correlated to a closed space, where the so-called fire-graph initially rises exponentially then flattens out with the diminution of available combustible material before finally, with the exhaustion of the material, the graph ends (fig. 1).

In the case of forest fire the financial loss – time function shows an exponentially rising curve rising into infinity. The rise of the curve is determined by two factors: one comes from the calculation of the area of the

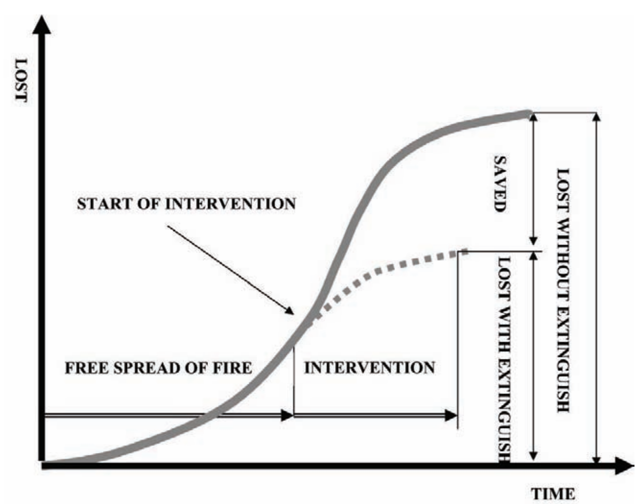

Figure 1. Damage – time function. Closed area.

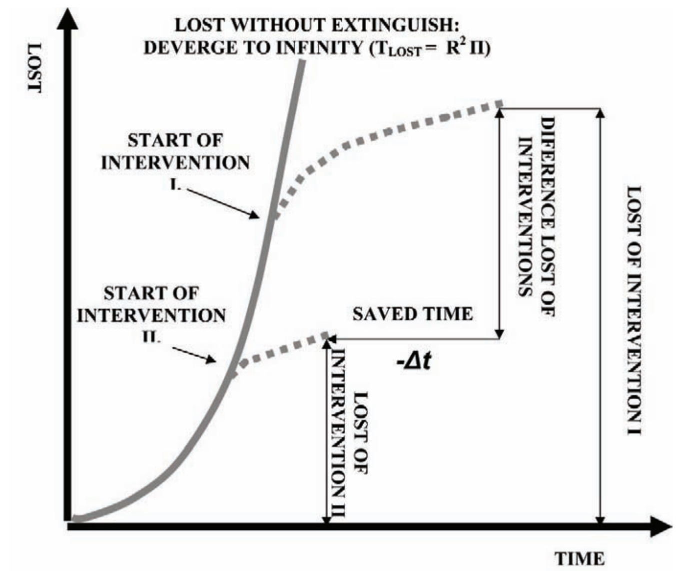

Figure 2. Damage – time function. Forested area.

circle that is the same as the second power of the radius; the second springs from the speed of velocity of the fire per single time unit. The two are not really divisible. In brief and simple terms: the size of the burnt area per time unit depends on the speed of fire velocity, which changes quadratically per time unit. The faster the fire's velocity, the larger the burnt forest area. In ideal conditions this goes on infinitely. It is clear that decreasing any Δt (finite difference in time), the size of the burnt area and thus the financial loss diminishes along an exponentially rising curve (fig. 2). The two very simple verdicts drawn from the infinite and exponential curve are the following:

1. The closer we can get to the moment of lighting-up, the easier it is to fight any given fire.
2. Accepting the limitations of the fire-fighting capacity of a unit it becomes clear that after a certain time a given fire can no longer be fought without help.

The analysis of fire-fighting ascertains a number of statements. The fire department becomes aware of the report through someone noticing the fire. The reporting individual's subjective assessment considerably influences the time of notification. The notification is independent of the fire department, the link between the report and the time of lighting is often simply the reporting individual's subjective assessment. Fire departments currently endeavor to increase the rapidity of reporting through the method of awareness-raising. Following the report the fire brigade reaches the location of a fire, or at least approaches it, with the minimum delay in accordance to its operational order. This time period can not practicably be lowered, and thus can be seen as being objectively set and minimal. Approaching the fire on foot could cause loss of time if there were a suitable path that was more rapidly negotiable by a cross-country vehicle.

That is dependent on the technical tool, a vehicle. At the scene of the fire the first task is investigation, which is simply gathering sufficient information to facilitate effective fire-fighting. The effectiveness of the investigation can be measured by the efficiency of the fire-fighting. A sufficient amount of quality information is needed for that. The first job is to establish the extent of the fire. A burning area of only 300 m radius represents a walk of nearly 2000 m. Accounting for the configurations of the terrain, the obstructive effects of plantation and equipment, exploration by foot may extend in time considerably. Investigation from the air resolves these problems, and this can be achieved by an on-location deployed unmanned robot-aircraft (UAV).

Conclusions drawn from the fire-fighting procedures:

1. The time that has passed before a fire is reported does not depend on the fire department, but does lead to a delay in intervention.
2. Time from the report to arrival at the location cannot objectively be reduced.
3. Reaching the location by foot results in delayed intervention.
4. Investigation on foot extends in time and results in a delay in the commencement of effective intervention.

Both the analyses of the financial loss – time function and of the fire-fighting procedure show that effective fire-fighting depends most on the time factor. Rapid intervention calculated from the point of lighting appears firstly in reduced financial loss and secondly in reduced costs for deploying forces and equipment.

Modules

The second part consists of three modules, further expandable later:

1. Tower based fire-detecting unit
2. A mobile deployment control and support unit
3. Static and dynamic decision-support unit
4. Complementaries (for example, module aimed at fighting large-expanse fires)

Tower based fire-detecting unit

The centrally installed monitoring and fire-detecting unit is the system's first module, which employs active detection in the place of the current passive system. Szár Hill, 520 m tall and located near the geometric centre of the area of operations of the Szendrő Fire Department, has had a 120m tall broadcasting tower installed on it. The promontory is the most important point of elevation in the region, and allows a large area to be monitored from there without any visual occlusion. In the course of the project two rotatable cameras would be installed on the first floor of the tower at a height of approx. 50 m, which would transmit to the dispatching centre of the Szendrő Fire Department. The duty officer will be able to detect any fire or smoke within a very short period from a fire igniting, and before it would be reported by telephone by anyone. The cameras, which have appropriate resolution, will also be able to generate automatic signals or alarms, depending on their settings. The accuracy of both automatic alarm signals and personal detection will deteriorate in proportion to distance, but even at the edge of the area to be monitored, defined as a circle with a 15 to 20 km radius around the tower, it will have to comply with the perceptual threshold of 160 m^2 (fig. 3).

The above shall ensure, both on the detection and the alarm side, that under normal conditions the unit arriving to extinguish the fire will be confronted by a vegetation fire that they are able to extinguish using their own resources.

The geographical features allow fires to be detected within a short period of their starting, either by direct visual observation of hillsides, in the valley of the Bódva and on unoccluded hillsides, or, depending on the location, directly or indirectly in the valleys of others and

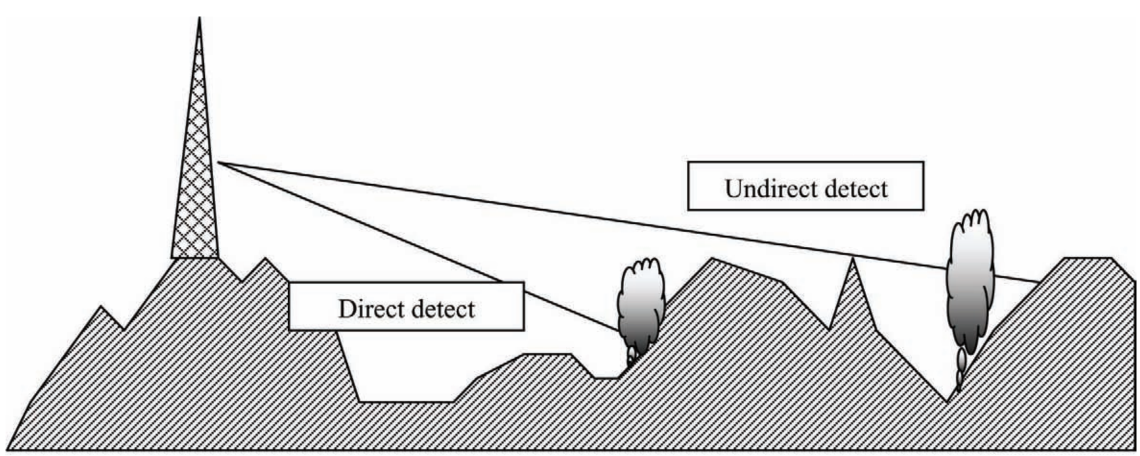

Figure 3. Detection.

indirectly by detecting the smoke rising from occluded hillsides. Fires in valleys and in lower-lying areas can be detected by detecting pillars of smoke. When the smoke rises over the ridge of the hill occluding the area, it can be detected by one of the cameras. The relatively small height differential between ridges and the lowest points of valleys (50m to max. 200 m) will allow even the pillars of smoke from small fires to be detected, despite the mixing of air and the resultant "thinning" of smoke.

Mobile deployment control and support unit

The mobile deployment control and support unit is the system's second module. Once a fire is detected, it is crucial that the site be reached as soon as possible in order to perform precise reconnaissance of the fire, and to commence extinguishing using the appropriate tactics. At present, since the roads are not negotiable by fire-engines, fires are often accessed by foot over distances of several kilometers, on some occasions with a fire-hose, which carries the risk of the hose being damaged or caught. On the one hand, that may cause significant delays in initiating efficient extinguishing of the fire, while on the other hand, if additional damage is incurred, that may mean having to take an unacceptable level of risk whilst also incurring generated delays. The delay caused by having to access a fire on foot may mean that the fire covers an area that is so large that our own unit is no longer sufficient to extinguish it. The transition to a higher level of emergency may, on the one hand, result in increased risk in other regions as resources are regrouped from there to the fire concerned, whilst on the other hand it also leads to increased costs.

The above considerations justify the use of a vehicle with strong all-terrain capabilities to access scenes of fire. The vehicle would also allow the traditional and modern equipment that is widely used in international practice to be transported to the scene (Nagy 2004).

Static and dynamic decision support

Static decision support—Appropriate information is a precondition for tactically correct intervention, which presupposes accurate reconnaissance performed by the leader of the fire-fighting unit. As areas are usually accessed from the direction of valleys, a good overview of the area affected by the fire is generally not available. Walking around the fire is time-consuming and, in the case of a larger area under flame, the leader of the fire-fighting unit is evidently physically too close to the fire to be able to make the correct decision concerning the type of intervention based on an assessment of both the fire and its environment (Restás 2004). International practice has produced a few examples for establishing the velocity of the fire based on preliminary calculations (Bryan 2003, Chandler and others 1983).

The above data-series can determine the velocity parameters of a fire if summarized with a mathematical algorithm (velocity model). This is the static fire velocity calculation that can be displayed for the fire-fighting leader on a digital map (3D – terrain model) on an on-site laptop. If we also summarise the parameters of the current weather conditions (temperature, humidity, speed and direction of wind), then the anticipatable fire velocity in accordance to situation at the time can be seen. All the data that may be represented in a map shall be stored in digitized format. User-friendly programs will also allow the risk levels of the area to be displayed in real time. Hence, instead of estimates concerning the spread of the fire based on previous experience, the likely spread of the fire can be determined on the basis of real, objective data.

Dynamic decision support—Accurate and rapid reconnaissance shall be facilitated by a Mosquito-type reconnaissance robot. The flying unit will support integrated decision-making based on geographic information systems. This is justified by the articulation of the terrain and the plant communities characteristic of the area, which can delay or even prevent accurate, rapid reconnaissance. Thus, serious delays in determining the correct emergency level and defining the correct fire-fighting tactics in time for them to be used can be incurred. This instrument, which can be deployed on site immediately, and which can provide an accurate and comprehensive view of the fire situation can eliminate the delays and inaccuracy caused by difficult terrain (Restás 2004).

The possibilities for employing a robot aircraft: With the use of a special "pencil," the fire-fighting leader draws the path of reconnaissance on a map displayed on a laptop. This is not difficult since the leader is able to judge the approximate size of the fire, but this is not yet enough to satisfy the preconditions for effective fire-fighting. The robot converts the path received onto the digital map stored on the machine's memory. Using its built-in GPS system, the robot, which can take off vertically, flies along the specified path and transmits a continuous, real-time image to the display of the laptop computer from the camera (thermal camera) that it carries. The accurate visual information received on the parameters of the fire (dynamic element) can be transformed onto the digital map as quickly as possible. If we now connect the hottest spots with a mathematical algorithm, objective information about the fire's exact line can be determined. Thus the fire-fighting leader can obtain information about a given fire that can satisfy the demands of effective fire-fighting, within a minimal amount of time.

Conclusions

Integrated Vegetation Fire Management involves a number of applications that have an innovative character in Hungarian fire-fighting. The system does not condemn the principle of fire extinguishing in the traditional way, it is a supplement to it. It is a local initiative that emerged to tackle local problems. However, favourable experiences from the system's application could also be adopted elsewhere in Hungary. Its effectiveness has to be judged on economic rather than emotional grounds. IVFM is not a cost-free system, it could not possibly be. If we accept that the efficiency of the current system is not optimal for fighting vegetation fires, then the reserves of the system not simply ought to be, but must be exploited. The analysis and its conclusions demonstrate that the premise of effective fire-fighting depends on the speed of intervention. As long as a time-reserve, unexploited in the current system, exists prior to the initiation of fire-fighting, using it is more than a possibility, it is an obligation.

The Area Monitoring and Fire Detection Unit installed on the tower ensures, from the perspective of recognizance and alarm, that the unit arriving for action will face a vegetation fire that in can fight with its own forces. The Mobile Deployment Control and Support Unit ensures an optimal approach to the fire and that the Static and Dynamic Decision Support Unit will reach the location. The tried and trusted principle of air-reconnaissance can be available to even the smallest fire department through the use of the reconnaissance robot aircraft. Traditional reconnaissance does not offer information quantitatively nor qualitatively appropriate to standards of the modern era. The robot aircraft, suited to the demands of fire departments, and that can also be used by small fire departments, significantly contributes to solving that problem. The dynamic decision support is able to provide initial data for static decision support. Thus, instead of an estimate of fire velocity based on previous experiences, the fire's actual scale and velocity can be objectively defined.

The application of the IVFM is expected to result in increasingly effective interventions, which can achieve a growth in the size of preserved forest areas, as well as a decrease in the area of territory destroyed. The costs of development and application need to be judged based on economic considerations, and seen as effective if returns are brought at the state economy level. The requisition of firemen may diminish, and the need for help may frequently be avoided. In the absence of superfluous requisitions, the potential risk to the general public diminishes in a higher degree of fire-security.

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Decision Support for Evaluating the U.S. National Criteria and Indicators for Forest Ecosystem Sustainability

Keith M. Reynolds, research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR

Abstract—*This paper describes and illustrates the use of the Ecosystem Management Decision Support (EMDS) system for evaluating the U.S. national criteria and indicators for forest ecosystem sustainability at the scale of Resource Planning Act (RPA) regions. The evaluation component of EMDS uses a logic engine to evaluate landscape condition, and the RPA-scale application demonstrates one practical approach to unifying knowledge for evaluation of forest ecosystem sustainability. EMDS (version 3.0.2) is an extension to ArcMap (ArcGIS 8.x), and is implemented as a general application framework that provides integrated decision support for environmental evaluation and planning at multiple spatial scales.*

In this study, national criteria two and six (productive capacity of forest ecosystems and socioeconomic benefits derived from forest management, respectively) were evaluated. Most data needed to evaluate criterion 2 were available in a recent national report, and results of evaluation indicate strong support for the proposition that productive capacity of forest ecosystems is adequate within all RPA regions. Evidence for suitable levels of socioeconomic benefits varied from weak to moderate across RPA regions, but conclusions were substantially influenced by missing data within all subcriteria.

Introduction

The 1992 Earth Summit (Rio de Janeiro, Brazil) enunciated principles for sustainable development of the world's forest resources (United Nations 1992). Subsequently, the 11 signatory nations to the 1995 Santiago Declaration, representing about 90 percent of the world's boreal and temperate forest cover, affirmed the recommendations of the Montreal Process that prescribed a set of seven criteria and 67 indicators for evaluating forest ecosystem sustainability (WGCICSMTBF 1995). Although the Montreal specifications provided relatively clear definitions of ecosystem attributes requiring evaluation, the Montreal Process did not prescribe how criteria and indicators (C&I) were to be interpreted to draw conclusions about the state of forest ecosystem sustainability. Reynolds (2001) suggested an approach to C&I evaluation based on a formal logic specification.

Gustafson and others (2003) discussed the potential use of logic models for ecological modeling in general. More specific examples of the possible uses of logic modeling in natural resource science include evaluating compatible resource uses (Reynolds 2002a), evaluating the social acceptability of decision processes (Reynolds 2002b), use of logic frameworks as a way to integrate diverse models (Reynolds 2003), and a way to integrate science and policy (Reynolds and others 2003a). Logic models also have been employed in decision support applications for landscape analysis and planning, including applications for design of biodiversity reserve systems (Bourgeron and others 2000), diagnosing departures in landscape structure and functioning (Hessburg and others 2004; Reynolds and Hessburg 2004), effectiveness monitoring (Reeves and others 2003; Reynolds and Reeves 2003), and watershed analysis (Reynolds and others 2000; Reynolds and Peets 2001).

Potential application of the Ecosystem Management Decision Support (EMDS) system for evaluating forest ecosystem sustainability has been described previously in a brief report (Reynolds 2001). This paper presents results on evaluating national criteria 2 (productive capacity of forest ecosystems) and 6 (socioeconomic benefits derived from forest management) at the scale of the Resource Planning Act (RPA) regions used by the U.S. Department of Agriculture, Forest Service in its periodic national reports.

Methods

Criteria and Indicators

Prabhu and others (2001) describe criteria and indicators as "information tools in the service of forest management" in the sense that they "can be used to conceptualize, evaluate, implement, and communicate sustainable forest management." For the purposes of this paper, I follow the definitions of C&I given by Prabhu and others (1999):

- Indicator: An indicator is any variable or component of the forest ecosystem … used to infer attributes of the sustainability of the resource and its utilization. Indicators should convey a 'single meaningful message.' This 'single message' is termed information. It represents an aggregate of one or more data elements with certain established relationships.
- Criterion: A standard that a thing is judged by. Criteria are the intermediate points to which the information provided by the indicators can be integrated and where an interpretable assessment crystallizes. Principles [for example, sustainability] form the final point of integration.

In addition to C&I, it is also necessary for subsequent discussion to define measurement endpoints. Some national indicators are simple; their definition suggests an obvious one-to-one correspondence between an indicator and a measure for that indicator. However, definitions of some indicators are more complex in the sense that they represent a synthesis of two or more data elements, which I refer to subsequently as measurement endpoints.

Data Sources

Most data used as measurement endpoints in this study were obtained from the 2003 national report on sustainable forests (Anonymous 2003). Some socioeconomic data, primarily used to normalize data on measurement endpoints obtained from the 2003 report, were obtained from the U.S. Census Bureau. Data available in the 2003 report were not adequate to evaluate productive capacity of non-timber forest products, so data for measurement endpoints related to this indicator were provided as subjective likelihoods from an expert source (Susan Alexander, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, personal communication).

The Ecosystem Management Decision Support System

EMDS version 3.0.2 (Reynolds 2002c; Reynolds and others 2003b) is a decision support system for integrated landscape evaluation and planning. The system provides decision support for landscape-level analyses through logic and decision engines integrated with the ArcGIS® 8.x geographic information system (GIS, Environmental Systems Research Institute, Redlands, CA). The NetWeaver logic engine (Rules of Thumb, Inc., North East, PA) evaluates landscape data against a formal logic specification, designed in the NetWeaver Developer System, to derive logic-based interpretations of ecosystem conditions such as sustainability. The decision engine evaluates NetWeaver outcomes (and data related to feasibility and efficacy of land management actions) against a decision model for prioritizing landscape features. This study did not use the planning component of EMDS, so it is not discussed further here. However, its potential use in conjunction with the evaluation component is considered subsequently in the Discussion.

Representing the National Criteria and Indicators in Logic

The criteria for productive capacity and socioeconomic benefits include four (table 1), and 19 (table 2) indicators, respectively. Each table presents the logic as an outline of topics for conciseness, but the logic structure of topics is actually represented graphically in NetWeaver during logic design (fig. 1). With 19 indicators and many more measurement endpoints, the full logic structure for socioeconomic benefits is too large to present even in outline form, so the outline (table 2) only presents a summarized overview of this topic.

In a logic-based approach, topics for evaluation have associated propositions (tables 1and 2), which evidence may tend either to support or to refute. The statement of a proposition is free-from text, and, particularly for topics higher in a logic structure that deal with relatively abstract concepts, this statement may be somewhat generalized. However, the logic construct of the topic (fig. 1), together with those of its underlying topics, makes the meaning of each proposition relatively precise in the sense that requirements for support of a proposition are well defined.

The representation of any problem evaluated by NetWeaver can be seen as a logical argument if each proposition is regarded as testing a conclusion, in which case the topics on which it depends may be regarded as

Table 1. Logic outline for U.S. national criterion 2, forest productive capacity.

Topic name[a]	Proposition
Forest productive capacity (AND)[b]	Forest productive capacity is adequate.
Forest land (CALC)[c] (indicator 2.10)	Productive forest land area is a suitable proportion of total forest land area.
Forest volume (CALC) (indicator 2.11)	Volume of nonmerchantable timber on productive forest land is not excessive.
Removals (CALC) (indicator 2.13)	Annual harvest volumes do not significantly exceed annual increment.
Nontimber forest products (UNION)[d] (indicator 2.14)	Productive capacity of nontimber forest products is adequate.
Edibles[e] (UNION)	Productive capacity of edible products is adequate.
Animals[f] (UNION)	Productive capacity of animals is adequate.
Plants[g] (UNION)	Productive capacity of key plants is adequate.

[a]Terms in parentheses following a topic name indicate operators by which topics at the next lower level of the outline are combined. When applicable, the national indicator designation (Anonymous 2003) with which the topic is most closely associated is indicated underneath the topic name.
[b]The AND operator indicates that topics at the next level in the outline are treated as limiting factors. The result of the evaluation is biased toward the most limiting factor.
[c]Topics followed by the CALC operator indicate elementary topics that evaluate the results of mathematical operations on one or more measurement endpoints. Mathematical details are omitted for brevity.
[d]The UNION operator indicates that topics at the next level in the outline are treated as incrementally contributing to the evaluation of their parent topic. The result of the evaluation is a weighted average, in which poor performance in one topic can be partially compensated by good performance on others.
[e]The edibles topic includes evaluation of berry and mushroom production capacities, both of which are elementary topics.
[f]The animals topic includes evaluation of production capacities for game and fur-bearing animals, both of which are elementary topics.
[g]The plant topic includes evaluation of production capacities for medicinal and decorative plants, both of which are elementary topics.

Table 2. Logic outline for U.S. national criterion 3, socioeconomic benefits.

Topic name[a]	Proposition	Frequency of missing values (%)
Socioeconomic benefits (AND[b])	A suitable level of socioeconomic benefits are being derived from current management of forests.	
Production[c] (indicators 6.29 to 6.34)	Current levels of production of forest products are adequate.	30
Recreation[d] (indicators 6.35 to 6.37)	Types and amounts of recreational opportunities are adequate.	34
Investment[e] (indicators 6.38 to 6.41)	Level of investment in the forest sector is adequate.	33
Cultural resources[f] (indicators 6.42 and 6.43)	Cultural, social, and spiritual needs are being satisfied.	50
Employment[g] (indicators 6.44 to 6.47)	Employment conditions in the forest sector are adequate.	51

[a]Terms in parentheses following a topic name indicate operators by which topics at the next lower level of the outline are combined. When applicable, national indicator designations (Anonymous 2003) with which the topic is most closely associated is indicated underneath the topic name.
[b]The AND operator indicates that topics at the next level in the outline are treated as limiting factors. The result of the evaluation is biased toward the most limiting factor.
[c] The production topic is a subcriterion of criterion 6, and includes evaluation of value and volume of wood and wood products production (indicator 29), value and volume of nonwood forest products (indicator 30), supply and consumption of wood and wood products (indicator 31), value of wood and nonwood products as percent of GDP (indicator 32), degree of wood product recycling (indicator 33), and supply and consumption of nonwood forest products (indicator 34).
[d] The recreation topic is a subcriterion of criterion 6, and includes evaluation of: area of forest land managed for general recreation and tourism (indicator 35), number and types of facilities available for general recreation and tourism (indicator 36), and number of visitor days attributed to recreation and tourism (indicator 37).
[e] The investment topic is a subcriterion of criterion 6, and includes evaluation of: value of investment (indicator 38), level of expenditure on research and development and education (indicator 39), use of new technology (indicator 40), and rate of return on investment (indicator 41).
[f] The cultural topic is a subcriterion of criterion 6, and includes evaluation of: area of forest land managed to protect the range of cultural, social and spiritual needs and values (indicator 42), and non-consumptive use of forest land (indicator 43).
[g] The cultural topic is a subcriterion of criterion 6, and includes evaluation of: direct and indirect employment in forest sector (indicator 44), average wage and injury rates (indicator 45), viability and adaptability to changing economic conditions (indicator 46), and area of forest land used for subsistence (indicator 47).

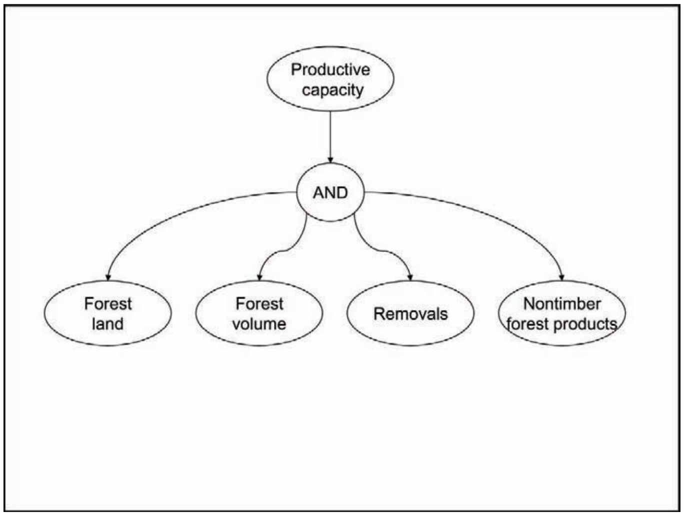

Figure 1. Graphic representation of a logic model in NetWeaver. Strength of evidence for the proposition that forest productive capacity is adequate depends on strength of evidence for its four premises, forest land, forest volume, removals, and nontimber forest products. Each premise similarly represents a topic to be evaluated for its strength of evidence. Partial details for the four premises are outlined in table 1.

its premises. Thus, fig. 1 can be interpreted as "forest productive capacity is adequate to the degree that each of its four premises is satisfied." Each premise contributes some strength of evidence for the conclusion about forest productive capacity. The measure for strength of evidence is a continuous-valued, dimensionless metric that originates with the evaluation of elementary topics (for example, forest land in table 1) that evaluate data (measurement endpoints) as evidence at the lowest levels of the logic. Reynolds and others (2003a) provide additional details about evaluating data as evidence and about basic logic operators such as AND and OR. The key point here, however, is that data in elementary topics are evaluated for the strength of evidence they provide with respect to reference conditions that ideally have been derived from scientific studies and perhaps policy considerations.

Derivation of the Logic

The basic structure for the logic (tables 1 and 2) was originally developed by the author to correspond as closely as possible to the topic outline suggested by the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (WGCICSMTBF 1995). However, the WGCICSMTBF topic outline did not include specifications for how topics might be combined through logic operators, so initial suggestions for synthesizing information with logic operators also were developed by the author (tables 1 and 2). A panel of internationally recognized authorities on issues of forest ecosystem sustainability was convened to review the resulting logic structure as an initial check on its reasonableness. Among others, the panel included John Gordon (Yale), Jerry Franklin (University of Washington), Norm Johnson, and Hal Salwasser (Oregon State University). Specific formulations for propositions at the lowest levels of the topic hierarchy (tables 1 and 2) were subsequently developed by the author. A key principle in formulating each proposition was that the relevant metric being evaluated by a topic should be normalized whenever possible. So, for example, rather than evaluating the absolute values of forest growth increment and harvest volume (components of indicator 2.13 in table 1), the Removals topic tests the proposition that there is a suitable ratio of growth increment to removals.

Results

Logic-based interpretation of data from the 2003 report (Anonymous 2003), census data, and expert opinion indicated strong support for the proposition that overall productive capacity of forest ecosystems within the four RPA regions was adequate (fig. 2). In fact, evidence indicated full support for the three premises associated with the forest land, forest volume, and removals topics (table 1). On the other hand, evidence for adequate productive capacity within non-timber forest products fell within a range that could be characterized as moderate

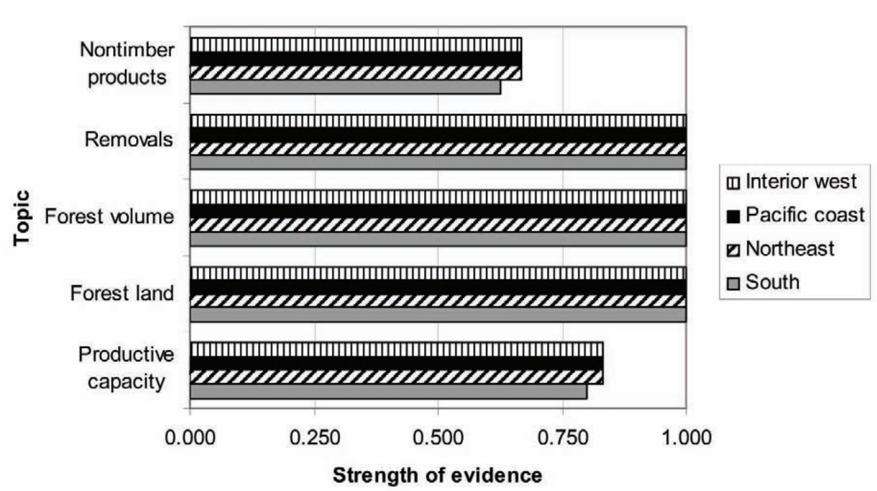

Figure 2. Evidence for adequate productive capacity of forest ecosystems in RPA regions of the U.S. Strength of evidence for the premises of productive capacity (table 1, fig. 1) also are shown.

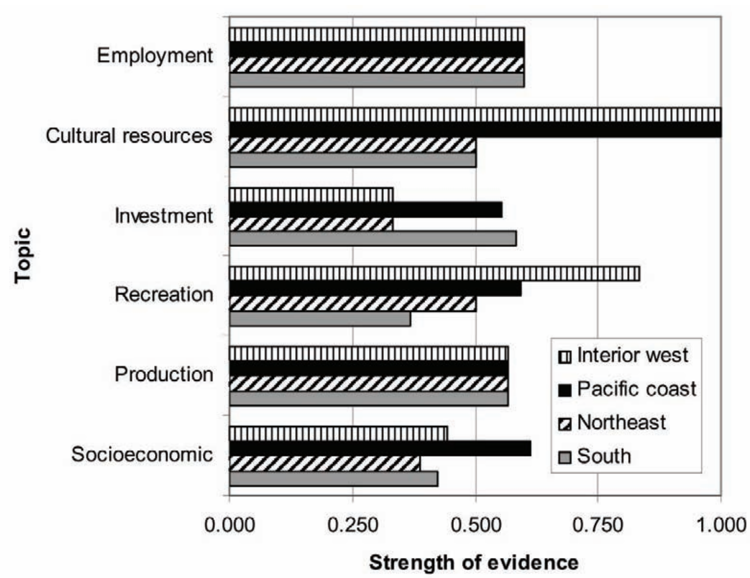

Figure 3. Evidence for suitable levels of socioeconomic benefits derived from forest management in RPA regions of the U.S. Strength of evidence for the premises of socioeconomic benefits (table 2) also are shown.

(fig. 2), and this result constrained the overall evaluation of forest productive capacity due to the influence of the AND operator (fig. 1) that treats individual premises as potentially limiting factors.

Overall strength of evidence for suitable levels of socioeconomic benefits derived from forest management varied from weak to moderate across the four RPA regions (fig. 3). However, the relatively poor performance on this criterion was partly due to negative conclusions about indicators. Instead, the lower levels for strength of evidence in this case are often attributable to significant data gaps in all subtopics (table 2). The influence of missing data on evaluation of production (table 2), for example, is typical. The production topic includes indicators 6.29 to 6.34 (although indicator 6.32 is not used in the current logic model) which are organized within the three subtopics, wood production, production of non-timber forest products, and recycling (indicator 6.33). Data were not available on recycling, and this lack of evidence constrained the strength of the conclusion about production, given available evidence, because strength of evidence on the other two subtopics was moderately strong.

Discussion

A Framework for Science, Policy, and Communication

Perhaps one of the most useful aspects of a logic-based approach to evaluating forest ecosystems is that logic provides a formal framework within which possibly numerous interdependent issues of science and policy can be organized to guide the needed dialogue between scientists and policymakers to perform an evaluation (Reynolds and others 2003a). Conceptual models can be very useful in the initial design stage of a logic-based approach, but, as Gustafson and others (2003) have discussed, they have significant limitations when used as stand-alone modeling solutions. In particular, lack of a formal structured logic in typical conceptual models can result in the entities and their relations being semantically vague at best and unintelligible at worst. Although formal logic frameworks are not entirely immune from such problems, they are far less prone to them. In fact, the graphical form of logic representation is not only a powerful form of communication among model developers, but an intuitive medium in which to explain the results of evaluations to audiences who may have little or no technical background in modeling (Reynolds and Reeves 2003).

Missing Data

The 2003 report on the state of forest ecosystems in the U.S. (Anonymous 2003) was a landmark publication with respect to the scope of the ecological and socioeconomic indictors that it attempted to address. However, not too surprisingly, even given several years of preparation to produce this report, there were numerous data gaps. An important contributing factor was that the scope and complexity of questions being asked about forest ecosystem had increased dramatically over the past 20 years. Indeed, missing data is a recurrent issue in most modern programs of landscape monitoring and assessment. In this particular study, all data on forest productive capacity were available in one form or another, but there were significant data gaps in all subcriteria of the socioeconomic criterion (table 2).

In a logic context, data are evidence, and missing evidence does not preclude a useful evaluation, but constrains the strength of conclusions (fig. 3). In the present study, for example, it is possible to conclude that available evidence indicates there is at least weak to moderate support for the proposition that levels of socioeconomic benefits derived from forest management are adequate across the four RPA regions. To appreciate the value of this partial answer, consider that 50 to 70 percent of the data on subcriteria of the socioeconomic criteria were available, and that none of the available data led to the conclusion that the levels of socioeconomic benefits were inadequate.

Perhaps just as importantly, logic engines such as that integrated in EMDS can interpret interdependencies in data and analysis topics to calculate a measure of the influence of missing information, and this information can readily be incorporated into simple decision models to evaluate the priority of missing information, taking into account its influence and other logistical considerations, such as how expensive it might to acquire the missing data (Reynolds 2002c, Reynolds and others 2003b).

Additional Lines of Future Development

The current application could easily be extended in two potentially useful respects.

First, the present example illustrates evaluation at a single spatial scale. However, EMDS applications can accommodate multiple spatial scales. Reynolds and Peets (2001) have illustrated integrated evaluation across multiple spatial scales in the context of watershed assessment for salmon habitat restoration. In the present context, virtually all of the indicators for criteria 2 and 6 could be evaluated at the scale of States, and State-scale results summarized to RPA regions as area-weighted averages. More generally, evaluations of criteria can be parsed among scales as necessary. For example, the biodiversity, global carbon cycle, and institutional framework criteria (1, 5, and 7, respectively) are most likely best evaluated at the broader scale of RPA regions. Multiple scales can be employed within a single EMDS application in other ways as well. For example, evaluations of criteria 2 and 6 at the scale of National Forests might be superimposed on their corresponding regional evaluations to place the Forest-scale evaluations in their broader regional context.

Second, the present paper does not consider analysis of management priorities for maintenance or restoration of forest ecosystems within the RPA regions. However, EMDS includes a planning component that uses a decision engine to evaluate planning models built with Criterium DecisionPlus® (CDP, InfoHarvest, Seattle, WA). The CDP models implement the analytical hierarchy process (AHP, Saaty 1994), the simple multi-attribute rating technique (SMART, Kamenetzky, 1982), or a combination of the AHP and SMART methods. Reynolds (2000) provided a detailed example of applying AHP and SMART to develop priorities for salmon habitat restoration. Reynolds and Hessburg (2004) provided an example of decision modeling with CDP in conjunction with EMDS applications.

The distinction between the evaluation and planning phases of analysis as implemented in EMDS has important consequences for users developing management applications because it simplifies the overall analytical problem into two simpler problems. In evaluation, the question of interest is, "What is the state of the system?," whereas, in planning, the question is, "Which areas are the highest priority for management?" Decomposing the problem is this way avoids confusion in the assessment process by cleanly separating issues about the current state of a system from issues about where management or restoration activities ought to occur. An important side effect of this problem decomposition is that logistical considerations about the feasibility or efficacy of potential management activities are easily accommodated within the planning component.

Conclusions

Evaluating forest ecosystem sustainability within a formal logic framework illustrates one practical approach to unifying knowledge within a large, abstract problem domain. Some specific benefits that derive from the logic-based approach include 1) a rigorous approach to problem specification that simultaneously expedites dialog among model developers while facilitating communication of model results to non-technical audiences in intuitive terms, 2) effective use of partial information in the early stages of monitoring when information is often incomplete, and 3) the availability of metrics for evaluating the influence of missing information which can help optimize how data gaps are subsequently filled.

Within the broader context of a decision support framework, knowledge unification in a logic framework can be viewed as a form of knowledge integration. Additional practical examples of integration within a decision support framework include the ability to link scales of evaluation, and the ability to explicitly link the evaluation and planning phases of adaptive management (Reynolds and Hessburg, 2004; Reynolds and Peets, 2001).

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Forests on the Edge: A GIS-based Approach to Projecting Housing Development on Private Forests

Susan Stein, Private Forestland Studies Coordinator and Mike Dechter, Natural Resource Specialist, USDA Forest Service, Cooperative Forestry, Washington, DC
Ron McRoberts and Mark Nelson, Forest Inventory and Analysis Researchers, USDA Forest Service, North Central Research Station, St. Paul, MN
David Theobald, scientist, Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO
Mike Eley, GIS Coordinator for American Farmland Trust, Washington, DC

***Abstract**—The private working land base of America's forests, farms, and ranches is being converted at the rate of nearly 1,620 ha (4,000 acres) per day with tremendous economic, ecological, and social impacts. The United States Department of Agriculture (USDA) Forest Service is sponsoring the "Forests on the Edge" project to develop a better understanding of the contributions of America's private forests to timber, wildlife, and water resources and the pressures exerted on these resources from development, fire, air pollution, and insects and diseases. The project uses Geographic Information Systems (GIS) techniques to construct a series of maps depicting pressures and opportunities on America's private forests in the lower 48 states. Phase I of the project identifies fourth-level watersheds with private forests that are projected to experience increased housing density by 2030. The majority of these watersheds are in the eastern United States, although some that are projected to experience the greatest percent change are in the West. The methodology, results, and planned uses of Phase I products are presented, as are examples of the potential impacts of increased housing density on forest attributes such as wildlife, timber, and water.*

Introduction

Comprising over 57 percent of total forest cover, America's private forests make enormous contributions to water quality, biodiversity, timber, recreation, and essential ecological and economic functions. However, the conversion of private forest lands to urban uses threatens to reduce forests' ability to provide these functions.

Although there are many areas of the country that are experiencing an increase in private forest land, overall private forest land area is declining slightly (Smith and others 2004). Between 1982 and 1997, over 4 million ha (10 million acres) of non-Federal forests were converted to developed uses across the conterminous United States (USDA 2000) and an additional 9.3 million ha (23 million acres) may be lost by 2050 (Alig and others 2003).

The effects of development on private forest management have been documented in several localized studies. These studies have illustrated both short and long-term negative impacts of population growth and urban expansion on forest management for economic functions, such as timber production. In western Virginia, increasing human population densities affected long-term timber management capabilities by reducing timber land area and growing stock volumes by approximately 40 percent (Wear and others 1999). Private forest stakeholders in Wisconsin indicated that parcelization caused by development makes timber production less profitable and can result in a shift from commercially valued aspen, pine, and oak to less valued species such as red maple (Gobster and Rickenbach 2004). In Mississippi and Alabama, proximity to urban land uses and higher population densities led to a net decrease in harvesting rates (Barlow 1998).

Population growth and urban expansion are also related to reductions in non-timber forest management and investment in private forest lands. A 2004 study focused in western Oregon concluded that increased building densities are correlated with reduced forest stocking and pre-commercial thinning, as well as a reduced likelihood for tree planting following thinning (Kline and others 2004). Private forest landowners in Georgia's metropolitan counties were less likely to participate in government incentive programs for protecting soils and tree planting than landowners in more rural counties (Harris and DeForest 1993).

The objective of this project, denoted Forests on the Edge and sponsored by the Forest Service, was to identify areas in the conterminous United States where private forests are likely to experience increases in housing density between 2000 and 2030. The project focused on lands projected to shift from rural or ex-urban use to urban use, and from rural use to ex-urban. These levels of "use" are based on housing density levels and are defined in the Analyses section.

Methods

Data

A 100-m spatial resolution dataset of the conterminous United States differentiating combinations of land cover and land ownership was constructed from the 1992 National Land Cover Dataset (NLCD) (Vogelmann and others 2001) and the Protected Areas Database (PAD) (DellaSala and others 2001). NLCD is a 30-m resolution, 21-class, land cover classification derived from nominal 1991 Landsat Thematic Mapper imagery and ancillary data by the U.S. Geological Survey. Forest/non-forest data were obtained from NLCD by collapsing its Transitional (33), Deciduous Forest (41), Evergreen Forest (42), Mixed Forest (43), and Woody Wetlands (91) classes into a forest class and the remaining classes into a non-forest class. PAD is an ArcInfo polygon coverage compiled by the Conservation Biology Institute (CBI). PAD contains boundaries of most Federal and State-owned/managed protected areas in the conterminous United States and Alaska, and includes county, city, and private reserves where data were available. Recoded NLCD data were re-sampled and recoded PAD data were rasterized to 100-m spatial resolution. The two resulting grid layers were combined, forming a single forest/non-forest ownership grid dataset that was denoted FOROWN100M and consisted of six land cover/ownership categories: public non-forest, public forest, protected private non-forest, protected private forest, unprotected private non-forest, and unprotected private forest. The area of land identified in FOROWN100M as forest is within a 95 percent confidence interval for the estimate of Conterminous United States (CONUS) forest land in the draft 2002 tables of the Resource Planning Act (RPA) Forest Resources of the United States (http://ncrs2.fs.fed.us/4801/fiadb/rpa_tabler/2002_rpa_draft_tables.htm). No formal accuracy assessment was conducted on the ownership attributes in FOROWN100M.

Watersheds were delineated using the HUC250 database (http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml), which is based on hydrologic unit maps published by the U.S. Geological Survey, Office of Water Data Coordination. Hydrologic units are encoded with an eight-digit Hydrologic Unit Code (HUC); with the first two digits indicating the hydrologic region, the second two digits indicating the hydrologic subregion, the third two digits indicating the accounting unit, and the fourth two digits indicating the cataloging unit. Watersheds corresponding to these hydrologic units are characterized as eight-digit HUC watersheds and are 1,735 sq. mi. (1,110,400 acres) on average. These data were digitized generally at a scale of 1:250,000 but with some portions at a scale of 1:100,000 and some at a scale of 1:2 million.

Housing density was estimated by drawing from historical and current housing densities at a fine resolution to examine spatial patterns of development. Using the historical and current housing density patterns as data inputs, a forecast simulation model of future housing density patterns was developed based on county-level population projections.

Nationwide estimates of population and housing density were computed from the U.S. Census Bureau's block-group and block data for 2000 (U.S. Census Bureau 2001a). To estimate current housing density patterns, housing density was computed using dasymetric mapping techniques (Theobald 2001a, in review). Census blocks were refined using public land information from FOROWN100 and water polygons from Census Bureau data. Because privately-owned houses are not allowed on public land, portions of blocks on public land were removed, as were portions of blocks identified as streams, rivers, ponds, lakes, and reservoirs. Using these refined census block geographies, the number of housing units per block, obtained from the 100 percent data of the 2000 Census STF1 (U.S. Census Bureau 2001b), were allocated throughout the refined blocks and weighted to reflect the likely heterogeneity of the placement of houses that are more likely to be located near roads and less likely in portions of blocks distant (greater than 1 km) from roads. The allocation of housing units is weighted based on road density (computed using an 800 m radius moving neighborhood).

Road density was classified into four arbitrary categories that distinguished different levels of development and were used to allocate housing density values to cells within a block: very low (0.0 - 0.25 km/km^2), low (0.25 - 1.0 km/km^2), medium (1.0 - 5.0 km/km^2), and high (>5.0 km/km^2). Housing density estimates for 1990 were generated from the "Year Housing Built" question from the sample data Summary File 3 dataset (US Census Bureau 2001c). These data are provided at the block-group level and were adjusted to ensure that the sum of units by block-groups in a county equaled the counts from decadal census using established methods (Hammer and others 2004; Radeloff and others 2001; Theobald 2001a).

The Spatially Explicit Regional Growth Model (SERGoM v1) was used to model the full urban-to-rural spectrum of housing densities. It uses a supply-demand-allocation approach and assumes that future growth patterns will be similar to those found in the past decade. Four basic steps are used in SERGoM v1 to forecast future patterns on a decadal basis. First, the number of new housing units in the next decade is forced to meet the demands of the projected county-level population. Population growth was converted to new housing units by the county-specific housing unit per population ratio for 2000. Population estimates were obtained from a demographic-econometric model (NPA Data Services 2003). Second, a location-specific average growth rate from the previous to current time step (for example, 1990 to 2000) was computed for each of four density classes: urban, suburban, exurban, and rural. These growth rates were computed for each 100 m cell using a moving neighborhood (radius = 1.6 km) that allows within-county heterogeneity and cross-county and State boundary growth patterns to be captured. Also, new housing units were spatially allocated based on these locally determined growth rates, which assumes that areas of future growth are likely to be near current high-growth areas or "hot spots."

Third, the distribution of new housing units was adjusted according to accessibility to the nearest urban core area. That is, urbanization and conversion to urban and exurban land use typically occurs at locations on the fringe of urban core areas where land is undeveloped. Accessibility is computed in terms of minutes of travel time from urban core areas as one would travel along the main transportation network. An urban core area is defined as a contiguous cluster of greater than 100 ha at urban housing density. The distribution of housing density was then adjusted by creating a weight surface based on travel time from urban areas and is used to modify the location of new housing units computed in the first step. Fourth, the new housing density was added to the current housing density, which makes the assumption that housing density does not decline over time, which is reasonable to represent patterns of expansion in suburban and exurban areas, but may under represent areas that are in fact declining in housing density through urban decay or expansion of commercial land use into residential areas.

Analyses

Watersheds were selected as the unit of analysis to focus on the contributions provided by forests to water and watershed quality and condition. Geographic Information System (GIS) techniques were used with the FOROWN100M and the eight-digit HUC watershed layers to select watersheds that satisfied two criteria: 10 percent or greater forest cover, and 50 percent or more of the lands with forest cover in private ownership. GIS techniques were also used with the housing density layer to create maps depicting the percentages of each selected watershed containing private forest projected to experience increases in housing density between the years 2000 and 2030. Note that the maps displayed conversion of private forest land as a percentage of all land within the watershed, not just private forest land in the watershed. The study was conducted in this way to focus on the potential impacts of housing development on the watersheds themselves.

Housing density projections displayed in the final maps reflect projections for private forest land only. All public lands and all non-forested lands were excluded from the analyses, as were private forest lands with conservation easements recorded in the PAD.

Housing density was used to characterize the most likely and widespread type of development and land use conversion facing private forests. There was no attempt to depict other types of development or conversion resulting from commercial development, road building, mining, or conversion of forest to farms or pastures.

Three categories of private forest land were defined based on three housing density thresholds: rural, ex-urban, and urban. For the purposes of this study, private forest lands were denoted "rural" if they contained 6.2 or fewer housing units per km^2 (16 or fewer housing units per sq. mi.). Forest lands with this housing density can generally support a diversity of economic and ecological functions commonly associated with private forests such as management for timber, most wildlife species, and water quality. Private forest lands were denoted "ex-urban" if they contained from 6.2 to 24.7 housing units per km^2 (16 to 64 housing units per square mile). Lands with these higher housing densities can still support many wildlife species and other ecological functions, although perhaps at a reduced level. However, management for commercial timber may be less likely. Private forest lands were denoted "urban" if they contained 24.7 or more housing units per km^2 (64 housing units per sq. mi.). Such lands are unlikely to be used for timber production and, in many States, do not qualify for favorable property tax assessments or technical or financial assistance through State or Federal forest management programs. Forest lands with this housing density are less likely to contribute to wildlife habitat and water quality because of increased road density, infrastructure, and human population levels associated with this level of development.

Shifts in private forest lands among these categories can have strong implications, with respect to management for timber, wildlife, and other values. In western Virginia, the transition from rural to urban use occurs over a range from 7.7 people per km^2 (approximately 20 people or 8 housing units per sq. mi.) to 27 people per km^2 (70 people or 28 housing units per square mile). The chance of commercial forestry drops from 75 percent down to 25 percent over this range (Wear and others 1999). Similar results have been found for western Oregon where pre-commercial thinning and planting following harvest are less likely, and forest stocking levels are somewhat lower on forest landscapes with higher population densities (Kline and others 2004).

Such shifts in land use can also lead to a decrease in wildlife habitat quantity and quality. The cumulative effects of removing native vegetation, constructing fences, increasing human contact, and increasing presence of small-sized predators (cats and dogs) associated with residential development in formerly rural areas can all contribute to the displacement of native wildlife populations (Theobald and others 1997).

Results

Maps based on the selected thresholds are displayed in figures 1 to 5. The criteria that watersheds have at least 10 percent total forest cover, of which at least 50 percent is in private ownership, focused the analyses on the eastern United States where forest cover is more extensive and most forest land is in private ownership.

Figure 1 displays the percentage of each watershed that contains private forests that are projected to shift from rural or ex-urban to urban. Our definition of “ex-urban” for this map is any forest land containing 6.2 housing units to 12.7 housing units per km^2 (16 to 33 housing units per sq. mi.), as opposed to the previous definition of 6.2 to 24.7 housing units per km^2 (16 to 64 housing units per sq. mi.). This was done to ensure that we were not including forest lands experiencing only small increases in housing density (for example an increase from 64 to 65 or 66 housing units per sq. mi.). By 2030, 8,773,847 ha (21.7 million acres) of private forest is projected to experience this type of increase in housing density.

Two watersheds, one in Maine and one in California, are projected to shift from rural or ex-urban to urban on 20 to 30 percent of their areas. Thirty-eight watersheds are projected to experience this shift on 10 to 20 percent of their area. Most of these watersheds are scattered across the eastern United States, although some are located in the Sierra Nevada foothills of California, and northern Washington State.

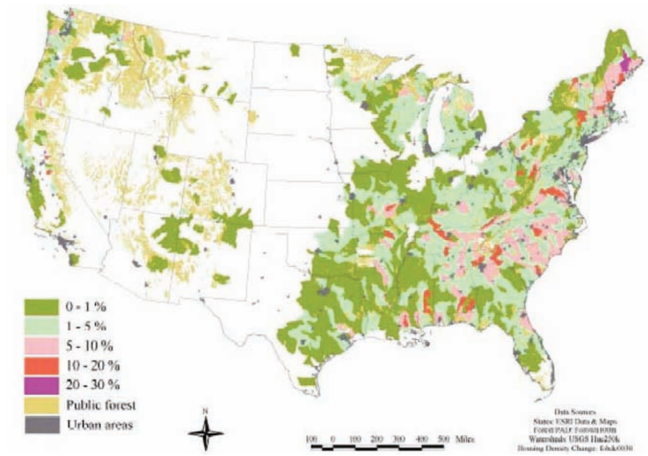

Figure 1. Percentage of watersheds with private forests projected to shift from rural or ex-urban to urban use.

The project also identified the number of acres of private forest projected to shift from rural or ex-urban to urban use by watershed. The top 20 watersheds are presented in figure 2 and table 1. The Lower Penobscot watershed in Maine ranks number 1, with 107,671 ha (266,066 acres) of private forest projected to experience this shift. This is followed by the Etowah watershed in Georgia with 84,928 ha (209,866 acres), the Middle Hudson watershed in New York with 76,436 ha (188,880 acres), and the Upper Oconee watershed in Georgia with 67,210 ha (166,084 acres). The Piscataqua-Salmon Falls watershed, covering parts of southern Maine and southeastern New Hampshire, ranks 20th, with 42,427 ha (104,842 acres) of private forest expected to shift from rural or ex-urban to urban.

Figure 3 depicts the percentage of each watershed containing private forest projected to shift from rural

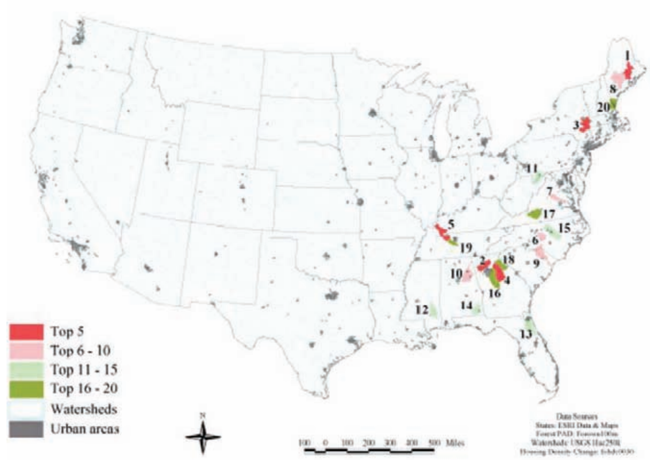

Figure 2. Top 20 watersheds with greatest acreage of private forests projected to shift from rural or ex-urban to urban use.

Table 1. Top 20 watersheds projected to shift from rural or exurban to urban use.

Watershed rank	8-digit HUC Identifier	Hydrologic Unit Name	Acres
1	01020005	Lower Penobscot	266,006
2	03150104	Etowah	209,866
3	02020006	Middle Hudson	188,880
4	03070101	Upper Oconee	166,084
5	05130205	Lower Cumberland	158,945
6	03030003	Deep	157,342
7	02080106	Pamunkey	156,015
8	01030003	Lower Kennebec	146,437
9	03040201	Lower Pee Dee	145,705
10	03150106	Middle Coosa	138,895
11	02070002	North Branch Potomac	138,829
12	03170005	Lower Leaf	134,499
13	03080103	Lower St. Johns	132,162
14	03140201	Upper Choctawhatchee	127,575
15	03020201	Upper Neuse	124,403
16	03070103	Upper Ocmulgee	120,375
17	03010101	Upper Roanoke	117,686
18	03060104	Broad	110,026
19	05130204	Harpeth	107,026
20	01060003	Piscataqua-Salmon Falls	104,842

to ex-urban. Our definition for "rural" for this map is any forest land containing less than 4.9 housing units per km^2 (12.8 housing units per sq. mi.), as opposed to the stated definition of less than 6.2 housing units per km^2 (16 housing units per sq. mi.). Just over 9 million ha (22.5 million acres) of private forest land is expected to experience this type of shift. About 20 watersheds contain forest projected to experience this shift on over 10 to 20 percent of their area. These watersheds are located in about 12 States in the Northeast and South. They include New Hampshire, Vermont, Pennsylvania, Virginia, West Virginia, North Carolina, Tennessee, Missouri, and Arkansas.

Results for the top 20 watersheds with the most private forest land projected to shift from rural to ex-urban are presented in figure 4 and table 2. The top watershed in this category is the Little Kanawa watershed in West Virginia, with 58,871 ha (145,476 acres) of private forest expected to experience this change. This is followed by the Upper Roanoke watershed in Virginia with 56,422 ha (139,424 acres), the Upper Green watershed of Kentucky with 55,874 ha (138,070 acres), and the Upper Susquehanna watershed in New York with 55,792 ha (137,867 acres). The Upper Alabama watershed ranks 20th with 42,292 ha (104,508 acres) projected to experience this change.

A map depicting the percentage of each watershed projected to experience either type of shift (from rural or ex-urban to urban and/or from rural to ex-urban) is presented in figure 5. A total of 17,882,073 ha (44.2 million acres) of private forest land is expected to experience

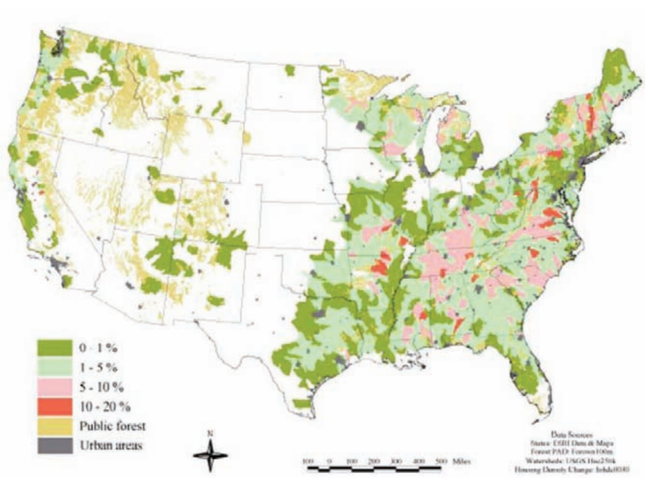

Figure 3. Percentage of watershed with private forests projected to shift from rural to ex-urban use.

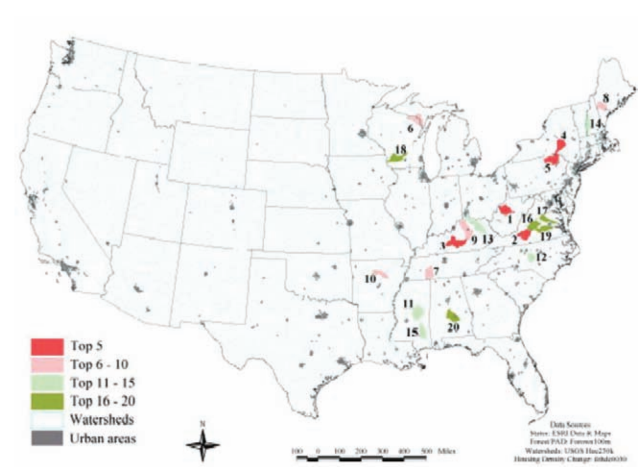

Figure 4. Top 20 watersheds with greatest acreage of private forests projected to shift from rural to ex-urban use.

Table 2. Top 20 watersheds projected to shift from rural to exurban use.

Watershed rank	8-digit HUC Identifier	Hydrologic Unit Name	Acres
1	05030203	Little Kanawha	145,476
2	03010101	Upper Roanoke	139,424
3	05110001	Upper Green	138,070
4	02050101	Upper Susquehanna	137,867
5	02050106	Upper Susquehanna - Tunkhannock	135,129
6	04030108	Menominee	133,753
7	06040001	Lower Tennessee – Beech	123,869
8	01040002	Lower Androscoggin	118,129
9	05100205	Lower Kentucky	117,822
10	11010014	Little Red	116,940
11	03180001	Upper Pearl	113,179
12	03030003	Deep	112,475
13	05100101	Licking	112,361
14	01080104	Upper Connecticut – Mascoma	109,176
15	03170005	Lower Leaf	108,259
16	02080203	Middle James – Buffalo	107,375
17	02080106	Pamunkey	105,988
18	07070005	Lower Wisconsin	104,958
19	02080207	Appomattox	104,632
20	03150201	Upper Alabama	104,508

one or both of these shifts by the year 2030 in watersheds that meet the forest coverage and ownership criteria. About 20 watersheds are projected to experience one or both of these changes on private forest covering at least 20 percent of their areas. Again, these watersheds are scattered primarily across the East (particularly across the Northeast and Southeast), with some occurring also in the northern Midwest, California, and the Pacific Northwest.

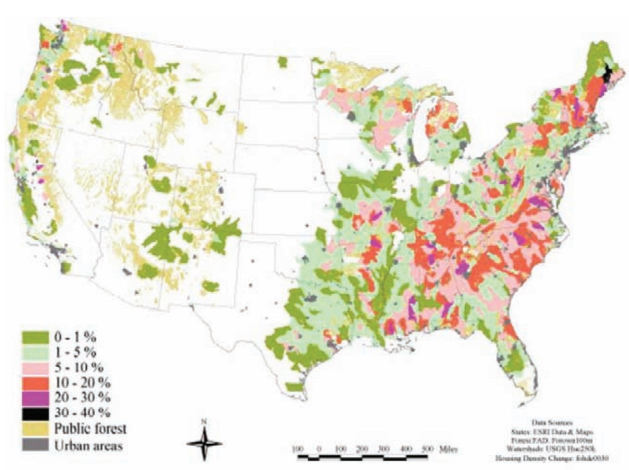

Figure 5. Percentage of watershed with private forests projected to experience increased housing density by 2030.

Discussion

The results of this project indicate that many of the private forest lands likely to experience increased housing density from 2000 to 2030 are located in the eastern United States. This makes sense as a majority of our private forests are located in this area. Much of the private forest projected to experience change is located in watersheds in the southeastern United States. This is consistent with the finding by Alig and others (2004) that development has been high in the South and will continue to be high due to above average population and income growth coupled with above average marginal consumption rates of land.

Private forests in certain areas of the Northeast (Maine, New Hampshire, Vermont, and New York) are also projected to experience housing density increases. Additional study of the possible causes of this would be useful. It may be that housing densities are increasing in these areas as a result of second home development because of the attractive recreational and aesthetic amenities they provide. A recent study of development in the north central United States indicates growth rates in attractive rural areas are among the highest and that this has major implications for forest ecology and management (Hammer and others 2004).

Although a number of watersheds in the Southwest met the selection criteria of forest coverage and private ownership, the private forests they contain were not projected to experience significant housing density increases. This does not mean that housing development will not occur in these watersheds or other areas of the Southwest. It only means that the development is not occurring on private forests that meet the selection criteria.

Private forests in the majority of the western watersheds that met the selection criteria are not projected to experience high housing density increases. It may be that in some localized areas, private forests will be developed, but those areas do not occur in watersheds containing at least 10 percent forest cover or where at least 50 percent of the forest is private. Private forests in a few watersheds in California and northwestern Oregon are projected to experience housing density increases. It is likely that many of these watersheds show up on our map because they will experience some level of housing development and because they are fairly small (thus, even change on a small amount of land makes them show up on the maps showing percent change in a watershed). The fact that none of these watersheds show up on either "top 20" acreage list indicates that the acreage projected to be affected is less than 40,000 ha (approximately 100,000 acres).

Conclusions

Private forests in watersheds across the eastern United States and particularly in the Northeast and Southeast, as well as in California and the Pacific Northwest are projected to experience a shift from rural or ex-urban use to urban use, or a shift from rural to ex-urban use between the years 2000 and 2030. While most watersheds meeting the forest coverage and private ownership criteria are projected to experience these types of development on less than five percent of their surface area, over 30 watersheds will experience one of these changes on 10 to 20 percent of their area. This has implications for the condition and management of the private forests projected to be affected and the watersheds in which they occur. Increasing housing density in forested areas can be associated with decreases in native wildlife populations, alterations in forest structure and function, decreases in timber production and active forest management, and increases in fire risk. Depending upon the location of the affected forest, the quality of water run-off could also be affected.

Admittedly, this study is but one chapter in the story of constant flux experienced by our Nation's private forest lands. The method used focuses on the quantity, rather than quality of private forest land in each watershed. Although this type of analysis can be important for targeting efforts to conserve functions and values bestowed by private forests, it will inevitably disregard some forest types, such as riparian areas in the Southwest, where quantity does not occur on the same scale as forest lands in the East.

While projections of this scope and nature do not necessarily provide accurate predictions of the future in all parts of the study area, spatial information about land use changes resulting from this and similar studies is a crucial input for scientists, resource managers, and communities in their efforts to plan for future growth and implement resource plans and policies. Furthermore, the results of this study can be used to identify watersheds for possible future research.

Future work in this area should focus on four areas: (1) validation of data identifying watersheds as having private forest most likely to experience housing density increases; (2) impacts of various levels of housing density on timber, wildlife, water quality, and other forest amenities; (3) projected shifts among the lower density categories (for example, from 0.5 to 1.5 housing units per square mile); and (4) a more in-depth look at private forests in the West and the pressures they face.

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Monitoring Global Crop Condition Indicators Using a Web-Based Visualization Tool

Bob Tetrault, Regional Commodity Analyst, and Bob Baldwin, GIS Specialist, USDA, Foreign Agricultural Service, Washington, D.C

Abstract—*Global crop condition information for major agricultural regions in the world can be monitored using the web-based application called Crop Explorer. With this application, U.S. and international producers, traders, researchers, and the public can access remote sensing information used by agricultural economists and scientists who predict crop production worldwide. For example, regional droughts or excessively wet conditions can be identified in thematic maps by the amount of ground-surface "greenness" depicted by the Normalized Difference Vegetation Index (NDVI).*

Crop Explorer automates the processing and extraction of certain agro-meteorological indicators from the source data. Information is presented using thematic maps and time series charts for weather, crop model, soil moisture and vegetation indices. These indicators—from weather and satellite data—are defined by crop type, crop region (sub-national), and season. The data visualization products are updated every ten days. The site includes more than 11,800 charts and maps. Partnerships with NASA provide near real-time satellite imagery (MODIS Rapid Response) and reservoir height estimates. MODIS satellite imagery is acquired twice a day and is posted on the site approximately six hours after acquisition. Reservoir height estimates are updated every 10 days and are derived from satellite data (TOPEX/Poseidon and Jason-1).

The Production Estimates and Crop Assessment Division (PECAD) of USDA's Foreign Agricultural Service (USDA/FAS) developed the site. PECAD is responsible for global crop condition assessments and estimates of area, yield, and production for grains, oilseeds, and cotton. The primary mission of PECAD is to produce the most objective and accurate assessment of the global agricultural production outlook and the conditions affecting food security in the world. Regional analysts use Geographic Information System (GIS) and web-based tools—such as Crop Explorer—to analyze crops, weather, and satellite data.

Introduction

Crop Explorer is an Internet web site that provides free, easy-to-read crop condition information for major agricultural regions in the world. This information is heavily used by farmers, agribusiness, traders, researchers, foreign organizations and U.S. federal, state and local agencies. At the Production Estimates and Crop Assessment Division (PECAD) of the U.S. Department of Agriculture (USDA), Foreign Agricultural Service (FAS) this information is used for global crop condition assessments and estimates of area, yield, and production. PECAD produces objective and accurate assessments of the global agricultural production outlook and the conditions affecting food security. Regional analysts use a Geographic Information System (GIS) to collect market intelligence, and forecast reliable global production numbers for grains, oil seeds and cotton.

The GIS utilizes several different satellite data sources, input databases, climate data, crop models, and data extraction routines for yield and area estimates to determine production (production=yield x area) (Tetrault, 2004). The FAS has a global network of attachés that provide on-the-ground reports of observed crop and contextual information. Also, the FAS regional analysts travel extensively in the countries they cover to more fully develop the context and constraints within which their assessments are made. The development of the interface and underlying structure of this application was built upon years of experience from PECAD crop analysts. Their knowledge of in-country conditions was essential to the creation of the areas of interest known as agro-meteorological zones. These zones are unique to Crop Explorer and are the basis for spatially representing the global crop condition information. Ancillary data from official governmental reports, trade and news sources play a significant role in interpreting the data. Final production estimates are approved by the USDA World Agricultural Outlook Board and published on the 10th day of each month. The methodology relies on an all source convergence of evidence. The final production estimates are used in a variety of ways:

- Official USDA statistics
- Principle Federal Economic Indicators
- Crop conditions and early warning alerts
- Agricultural monitoring and food security
- Foreign aid assessments for food import needs
- Disaster monitoring and relief efforts related to food aid
- Commercial market trends and analysis
- Trade policy and exporter assistance

The web site automates the processing and extraction of specific crop condition indicators from an immense amount of agriculture data stored on PECAD's database servers. Baseline data sets include atmospheric data and satellite imagery. The near real-time estimates of meteorological indicators, such as precipitation and soil moisture, are used by agricultural economists and scientists to forecast crop production worldwide.

Crop Condition Monitoring

PECAD relies on remote sensing data from satellite sensors (fig. 1) as an important source of data for its GIS. Selected data sets provide daily, weekly, and targeted coverage with resolutions ranging from 1km to less than 1m. The data is stored on a terabyte server accessible to each analyst workstation. The most common data formats used operationally with ArcGIS at PECAD are TIFF and compressed MrSID images.

The Crop Condition Data Retrieval and Evaluation database (CADRE) is the main decision support tool used in the GIS by PECAD analysts. CADRE is a global grid-based, geospatial database that stores daily, monthly, and decadal (10-day) data. The sources for this data are

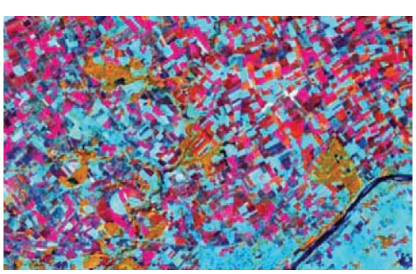

Figure 1. False color Landsat TM image in Central France taken on May 29, 2003. Red colors indicate vegetation.

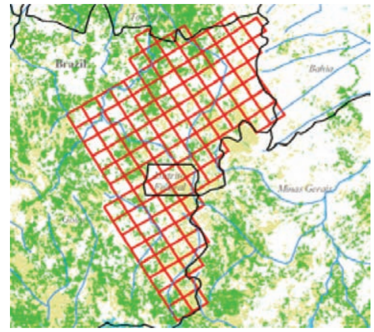

Figure 2. Polygons outlined in red are selected AFWA grid-cells for crop producing region in Brazil. The average grid-cell size is 40 km.

the Air Force Weather Agency (AFWA) and the World Meteorological Organization (WMO). PECAD takes this source data and models precipitation, temperature, soil moisture and crop stages. To measure vegetative vigor, PECAD calculates vegetation index numbers (VINs) from satellite derived data. The data is imported into 1/8 degree mesh grid cells (fig. 2) and can be categorized by:

Time-series Data Sets

Daily agro-meteorological data derived from station and satellite data include precipitation; min and max temperatures; snow depth; solar and longwave radiation; potential and actual evapo-transpiration. Daily and decadal VINs derived from Local Area Coverage (LAC), approx 1.1-km pixels and Global Area Coverage (GAC), approx 8-km pixels from the NOAA-AVHRR satellite series (Reynolds, 2001).

Normal Baseline Data Sets

Normal precipitation, temperature, potential evaporation, and elevation values; soil-water holding capacity based upon the United Nations Food and Agriculture Organization's (FAO) Digital Soil Map of the World at 1:5M scale; decadal VIN normals or averages for the GAC data set.

Crop Information and Models

Crop type and average start of season; average yield and area planted; percent crop production within a country; two-layer soil moisture algorithm; crop calendars based on growing-degree days; crop stress or alarm models for corn and wheat based on soil moisture and temperature thresholds; crop water production functions to estimate relative yield reductions (yield reduction models); and crop stage models by Ritchie (1991).

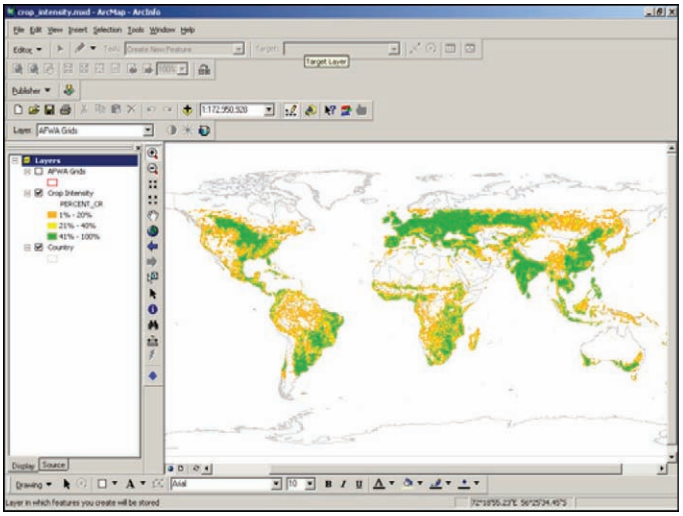

Figure 3. ArcMap project depicting global crop land and crop intensity distribution.

The GIS is essential in managing the geospatial data from CADRE and the various other data sources used at PECAD. Much of the baseline data sets are stored as shapefiles (fig. 3) on PECAD servers. ArcMap is used to geographically combine the varied data sets in a visual assessment to determine a 'convergence of evidence' analysis. Commodity production is then estimated from the yield and area parameterization. Although each analyst has a disparate array of region specific data sources and crop growth models at their disposal, PECAD's GIS allows analysts to spend less time on repetitive analysis tasks and more time on utilizing all available data for the monthly crop production assessments. ArcIMS is being used by PECAD to automate these tasks and make data model results and ancillary data more accessible. Dynamic datasets for temperature, precipitation, soil moisture, and snow cover are updated every 10 days (decadal). Global base maps for land cover, agricultural regions, weather stations and grids are updated as needed. There are currently fourteen ArcIMS Image Services for global crop condition data on the USDA-FAS server. These are all accessible through the Geography Network (www.geographynetwork.com).

The Internet web mapping application (fig. 4) uses Cold Fusion, Java, ArcIMS, SQL Server, and ArcSDE to manage and store the geospatial data. ArcSDE relationships are set up between PECAD "regions" and the various feature classes used by the maps (e.g. rivers, administrative boundaries, etc.). The Crop Explorer ArcIMS MapService is built using these same ArcSDE features. During a map generation request, the grid-cell layer feature class is joined to the appropriate attribute data such as precipitation, soil moisture, or temperature. Java is used to build the necessary AXL code to make the request to ArcIMS. Cold Fusion manages the map display in the web browser.

As a result, for every major crop growing region in the world, thematic maps are produced (fig. 5) that depict fourteen distinct data types derived from baseline datasets about precipitation, temperature, soil moisture and snow cover. Time-series charts depict growing season data about these same data types for specific agro-meteorological zones. Regional crop calendars and crop area maps are also available for many of the regions.

The visual display (fig. 6) of the amount of ground-surface "greenness" as depicted by the measure of vegetative vigor is accomplished by using Normalized Difference Vegetation Index (NDVI) products from several satellite imagery sources. Products from the vegetation indices provide additional resources for crop condition information on the web site.

Regional droughts or excessively wet conditions can be easily identified using these products. Crop Explorer displays three thematic maps created from the SPOT-VEG data:

1) Current 10-day conditions, 2) Departure from 4 year average and 3) Departure from last year. The data is provided to the National Aeronautics and Space Administration (NASA) by Spot Image Corporation on behalf of USDA-FAS-PECAD. NASA in turn performs a variety of processing on the imagery and provides PECAD with decadal (every 10 days) global Spot mosaics which include 3 mosaic-ed imagery bands, a mosaic-ed NDVI band, a status map, as well as other data (Kittel, 2003). Partnerships between USDA and NASA have also made possible the recent addition of data from the MODIS, TOPEX/Poseidon and Jason-1 satellites.

MODIS images from the Rapid Response system are added twice a day and posted on the web site approximately six hours after acquisition for each agricultural region. Mosaic images were created by the NASA MODIS Rapid Response System team to overlap agricultural regions identified by USDA-FAS-PECAD.

Figure 4. Crop Explorer – www.pecad.fas.usda.gov/cropexplorer.

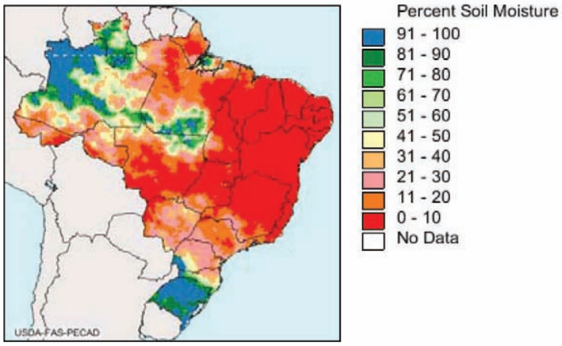

Figure 5. ArcIMS generated map of Percent Soil Moisture from October 1-10, 2003 in Brazil. Each 40km grid cell represents a percent soil moisture value. A relationship class in ArcSDE joins the attribute data (soil moisture) at the grid cell level to the region layer for Brazil.

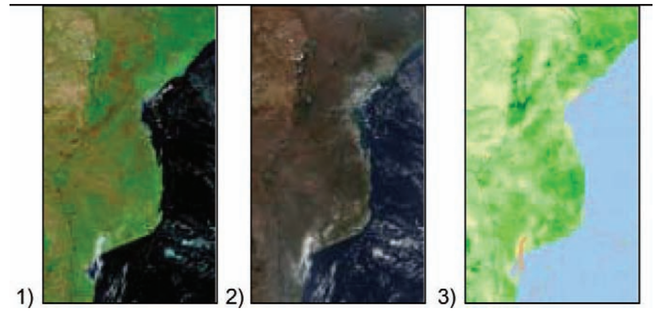

Figure 7. Three examples of the MODIS Terra satellite image of Mozambique on 8/31/2004 : 1)False color image with bands 7,2,1 (Short Wave Infrared, Near-Infrared, Red); 2) True Color; 3) NDVI. All at 1km resolution.

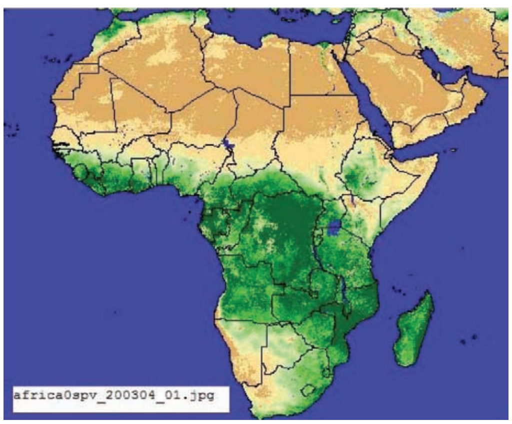

Figure 6. SPOT-VEG NDVI map of Africa for April 1-10, 2003.

New MODIS mosaics (fig. 7) are produced daily for each agricultural region in false color, true color and NDVI from the Terra and Aqua satellites at 1km, 500m and 250m resolution. The entire archive can be browsed and images can by selected for downloading.

Since the beginning of 2004, NASA has supplied the USDA with near-real time data on lake and reservoir heights from around the world. Lake and reservoir surface elevation maps are produced via a semi-automated process and updated in Crop Explorer's Global Reservoir Monitoring database every 7-10 days. Time series charts of the lake height variations are expected to be accurate to better than 10cm rms. Analysts who forecast crop production, scientists, in-country water and irrigation managers, those involved in fishing industries, and the general public have all been making use of the web site. NASA and the French space agency Le Centre National d'Etudes Spatiales (CNES) teamed up to design, build and launch the TOPEX/Poseidon and the Jason-1 satellites.

These satellites were designed to study many aspects of the ocean. The TOPEX/Poseidon satellite, for example, orbits at a height of 1336 kilometers (830 miles) above Earth, and can measure the height of the ocean surface directly underneath the satellite with an accuracy of 4-5 centimeters (better than 2 inches) (Ramanujan, 2004). Jason-1 and TOPEX/Poseidon cover the global oceans every 10 days. With these capabilities, this technology is surprisingly valuable for looking at larger areas of inland water (fig. 8).

PECAD regularly uses computer models that simulate agricultural production based on inputs that include weather information. But in irrigated areas that are not rain fed, these methods are limited. For irrigated areas, a determination of how much water is actually stored, after seasonal precipitation passes is required. The data from the Global Lake and Reservoir database can be used for this purpose. This type of information is especially important for food aid partners, who must budget ahead for how much and where food aid is distributed.

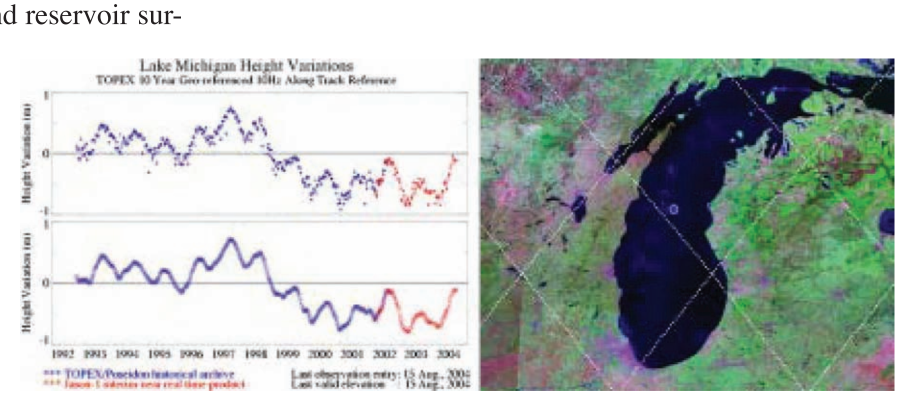

Figure 8. Lake Michigan data from the Global Lake and Reservoir database on the Crop Explorer web site.

Summary

The Crop Explorer web site is a primary data category for Agriculture and Farming in two government information portals: 1) the Geospatial One-Stop (http://www.geodata.gov/gos) e-gov initiative and 2) NASA's Global Change Master Directory (http://gcmd.gsfc.nasa.gov/) for earth science and data services. Both of these portals are nodes of the Federal Geographic Data Committee (FGDC) Clearinghouse for metadata. Live data and maps from the Crop Explorer ArcIMS services are also directly linked through the Geography Network (www.geographynetwork.com).

Crop Explorer provides a specialized service to its customers with timely, accurate crop condition information on a global scale. Partnerships with other organizations such as NASA have introduced near real-time satellite imagery and derived products specifically for agriculture analysis. Region and country-specific linkages to these external data sources is inherent in its geospatial design. This relationship has resulted in new and innovative products that can be shared by NASA and USDA customers.

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Technology Innovations and Applications

A Conceptual View for Advancing Monitoring and Assessment of Land Resources in the Mexican State of Jalisco

Celedonio Aguirre-Bravo, Research Coordinator for the Americas, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO

Abstract—*This paper addresses key elements of a conceptual view for advancing monitoring and a variety of applications to land resources and environmental management in the state of Jalisco, Mexico. Fundamental to this conceptual view is what we know about the structure and functioning of nature: the spatial and temporal dynamics of processes (for example, objects, outcomes), the multirelational matrix of cause-effect relationships, the uncertainty of location and duration of outcomes, and the power of human intelligence that can alter the structure of order in nature. Because knowledge is constantly evolving, we discuss why a new vision of monitoring is needed and how to implement it so through the appropriate use of changing technologies. Articulation of this evolving vision in order to make it operational across the actors and players of the sustainability equation is perhaps the most defining challenge that individuals and institutions face now and in the years to come. The Jalisco Monitoring Pilot Project, an ongoing process of intellectual discovery for practical applications, has provided the fertile ground and multidisciplinary environment for structuring and advancing this conceptual multirelational view of monitoring and assessment of ecological and economic systems.*

Introduction

Most forms of human interaction with the natural environment are increasingly challenged by the growing complexity of systems interdependence (for example, ecological, social, economic, cultural) at multiple geographical scales. Because human activities and impacts transcend geopolitical boundaries (for example, nations, states, counties, property rights), orthodox distinctions between matters of individual, local, regional, national, and global significance are taking a new direction, one that is guided by sustainability principles that cut across natural and human systems. While a variety of conceptual sustainability views have gained worldwide political support, as indicated by the proliferation of accords between and among national governments, making them operational has been and will be one of the most serious institutional challenges in the twenty first century.

Information and knowledge is central to understanding the multi-relational physical nature of sustainability. No complete and uncompromising theory about sustainability, whether scientifically-based or not, exists and will ever be proposed to the scrutiny of the human world. What one knows about sustainability is also a multi-relational process where cultural contexts condition to a large extent what one perceives, recognizes, sees, measures, and understands. Cultural contexts by themselves are also multi-relational processes. Recognizing their uniqueness is central to how they measure, understand, improve, and maintain the sustainability of ecological, economic, social, cultural, and political systems. There is no such thing as one way road towards sustainability science and its supporting research and monitoring processes.

When formulating a conceptual approach to monitoring and assessment one has to take into account the multi-relational reality of nature in space and time. For example, nowhere and at no time is what we can or can not recognize and measure exactly the same; nothing remains the same as it was originally created. Material (for example, objects, structures, things) and non-material things (for example, energy, thoughts, decisions, knowledge, etc.) are under flux, at different dynamics, therefore taking place at different locations and times, and at distinctive spatial and temporal resolutions. Life forms (for example, micro-organisms, plants and animals, populations, communities, landscapes, ecosystems, etc.), their attributes and health, and all other components (for example, soils, landforms, etc.) and processes (for example, water, climate, fire, etc.) of their physical environment are subject to the uncertainty of how causal forces (potential energies) converge in space and time.

Human processes, whatever their nature (for example, government, policy, the economy, social, educational, cultural, cities, corporations, individuals, etc.), no matter the geography of their location, they are also subject to the same principles and laws of nature.

Given the multi-relational nature of the world we inhabit we can expect a myriad of responses with respect to questions of monitoring and assessment of ecological and economic systems. Each response will be different in terms of perceiving, recognizing, measuring, assessing, and understanding the causal structure of problems and issues and the multi-relational dimension of their nature. For example, what is the current extent and condition of land resources, particularly forests and agricultural lands? Were the question asked by a government institution, it would generate a chain reaction of response processes across the hierarchies of the human dimension. Few will be interested in listening to the response of a farmer who lives in the remote Sierra Madre Occidental in Mexico. How that person perceives the question would be different from an intellectual in Mexico City, or from a German Green Peace activist. Scientists, particularly statisticians, may never agree on how best to monitor and assess what the question implies. However, they are expected to reach a consensus about a sampling strategy. In a multi-relational world, where the potential becomes the real, the design of monitoring and assessment programs must always take into account the probabilistic framework of how events and processes in nature occur in the dynamic matrix of space and time.

The success of monitoring and assessment programs will be determined in terms of their dynamic performance as to how significant and meaningful their outputs are to answer, describe, and explain the multi-relational nature of the question's object of study, but most importantly, the probabilities and uncertainties associated to their spatial and temporal dynamics. Global estimates to address these questions are useful, but they are powerless when accurate spatial and temporal information is needed to address local sustainability problems and issues, at fine resolution levels. This paper addresses these and other institutional challenges encountered while formulating a conceptual framework for inventorying and monitoring the land resources of the state of Jalisco in Mexico.

Why a New Vision

It is in the nature of the multi-relational world we live in that nothing we do will ever be the same. Each time a knowledge quantum leap takes place it has served the purpose of its time. Creativity process then takes care of evolving that knowledge towards higher levels of enlightenment so that we can understand its dynamic multi-relational nature. In a way, knowledge is the past, while new discoveries are the present, thereby creating new dynamic conditions for exploring and understanding the future. Decades ago, for example, there was a sort of a revolution in the scientific and technical domains of agriculture, forestry, natural resources, and the environment. New sampling and statistical analysis methods and approaches for inventorying and monitoring forest and natural resources came to be and served well the needs and challenges of their time. In today's world, that knowledge and technology represents the past; it is powerless to address the multi-relational nature of needs and challenges of today and future generations.

Change has brought us to a new dynamic condition so that institutions and people can begin to address complex needs and challenges of their time. Nature in the myriad forms of how it comes to be and perceived it is never the same. Welcome to the "Knowledge Age Era," the time of knowledge workers, where more and more people are being enabled to understand the complexity of living in a dynamic multi-relational world of physical processes, the foundation of systems sustainability, whether they are ecological, economic, social, cultural, political, unified, or nondenominational. It is at the intersection of these systems, in each spatial and temporal point of the world geometric grid, where processes of multi-relational nature converge to bring about what we can perceive and recognize (for example, things, objects, structures, information, knowledge), and perhaps measure, the ultimate condition where information and knowledge exists in dynamic unified form. When we function at this level of knowledge resolution, which is the fertile ground for sustainability science and policy, then the voids that separate facts and actions dissolve, and the "what is" can then be perceived, recognized, measured, improved, maintained, and sustained within the changing framework of their spatial and temporal dynamics. From this dynamic multi-relational vision of the world, a seamless web of cause-effect relationships —and options for investigating and acting upon them— become clearer for advancing research, monitoring and assessment, as well as policy and decision making for sustainability.

How this vision is articulated to advance monitoring and assessment of land resources in the Mexican state of Jalisco will significantly impact the scientific and economic utility of products and outcomes to support policy, planning, and decision making processes. The vision implies that fundamental changes have to take place in the current technical and scientific establishment that is responsible for how monitoring and assessment programs are designed and carried out. Important issues and considerations to take into account include the following: (1) things in nature are the resulting events of convergent multi-relational processes; (2) things in nature have their own spatial and temporal dynamic framework; and (3) things in nature have a probabilistic pattern of spatial and temporal distribution. Everything that has "matter matters massively (Schearer 2004)" as far as these considerations for advancing monitoring and assessment strategies and programs.

Technology to Make it So

Knowledge has become the most fundamental organizing principle driving technological progress into the 21st century. New ways of generating, presenting, and distributing information and knowledge to institutions and people are significantly changing how we learn, create, plan, decide, work, and live. Today, we live in a multi-relational world that is being rapidly transformed by advances in high-speed computing, communications, and information technologies. Better and more powerful technologies are connecting people-to-people, scientist-to-scientist, resource manager-to-scientist, people-to-digital libraries and instruments, and people-to-institutions and markets around the world. In this technological revolution, connectivity and networking have become common denominators of ongoing multi-relational processes, at all geographical scales. Now the human dimension is like a global virtual mind that is empowering people throughout the world to become effective stakeholders in the pursuit of knowledge for multiple applications.

What is happening today is just a glimmer of the rich possibilities of the Knowledge Age that is emerging. Quantum leaps in computational power, connectivity, and user-friendly technologies to improve learning and creativity processes are now part of our multi-relational reality. Many of these astonishing developments will experience significant improvements in the near future. In many ways, they are significantly enhancing our ability to explore, discover, collect, analyze, represent, transmit, and apply information, thereby improving the way we generate knowledge for planning, decision making, scientific research, engineering, education, business, management, and policy making. The common goal that seems to fuel this technological explosion is to create networked systems that can make all kinds of knowledge available to everyone, located anywhere, at any time. As this emerging paradigm continues to unfold, it becomes clear that its outputs could become powerful multipliers of progress in a wide range of scientific, educational, social, and economic endeavors.

Driven by these transformations, people and institutions around the world are continuously reassessing and redirecting their programs and capabilities. Central to these processes is how to handle and interpret the enormous amounts of data and information that accumulate at increasing rates, and how to transform them into knowledge that is meaningful to users spatially. Knowledge that has no connection to location and context has limited value to people and society. However, the magnitude of these challenges pales in comparison to the socioeconomic and cultural challenge of transforming more and more people around the world into Knowledge Workers. New strategies for representing and distributing spatial knowledge are not only essential for advancing human intellectual progress, but also for confronting complex economic and environmental sustainability problems. Enabling people and institutions to be effective stakeholders through the power of spatial and temporal knowledge is the greatest sustainability challenge facing institutions in the 21st century.

Harnessing the power of the Knowledge Age is essential for ensuring the well being of future generations. The great technological transformations of this new era are now making it possible to represent knowledge within a geo-spatially explicit framework, at any spatial and temporal scale, and to distribute it to society throughout the world via a variety of electronic means. Spurred by this technological evolution, the development of Geo-Spatially Explicit Knowledge (GSK) may be the most defining technological innovation of the early 21st century. Potential uses and applications of GSK are seemingly endless. The growth in the content, capacity, connectivity, and flexibility of technologies to represent and communicate GSK is so powerful that it is dramatically reshaping relationships among people and organizations, and quickly transforming our processes of discovery, learning, exploration, cooperation, and communication. Realizing this potential is an essential response to a 21st century that is being shaped by science and rapidly changing technologies.

How to Articulate this Vision

Today, because we know more about the workings of the human mind and the nature of our multi-relational world, have the technological capabilities to collect and generate tremendous amounts of spatial and temporal data, and have learned the lessons of failed scientific and technical paradigms, there is a growing understanding that there exists an opportunity to simultaneously improve the human condition and the sustainability of ecological systems.

Through modern psychology, we have gained a greater understanding of how the human brain works and how information is received, processed, and retained. It is known that people have the ability to absorb billions of bits of information instantly. When the brain receives information that is in an isolated form and disconnected from a larger multi-relational context, its significance is analogous to that of a single piece of a jigsaw puzzle. Any one piece has very little meaning in and of itself. However, when each of the individual pieces of the puzzle is seen in the context of the adjacent pieces, a picture begins to form which is recognizable and has meaning. Historical means of information transfer have presented information as an individual puzzle. Future methods and approaches will have to present the information in a complete contextual, multi-relational, and integrated framework.

Spatially explicit model representations of the multi-relational nature of things and processes are analogous to a time series of high resolution digital pictures taken of a forest site. As pictures, spatial models are means to aid and improve how people best acquire, retain, analyze, synthesize, and utilize geo-spatial information for multiple applications. Fundamental to articulating this conceptual view is the consideration of the value of any bit of information in its spatial and temporal multi-relational contextual location. Each information bit takes on greater meaning when it can be viewed in relation to its position in space and time relative to neighboring bits. Higher utility is achieved when it is possible to view the change of each bit as a function of time or other relational variable. Technological advances in geo-spatial sciences provide us with a flexible and adaptable approach to acquire, analyze, model, visualize, and disseminate spatially- and temporally-explicit information and knowledge to wider audiences quickly and efficiently.

A fundamental revolution is taking place in the geo-spatial sciences with tremendous implications in fields as diverse as those related to sustainability science and applications. Historically, for example, modern medicine has taken the approach that people are generic and that those with similar conditions or ailments constitute a common human landscape to be prescribed similar medicines and/or treatments. Under the traditional paradigm, the human population is treated homogeneously without regard for the unique attributes of each individual. Visionaries see the day when medicines and prescriptive treatments will be developed on a person-by-person basis (in the language of geo-spatial sciences, on a pixel-by-pixel basis). In other words, the correct prescription for a person with a certain ailment will be tailored to reflect the unique genetic, chemical, and other multi-relational features of that individual. The logical extension of this thinking is expected to be the anticipation and treatment of medical problems well in advance of their arrival. For example, a 30 year old person will be treated with an individually designed medicine for a cancer that has not yet appeared but will develop at about age 50 and be fatal to the person at about age 60. Analogous thinking can be applied to the design of new geo-spatially monitoring strategies for the assessment of ecological and economic systems sustainability.

Historically, research and monitoring have been conducted on a landscape type and as a result vast generalities were identified that were then applied to all other similar landscapes. However, in this model, little or no consideration was made of the multi-relational nature of the landscape (for example, climate, soil chemistry, air quality, human impact, hydrology, etc.) and its temporal and spatial dynamics. A more enlightened approach to sustainability science will have to evaluate natural systems on a pixel-by-pixel basis for their unique social and environmental circumstances. Then, unique management prescriptions can be made to reflect both societal and environmental needs. With the advent of geo-spatial sciences, a variety of spatial and temporal information layers are able to be developed which allow for the accounting of the myriad relational variables that influence the expected outputs in each point (pixel) of the space-time matrix of a given geographical area. As such, land resource management prescriptions can be made which reflect the multi-relational nature of a landscape in the same way that future medicines will reflect the unique traits of a person.

Conclusion

It is now clear to a growing number of people throughout the world that a new paradigm in sustainability science is emerging. At the center of this new way of thinking is how research and monitoring methods need to be adapted to the technical and scientific challenges of providing the appropriate data and information to advance the understanding of ecological and economic sustainability and its spatial and temporal dynamics, at multiple resolution levels. No longer will it be satisfactory to disseminate information and knowledge to stakeholders in forms that are obscure and interpretable only to those familiar with the technical or scientific arcana. Disappearing are the days when it was acceptable to make policy and management decisions derived solely from general information that is not multi-relational to a particular geographical landscape.

In the 21st century, the geo-spatial knowledge era of sustainability science, it will be necessary to ask what is the solution to the problem that is found on a particular landscape having a certain set of time-dependent multi-relational processes and features, and define the solution at a resolution of one pixel (regardless of the pixel size). Solutions of this type will not result from traditional monitoring and assessment approaches that were developed and used throughout most of the 20th century. Though useful, it is now part of the past. Furthermore, solutions of this type will not be developed by people who are trained in a certain discipline and lack the ability to work with people who can utilize the entire spectrum of analytical tools and procedures that constitute the body of knowledge of modern geo-spatial sciences. Ernst Mach's legacy (Malin 2001), "it is theory which decides what we can observe," has no place in this new paradigm that fosters freedom from the known. The most successful problem solvers in the 21st century will be those who can think multi-relationally and free themselves from the mental conditioning of theories, methods, and technologies. Individuals who have this mental potential can easily work with interdisciplinary and multidisciplinary teams that can apply the tools of geo-spatial sciences in an integrated, multi-relational, cohesive, unconditioned, and seamless fashion to the solution of unique sustainability problems.

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Learning Center for Advancing Natural Resources and Environmental Sustainability in the Mexican State of Jalisco

Celedonio Aguirre-Bravo, Research Coordinator for the Americas, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO
Hans Schreuder, retired Mathematical Statistician, USDA Forest Service, Fort Collins, CO

Abstract—*This paper addresses the need and opportunity for creating a learning center for advancing the monitoring and assessment of ecosystems resources and their sustainability in the Mexican state of Jalisco. It is an initiative that responds to the growing needs of a more sophisticated world in which knowledge is the tool for creating social and environmental progress and information is the key that unleashes this power. One of the goals of governments in this "Knowledge Age Era" is to create an environment in which ecosystem resources can be managed and utilized in a fashion that simultaneously allows societies to meet their needs, economies to grow, and the ecosystem resources to be sustained for future generations. It is among the most pressing demands of science and technology in the 21st century. The main actors and players of these evolving processes advocate the empowerment of people to make management and utilization decisions as the most rational approach to achieving profitable and sustainable ecosystems. However, to do this, a drastic change to information- and knowledge-based technologies will be needed as the new paradigm will have to be adopted on a large scale. At the heart of these transformations is the generation of data, information, and synthesis based on geo-spatially explicit frameworks that are scientifically credible and technically defensible. Key strategic components of this initiative are discussed in this paper.*

Introduction

Throughout the 20th century, a set of scientific and technological developments converged to bring about a new and evolving view of the relationship between the natural environment and human society. For many years, extreme views regarding this relationship, advocating either preservation of the environment at the expense of social and economic progress or social and economic development without regard to environmental health, dominated the discussion with each side demonstrating little tolerance for the other opinion. Today, because we know more about the workings of the human mind, have the technological capabilities to collect tremendous amounts of spatial and temporal data, and have learned the lessons of failed paradigms concerning ecosystem resource management, there is a growing belief that there exists an opportunity to simultaneously improve the human condition (for example, economically, socially, environmentally, etc.) and the sustainability of ecosystems.

Through modern psychology, we have gained a greater understanding of how the human brain works and how information is received, processed, and retained. It is known that people have the ability to absorb billions of bits of information instantly. When the brain receives information that is in an isolated form and disconnected from a larger context, its significance is analogous to that of a single piece of a jigsaw puzzle. Any one piece has very little meaning in and of itself. However, when each of the individual pieces of the puzzle is seen in the context of the adjacent pieces, a picture begins to form which is recognizable and has meaning. Historical means of information transfer have gathered and presented information as individual puzzle. Future methods will have to present the information in a complete contextual and integrated framework.

A new paradigm in information technology is forming that recognizes how people best acquire, retain, and utilize information. Fundamental to this paradigm is the consideration of the value of any bit of information in its spatial and temporal context. Each information bit takes on greater meaning when it can be viewed in relation to its position in space and time relative to neighboring bits. Furthermore, a higher utility is achieved when it is possible to view the change of each bit as a function of time or other variable. Technological advances in geo-spatial sciences provide us with a flexible and adaptable approach to acquire, analyze, visualize, and disseminate spatially- and temporally-explicit information and knowledge to wider audiences quickly and efficiently.

For this information to have the greatest social utility, it is imperative to have a firm grasp of the natural processes that support environmental sustainability; the social, economic, and other factors that promote social growth; and their interactions. Until fairly recently, there was very little opportunity to consider these issues in the context of time and geographic location. Today, with the use of geo-spatial technologies that involve space and aerial photogrammetry, global positioning, information management, spatial analysis, and statistical procedures, Bayesian statistical decision making methods, communications, and innovations in computer and peripheral equipment, the ability exists to examine a wide range of environmental, social, and economic issues and incorporate their spatial and temporal interactions on a pixel-by-pixel basis. As such, the tools are becoming increasingly available to make more intelligent decisions regarding ecosystem resources sustainability and management. Furthermore, complimentary innovations in information and communication technologies, that when combined with geo-spatial technologies, are making it increasingly possible to get high-quality, spatially-explicit information and knowledge into the hands of a wide range of decision makers (for example, agencies, governments, scientists, industrialists, land managers, farmers, educators, etc.).

People throughout the world are realizing that in order to achieve both a healthy and vital environment for this and future generations and create a thriving and sustainable ecosystem resources-based economy which will provide numerous social benefits, it is imperative that a framework be put in place that will empower people with high-quality, temporally- and spatially-explicit information and knowledge of high social and scientific utility. Furthermore, this information and knowledge must be available to all ecosystem resource stakeholders. To achieve the desired goals, an infrastructure, both human and physical, must exist to integrate the entire spectrum of disparate, but related, sciences and technologies into a cohesive and seamless system of data collection, storage, and management; analysis; visualization; and dissemination.

This initiative, a learning center for advancing the monitoring and assessment of ecosystems resources and their sustainability, describes the vision of a strategy designed to support the creation of this center in a new and innovative fashion which involves the principles associated with the integration of an array of scientific and technical disciplines related to spatial estimation and modeling at multiple scales and resolution levels.

Vision

Through this Center, the vision is to develop the human and physical infrastructure necessary to implement 21st century capabilities in the field of integrated geo-spatial sciences and modeling to enable individuals, agencies, organizations, communities, governments, and other entities to effectively inventory, monitor, assess, and manage their ecosystem resources in a scientific credible and technically defensible manner, and at multiple temporal and spatial resolution levels.

Mission

In pursuit of that vision, the mission of the Center is to be an instrument which fosters a climate of intellectual discovery and growth in the subject areas and applications related to monitoring and assessment of ecosystem resources and their sustainability, and more importantly, instills the spirit of an integrated approach to problem solving that recognizes the value of each scientific and technical discipline and their interrelations.

Through this mission, the Center will contribute to:

- Developing new knowledge and applications through the interaction of professionals involved with environmental, social, and economic issues through technology transfer and development projects.
- Instructing the experts who will train a variety of technicians in the applied components of monitoring and assessment in Jalisco or institution of the individuals involved in this process.
- Facilitating the creation of the technical capabilities for acquiring and geo-referencing field and remotely sensed data; transforming this data into useful, precise, and accurate geo-spatial information and knowledge; and disseminating that product through visualization to desired locations.
- Forming an "Inventory and Monitoring Network" that will close the gap between the demand for and supply of geo-spatial information and knowledge and between the prevailing problems and potential solutions.

Goal

The goal of the Center is to fulfill the mission through a strategy that incorporates education, research, training, and infrastructure development to enable a variety of ecosystem resource-related institutions, individuals, organizations, communities, governments, and other entities to make wise managerial and utilization decisions regarding monitoring and assessment, using the tools and critical thinking associated with spatial modeling and representation of the information resulting from these processes. As a growing assortment of highly-sophisticated, user-friendly technologies become available to a diverse cadre of ecosystem resource stakeholders, a physical infrastructure will grow which will allow information and knowledge with high social utility to be delivered in an efficient, visual form to the intended audience.

Objectives

To achieve the desired goals and guide the investments in this Center, the following specific objectives will be achieved:

Create the next generation of human infrastructure (through education, training, and other outreach) that will have the scientific and technical expertise to use knowledge and technologies in an integrated fashion to acquire, geo-reference, and analyze geo-spatial data; synthesize the data into scientifically-credible, geo-spatial information and knowledge that is technically defensible and of high social and economic utility; and visualize and disseminate the results to the user groups.

Develop a set of integrated monitoring and assessment technologies through a comprehensive program of applied research that for the most part will be associated with experts from universities and result in the development of a broad spectrum of application tools.

Support the development and organization of a geo-spatially-based infrastructure for monitoring and assessment (both physical and human) through which scientific and technological expertise can flow on a variety of projects to be conducted under the auspices of sponsoring and partner institutions.

Facilitate the formulation and implementation of an Internet-based expert system to structure, manage, and communicate monitoring and assessment syntheses and their application for use in decision-making and planning for sustainable ecosystem resource management and utilization.

Program Design

The program activities of the Center must be designed to enhance the technical capabilities of the participating institutions and organizations. It is expected that some of the clients involved in the program will (in time) become self-sufficient with respect to sustaining their own human and physical infrastructure. Others may never have in-house training and research capabilities, and therefore, may choose to participate in the Center on a more frequent basis. Great effort will be made to ensure that the program maintains the flexibility needed to accommodate all participants and create deliverables suited to individualized sets of needs, while at the same time, retain its focus on the advancement of monitoring and assessment technology and their application.

Education and Training

The development of a capable human infrastructure is an evolving process that requires a considerable amount of time. However, when a series of well-organized, high-quality, and focused educational and training experiences (short courses, workshops, seminars, etc.) are delivered, positive impacts will be felt over a fairly short period of time. Training and educational programs will begin almost immediately in a variety of subject areas that relate to monitoring and assessment, geo-spatial sciences, spatial statistical modeling, and specific technology applications. Short courses will be tailored to specific experts, technicians, resource managers, as well as to the highest level of scientists wishing to elevate their understanding of some component(s) of monitoring and assessment, remote sensing, and spatial statistical modeling. The unique feature of this program is that all courses, regardless of the topic, will include the role of the particular subject in the context of an integrated approach to monitoring and assessment, and the use of information for ecosystem sustainability. Leaders in their fields will be asked to present workshops and short courses to groups of participants in the appropriate geographical locations. Course subject areas may include, but are not limited to:

Geodesy	Spatial Statistics
Field Measurements	Geography
Data Mining	Statistical Sampling
Remote Sensing	Telematics
Point Process Modeling	Spatial Data Management
Spatial Mathematics	Ecosystem Management
Global Positioning Systems	Statistical Programming
Monitoring Methodology	GIS Applications
Quality Assurance	Assessment Methodology
Spatial Modeling	Quantitative Ecology

Workshops and short course schedules will be flexible to accommodate the needs of participants. Conferences and seminar series can be offered as the need for such instruments becomes apparent.

In addition to the courses listed above that are fairly specific in scope which will be offered from time-to-time and are designed to elevate the student's knowledge in a particular science or technology area, an exciting and unique course, entitled Spatial Analysis and Statistical Modeling, will be offered three times per year (January, May, and August). This course, offered in three parts, will serve as the flagship of the entire training program and cover the spectrum of issues in geo-spatial analysis and modeling from statistical sampling, remote sensing, through data management and analysis using geographic information systems to spatial statistics.

Development of Organizational Physical Infrastructure

Any organization that wishes to be self-sufficient in monitoring and assessment methodology and applications will need to develop both the human and physical infrastructure necessary to perform the required tasks. The physical infrastructure needed to support a comprehensive integrated Ecological Monitoring and Assessment Laboratory (EMAL) is highly dependent upon the desired outputs, personnel, resources, and other considerations of an organization. A successful EMAL will not only need to be equipped with the most modern and functional hardware, but also contain a wide variety of computer software and analytical models to perform the myriad of activities that monitoring and assessment processes and information results applications demand.

Hardware

Such technical equipment as computer hardware and software, assorted peripherals, image interpretation devices, communications and high-speed and high-access telephone equipment are among the components of a modern EMAL facility. The development of organizational physical infrastructure will undoubtedly take place over time. Partner institutions can always assist in the processes of providing technical support for decision making and facilitate the acquisition of desired equipment, as they are needed.

Software and computer models

Physical infrastructure requirements can include a variety of software products. An array of data management, geographic information systems, image processing, statistical, and other widely used commercial products will be needed in a comprehensive EMAL facility. These products can be purchased from vendors and consultants who can always be available to provide advice on product suitability and facilitate the purchase. Consultants can work closely with companies who create the products that are at the cutting edge of technological development.

Scenarios and Applications

While focused on the goals described above, the Center can address a variety of critical questions that specify the data and information that is needed for assessments of ecosystem sustainability at multiple scales and resolution levels. For example, what is the spatial and temporal condition of a watershed's critical resources (for example, vegetation, soils, water, animals, landscapes, runoff, erosion, human activity, etc.)? What components/parts of watersheds are changing and why? Where are the identified changes taking place (for example, within and across watersheds)? Why are specific resources changing faster than others and where are those changes are taking place (for example, within and across watersheds)? As ecosystems, what is the quantity, quality, extent of services provided by watersheds, and how do human systems benefit from them across jurisdictional spatial and temporal scales? Within and across watersheds, where is mitigation/restoration of resources and processes most practical and beneficial, and how are human systems sustaining the ecological integrity and societal value of watersheds? Will the current extent and condition of resources/services of watersheds meet future ecological and economic needs? How can stakeholders (for example, landowners, federal and state government, industry, academia, and nongovernmental organizations) work together to confront appropriately the complexity of problems and issues within and across watersheds so that we can ensure the health of these systems and the well being of present and future generations? These and other important questions open a world of opportunity for advancing monitoring and assessment technologies and their application to a portfolio of environmental resources. Other scenarios and applications are limited only by our imagination.

Products and Benefits

The Center study creates a window of opportunity for a coordinated national and multinational effort to design and implement appropriate approaches to inventory and monitoring of ecosystem resources in the Mexican state of Jalisco. Central to this initiative is the opportunity to further improve information compatibility and procedures for use in integrating and evaluating information on the status, extent, trends, and projected changes of ecosystem resources within and across jurisdictional scales, and at multiple scales and resolution levels. It will promote the sharing of scientific and technical information and approaches to gain common understanding on a variety of issues and problems of current and future concern within and across jurisdictional boundaries and geographical scales. Integrated environmental synthesis focused on addressing critical issues and problems will be important outputs produced by the Center and its institutional partners. For Latin American countries, and particularly for Mexico, the Center will serve as a learning facility within which scientists and resource managers would be able to:

- Discuss issues and problems of technical and scientific nature related to integrated- interoperable approaches to inventory and monitoring of ecosystem resources.
- Design, plan, and execute specific inventory and monitoring projects for ecological assessment and management of ecosystem resources.
- Have access to data, information, technical expertise, and technologies related to integrated/interoperable approaches to inventory and monitoring of ecosystem resources.
- Work with technical experts from cooperating organizations to standardize protocols, eliminate redundancy and inconsistency, and promote Quality Assurance/Quality Control procedures on data collection, management, statistical analysis and modeling, and reporting.
- Obtain technical assistance on developing procedures to assess and certify the scientific credibility of data and information from inventory and monitoring projects, as well as technical support on identifying where weaknesses exist and how they should be corrected.

Through this synergy, the Center would function as a network system to deliver geo-spatial environmental syntheses, results, technology, and interoperable data and information to scientists, managers, landowners, policy makers, and the public of the state of Jalisco, as well as other Mexican states and institutions abroad. Moreover, it would provide resource managers and stakeholders in other regions and states in Mexico with a model for developing similar approaches. In addition, the project is innovative and will enhance institutional capacity in that:

- It is the first Western Hemisphere effort to focus on using an integrated-interoperable approach to inventory and monitoring of ecosystem resources across jurisdictional levels and at multiple scales and resolution levels.
- It will link a diversity of stakeholders concerned with the inventory and monitoring of ecosystem resources in Mexico and abroad.
- Experts from cooperating institutions of the Western Hemisphere will work together as a team to address technical and scientific issues and problems concerning the design and implementation of integrated-interoperable inventory and monitoring systems of ecosystem resources.
- Participating experts of cooperating institutions and organizations will become more aware of what has been accomplished in their respective countries, and will have the opportunity to develop stronger linkages through technical and scientific cooperation and collaboration on a variety of disciplines related to monitoring and assessment for ecosystem sustainability.

While the state of Jalisco will clearly receive the most tangible and direct benefits from the Center, it is also clear that this project will benefit many other institutions and people, both nationally and abroad. Additional benefits to cooperating institutions and organizations include: (1) the development of cost-effective, state of the art approaches to integration of data bases developed for diverse purposes into a useful inventory and monitoring system, thus assuring comparability and interoperability across institutions; (2) the integration of multiple scales into one study which has wide application for ecosystem resource management and planning; and (3) the Center addresses many of the technical and organizational problems that face current inventory and monitoring systems, and solutions to these problems would greatly benefit them. Designed as a multi-institutional response capability, the Center will bring about the formation of highly diverse partnerships capable of integrating human and capital resources to understand and confront common problems and issues, define and establish priorities, and seek out ways for alternative options for conflictive solutions.

Organizational Considerations

To achieve successful results, it is necessary that this initiative be organized, administered, and managed by the most effective means possible. It is highly recommended that the state government of Jalisco, through FIPRODEFO, take the responsibility to organize and fund its implementation, as well as its programmatic direction. The organizational structure of FIPRODEFO is well suited for housing and carrying out this initiative and its programs. Other sources of support can be provided through institutional partners of FIPRODEFO and the Jalisco state government. Other possibilities for organizing and funding this center must be analyzed within FIPRODEFO's internal decision making structure in coordination with its clients and institutional partners. Scientific and technical support can always be provided by CAMESA's international partners.

Conclusion

The proposed Center provides a flexible and adaptable strategy for advancing the development and application of pixel level estimation and modeling approaches to monitoring and assessment for ecosystem sustainability, at multiple spatial and temporal scales and resolution levels. Specifically, the Center will focus not only on the use of modern technology tools as a collection of separate entities whose value lies in their independent application, but extends the concept to the integration of scientific and technical disciplines into a seamless fabric of cost-effective and scientifically credible approaches to sample, collect, store, summarize, and manage data; analyze data to synthesize information and knowledge into geo-spatially explicit pixel-based applications; and finally, visualize and communicate the resulting outputs and syntheses in ways that are comprehensible to people of all cultural backgrounds. Most importantly, it is expected that its products and outputs will account for specific stakeholder needs and wants so that they can be readily used to support local planning and decision-making processes for sustainability in a timely and meaningful manner.

A Research/Teaching Inventory and Monitoring Institute for the State of Jalisco, Mexico

Cele Aguirre Bravo and Hans T Schreuder

Abstract—*A brief outline is given of what is considered required for a research/teaching Institute for inventory and monitoring in the state of Jalisco, Mexico. An important part of this presentation is to get feedback from the audience on suggestions of how to best implement such an institute.*

Vision

The vision of the proposed Institute is to develop the human and physical infrastructure necessary to implement modern technologies in the field of inventory and monitoring. This includes the following fields only as a starting point: classical statistical methods, Bayesian statistical decision making methods, remote sensing and aerial photography, geomatics and modeling to enable individuals, agencies, organizations, communities, governments, and other entities to effectively manage and enrich their ecosystem resources and their social and cultural environment. To implement this vision requires close collaboration between FIPRODEFO, the University of Guadalajara, Industries and Environmental Organizations in Mexico, the Federal Government of Mexico, the Rocky Mountain Research Station of the US Forest Service and the National Resources Conservation Service (NRCS) of the USDA.

Mission

In pursuit of that vision, the Institute mission is to be an instrument which fosters the climate of intellectual discovery, growth and effective dissemination in the subject areas described above as well as new ones still to be developed. Through this mission, the Institute will contribute to:

1. Educating high-quality professionals and technicians with respect to the integrated approach of the above fields through a program of classroom studies and applied and theoretical research wit emphasis on people in Latin America.
2. Creating and promoting new information and knowledge through the interaction of such professionals and technicians with researchers and teachers of the Institute involved with environmental, social, and economic issues through research and development projects.

In summary the mission is to educate Latin Americans in the methodology of inventory and monitoring and to conduct research in improved methods to do so.

Goal

The program goal is to fulfill the mission through a strategy that incorporates education, research, training, and infrastructure development to enable a variety of ecosystem resource-related agencies, individuals, organizations, communities, governments, and other entities to make wise managerial and utilization decisions regarding ecosystem resources using the tools and critical thinking associated with the above fields to a diverse cadre of ecosystem resource stakeholders, a physical infrastructure will grow which will allow information and knowledge with high social utility to be delivered in an efficient, visual form to the intended audience.

Objectives

To achieve the desired goals and guide the investments in this program, the following specific objectives will be achieved:

1. Create the next generation of human infrastructure (through graduate education, training, and other outreach) that will have the scientific and technical expertise to use the tools of the above specialties to synthesize the data into scientifically-credible, geospatial information and knowledge that is technically defensible and of high social and economic utility; and visualize and disseminate the results to the user groups.
2. Develop a set of integrated tools from these specialties through a comprehensive program of applied and

theoretical research that for the most part will be associated with education and result in the development of a broad spectrum of application tools.
3. Support the development and organization of a geomatics-based infrastructure (both physical and human) through which scientific and technological expertise can flow on a variety of projects to be conducted under the auspices of this program.
4. Facilitate the formulation and implementation of a digital-based expert system as a training device to structure, manage, and communicate geospatial knowledge and applications for use in decision-making and planning for sustainable ecosystem resource management and utilization.

Organizational structure:

Director

Requirements for the position:
1. Both strong demonstrated technical (in inventory and monitoring) and administrative experience with a professional and technician workforce.
2. Fluency in both Spanish and English.
3. Considerable experience throughout the Americas.

This person would be in charge of the Institute with key responsibilities of managing the personnel of the Institute, interaction with key user groups, obtaining additional financing as needed and interacting with important other professionals in equivalent positions in the Americas.

Professionals

Required courses for professionals: Basically we are aiming for people finishing with a MS degree in forest inventory. These people would be trained to become the managers of inventory and monitoring efforts in the various states of Mexico or in other Latin American countries. The below core courses should consist of a close integration of both theory and field work to make the ideas come alive and crystallize in the student's mind:

A thorough understanding and knowledge of books like Schreuder, Ernst and Ramirez (2004) for having a solid grasp of the fundamentals of statistical methodology. One year's course ideally. There should be considerable experience with simulation exercises such are emphasized in Schreuder et al (2004) but also actual field experience working with experienced field people.

A thorough understanding and knowledge of books for having a solid grasp of modeling with special emphasis on spatial data analyses. One year course ideally. There should be considerable experience with simulation exercises and actual field experience working with experienced field people.

1. A thorough understanding and knowledge of the following books for having a solid understanding and knowledge of instrumentation and measuring instruments.

- Remote Sensing of the Environment: An Earth Resource Perspective by John R. Jensen (Prentice Hall series in geographic information science) 2000 Prentice-Hall, Inc.NY.
- Aerial Photography and Image Interpretation, 2nd Ed., by David P. Paine, James D. Kiser, John Wiley & Sons, Inc. NY.
- Elements of Photogrammetry with Applications in GIS, 3rd Ed. 2000 by Paul R. Wolf and Bon A. Dewitt McGraw Hill, ISBN 0-07-292454-3
- Introductory Digital Image Processing: A Remote Sensing Perspective, 3rd Ed. 2005 by John r. Jensen. (Prentice Hall series in geographic information science) Pearson Prentice Hall. NY.
- One year course ideally.
- One semester in the office and one semester in the field.
- Considerable experience with simulation exercises.
- Actual field experience working with experienced field people.
- A semester course in human relations and management of humans.

Technicians

These people would be trained to become the key crew leaders in inventory and monitoring efforts in the various states of Mexico or other Latin American countries. Core courses would include:

1. The above for professionals covered in one semester at clearly a more superficial level. We are basically talking about training for what would be equivalent to a 2-year junior college degree in the USA.
2. One full semester of field work emphasizing inventory and monitoring methods. Considerable amount of this work could be done doing actual plots in Jalisco under the close supervision of experienced field crew leaders.
3. A short course in quality control and quality assessment methodology.

Researchers

These people would be hired directly by the institute to direct research efforts in the field of inventory and monitoring. The initial core group should consist of a PhD researcher in remote sensing, one in statistics and one in modeling and GIS.

The Trust Fund for the Administration of the Forest Development Program, and the Inventory and Monitoring of Jalisco's Natural Resources

Luis Artemio Alonso T.

***Abstract**—In 1966 the State Government of Jalisco conducted a review of the state's forest sector. A new forest agenda resulted from this review, which led to a set of ground breaking actions creating a long term forest development program known as FIPRODEFO (Trust Fund for the Administration of the Forest Development Program of Jalisco). Among the relevant issues, the survey revealed the need to reclaim damaged forest land, strengthen silviculture programs for natural temperate forests, support commercial plantation efforts, update and improve forest industry infrastructure, and improve information gathering and dissemination in support of policy planning. Solving these problems became the agenda for FIPRODEFO.*

Disappointment with quality and opportunity in national forest statistics reports, and the clear notion that information gathered for national purposes lack the detail and depth to support local decisions was building a demand for a state of the art statistical and geographical information system tailored for Jalisco's conditions and agenda. Responding to this opportunity, FIPRODEFO joined in a strategic knowledge partnership with CAMESA (Consortium for Advancing Monitoring for Ecosystem Sustainability in the Americas). The two year process of scientific and technical development of IMRENAT, Jalisco's natural resources inventory and monitoring project, ensued. Guidelines, technology, and procedures derived in the development phase shaped IMRENAT operational phase, up to the point of completion of the first of six regions.

Introduction

In 1966 the State Government of Jalisco conducted a review of the state's forest sector. A new forest agenda resulted from this review, which led to a set of ground breaking actions creating a long term forest development program known as FIPRODEFO (Trust Fund for the Administration of the Forest Development Program of Jalisco). Among the relevant issues, the survey revealed the need to reclaim damaged forest land, strengthen silviculture programs for natural temperate forests, support commercial plantation efforts, update and improve forest industry infrastructure, and improve information gathering and dissemination in support of policy planning. Solving these problems became the agenda for FIPRODEFO.

FIPRODEFO relies on Consejo Agropecuario de Jalisco A.C. (CAJ, The Farming Council of Jalisco), to operate development projects. CAJ is an advisory board to Jalisco's governor, and it is made up of landowners, industry representatives, and public agencies. Through the leadership of CAJ, FIPRODEFO has been able to undertake commercial plantation projects, technical cooperation agreements, and other activities in favor of innovation in the state's forest sector.

Guiding principles in FIPRODEFO's activities include clear and open checks and balances of fund appropriations, no nonsense responsive decision making, and efficiency. FIPRODEFO's outsourcing policy permits state wide allocation of opportunities for local contractors, taking advantage of an ample base of talented professionals.

Disappointment with quality and opportunity in national forest statistics reports, and the clear notion that information gathered for national purposes lack the detail and depth to support local decisions built a case justifying the creation of a state of the art statistical and geographical information system tailored for Jalisco's conditions and agenda. Responding to this opportunity, FIPRODEFO joined in a strategic knowledge partnership with CAMESA (Consortium for Advancing Monitoring for Ecosystem Sustainability in the Americas). The two year process of scientific and technical development of IMRENAT, Jalisco's natural resources inventory and monitoring project, ensued. Along this path, FIPRODEFO called upon the cooperation and partnership with diverse institutions including Colorado State University, USDA FS Forest Inventory and Analysis, Environment Canada, and the Mexican Institute for Forest, Agriculture and Animal Science Research (INIFAP).

IMRENAT began as an exercise to translate into measurable goals a set of general principles about seamless integration of multiple scale and multiple resolution levels of inventorying and monitoring of natural resources. Goals were then used in designing a scheme for sampling specific variables in the field, and modeling imagery information. A pilot area was selected to test a number of variants in sampling and measuring schemes. This area was conveniently close to the capital city of Guadalajara. At the same time this region encompasses a wide array of vegetation cover types, and offers numerous challenges to field crews, from an enormous biodiversity, up to terrain so rough as to present frequent cases of unreachable sample sites. In the near future, experiences gained in the pilot area will permit a large scale field sampling of the rest of the state. Afterwards, a monitoring survey will provide updated figures every 5 years, if 20 percent of the state area were remeasured annually.

An Agenda Fit for IMRENAT

FIPRODEFO first became interested in IMRENAT when a complaint by Jalisco's wood industries about scarce lumber in the local market was being blamed for increased imports from other regions and from abroad, and that were still insufficient to dampen illegal timber harvesting. A review of past inventory data supported the idea that standing stock in Jalisco's forestlands declined over the medium range, but this idea conflicted with the latest national forest inventory data. The 2000 inventory reported net timber increment three times the harvest rate. A careful examination stumbled into a confusing set of technical complications. A new forest inventory was then seen not only as a check up on previously available data, but an urgent development opportunity to create a monitoring system that will try, once and for all, to provide a coherent stream of forest statistics for medium and long term planning purposes.

Fragmentation was one of the noise factors in estimating deforestation rates, one of the politically important figures that forest inventories are expected to yield. Facing this problem led to the use of new conceptual frameworks about borderless interpretation of landscapes. This idea changes the way that remote sensing images are interpreted. Under the new concept, the basic land unit will be as small as the image pixel. Interpreting pixels cannot be done as before, by expert opinion, but it can be done mechanically by using spatial modeling. In this scheme, land classification will be one spatial modeling application.

The fact that IMRENAT was born as a seamless multiple scales and resolutions monitoring technology further increased its potential utility to address FIPRODEFO's agenda. Now, the new tools will be useful in addressing interactions between land uses, environment, and long term cumulative regional effects.

The Mexican government, like other governments in the world is interested in integrated operation of all public programs that deal with a specific thematic area. In this process, FIPRODEFO has been mandated to coordinate actions and views with other institutions dealing with rural matters. The general attitude to land development in rural institutions demanded from FIPRODEFO reconsidering its list of forest policy issues, and move them away from managing timberlands, to address forest-non forest processes such as deforestation, fragmentation, land development, agroforestry activities, and other interface opportunities and conflicts. Facts are one means to talk between agencies and FIPRODEFO, and IMRENAT is an ideal way to do this.

IMRENAT Features

From FIPRODEFO's point of view, IMRENAT is one more activity that eventually should be handed away to institutions or firms in the forestry sector of Jalisco. This policy follows the general principle that FIPRDEFO is a promoter of innovation who provides seed money and carries out the development phase of new ideas, techniques and programs.

Another FIPRODEFO policy is to hire field crews among foresters and technicians from the study region. This policy reduces costs and makes FIPRODEFO an organization that can quickly change and respond to needs and opportunities, but the real reason for outsourcing is to train and induce interest among state foresters in the new concepts, techniques, and tools. The more the inner workings of INRENAT are known, the more likely it is that foresters will be inclined to use them and suggest others how to take full advantage of IMRENAT resources and availability. This policy contrasts with traditional national forest inventories. The latter ones have been conducted by specialists and reclusive organizations whose only output is a set of statistics and maps, but little idea on what those items can be used for.

Users have previously experienced disappointing reliability of forest inventory outputs, despite considerable efforts and expense invested in them. One specific reason for the poor performance of past inventories is the fact that their design was optimized to answer national level inquires, but lack depth and detail to describe local variations, issues, causal connections, and other important information with local and specific focus. IMRENAT is not fit to fully respond to these demands and quality requirements, but its performance is expected to excel in ways that will be evident because its design is guided to describe and explain dynamic processes, and to make connections between disparate factors, locations, and time frames.

Knowledge Partnerships, a Practical Exercise

Although it is natural to seek collaboration and resource sharing to improve the work in innovative projects, partnerships also offer other important benefits. User feedback, faster adoption of new ideas, credibility and better linkage between program outputs and how they are used are the major reasons to foster close relations with the institutions and organizations involved in land management.

Bringing together a wide array of stakeholders into the planning, realization and usage phases of inventory and monitoring projects such as IMRENAT is a matter of great importance beyond their immediate roles played and resources shared. As important as the technology and science, the political support can be harnessed in favor of completing the project, and enthusiasm can be enticed in otherwise reluctant users.

These are the reasons behind the considerable effort in IMRENAT to foster a creative environment of collaboration with a varied number of partners. Some of these associations are with academic institutions that offer technical support and scientific credibility. INIFAP has been instrumental in IMRENAT, both as institution and as a group of talented specialists committed to give IMRENAT the best counseling. Government institutions such as CAJ have given a considerable leverage and political clout that provides ample public exposure to IMRENAT outputs. CAMESA and the US Forest Service have brought international visibility and institutional strenght to the project. An improved communication is necessary with other institutions like INEGI (the Mexican Institute of Geography, Statistics and Informatics), in the future, when numerous applications will demand the benefit of adding information layers from other sources beyond those measured directly by IMRENAT.

In short, FIPRODEFO has taken IMRENAT as a high priority project that will offer reliable information in a sustained manner. This information stream has been designed from start to be specific to Jalisco's forest, natural resources and land management issues and concerns, and at the same time, monitoring has been designed in a way to be flexible and responsive to evolving situations. The seamless nature in IMRENAT is particularly suitable to understand and keep tabs on interactions between natural and developed environments. These interphase relations between land uses and ecological processes have interconnections that are better handled by tools as those in IMRENAT.

Trace Chemical Detection through Vegetation Sentinels and Fluorescence Spectroscopy

John E. Anderson, Robert L. Fischer, and Jean D. Nelson

Abstract—*Detection of environmental contaminants through vegetation sentinels has long been a goal of remote sensing scientists. A promising technique that should be scalable to wide-area applications is the combined use of genetically modified vascular plants and fluorescence imaging. The ultimate goal of our research is to produce a bioreporter that will express fluorescence when encountering nitro-aromatic compounds such as munitions contaminants. To test the recovery of gfp, our study used tobacco plants (*Nicotiana tabacum*) that were genetically modified to express the m-gfp5-ER variant of the green fluorescent protein (gfp) in conductive tissues. Induction of the gfp was stimulated by the uptake and translocation of a systemic organo-phosphate pesticide. The first objective of the study was to detect the induced gfp emission in plants exposed to the pesticide. The second objective of this effort was to use a field spectrometer and imaging system to determine if the fluorescence signature (from the induced plants) was spectrally separable from negative controls and permanently expressing plants. Concurrent research is underway to optimize the induction specificity of the gfp for a variety of target materials (e.g., TNT, RDX, HMX). Here, we report results from a Phase I small-business technical transfer research grant (STTR) conducted in Edgefield, SC. Our tests showed that gfp could be detected by spectrofluormetry and laser imaging and that expressing plants produced approximately three times the fluorescence at 510 nm as the negative control. Correlation and agreement between the non-imaging and imaging spectrometer also showed the optimal excitation wavelength (gfp absorption maxima) to be between 390 nm and 410 nm. When matched with the emission wavelength, these numbers represent a broad Stoke's shift of almost 100 nm that is optimal for gfp signal recovery.*

Introduction

The detection of unexploded ordnance (UXO) and landmines is a major concern for ground forces, land reclamation, and commercialized infrastructure projects. In addition, mandated clean up and reclamation of military bases requires a robust method to detect contaminants related to UXO and explosive waste materials. The Base Realignment and Closure Act (BRAC) and the efforts for environmental recovery of Formerly Used Defense Sites (FUDS), has demonstrated that many of these military bases undergoing recovery possess range sites littered with the hazards of unexploded ordnance (UXO), explosives-related waste, and other soil-based contaminants. Other issues include the vast number of landmines in regions around the world that threaten human health and the socio-economic structure of many nations. Additionally, buried ordinance and explosives limit access to vast natural resources (CalEPA, 2000).

Safe, expedient, and cost effective remediation necessitates technological developments that can detect UXO hazards over vast areas, sometimes involving hundreds of square miles. Detection by an airborne platform is preferred alternative over the current state-of-the-art that involves discovering ordinance using specialized technicians on foot. Technicians must use manual means to tediously explore extensively contaminated areas. In many instances, this work is not only cost-prohibitive but orders of magnitude more dangerous than a remote detection technology.

The use of vegetation as sentinels to indicate presence/absence of contaminants provides an ideal mechanism for a wide-area detection scenario. With the exception of extreme arid, polar, and oceanic environments, vegetation is the dominant cover-type viewed from remote sensing platforms. Plants also have the ability to interrogate their environment spatially and temporally through roots and leaf stomata. It has been demonstrated that visible, near-infrared, and short-wave infrared spectral cues produced by natural vegetation can indicate the presence or absence of (toxic) materials (Milton and others 1991; Vane and Goetz, 1993). However, research has shown that it is difficult to positively attribute spectral phenomena to a specific plant-contaminant interaction. In most cases, morphological and photosystem stress cues are difficult to correlate with specific toxicants, particularly when both organic and inorganic compounds are present (Carter and others 2000). Furthermore, quantification of toxicants (in mass equivalent levels) that are available for uptake is nearly impossible remotely.

One solution to this problem is to modify a desired plant species through mutagenesis or genetic engineering to produce a diagnostic spectral response only when that plant comes into contact with a particular target material. A technique that has received the greatest amount of interest is the insertion of genes that promote the expression of the green fluorescent protein (gfp). Using genetic engineering, gfp can be inserted into specific tissues of plants, optimizing signature recovery. The protein originates from the jellyfish *Aequorea victoria*, and is often used as a marker for the non-destructive visualization of molecular biological processes involving both eukaryotic and prokaryotic cells. For the indication of contaminants, fluorescent protein expression is induced by specific (gene) promoters; linked to the synthesis or hyper-accumulation of a target material or substrate. Depending upon the variant, gfp produces a diagnostic fluorescence emission at ~ 509 nm that can be detected in dark field or separable from background light (Niwa and others 1999; Chiu and others 1996). Current research is examining application of proteins that emit in the yellow and red spectral regions (i.e., yellow fluorescent protein (yfp) and red fluorescent protein (rfp)). Many of the biochemical pathways for assimilation and bio-degradation that can foster fluorescence have been extensively studied by Meagher and others (2000). As sentinels, plants offer the best buffer to maintain stability of fluorescent proteins that can be sensitive to fluctuations in charge state (Smith, 2002).

Methods

Testing for the Phase I small-business technical transfer research grant (STTR) was conducted at NEWTEC Inc. of Edgefield, SC during May 20-22, 2002. NEWTEC provides a 1,500 acre federal and state licensed explosive test facility with approved storage magazines and an inventory of explosive materials in support of the original LIFI/bioreporter development program. NEWTEC coordinated and developed all previous permitting reports and gained approvals for deployment of the technology at its facility via the US Environmental Protection Agency, and South Carolina Department of Health and Environmental Control.

The genetically modified plants were tobacco (*Nicotiana tabacum*), engineered with the modified gfp gene (m-gfp5-ER or MGFP) through agrobacterium mediated transformation. Wild type tobacco plants were utilized as negative controls (NC population); plants engineered for permanent gfp expression (constitutive expressers, MGFP population) served as positive controls. Induction of gfp in test plants was mediated by the translocation and metabolism of a systemic organophosphate pesticide. Expression of fluorescence occurred in both leaves and conductive tissues.

The spectroscopic properties of the tobacco plants were investigated with a variety of instruments and methods. Reflectance was measured with the Analytical Spectral Devices (ASD) Field Spec Pro. Fluorescence detection hardware consisted of a portable gfp Meter, a JY Horiba Fluoromax-3 spectrofluorometer, and Laser Induced Fluorescent Imaging and Spectral (LIFI/LIFS) sensing equipment.

Results

Visible – near infrared reflectance signatures were collected using the ASD FieldSpec radiometer on May 20 and May 22. The spectral response of the individual signatures varied as a function of canopy dimensions (i.e., amount of potting visible to the radiometer) and canopy geometry. Comparisons between negative control plants and constitutive expressers showed no substantial difference in the specific population average reflectance spectrum (fig. 1). The only notable difference is a few percent offset between 750 and 900 nm, which is negligible when considering the ± 1 σ error bars. The spectral

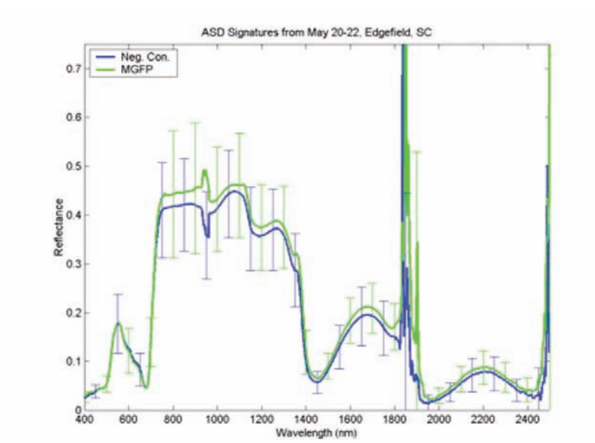

Figure 1. Reflectance signatures from NEWTEC, South Carolina. Blue is negative control, green is MGFP population. Error bars represent ± one standard deviation. Nineteen samples were used for the negative control, 17 for the MGFP.

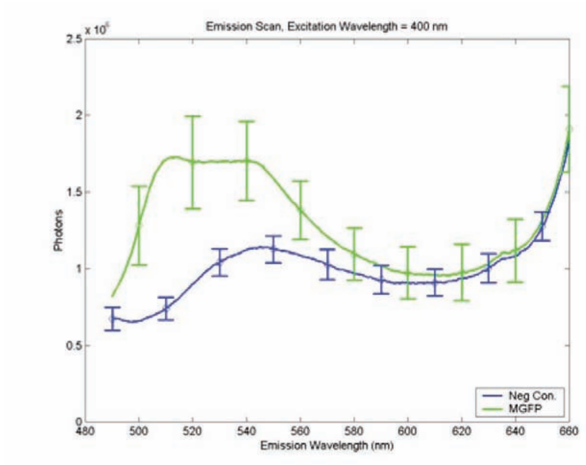

Figure 2. Fluorescence excitation signatures for negative control and MGFP plants. Emission wavelength = 510 nm. Eight samples were used to create each of the signatures.

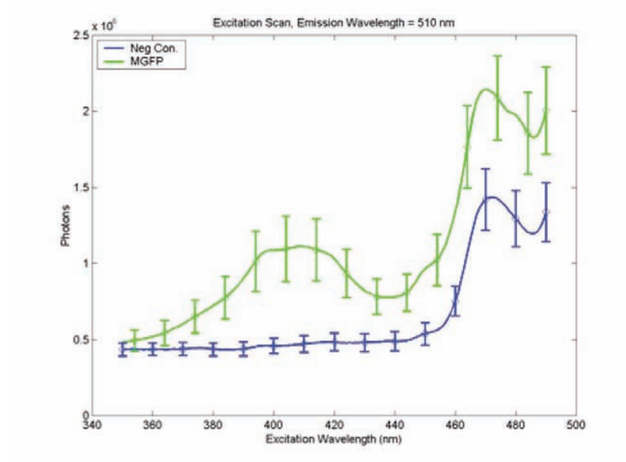

Figure 3. Emission spectra from May 22. Excitation wavelength = 400 nm.

"spikes" at 925, 1900 and 2500 nm are due to atmospheric absorption that was not removed or smoothed by the post processing software.

Fluorescence spectra obtained using the Fluoromax-3 was successful in detecting enhanced gfp expression from the MGFP population. Figure 2 shows the excitation spectra collected at 510 emission. The 510 nm data represent excitation potential at the gfp emission maximum. Figure 2 shows that the negative control and MGFP plants separate at excitation wavelengths between 390 and 420 nm. The maximum separation between the two curves is found at approximately 410 nm, with the MGFP plants fluorescing almost three times as many photons as the negative control plants. Separation is good in this spectral region as shown by the one standard deviation error bars. This data suggests that the optimum excitation to differentiate the negative control plants from the constitutive expressers and, potentially, the experimental plants, is an excitation source at 400 nm.

Figure 3 shows the emission scan collected at 400 nm excitation for the control and MGFP plants. As indicated by Figure 3, maximum spectral separation is evident in the 510 nm emission range. At wavelengths longer than 550 nm, the signatures converge and separation is no longer possible. This figure shows that the emission at 510 nm from the MGFP plants is roughly three times that of the negative control plants as shown by the emission scan in Figure 2. One standard deviation error bars show the spectral difference is significant.

Figure 4 shows the LIFS-derived data demonstrate that gfp modified plants are spectrally separable from the control plants, most strongly at the gfp emission maximum of 510 nm (with an excitation of 400 nm). The LIFS data were collected at a distance of approximately one meter demonstrated the concept of stand-off detection. These data corroborate the data acquired with the gfp meter as well as the Fluoromax-3. Leaf canopies were interrogated at 400 and 355 nm excitation. A small difference in emission intensity is observed at 355 nm excitation between MGFP and NC plants (not shown) but the difference in fluorescence emission is much more distinct when the excitation is at 400 nm.

Figure 5 shows the results obtained from the Laser Induced Fluorescence Imaging system. These data were also collected at a one meter stand-off distance. The laser light was pulsed at an excitation wavelength of 355 nm. An optical receiver with a bandpass filter of 510 nm captured the resulting fluorescence. An algorithm was used to remove the green background chlorophyll fluorescence. The resultant images show that MGFP plants produced

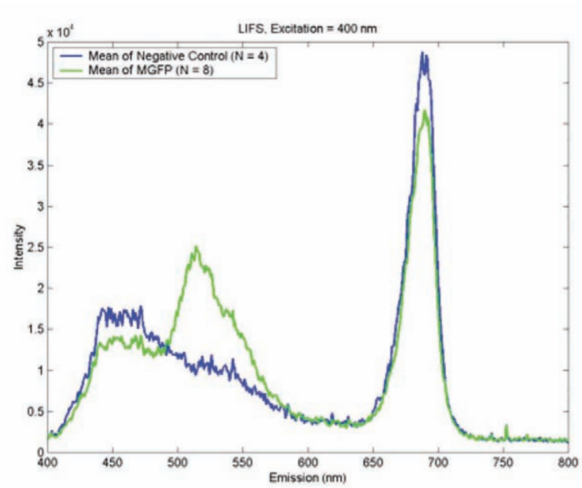

Figure 4. LIFS signatures from control and gfp expressing plants.

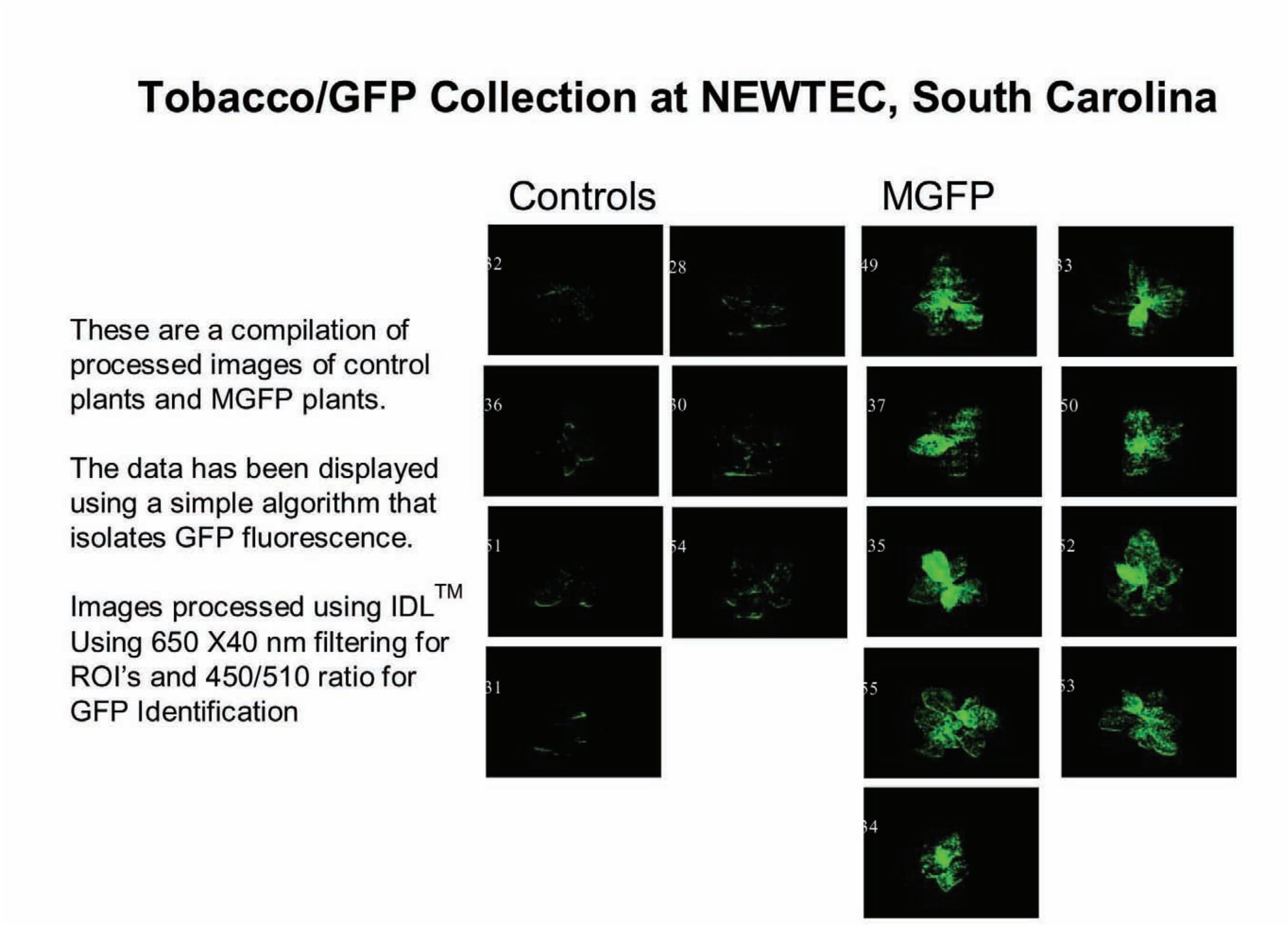

Figure 5. LIFI images of negative control (left) and expressing tobacco plants (right).

a detectable response. This result is encouraging when considering that these plants were excited at a non-optimal wavelength of 355 nm.

Conclusions

The focus of the research effort was to generate and evaluate fluorescent signatures of genetically modified plants and to tailor the plant fluorescence to optimize the use of existing passive or active imaging technology from an airborne platform. The purpose of this test was to perform a field demonstration and proof of concept that plants genetically programmed to express were detectable and separable from negative control plants.

Fluorescence spectra obtained from the Fluoromax-3 was successful in detecting the gfp expression from the constitutive expresser population at the gfp wavelength of 510 nm. The maximum separation between the two curves is found at an excitation wavelength of approximately 410 nm, with the MGFP plants fluorescing almost three times as many photons as the negative control plants. Separation is good in this spectral region as shown by the error bars.

The results found by the Fluoromax spectrofluorometer were supported by the stand-off LIFS and LIFI systems. The LIFS also detected a factor of three intensity difference between the negative control and expressing plants. While numerical measurements from the LIFI system were not available, the MGFP plants were separable from the NC plants after the removal of green chlorophyll fluorescence.

The test showed genetically modified plants expressing gfp can be successfully interrogated and detected with spectroscopy and stand-off fluorescence systems. Research is actively underway to develop a host of different plants that possess higher selectivity and express (gfp) only after synthesis of specific contaminants (such as TNT). If plants can be developed to respond (by fluorescence) to a particular contaminant at intensities seen in the MGFP population, then detection of target contaminants should be feasible by fluorescence remote sensing.

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Developing a Methodology to Predict Oak Wilt Distribution Using Classification Tree Analysis

Marla C. Downing, USDA Forest Service, Forest Health Technology Enterprise Team, Fort Collins, CO
Vernon L. Thomas, INTECS International, Inc., Fort Collins, CO
Robin M. Reich, Department of Forest Sciences, Colorado State University, Fort Collins, CO

Abstract—*Oak wilt (*Ceratocystis fagacearum*), a fungal disease that causes some species of oak trees to wilt and die rapidly, is a threat to oak forested resources in 22 states in the United States. We developed a methodology for predicting the Potential Distribution of Oak Wilt (PDOW) using Anoka County, Minnesota as our study area. The PDOW utilizes GIS; the classification tree statistical test; field sample data; commonly acquired, coarse-resolution auxiliary data; and a unique application of data from the Landsat Thematic Mapper (TM) satellite to predict the spatial distribution of oak wilt. Two accuracy assessments, one being a ten-fold cross validation, the other using verified oak wilt data from a later date, indicate that, at the landscape scale, PDOW correctly models the presence of oak wilt, and accurately predicts oak wilt distribution in Anoka County. Important variables in predicting oak wilt distribution in Anoka County included: Landsat TM Bands 3, 4, 5, and 7; distances between sample sites and lakes (Distance to Lakes); density of streams within a 400 x 400 meter grid surface (Stream Density); slope; aspect; and density of roads within a 400 x 400 meter grid surface (Road Density).*

Introduction

Oak wilt (*Ceratocystis fagacearum*) is a serious tree disease that kills many species of oaks. The disease spreads in two ways, via insect vectors and root grafts. Untreated infection centers kill thousands of oak trees annually throughout 22 middle and eastern states in the US, and as far south as Texas (Appel and Maggio, 1984; Juzwik, 2000; USDA Forest Service, 2001; O'Brien et. al., 2003), (fig. 1), creating ever widening pockets of disturbance in forests, woodlots, and home landscapes.Oak trees dominate the Minneapolis/St. Paul urban landscape and are both a valued element of the forest ecosystem (International Society of Arboriculture, 1992; Nowak et. al., 2001; USDA, 2001) and an important food source for many animals (Juzwik, 2000; Sander, 2003). But the oaks are threatened: in 1998, the Minnesota Department of Natural Resources (MNDNR) identified and treated 3,182 acres of infected oak wilt trees in Anoka County. The MNDNR projects that, at current infection rates, there will be a two-fold increase in oak wilt by 2008 (MNDNR, 2001).The purpose of our study was to test the feasibility of using a classification tree on commonly acquired datasets and location data collected in Anoka County, Minnesota, to create a surface of potential oak wilt distribution. Tree-based models (decision trees) are useful for both categorical classification and regression problems. The classification or regression tree is a collection of many rules displayed in the form of a binary tree. The rules are determined by a recursive partitioning procedure (MathSoft, 1999). Such an approach offers a way to describe the spatial continuity that is an essential feature of many natural phenomena (Isaacs and Srivastasa, 1989), and have been used to predict spatial patterns and develop indicators of sudden oak death in California, USA (Kelly and Meentemeyer, 2002), classify remote sensing imagery (Michaelson and others 1994; Friedl and Brody, 1997; Joy and others 2002; Ruefenacht and others 2003), and estimate fuel loads in the Black Hills, USA (Reich and others 2004).

Advantages of using decision trees include the non-parametric nature of the model, ease of interpretation, and the robustness of the test (De'Ath and Fabricius, 2000). Decision trees are appropriately used with datasets that are a mix of both numeric and factor information, non-linear and/or non-additive data. A potential disadvantage to using decision trees is the need for large numbers of samples (Joy, 2003).

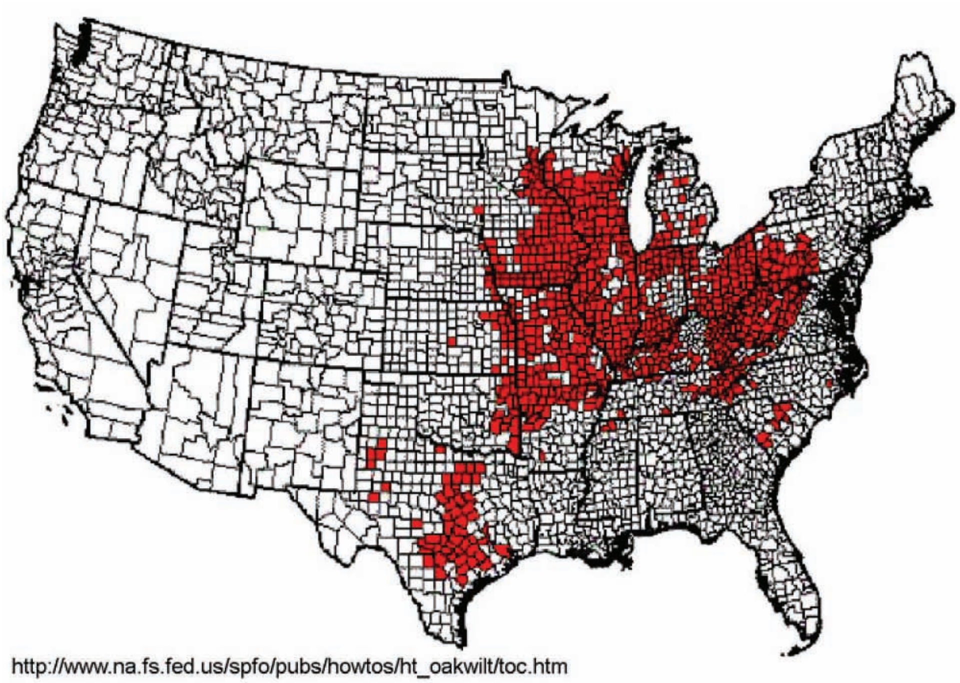

Figure 1. U.S. distribution of oak wilt by County—1999 USDA Forest Service.

Materials and Methods

Study Area

Anoka County, just north of the Minneapolis/St. Paul urban area, is comprised of 110,000 hectares, and has a population of nearly 300,000 (U.S. Census Bureau, 2003). The northwest corner of the county lies at the latitude of 45.41 degrees north and longitude of 93.51 degrees west.

The county is considered to be relatively homogeneous with primarily sandy soils and oak forest landcover. It falls within the Anoka Sand Plains (MNDNR, 1999), a subsection of the Minnesota and northeast Iowa Morainal Oak Savanna Section (Bailey, 1994), a part of the Eastern Broadleaf Forest Continental Province (Bailey, 1995), in the Hot Continental Division (Bailey, Ecoregion 220). The climate consists of cold winters and hot summers. The natural vegetation is characterized by winter deciduous forest dominated by tall broadleaf trees (Bailey, 1996). The landform is a broad sandy lake plain containing small dunes, kettle lakes, and level to gently rolling topography (Wright, 1972). Elevation ranges from 243 to 342 meters above sea level (USGS 30-meter resolution, 1:24000 scale DEM).

Anoka County's Land Type Associations (LTAs) are: Anoka Lake Plain (72 percent of the land mass); Mississippi Sand Plain (12 percent); Burns Till Plain (9 percent); Forest Lake Moraine (4 percent); Maplewood Moraine (2 percent); Elk River Moraine (1 percent) (MNDNR, 2000). Anoka County is made up of oak forest (5 percent), other hardwood forest (9 percent), coniferous forest (1 percent), shrubs and grasslands (17 percent), agriculture (22 percent), water bodies (5 percent), and urban areas (41 percent) (U of MN, 2002; Ward, 2002).

Spatial Information Database

Our database consisted of two components: 1) the dependent variable, and 2) the independent variables. The sample point field location data served as the dependent variable. There were twenty-two independent variables used in the analysis, which were collected, aggregated, or re-sampled to a 30 x 30 meter spatial resolution.

Dependent Variable datasets were merged to become the Sample Point Theme against which the independent variables were tested for correlation:

- Oak wilt presence and absence field sample data from the Land Management Information Center (LMIC), Forest Health, Oak Wilt, treated site polygon data, 1998.
- Field visits by the USDA FS NCRS Forest Disease Unit and the Forest Health Technology Enterprise Team (FHTET) to the LMIC, Forest Health, and "active" oak wilt sites.
- Field visits by the USDA FS NCRS Forest Disease Unit and FHTET to randomly selected healthy oak forest sites.

Independent variables used in the binary Classification Tree to determine the level of correlation with the dependent variable:

- Landsat TM Path 27 Row 29 bands 1-7, acquired May 1998.

- Landsat TM Path 27 Row 29 bands 1-7, acquired September 1998.
- Elevation, derived from the USGS 30 meter resolution DEM (1:24000 scale).
- Slope degrees, derived from the USGS DEM using ArcView Spatial Analyst (ESRI) slope function.
- Aspect (compass direction), derived from the USGS DEM using ArcView Spatial Analyst (ESRI) aspect function.
- Landform (independent of slope), created from a custom ArcView Avenue application, which uses an irregular 3 x 3 kernel, where positive values indicate concavity and negative values indicate convexity, to calculate landform from a USGS DEM. A zero value indicates flat terrain (McNab, 1989).
- Distance to Streams USGS 1:100,000 DLG data, measured using ArcView Spatial Analyst, distance in meters from line feature function.
- Distance to Lakes USGS 1:100,000 DLG data, measured using ArcView Spatial Analyst, distance in meters from feature function.
- Road Density was measured using ArcView Spatial Analyst, distance in meters from line feature function. It was calculated as the sum of roads within 400 x 400 meter grid surfaces. Roads include City Streets, County Roads, and TWP Roads from USGS 1:24,000 data and Major and Ramp roads from MN Department of Transportation data.
- Stream Density, calculated as the sum of all stream surface area within 400 x 400 meter surface grids.

A dependent variable GIS Sample Point Theme was created for this study using the LMIC oak wilt database as our primary data source. Many sample locations were acquired from the 1998 LMIC oak wilt "treated" polygon data. Additional sample locations, coded as "possible active" oak wilt sites during the 1998 growing season, from the same database, were also randomly selected and visited in July and August, 2002, by USDA FS NCRS Forest Disease and FHTET personnel. GPS location points were collected if evidence suggested these "possible active" sites had active oak wilt infection centers in 1998. Healthy oak site locations also were acquired during this time period. All field visited sample point locations were collected using a GPS (Garmin E-Trex Legend) at tree locations. Of the 422 sample points collected, 121 were identified as being healthy oak sample points, and 301 were identified as having been active oak wilt sites in 1998.

All polygon centroid locations and sample point locations (from LMIC, NCRS and FHTET) were merged to create the final dependent variable GIS Sample Point Theme in ArcView 3.2a. Location points were acquired from polygon centroids using the ArcView command "ReturnCenter" (ESRI, 2000) with customized ArcView Avenue code to automatically create points from the polygon centroid. Healthy oak wilt sample point locations were assigned a value equal to zero, and oak wilt sample point locations were assigned a value equal to 1.

Twenty-two auxiliary, or independent variable, GRID themes were also constructed for this study: Fourteen were created from two, multi-temporal Landsat TM images using the ERDAS Imagine software Grid Export function, which un-stacks each band to an individual grid. (ERDAS 2001); eight were constructed using the Spatial Analyst extension for ArcView. The DEMs were used to create the slope and aspect GRID themes. Anoka county lakes and streams data were used to construct the distance-to-streams, and distance-to-lakes GRID themes. Customized ArcView functionality, created with ArcView Avenue, was incorporated to create the GRID themes of landform, road density, and stream density.

The twenty-two independent variable attributes were added to the Sample Point Theme to produce a Spatial Information Database. This was accomplished using an automated ArcView function (written with ArcView Avenue script language), to extract the grid cell values from each of the twenty-two independent data themes at each of the 422 oak wilt presence or absence sample point locations. These grid cell values, taken at the sample point locations, were then used to populate the Spatial Information Database (USDA Forest Service, FHTET, 2003).

Stratification

The southern section of Anoka County has a higher degree of urban coverage than the northern section of the county. More oak wilt sample point locations were found in the more urbanized southern half of Anoka County. To determine whether spatial correlation exists between oak wilt and urban or natural landscape features, and to ensure that the urban condition in the south was not affecting the results of the model for the non-urban area to the north, the county was stratified into urban and non-urban datasets and two models were created (fig. 2).

Classification Tree Analysis and Oak Wilt Presence/Absence Surface Map

The Spatial Information Database for Anoka County, comprised of 30 x 30 meter biological, geological, hydrological, landscape, and physical information, was the basis for our classification tree analyses to predict the distribution of oak wilt for the urban and non-urban models.

S-PLUS© statistical software was used to fit the classification tree to the Spatial Information Database

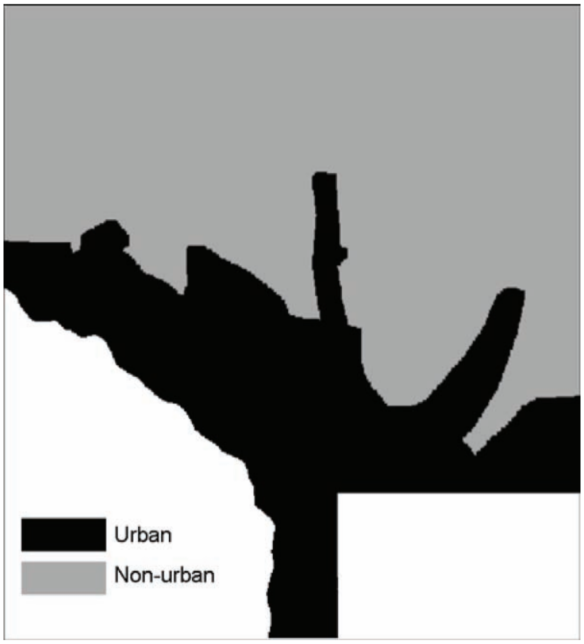

Figure 2. Urban (black) and non-urban (gray) spatial stratifications for Anoka County.

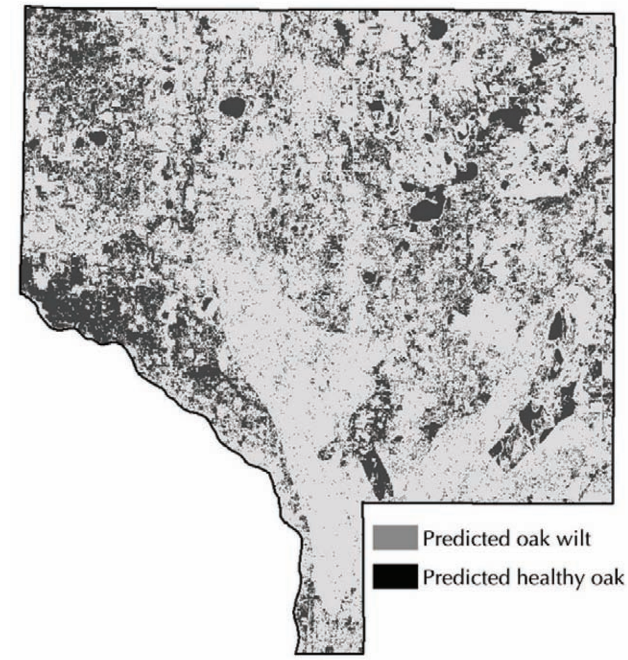

Figure 3. The predictive oak wilt surface for all of Anoka County.

for both the urban and non-urban models (TREE; S-PLUS©, Statistical Sciences, 2000). The output from the classification tree was the input for conditional statements (CON statements), (ESRI ArcView, 2000). CON statements were used to create an oak wilt presence or absence raster grid surface. The CON request performs a conditional if/else evaluation on a cell-by-cell basis. Grid theme cells with values of 0 indicated lower probabilities of oak wilt presence (defined as absence). Grid theme cells with values of 1 indicated higher probabilities of oak wilt presence.

After modeling the urban and non-urban sections of Anoka County, the two models were merged according to the predicted binary output for the entire study area into a single Potential Distribution of Oak Wilt grid surface (fig. 3).

Accuracy Assessment

There were two accuracy assessments performed. The initial accuracy was estimated as a sample-based misclassification error rate, the tenfold cross-validation, (Efron and Tibshirani 1993), calculated in S-PLUS© as part of the classification tree procedure. The cross-validation procedure validates the tree sequence by shrinking and/or pruning the tree by portioning the data into a number of subsets, fitting subtree sequences to these, and using a subset previously held out to evaluate the sequence. This procedure was used to identify the tree size that minimized the prediction error.

The second assessment estimated the accuracy of the urban and non-urban models, using actual treated oak wilt polygon data from a later date (LMIC data, 1999-2000). The assessment data contained polygons of known and verified oak wilt locations. To assess the accuracy of the urban model, a total of 164 known oak wilt polygons, with a mean size of 0.76, minimum size of .07, and a maximum size of 10.01 acres, were used. To assess the non-urban model, a total of 65 known oak wilt polygons, with a mean size of 1.94, minimum size of 0.14, and a maximum size of 13.16 acres, were used. These known oak wilt polygons were intersected with the predicted urban and non-urban models to determine the rate at which we accurately predicted the presence of oak.

ArcView Avenue code was used to measure the percentage of predicted oak wilt area within each assessment polygon (fig. 4). The data was assessed in three ways:

- presence of oak wilt in 50 percent or more of the assessment polygon.
- presence of oak wilt in 67 percent or more of the assessment polygon.
- presence of oak wilt in 100 percent of the assessment polygon.

To determine the presence of oak wilt in 50, 67, and 100 percent or greater of the assessment polygon, we intersected the assessment polygon with the results from the PDOW, then divided the area of predicted oak wilt within the assessment polygon by the total area of

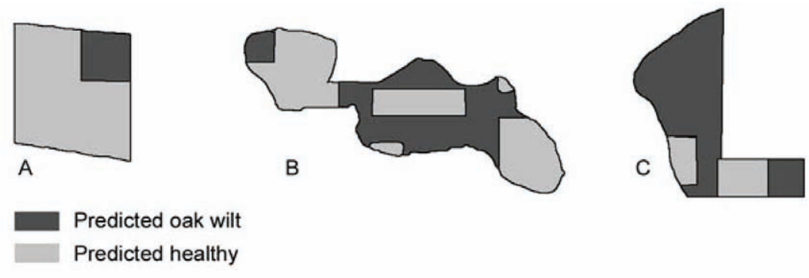

Figure 4. Examples of accuracy assessment polygons and the potential amounts of predicted oak wilt within any individual polygon. The dark gray denotes areas of predicted oak wilt and the light gray denotes areas predicted to be healthy oak. Figure A is an assessment polygon that has less than 50 percent predicted oak wilt by area; figure B has at least 50 percent predicted oak wilt; figure C has at least 75 percent predicted oak wilt.

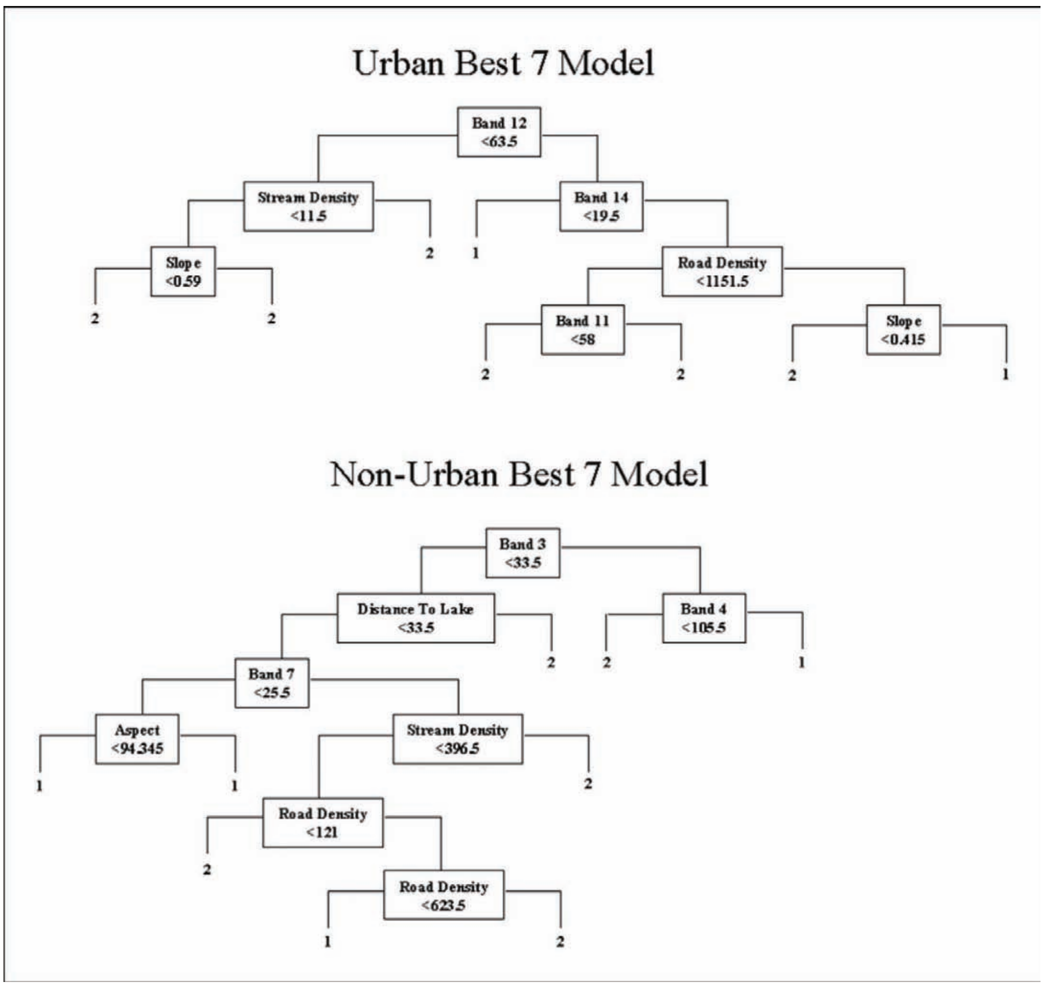

Figure 5. Urban and Non-urban decision tree models.

the assessment polygon. For an overall percentage of accuracy in predicting the presence of oak wilt, the number of assessment polygons that had 50 and 67 percent or more, and 100 percent predicted oak wilt by area, were totaled and divided by the total number of assessment polygons.

Results

Oak Wilt Potential Distribution Surface

The combined PDOW model predicted a potential for oak wilt presence in 79 percent of the County. The remaining 21 percent of the county had less potential for oak wilt presence and was identified as healthy. There were eight terminal end nodes, which accounted for 87.5 percent of the variability in the urban model. The combination of independent variables important in predicting the presence or absence of oak wilt were: Band 5 (September 1998), Stream Density, Slope, Band 7 (September 1998), Road Density, and Band 4 (September 1998).

For the non-urban model, there were nine terminal end nodes, which accounted for 82.4 percent of the variability in the non-urban model. The combination of independent variables important in predicting the presence or absence of oak wilt were: Band 3 (May 1998), Distance to Lakes, Band 7 (May 1998), Aspect, Stream Density, Road Density and Band 4 (May 1998) (fig. 5).

Proportion of Predicted Oak Wilt and Healthy Oak in Urban/Non-Urban Models

The proportions of predicted oak wilt and non-oak wilt of both models were calculated and compared for the entire study area (table 1). The comparison was made between the urban and non-urban models in relation to the proportion of the area predicted for oak wilt and healthy forested area. Results show there was 17 percent more predicted oak wilt in the urban model than in the non-urban model (table 1).

Accuracy Assessment

The classification tree selected through cross validation for each of the urban and non-urban models had

Table 1. Proportion of predicted oak wilt to healthy oak in the urban and non-urban models for the entire study area.

	Urban Model	Non-Urban Model	County Average
Predicted Oak Wilt	87.8 percent	70.7 percent	79.25 percent
Predicted Healthy Oak	12.2 percent	29.3 percent	20.75 percent

Table 2. A) Non-Urban Error matrix for the tenfold cross validation accuracy assessment. Non-urban errors of omission: Absent 24/62+24 = 27.9 percent; Present 15/15+121 = 11.0 percent. Non-urban errors of commission: Absent 15/62+24 = 17.4 percent; Present 24/15+121 = 17.6 percent. **B)** Urban errors of omission: Absent 21/14+21 = 60.0 percent; Present 4/4+161 = 2.4 percent. Urban errors of commission: Absent 4/14+21 = 11.4 percent; Present 21/4+161 = 12.7 percent.

A. Non-Urban	Classified Absent	Classified Present	B. Classified Urban	Classified Absent	Classified Present
Actual Absent	62	24	Actual Absent	14	21
Actual Present	15	121	Actual Present	4	161

Table 3. Accuracy assessment results using verified oak wilt assessment polygons from the 1999 and 2000 LMIC database. These assessment polygons were not used in the modeling process. **Column A:** Portion of assessment polygon predicted as having the potential for Oak Wilt; **Column B:** Proportion of assessment polygons that were accurately predicted with having oak wilt by the Urban Model; **Column C:** Proportion of assessment polygons that were accurately predicted with having oak wilt by the Non-Urban Model.

A	B	C
Half of Assessment Polygon	93.3 percent	87.7 percent
Three quarters of Assessment Polygon	90.9 percent	64.6 percent
Entire Polygon	70.1 percent	24.6 percent

misclassification errors of 0.125 and 0.1757, respectively. The error matrices are shown in table 2.

A second accuracy assessment was conducted on the oak wilt predictions for both the urban and non-urban sections of the county. Accuracy assessment results of the urban and non-urban models, using the LMIC actual oak wilt locations from 1999 and 2000 are found in table 3. The oak wilt locations from 1999 and 2000 were not part of the dataset used to develop the oak wilt models.

Discussion and Conclusions

We showed that using a classification tree on commonly acquired datasets could reliably predict the distribution of oak wilt across Anoka County, MN. Although our potential distribution of oak wilt might be considered a theoretical construct, (Felicisimo and others 2002) our accuracy assessment using additional oak wilt locations establishes that the classification tree analysis of large-scale, commonly acquired data can be successfully used to construct a model for the spatial distribution of oak wilt in both the urban and non-urban landscapes.

Land use, specifically the urban and non-urban categories, played an important role in modeling oak wilt. The total area of predicted oak wilt in the urban model differed from that in the non-urban model by 17 percent with more oak wilt predicted in the urban model than in the non-urban model. These results seem to suggest that stratifying the landscape according to urbanized and non-urbanized land cover produces more accurate predictive oak wilt models.

We showed that a classification tree analysis of large-scale data, combined with location data collected in the field, is useful for identifying indicator variables that are correlated with the presence and/or absence of oak wilt in Anoka County. Our model shows that Landsat TM Bands 3, 4, 5, and 7 are significant for predicting the presence or absence of oak wilt in Anoka County. Bands 3 and 4 are commonly used for vegetative analyses and are logical variables for predicting healthy or stressed vegetation. Bands 5 and 7 have also been related to vegetative condition but also to soil moisture retention. To substantiate the importance of these variables, further application of these methods in another study area dissimilar in characteristics to Anoka County is suggested.

Time spent in the field was limited to the collection of only one healthy sample site for every 2.5 oak wilt sites. We believe this biased our results: The greater percentage of oak wilt sites likely skewed the model, causing it to over predict the potential for oak wilt. An appropriate sample design is critical for modeling success. Acquiring more of the healthy sample sites, selected with a systematic sampling routine, will result in a model that is equally robust at predicting the location of oak wilt and healthy locations.

We were mindful of project costs as we constructed a methodology to be used by forest managers. We restricted our analysis to variables that were easily obtained and with minimum costs. In so doing, we reduced our ability to illuminate factors affecting oak wilt on a smaller spatial scale. Given additional resources, additional variables could be collected in the field at the sampling locations, such as: type of oak species, other tree species present, percent oak species, dominant over and under story, tree diameters, tree height, soil samples. These variables tend to change over short distances and may explain some residual conditions essential to the presence or absence of oak wilt. Future studies should also include soil information collected at the sample locations.

Acknowledgments

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Web Services—A Buzz Word with Potentials

János T Füstös

Abstract—*The simplest definition of a web service is an application that provides a web API. The web API exposes the functionality of the solution to other applications. The web API relies on other Internet-based technologies to manage communications. The resulting web services are pervasive, vendor-independent, language-neutral, and very low-cost. The main purpose of a web API is to enable application integration, and bring providers (developers) and requestors (users) together. More specifically, web services allow integration of heterogeneous applications. With solutions in place agents and other applications can connect to the service, and use the predefined processes. A centralized depository keeps track of the available functions and services, and with intelligent recognition and discovery semantics dynamic solutions can be created. Standardized description, self-describing structure, and discoverable providers make it easier to use existing solutions in new services and setups. In a long term it also offers the promise of the automated web.*

Introduction

Web services represent one of the latest and very exciting online technologies. They are based on a uniform and widely accessible interface, and use solutions that are implemented using traditional middleware platforms. (Vasudevan 2001) There are two different ways how they are generally introduced. One assumes that web services provide an overall solution to all existing problems by integrating different solutions, programming languages, applications, and software. This can be really confusing and disseminates false understanding about the true nature and the real opportunities what web services can represent. The other approach is highly technical, uses acronyms like .NET, J2EE, XML, WSDL, WSI, SOAP, ebXML, UDDI, JAX-RPC, JAXM, XAML, BEEP etc., and juggles with them as given and apparently well-known expressions without really explaining their meaning, content, and relationships. This paper takes a middle road, and provides an introduction of web services somewhere between these two approaches. It will use some technical terms with detailed explanations, refers to some of the most important aspects of web services focusing on general business applications, and drafts some new potential areas for service integration.

What is a Web Service?

There are several definitions for web services that emphasize different aspects, and approach the idea from different perspectives. The first introduction using a simple, general explanation can be "A web services is any service that is available over the Internet, uses a standardized XML messaging system, and is not tied to any operating system or programming language." (Cerami 2002) An IBM tutorial provides a more functional description: "Web services are a new breed of Web application. They are self-contained, self-describing, modular applications that can be published, located, and invoked across the Web. Web services perform functions that can be anything from simple requests to complicated business processes. A sample Web service might provide stock quotes or process credit card transactions. Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service." (IBM developerWorks 2003) For development purposes the most comprehensive definition comes from the World Wide Web Consortium: "A Web service is a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-process-able format (specifically WSDL). Other systems interact with the Web service in a manner prescribed by its description using SOAP messages, typically conveyed using HTTP with an XML serialization in conjunction with other Web-related standards." (W3C Working Group 2004) Web services can also be considered as a new architectural paradigm for shared and reusable applications. They are solutions that apply industry-wide standards, interfaces, and protocols (Chatterjee & Webber 2004). Using existing solutions, servers and protocols web service developers can implement application integration projects, consolidate development efforts, reduce redundant applications; in work-flow development web services can help to implement a general-purpose integration platform for application systems; and they can make it easier for partners to do business based on similar solutions.

Web Service System Architecture

Web services are built on the top of the HyperText Transfer Protocol. The eXtensible Markup Language provides the portability of solutions between different operating systems, programming languages, and standards. XML acts as a meta-language that allows description of complex structures and also assures interoperability between applications, between functional parts of services, and between servers and clients requesting services. Solutions that can be developed in any programming language handling any kind of data resources will use XML when communicating with other applications. These applications can provide functionality (e.g. common calculations), can request or deliver data (e.g. data stream, map, sound), or can represent building blocks of business processes, for example(payment operation).

Players and Their Roles

It seems that nearly every hardware and software vendor is touting a Web services strategy. The motivation behind Web services is integration: managers consistently list application integration as one of the top three technology issues facing businesses. The gained competitive advantages are two-folded: from a tactical perspective, application integration improves operational efficiency, resulting in reduced costs; from a strategic perspective, application integration enables better access to information resulting in better decisions. Unfortunately, it is very hard to integrate heterogeneous systems. The issue becomes much more challenging when a business tries to integrate its systems with those of its partners, suppliers, and customers. Web services using their generalized solutions and standardized protocols can contribute to these efforts. The integration and cooperation efforts can be approached in general terms when looking at the setup and construct of web services. There are three major roles in the web service architecture:

Service provider—Web service providers create, define and develop web services, and then publish them with access information in service repositories or make them available to web service requestors directly. Originally the services were:

Service requestor—Web service requestors perform a find operation to locate desired services made available by web service providers and then request those services from either web service registries or the publishers directly. Once the service has been located, web service requestors can then bind to those services to their applications and use their functions.

Service registry—Web service registries serve as centralized directories and repositories for web services defined and published by web service providers. The discovery framework offers APIs that allow the client to access services conforming to the various specifications. Service discovery is accessible to client applications, as well as to other parts of the architecture.

Service Layers

The web service protocol stack currently has four main layers. Like with other protocol stacks there is a close connection between the layers, and each of them has a different role. The stack is still evolving. Depending on specific solutions and requirements, other technologies might be added that are not required for all services but deliver additional solutions when needed (for example, authentication, certifications, or registration).

Transport—Web services are generally built on top of HTTP. Because web browsers can handle several additional protocols, data transport can be implemented by using FTP (file transfer), SMTP (mail), and also some newer solutions like BEEP (simultaneous and independent exchange of both textual and binary messages) or instant messaging.

Messaging—Extensible Markup Language (XML) is the lingua franca of web services. Using its own definitions (by implementing name spaces), and individualized data structures (which can be highly structured and complex) described in schemas, XML delivers a flexible way for data exchange that is independent from operating systems, programming languages, and data handling solutions. There are parsers, editors, and validators available on every platform for XML development. There are two different solutions how programs and processes can communicate with each other: RPC and SOAP.

Remote Procedure Call (RPC also called XML-RPC) is using the POST method of the HTTP protocol. Both requests and responses travel in XML format, and arrive in the body of the messages.

The Simple Object Access Protocol (SOAP) defines another method for programs running in one kind of operating system to communicate with programs in the same or another kind of operating systems by using HTTP and XML for information exchange. SOAP specifies how to encode an HTTP header and an XML file so that programs in one computer can call programs in another computer, and pass information. It also specifies how the called programs can return responses.

Description—Web Service Description Language (WSDL) creates a technology that enables services to publish their interfaces. It specifies the syntax, vocabulary, and the controls for publishing web services. It defines the input and output operations, ports that are involved, includes information about data, data types, location of the service, and also how the information exchange can be bounded to a specific transfer protocol. WSDL is using XML to specify an abstract description of network service operations. Combined with concrete network protocol and message format they define an endpoint for data and service communication.

Discovery—Universal Description, Discovery, and Integration (UDDI) plays a key role in discovery services. It describes and provides a general solution for clients to dynamically find web services. Using a common interface, requestors can dynamically connect to services provided by external partners. A UDDI discovery registry can be thought of as a clearing house for business applications. The registry has two kinds of clients: businesses that want to publish and provide services, and clients who want to obtain services of a certain kind and invoke them as integrated parts of their solutions.

Data delivered by the discovery layer can be divided into three main categories:

- White pages: general information of a given business such as the name, address, telephone number, and other contact information.
- Yellow pages: general classification data that categorizes either the business, or the delivered service. This is based on existing (non-electronic) standards. Data may include industry, service description, and product codes.
- Green pages: technical information about the Web services provided by a given business, pointer to specification description, and information about how to invoke the service.

Solutions

There are several different implementations of web services and architecture. The existing solutions can be categorized as message-, policy-, resource-, or service oriented models depending on what is in the focus of the provided service architecture.

The *Message Oriented Model* looks at the ways how services are offered to agents, what are the structural parts of the messages, how are they delivered by the senders to the receivers. It also looks at delivery policies and covers reliability issues.

The *Policy Oriented Model* focuses on actions and states that are allowed in the setup for software agents, individuals working with the system, or for organizations that are part of the integrated solution.

The *Resource Oriented Model* looks at resources as main elements of the architecture. It focuses on attributes like ownership, location, policies that are related to the resources. In this context the role of a resource (whether it was provided or requested) plays only a secondary role.

In the *Service Oriented Model* the service and related actions are in the middle, and the other elements are built around them. The role of the players (providers or requestors) defines the connections and relationships to other services. This model will connect systems together at both the information and service levels (actually builds on top of the message oriented model), and includes solutions that provide quality of service and security. (Linthicum 2004).

Examples

Software vendors offer web service solutions and frameworks that allow developers and users to create applications.

- OASIS is a non-profit consortium that is coordinating the global development and adoption of e-business standards. Through the member organizations that are working together in technical committees developing recommendations and standard it is promoting open, scalable, and language neutral solutions.
- Oracle offers J2EE web service solutions which use JAX-RPC for remote connection. With additional Java-based elements (JCA Java connectors, Java messaging, standard beans) businesses can extend their ERP systems, and create connections between market-leader solutions like SAP, PeopleSoft, and Siebel.
- HP developed the first commercial implementation of a proposed Business Transaction Protocol. Their Web Services Transactioning system supports both B2B and B2C relationships.
- Sun Microsystems is one of the major developers of web service components and development tools. Their Java APIs, J2EE platform, server-side solutions, and enterprise java beans are highly flexible, scalable, and offer wide range of possibilities and options for development and integration.
- Microsoft supports web service development through their .NET environment. The available programming

tools support several APIs, and rely on different server technologies.

- IBM integrated several web service technologies and offers developing tools with their WebSphere application server. The available solutions support development of J2EE applications, publishing and deploying web services in both an extranet and intranet environment.
- ColdFusion MX from Macromedia can act as a registry, can consume, and also produce (offer) web services. The building blocks are using ColdFusion components.
- BEA Systems, IBM, Microsoft, SAP, and Sun are working together on a joint proposal to the World Wide Web Consortium that will standardize web services addressing. With that solution developers can simplify messaging services, and it will be easier for them to identify and exchange data and services between multiple end points.
- Esri is one of the major developers of map web service products. Their latest WMS solution integrates business data delivery and analytical capabilities with geographical services.
- The fact that Microsoft came out with their MapPoint web service solution indicates that web-based map services might play an important business role in the close future.
- Open GIS Consortium is very active in developing map service specifications for the web. Their Context Document Specification, Web Feature Services, and Web Coverage Services proposals are under review and discussion, and will possibly result in OpenGIS standards.
- XMethod (www.xmethods.com), UserLand (www.xml-rpc.com), OGC (www.opengeospatial.org), OASIS (www.oasis-open.org), and Microsoft (msdn.microsoft.com/webservices) have lists of publicly available web services and solutions.

Conclusion

Web services offer standardized solutions for integrated and distributed environments. They emphasize interoperability, platform independence, and support implementations in different operating systems and programming languages. These technologies are being standardized by W3C and OASIS. Another organization, WS-I, is defining additional guidelines for Web services interoperability. Companies like Sun, Hewlett-Packard, ebPML are working on additional functions to extend web services with security layers, authentication options, choreography and coordination languages, and business languages. According to new research from The Yankee Group some 70 percent of new IT spending is earmarked for integration technologies at the edge of the enterprise. "With the ongoing development of Web services code for workflow, messaging, e-commerce and security standards, enterprises are ready to create service-oriented architectures for software vendors to build next-generation applications …" (The Yankee Group 2004)

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Forest Stand Canopy Structure Attribute Estimation from High Resolution Digital Airborne Imagery

Demetrios Gatziolis, Research Forester, USDA Forest Service, PNW Research Station, USDA-FS, Portland, OR

Abstract*—A study of forest stand canopy variable assessment using digital, airborne, multispectral imagery is presented. Variable estimation involves stem density, canopy closure, and mean crown diameter, and it is based on quantification of spatial autocorrelation among pixel digital numbers (DN) using variogram analysis and an alternative, non-parametric approach known as slope-break analysis. Variable estimation proceeds from identification of tree tops. Variable accuracy assessment is obtained via value comparison with a spatially precise set of 34 Forest Inventory and Analysis (FIA) design plots installed in five cover types common in the Midwest region. Results show that slope-break-based variable estimates are superior to those obtained using variograms. Estimated root mean square errors for the former average at the plot level were 6.5 percent for stem density, 3.5 percent for canopy closure, and 2.5 percent for mean crown diameter. These error rates are equivalent, if not superior to (lower than), those obtained via traditional forest stand cruising by experienced personnel. The approach benefits from parsimonious parameterization and is amenable to automation.*

Introduction

High spatial resolution digital imagery holds promise for extracting forest canopy structure information, including delineation of individual tree crowns (Brandtberg, 1997), canopy closure, stem density, species composition and crown classification (Gerylo and others 1998; Sheng and others 2001). However, to date, forest inventory and canopy structure information is still almost exclusively derived from aerial photographs (Wulder and others 2002) via manual interpretation, a process known to be time consuming, labor intensive, and error-prone (Biging and others 1991). This is likely due to the absence of examples of methodologies that operate on high resolution imagery and are capable of reliably assessing forest canopy structure variables in a variety of forest conditions. The handful of studies that have successfully used such imagery in forest inventory parameter estimation operated on a single stand, or a very limited number of, typically coniferous, stands. Spatially extended investigations have been hindered by logistic concerns related to the acquisition of field information (Gong and others 1999), imagery idiosyncrasies (variable brightness regimes, registration issues) (Mikkola and Pellikka 2002), and absence of process automation paradigms (McGraw and others 1998). Hence, little is known about whether high spatial resolution imagery can be used to reliably predict forest structure attributes for stands different from those used for methodology.

The USDA Forest Service Forest Inventory and Analysis (FIA) program is perhaps the only effort with the knowledge, experience, infrastructure, and demonstrated capability to realistically support investigations that require spatially explicit forest inventory information over a variety of cover types, ecological conditions, and ownership regimes at the national level. However, in its current configuration, the FIA program assesses only some of the key aspect of canopy structure: height, stem location relative crown position with dominance class for each tree. Two other variables, canopy closure at the plot level and individual tree crown size, usually expressed as horizontal crown width (or diameter), known to be important inputs to forest models (Sprinz and Burkhart, 1987; Deutschman and others 1997; Trichon, 2001) and critical in modeling forest fires (Keane and others 1999) remain unknown. Reliable estimation of these two variables, along with identification of individual trees, (both considered prerequisites for a complete description of forest stand canopy structure) from high resolution digital imagery analysis would complement the FIA-collected data, and could be widely applied to a variety of forest conditions.

Unlike coarse resolution imagery where each pixel comprises the composite reflectance of many trees, in high spatial resolution digital imagery of forested landscapes each tree crown is represented by multiple pixels.

Some of them correspond to the sunlit portion of tree crowns; others represent crown portions in shadow. View and illumination angle, tree geometry, foliage orientation and bidirectional reflectance operate synergistically to result in a variation of radiance, represented by pixel digital numbers (DN), at different locations within an individual crown (Leckie and others 1992). Spectral DN values also vary as a function of the tree crown depth and reach a maximum (highest reflectance) near the crown center, diminishing as distance from crown center increases) (Li and Strahler, 1992). Hence, individual trees may be discerned in high resolution imagery as localized regions of DN characterized by higher values in the center, or close to the center, of the region and progressively lower DN values towards the region's periphery. The identification and descriptive characterization of such regions in the imagery, and, therefore, the identification of individual tree crowns and their attributes (e.g., distance between crowns), can potentially be accomplished by quantifying the spatial autocorrelation present in the imagery, or, equivalently, the maximum distance at which pixels exhibit DN value correlation.

The objective of this study was to investigate whether forest stand canopy structure variable estimates (stem density, average crown diameter, canopy closure) could be obtained reliably via pixel DN spatial autocorrelation structure analysis. The investigation was performed on five cover types common to the Great Lakes region using a detailed set of field observations that conform to the current FIA field data collection protocol from multiple, non-adjacent stands.

Methods

The two study sites in Michigan's Grand Traverse and Wexford Counties, were about 10 km apart: Site I's 8,805 hectares centered at 48°38'N, 85°35'W and Site II's 12,626 hectares centered at 44°29'N, 85°32'W. Both sites are flat and contain a wide variety of forest cover types, including most of those found in Michigan's northern lower peninsula: 1. aspen [big tooth (*Populus grandidentata*) and quaking (*Populus tremuloides*) aspen], 2. northern hardwoods [mainly sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), American beech (*Fagus americana*), black cherry (*Prunus serotina*), basswood (*Tilia americana*) and white ash (*Fraxinus americana*)], 3. oak [white (*Quercus alba*) and red (*Quercus rubra*) oak], 4. natural pine [mainly white pine (*Pinus strobus*)], and 5. pine plantations [mainly red pine (*Pinus resinosa*)].

Imagery was acquired on August 11, 1999, using the Digital Airborne Imaging System (DAIS [Space Imaging, 1999]). The 16-bit, four-band images over the visible and near infrared (NIR) part of the electromagnetic spectrum was acquired by frame (digital array) cameras equipped with appropriate band-specific filters on a 2x2 arrangement. Nominal resolution ranged from 0.890 to 0.926m and flight height averaged 2000m above ground level.

A total of 34 plots, (16 at site I and 18 at site II), were established in five forest cover types that had a minimum of 60 percent canopy closure. Plots were situated on flat ground, and within the interior of homogeneous stands. Stand homogeneity was evaluated with field inspections. Field data was collected in the summer of 2000, using a protocol patterned on the National FIA plot design (fig. 1). To ensure an adequate sample of trees in each subplot, subplot radius was increased from the standard 7.32m to between 10 and 15m, depending on the mean tree stem diameter for the plot. Canopy structure variables, including the horizontal extent of individual tree crowns as observed from the ground, and stem locations were assessed. All spatial and tabular data on tree crowns and stem locations were organized as Geographic Information System layers transformed into the coordinate system of the plot's corresponding DAIS image.

The derivation of canopy structure variables followed a four step procedure (fig. 2). Initially, for each image frame containing a plot, spatially distributed estimates of spectral autocorrelations were computed for each pixel via variogram analysis (Curran and Atkinson, 1998) and a non-parametric approach known as slope-break analysis (Wulder and others 2000). The latter is described below. In the second step, often referred to as local maximum filtering (LMF), the distributed autocorrelation estimates obtained by using the variogram and slope break analyses, here after referred to as variogram range and slope break length respectively, were used to determine the size of a kernel (moving window) passed over the pixels representing a plot. At each instance of the moving window, the pixel with the highest DN was identified as a tree top. Subsequently, the number of identified tree tops was used as an estimate of stem density for the plot. In the third step, the variogram range and slope break length identified in step one for each pixel identified as a tree top in step two were used to delineate the tree crown around each of the tree top pixels. Because variogram analysis produces omnidirectional imagery autocorrelation estimates, the tree crowns delineated using variograms were circular. The directional autocorrelation estimates produced using the slope break approach, delineated crowns that, in general, approximated ellipsoids. In the final step, the overlay of all crowns produced estimates of plot canopy closure and mean crown size. The estimates of stem density, canopy closure and crown size were then compared to those obtained with field measurements.

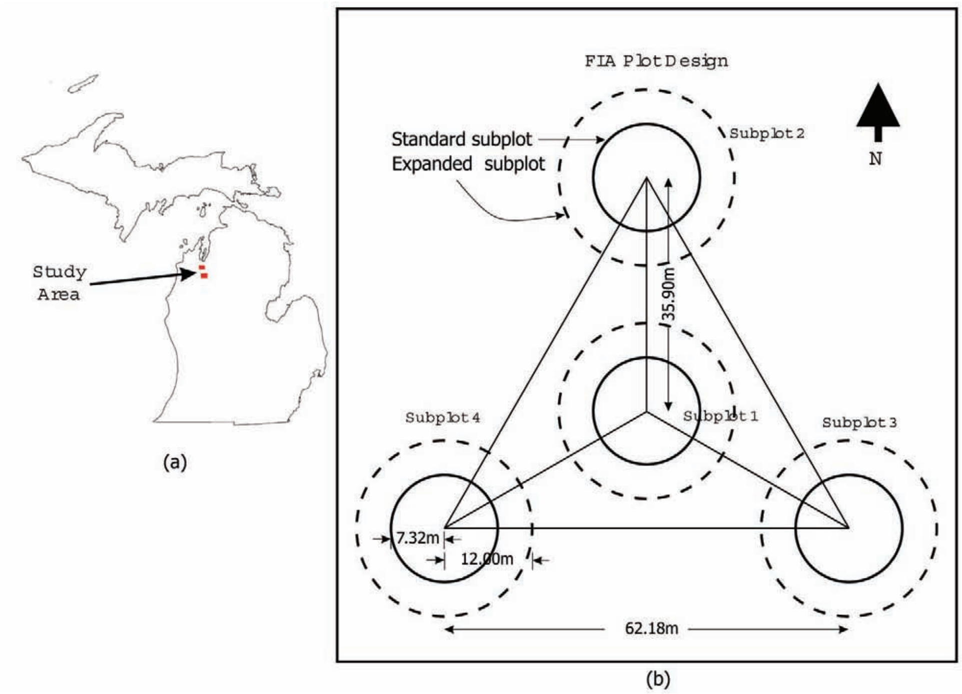


Figure 1. a. Location of the study area, and b. pictorial depiction of the Forest Inventory and Analysis plot design used for the collection of field observations of canopy structure.

Although all imagery bands were initially considered for the estimation of canopy structure parameters, preliminary investigations showed that the use of the blue band produced results consistently inferior to those obtained by using the remaining bands. This finding was attributed to the substantial scattering of sunlight at the blue wavelength, and, hence, diffuse canopy illumination, which results in reduction of imagery contrast and an overestimation of imagery spatial autocorrelation over forested landscapes (Gatziolis, 2003). Given the similarity of canopy structure parameter estimates obtained by using the green, red, and NIR bands on a selected subset of plots and in the interest of reducing the computational and processing load, only the NIR band was used further.

Slope break-based estimates of local image autocorrelation were obtained by relaxing the parametric structure of the variogram. For each pixel in the imagery, an omnidirectional set of transects was analyzed to assess the distance (in whole pixel increments) at which a minimum DN was encountered. Slope breaks could also be described as the first inflection point in the gradient of reflectance or brightness along a transect. Although a large number of transects can be considered, in practice, slope breaks are computed along the eight cardinal directions. The extent of spatial autocorrelation or, equivalently, the slope break length, was computed as the average distance from the center of the processed pixel to the inflection points along all transects. The standard slope breaks algorithm introduced by Wulder et al. (2000) was modified in this study and furnished with a set of heuristics, which were adaptive to the local brightness conditions

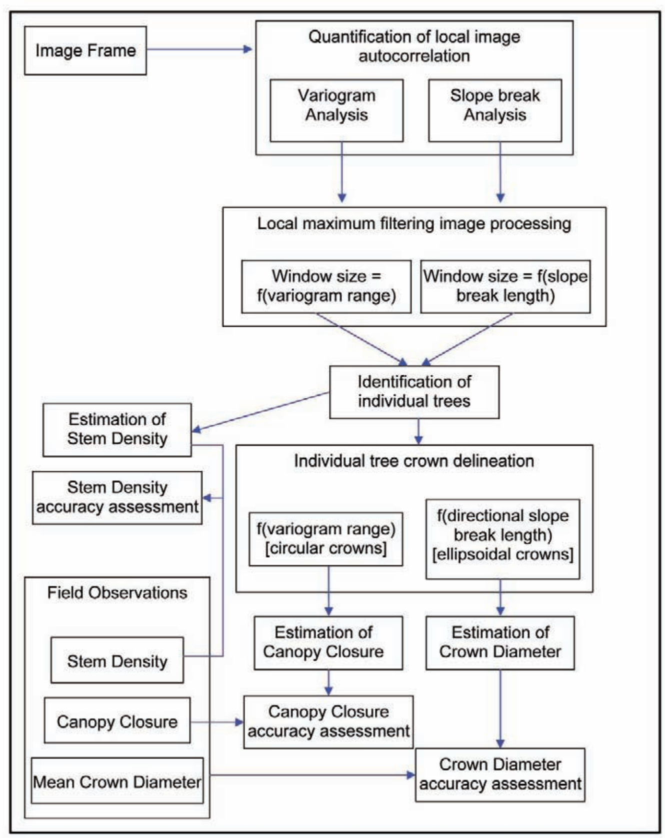


Figure 2. Flow chart of the procedures employed in the estimation of canopy structure parameters from high resolution digital imagery and assessment of their accuracy against field observations.

(DN along the processed transect) and were designed to prevent the extension of the transect inflection point beyond the edge of a crown towards shaded canopy openings. Local imagery autocorrelation estimates via slope breaks offered substantial improvement in computation efficiency when compared to those obtained via variogram analysis. Because, however, fewer pixels were engaged in the computation of slope breaks, the resulting autocorrelation estimates were likely more susceptible to bias introduced by random noise embedded in pixel DNs (Pouliot and others 2002).

Results and Discussion

Variogram ranges and slope break lengths computed for a large number of pixels representing tree crowns showed the former to vary substantially less than the latter. For all 136 subplots, the mean variogram range exceeded the mean slope break length. Often though, the variogram range computed for a particular pixel would be shorter than its slope break equivalent measure, particularly for pixels positioned at or near the center of the sunlit portion of a large crown. Slope break lengths computed for transects parallel to the solar plane and extending through canopy openings were sometimes shorter for pixels situated on sunward crown portions than those for crown portions facing away from the sun. Such instances occurred sporadically in northern hardwoods and oak subplots and rarely in the other cover types.

Strong linear relationships were found between predicted and observed plot stem densities for both variogram and slope break methods (table 1). Linear regression models developed by fitting image-processing-derived canopy structure variables onto variable estimates obtained from field observations exhibited regression slope coefficients always less than 1, with the exception of canopy closure estimated using variograms for which the regression slope coefficient was 1.078. This observation suggests LMF image processing, in general, would tend to overestimate stem density and mean crown size for low density stands and/or those composed of small diameter crowns, and underestimate them in high stem density or large crown forest stands. Unlike stem density and crown diameter, the estimation bias appeared to be analysis-method specific, with variograms underestimating the canopy closure of stands containing openings and slope breaks overestimating it. The estimation bias patterns are evident when prediction errors are plotted against the corresponding observed values (figs. 3 to 5). Irrespective of analysis method, densities at approximately the 350 stem/ha level, and mean crown diameter of 5m, yielded minimal or no estimation bias. Variogram-derived stem density exhibited, in regard to observed density, root mean square errors (RMSE) approximately two times larger than the slope break-derived stem densities (table 2). Variograms and slope breaks appeared to perform equally well in the assessment of crown closure with RMSE of only about 3.5 percent. Finally, slope breaks emerged as crown diameter predictors superior to variograms with an RMSE for the former only about 1/3 of that for the later (2.5 and 6.9 percent respectively, table 2).

Several oak and northern hardwood subplots in this study contained large, mature trees with crowns of complex morphology and often two or more reflectance maxima, and several canopy openings. These subplots sometimes had crowns of similar size and uniform distribution and sometimes had crowns of variable size and distribution. Further stand structure complexities were introduced by tree tops of shorter codominant trees positioned at the edge of larger adjacent crowns with which they formed composite crowns. Individual tree crowns in such instances were sometimes difficult to discern even with field inspection. In the presence of large-crown trees, and uniform crown and canopy opening size distribution,

Table 1. Parameter values of linear regression models constructed by fitting canopy structure estimates generated via local-maximum-filtering-based image processing to corresponding estimates derived from field observations in 34 FIA-design plots.

					Observed Values		
	LMF Prediction Method	R^2	Slope	Intercept	Range	Mean	St.Dev.
Stem Density (trees / ha)	Variograms	0.986	0.741*	91.81*	180 – 707	449.2	164.2
	Slope Breaks	0.996	0.864*	44.70*			
Canopy Closure (percent)	Variograms	0.941	1.098*	-7.70*	66.0 – 98.8	83.9	10.3
	Slope Breaks	0.930	0.817*	15.30*			
Mean Crown Diameter (m)	Variograms	0.942	0.700*	1.58*	4.00 – 7.54	5.1	1.0
	Slope Breaks	0.990	0.921*	0.42*			

* Significant at $\alpha = 0.01$

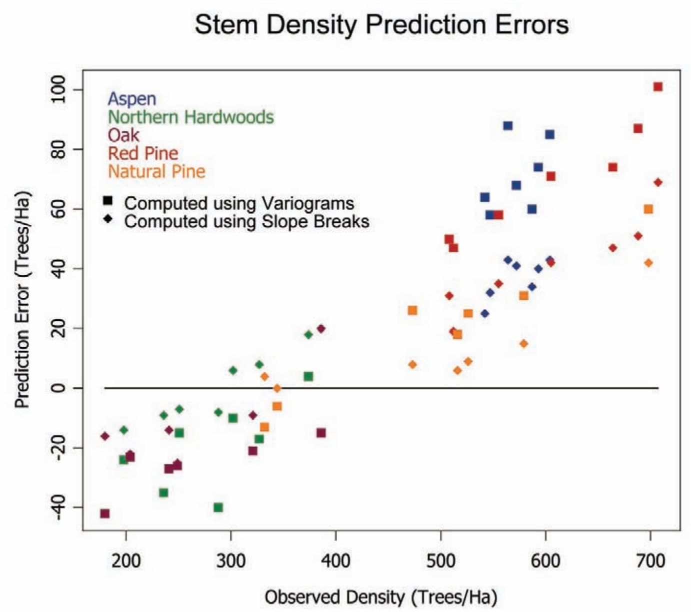
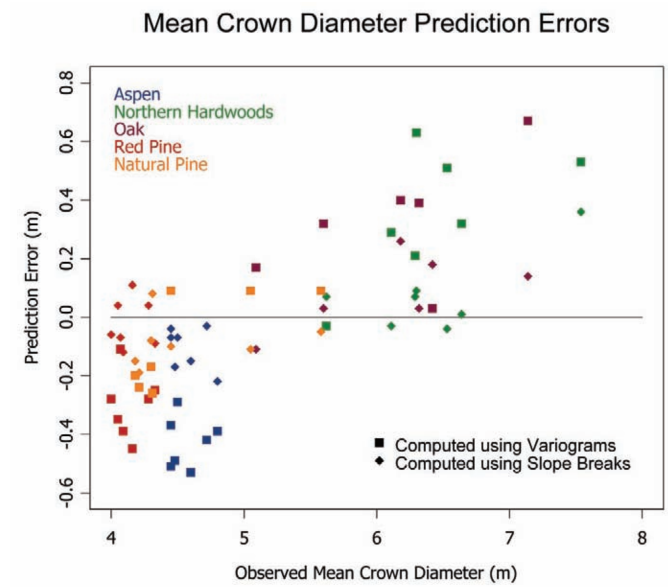


Figure 3. Plot stem density discrepancies between values obtained by using local-maximum-filtering-based image processing and corresponding field measurements.



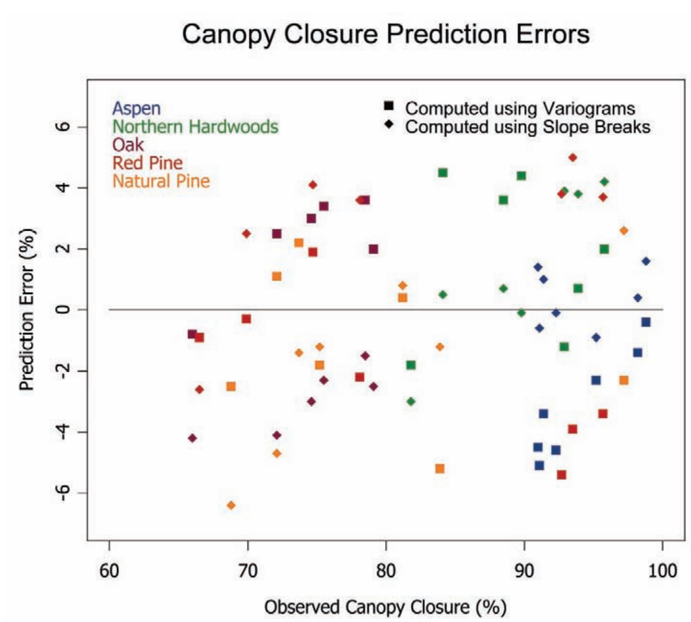


Figure 4. Plot canopy closure discrepancies between values obtained by using local-maximum-filtering-based image processing and corresponding field measurements.

the slope break-based and variogram-based methods performed equivalently in stem density prediction. By contrast, the presence of crown size variability or variable-sized canopy openings resulted in better accuracy for slope break-derived predictions of stem density, thereby corroborating that slope breaks are capable of adjusting well to local stand structure conditions. Low levels of variability in canopy openings and crown sizes precluded a reliable assessment of those canopy structure conditions on stem density predictions for the other three cover types.

Errors of commission in identifying trees due to multiple tree crown maxima and corresponding tree tops identified using variograms in the presence of large northern hardwoods and oak trees produced mean crown diameter underestimation proportional to crown size but appeared to only minimally affect the accuracy of canopy closure predictions. Because it requires only 1 out of 10 trees with average crown diameter of 10m to be mistakenly identified as two separate stems in a subplot for an 8 percent reduction in subplot mean crown diameter value to occur, crown diameter predictions in large tree crown stands were more susceptible to errors of tree commission than of omission.

Stem density was underestimated for most of the natural pine and all of the red pine plantation and aspen subplots largely because the presence of small crowns increased omission error rates. Errors of omission would often occur where most of the sun-facing crown of a codominant tree was shadowed by adjacent dominant trees, resulting in a lower brightness value for the top of that tree.

A special case of variogram range-based stem density overestimation could arise in stands in which tree arrangement follows systematic and anisotropic patterns such as in red pine plantations with past thinning operations restricted along plantation rows. In thinned red pine plantation stands, the reduced variability in canopy reflectance along planting rows often resulted in variogram ranges that exceed the planting space between rows by 50 percent or more, particularly for planting row

Table 2. Root Mean Square Error (RMSE) between canopy structure variable estimates predicted via local-maximum-filtering-based image processing and corresponding field measurements. Values in parentheses represent percent absolute error from observed values.

	LMF Prediction Method	RMSE
Stem Density (trees / ha)	Variograms	50.67 (11.3)
	Slope Breaks	29.06 (6.5)
Canopy Closure (percent)	Variograms	3.00 (3.6)
	Slope Breaks	2.93 (3.5)
Mean Crown Diameter (m)	Variograms	0.36 (6.9)
	Slope Breaks	0.13 (2.5)

orientation in the east-west direction. Variogram range overestimation was then translated into artificially large moving windows, and ultimately tree omission errors. Such canopy structure conditions would also promote overestimation of canopy closure and crown diameter, because the stand canopy portion actually occupied by omitted trees would be typically assigned during the crown delineation process to adjacent trees along the rows, thus inflating crown diameter, while rarely predicting canopy openings.

The imposition of heuristic rules on slope break computations was intended to avoid substantial overestimation of LMF window sizes, and canopy closure and mean crown diameter predictions. Without the heuristics, canopy openings between trees would occur only as sliver polygons between adjoined crowns because of crown representation fidelity issues due to the limited number of directions analyzed around each identified tree top. The implication of these limitations on canopy structure variable values would likely be negligible in high canopy closure stands but could be substantial in the presence of canopy openings.

The application of these methods for canopy structure prediction via high resolution imagery might not be advisable for stands with medium or low canopy closure or where stand conditions permit direct illumination of the forest floor or background vegetation. In such conditions, grass, exposed soil, or bushes could easily be misidentified as tree tops during LMF processing, and variogram ranges could represent the mean diameter of canopy openings rather than the size of crowns. The 60 percent minimum canopy closure threshold imposed as a prerequisite for plot installation in this study precluded any occurrences of sunlit background in the plots. Although openings did exist and were sometimes equivalent in size to the crowns of dominant trees, the height of adjacent trees placed them in shadow. Band-ratio-based imagery pre-processing could potentially reduce the effect of non-vegetated, sunlit stand background on predicted canopy variable values.

Conclusion

The two forms of DN autocorrelation quantification used in this study, one parametric based on variogram analysis and one non-parametric based on a set of simple heuristic rules, have revealed promising potential of high spatial resolution digital imagery as a source for extraction of reliable forest canopy structure information. The few known other investigations that have attempted stem density predictions, primarily in coniferous forests, found prediction error rates that have rendered them and the methodologies employed of little utility for inventory or management purposes. In this study, the field acquisition of a detailed and positionally precise set of observations on stand structure was distributed among five deciduous and coniferous cover types in northern Michigan. This has provided a better understanding of the relationships between canopy characteristics and reflectance regimes embedded in digital imagery. The study has also developed methods that are capable of producing reliable predictions not only for forest stand density but also for canopy closure and mean crown diameter.

Unlike traditional investigations that rely strictly on the spectral properties of pixels representing tree crown portions to describe the horizontal structure of forest canopies, all analysis methodologies employed in this study are local in scope. As such, they are independent of brightness variability between image frames and bidirectional reflectance effects, issues that are known to burden the application of traditional spectrally-based investigations (Gatziolis, 2003). Therefore, the methods presented here are perhaps well-suited to determining the canopy structure of plots that are sparsely distributed across the landscape, such as those in the FIA plot allocation scheme. With high resolution imagery lately available even from satellite platforms, and in light of the projected reduction in acquisition cost, it is likely that certain types of forest inventory information at the individual tree level extracted from such imagery would become an integral part of forest management and planning.

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A New FIA-Type Strategic Inventory (NFI)

Richard A. Grotefendt, College of Forest Resources, University of Washington, Seattle, WA
Hans T. Schreuder, U.S.D.A. Retired. Formerly Mathematical Statistician USDA Rocky Mountain Research Station, Fort Collins, CO

Abstract—*New remote sensing technologies are now available to lower the cost of doing strategic surveys. A new sampling approach for the Forest Inventory and Analysis program (FIA) of the U.S.D.A. Forest Service is discussed involving a bi-sampling unit (BSU) that is composed of a field sample unit (FSU) centered within a large scale (1:1,000 to 1:3,000) photo sample unit (PSU) of the same size and shape. Within the PSU, a circular plot size is used for timber inventory and a strip plot for riparian buffer assessment and down woody material. On PSUs in previous studies in Alaska and Washington we counted or measured individual trees, tree height, crown area by digitizing the perimeter, plot crown closure, tree crown closure, tree branch density, plot area, and tree type (species and decay class). FSUs provide ground truth for PSUs as well as permanent and forest health plot information. Data for core FIA variables such as species, diameter, crown class, rotten/missing cull, and decay class may also be furnished by FSUs. National gross board foot volume per hectare estimates will be made from PSUs. Then permanent FSUs will provide growth, mortality, and defect factor information that are combined with the PSU estimates. Integration of PSUs with simultaneously collected Lidar data is used to improve tree height measurement accuracy in dense forest stands by providing local digital elevation models. Annual national estimates of stocking, mortality, and growth by tree species or forest type are obtained on a random sample chosen from a grid. Strata will be superimposed over this grid. The FSUs collected in the past will be incorporated in the new design which has the potential to result in a 50 percent reduction in cost relative to current FIA.*

Introduction

Why Forest Inventory is Needed

Throughout the development of the United States, forests that cover about one-third of the land base have been seen as a provider of goods and services (i.e., scenic, subsistence, industrial, and spiritual or cultural) (Haynes, 2003). This forest land supplies wood products, range land, recreation, and wildlife habitat. About 45 percent is public and 55 percent is privately owned (Haynes, 2003), (Wright and others, 2002), (USDA, 2002b). Because of the substantial interest in the economic, ecological, and sustainable basis of these forest resources, government agencies, industry, and others need a current and accurate inventory of their extent and condition (AF&PA, 1998). This inventory is used for substantive discussion and planning of forest land issues, such as "sustainability, national forest policy, carbon sequestration, changes in growth and productivity, changes in land use and demographics, ecosystem health, and economic opportunities in the forest sector" (Van Deusen and others, 1999). The Forest Inventory and Analysis program (FIA) of the U.S.D.A. Forest Service provides the only inventories broad enough in scope to serve these varying needs (Van Deusen, 1998).

The FIA Inventory Background, Current Approach, and Drawbacks

The statistical technique of double sampling became the foundation of the FIA forest inventory design in the 1950s. This technique uses remote sensing and ground sampling in conjunction with permanent sample plots for estimating forest area and volumes, growth, removals, and mortality (Birdsey and Schreuder, 1992). Currently there are 3 phases in the double sampling scheme: Phase 1, a relatively inexpensive land cover classification by Landsat Thematic Mapper or aerial photo plots; Phase 2, collection of detailed forest composition and condition by permanent and non-permanent field plots; and Phase 3, collection of expensive field plots from a subsample of Phase 2 plots that monitor indicators of forest health (Czaplewski, 1999); (USDA, 2003). These plots are located on an interpenetrating design of hexagonal cells with each representing 6,000 acres and sample locations that are distributed systematically about every 3 miles (5 km) (McWilliams and others, 2002). Limitations of the Phase 2 and 3 field plots are that private landowners may deny access and consequently information (Czaplewski, 1998a) or plots may be inaccessible.

The program mission of the FIA is to meet "the nation's needs for high quality information on the extent and condition of forests and forest resources in the U.S." (AF&PA, 1998). The operation of FIA conflicts with this national mission by operating in five regional offices (Cost, 1996) and as of 1998 resulted in "limited consistency for drawing conclusions at the national level" (Gillespie, 1998). As of 2002 one-fourth of the country was delayed or excluded from the implementation strategy of the Forest Service Strategic Plan (FSSP) (Willits and others, 2002), (USDA, 1999). The continuation of this condition was favored by a majority of those present at a 2002 FIA joint band meeting in Arizona (Willits and others, 2002), evidently favoring regional over national interests. This has contributed to the inability to completely sample all U.S. forest land. In addition FIA's role in data collection has significantly expanded to include forest health assessment and a vast array of non-timber resources, but all states are not included due to a 2002 and 2003 fiscal year funding shortfall (Willits and others, 2002).

State, federal, native, public, private, and international FIA data users have been demanding improved and more timely information on five politically sensitive issues: (1) timber supply, demand, and availability; (2) maintenance of biodiversity; (3) forest sustainability; (4) forest health; and (5) global climate change (AF&PA, 2001). They formed a panel of experts that felt that the usefulness of FIA was threatened by increasing inventory cycle length, lack of an accountable, responsive organization, and lack of funding. These demands for change were reflected in the Agriculture Research, Extension, and Education Reform Act of 1998 (16 USC 1642 (3)) or the Farm Bill of 1998 (USDA, 2001), (Smith, 2002) which specified a national, annual inventory and resulted in the merger of FIA with the USFS and EPA's Forest Health Monitoring program in 1999.

The new geo-positioning systems (i.e., global positioning systems (GPS), inertial navigation systems (INS), and inertial measurement units (IMU)) that have made light detection and ranging (Lidar) (Carson and others, 2004) and large scale photography (LSP) (Schwarz and others, 1993) practical have largely been overlooked by FIA. They have the potential to offer assistance in meeting the demands of FIA stakeholders and enabling all U.S. forest land to be sampled. LSP provides detailed, 3D-views of forests that can be interpreted and measured with accuracies comparable to field visits (Titus and Morgan, 1985), (Megown and others, 2003). Past research has indicated that LSP and Lidar may replace and/or supplement field data collection of timber inventory and ecosystem data (Grotefendt and others, 1996), (Andersen and others, 2001).

A New FIA-Type Strategic Inventory (NFI)

We think change in an inventory setup in the USFS is desirable. The new LSP and Lidar technologies are available and not being used. Although there is significant pride in what has been done and in what they are doing within the FIA organization an entirely new strategic inventory may enable the national mandate to be realized within budget.

Our proposed New FIA-Type Strategic Inventory (NFI) would incorporate large scale photography (LSP) as the primary sample unit with field subsampling for some variables, validation, and trend data. There are many remote sensing sources, but only LSP provides 3D vision and measurement comparable to field plot visits at less cost. Many of the FIA problems, such as excessive costs, landowner-imposed or dangerous access restrictions, inconsistent classification of conditions especially on or near boundaries, insufficient ecosystem sampling, and lack of timeliness, will be eliminated or reduced through LSP use. A grid that is one hundred times the current FIA grid will be superimposed over all national lands and territories. Available funds will determine the sample size collected from this grid. The current core and extended core FIA variables will be reduced to only those absolutely requisite for reporting. Generalized regression estimation will be used to analyze photo-field relationships. Annually, sampling costs have the potential to be reduced by 37 to 78 percent over the proposed U.S.D.A. Forest Service Strategic Plan (FSSP) (USDA, 1999). Because of the dramatically improved flexibility, suddenly emerging issues can be addressed much more rapidly and cheaply so that an increase in demand for data and an expanded clientele can be expected and should be planned for.

Methods

The components necessary to sample the entire U.S. forest land area with available funds are presented in the methods section. The sampling locations, units, and size are detailed as well as examples of the variables to collect. Point and change estimation and analysis are addressed.

Sample Locations

A fine grid with distances between plots of 0.5 km that overlays the entire U.S. land base and the current FIA sample locations will increase the potential sample location number by one hundredfold. This allows past FIA permanent plots to be re-sampled for change estimation, concentrated sampling for sudden changes such as storm or insect damage, change in sample plot design for key variables, and an increase in sample size if needed.

Sample Units

A primary, large scale photo sample unit (PSU) and a secondary field sample unit (FSU) will be used to collect timber and non-timber information. Both sample units have the same shape and the FSU is centered in the PSU. A circular plot is used for timber inventory and a strip plot for riparian buffer assessment and down woody material. Different ecological type surveys may have different plot shapes, but the photo and field plot shape will usually be the same to ensure that there is a one to one correspondence between visible photo and field measured variables.

Photo sample unit (PSU)—Navigation to PSU grid points will be by a camera equipped helicopter. Large scale photography (1:1,000 to 1:3,000) provides a large enough image size for measurement and interpretation of key field collected variables such as tree height and species. Metric film cameras will be used to eliminate the error that is introduced with non-metric cameras that can reach 5 percent (Reutebuch and Ahmed, 1997). Camera lens position and orientation provided by global positioning system/inertial navigation system (GPS/INS) (Schwarz and others, 1993) or a fixed-base camera system (Bradatsch, 1980), (Veress, 1980) will provide scale to enable photo measurement. Analytical stereoplotters or softcopy systems will be used for PSU interpretation and measurement. Improvement in ergonomic viewing and interpretation will be made. Regression estimation using relationships between PSU and FSU variables will permit efficient reporting of key parameters such as volume and forest type. Primary sampling by PSU will eliminate the majority of owner access restrictions or inaccessibility, avoid misclassification of condition classes, allow sampling of remote wilderness areas, and enable complete national coverage. Tree heights may be impossible to measure from PSU when stand densities preclude formation of a digital elevation model (DEM) due to an insufficient number of visible ground points. In this case extra field sample units (FSU) will be collected or light detection and ranging (Lidar) will be used to form a DEM. Circular or strip plot area will range from 0.2 to 30.0 ha for the given overlaps, scales, and camera formats (for example, 70 mm, 5x5 in, and 9x9 in). The use of smaller format metric cameras (in other words, 70mm or 5x5 in), that have significant cost savings over 9x9 in format cameras, will be encouraged.

Field sample unit (FSU)—The field sample unit (FSU) is a subsample that provides: information for developing relationships with PSU measured variables; validation of photo measurements or interpretation; information obtainable only by field visits; and change information through repeat measurements. Change information provides growth, mortality, removal, and defect. PSU orthophoto prints overlaid with photo interpreted stem maps, GPS receivers, and smaller scale resource photography will facilitate navigation to the FSU and verification of the plot center location. The collection of FSU data may still be limited but less frequently due to landowner restrictions. Portable stereo cameras will collect field plot stereo views (in other words, a terrestrial photo sample unit) from 3 angles to enable future data capture of new variables without a field visit.

Selection of Sample Size

The total survey cost depends on the overhead, sample unit cost, and sample size. Optimum sample size is determined by either fixing the total cost or the standard error (Schreuder and others, 2004). Even though there has been a dramatic recent increase in FIA funding above the FY99 funding level of $37 million (pers. comm. [Rhoads, 2003], [Schreuder, 2003]) the $82 million required by the U.S.D.A. Forest Service Strategic Plan still has not been reached (USDA, 1999). "It is unlikely there will be an increase in the Forest Service budget for the next 3 to 5 years" (remark [Rey, 2003])." Therefore, the number of samples taken in our new FIA-Type Strategic Inventory (NFI) will be limited to the available funding. The current United States land base that is delineated as forested will be used until a validated stratification method is employed.

The method of PSU and FSU sample location selection is as follows. Two coarse grids, each with different variable cell sizes, will be superimposed over the fine grid each year to ensure systematic and complete coverage (figure 1). Two cell sizes will be used that provide the number of PSU and FSU samples funded. The FSU grid will always be more coarse than the PSU grid.

NFINE = population size of fine grid points = 36,000,000

nPSU = current annual number of PSU funded

nFSU = current annual number of FSU funded (assumed 10 percent of nPSU)

The proportion of PSU that are field sampled could vary due to experience (for example, even-aged conifer stands may require fewer samples than old-growth stands).

NPP = population of existing permanent FIA field plots (EP) = 121,993 (USDA, 1999)

nPP = current annual number of EP plots to re-sample

Within each PSU coarse grid cell simple random sampling without replacement (SRS) will be used to form a list of the NFINE that fall within it. The first unsampled fine grid point in each list will become a PSU location and part of the nPSU. SRS without replacement will be used for each FSU coarse grid cell to form a list of the nPSU that fall within it. The first unsampled PSU location of each list becomes the FSU. If additional funding is provided by a stakeholder or a special event occurs requiring additional sampling the next unsampled points from the random list are chosen.

The NFI has no previous FSU for change estimation. Therefore a transition sample selection method will be followed for the first five years. Under this transition plan, the nFSU will be sorted into a random list. The first 50 percent of the FSU sample that have at least one EP plot in its cell will be used to select the sample nPP for re-measurement. A geographic information system (GIS) program will be used to locate the EP plot that is closest to each FSU. The FSU will be shifted to the EP position, a transition method of field measurement will be developed and used, and the PSU that was associated with that FSU will also be shifted to the EP plot location.

After the first five years, re-measured FSU plots will include NFI FSU plots as well as NPP. In the subsequent annual surveys half of the FSU are re-measured plots and half are newly located. This provides a constantly increasing field sample size for improvement in FSU prediction from PSU. Annual surveys are frequent and standard error of estimates will indicate survey reliability. If it is too low for concerned stakeholders this will provide justification for increasing the budget. Sampling PSU without replacement will allow more accurate area verification and adjustments over time; increase the probability of encountering small area ecotypes; and sample more riparian habitat. After other remote sensing methods

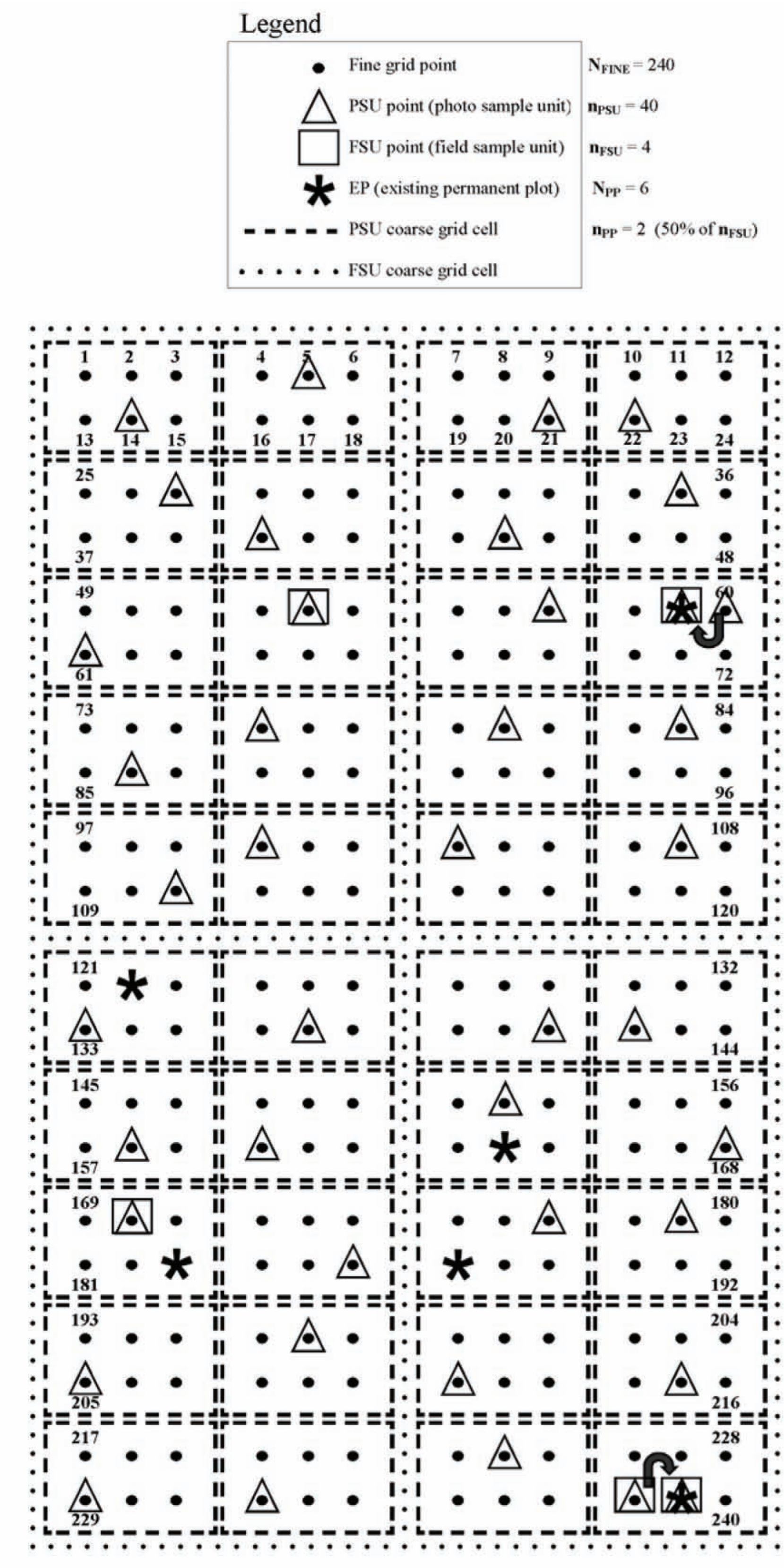

Figure 1. Example NFI sample size selection process.

Table 1. Example U.S.D.A. Forest Service Strategic Plan (FSSP) core and extend core variables [USDA, 1999 #295], [USDA, 2002 #402] forming the basis for the new FIA-Type Strategic Inventory (NFI) variables with their priority and sampling combinations.

Variable Name	Core (C) or Extended Core (EC)	Sampling Unit Combination	Priority Code	Reliability Code
Plot Number	C	PSU	1	1
Forest Type	C	PSU	1	2
Owner Group	C	PSU	1	OFC
Stand Structure	C	PSU&FSUi	1	2
Slope	C	PSU	2	CG
Ground Cover	C	FSUi	2	1
Crown Cover	C	PSU	1	1
Soil Erosion	C	FSUi	2	1
Species	C	PSU	1	2
Diameter at Breast Height	C	PSU&FSUi	1	2
Percent Rotten/Missing Cull	C	FSUi	1	2
Uncompacted Crown Ratio	C	FSUi	2	2
Site Tree Diameter	C	FSUi	1	1
Site Tree Total Height	C	FSUi	1	1
Lichen Species	EC	FSUi	1	2
Lichen Relative Abundance	EC	FSUi	1	2
Crown Diameter - Wide	EC	PSU	1	1
Foliage Transparency	EC	PSU&FSUi	2	2

NFI Priority Codes: 1 = required for annual reporting, 2 = collected if funding provided;
Method Codes: OFC = office work, CG = compute from GIS; and
Reliability Codes: 1 = certainty, 2 = very good likelihood, 3 = maybe as shown from research.
Note: FSUi is the ith type of field plot used.

have been validated, strata may be superimposed over this grid.

Variables

The PSU and FSU variables collected must relate to the required annual reporting items such as land area, number of trees, and growth and the required classifications, such as forest type and diameter class (USDA, 1999). These variables will be chosen from the current core and extended core variables in the U.S.D.A. Forest Service Strategic Plan (FSSP) (USDA, 1999), (USDA, 2002a) and will be collected by three sampling unit combinations: PSU only; PSU and FSU combined with generalized regression estimators (Schreuder and others, 2004); and FSU only. The final list of variables will be broken down by priority of collection and which sampling unit combination will be employed to collect them. Companies or environmental groups interested in priority 2 variables could supply funding to collect them. Examples of priority 1 variables are tree height from PSU only, photo predicted volume from PSU and FSU combined, and tree age from FSU only. Table 1 provides additional examples.

Point and Change Estimation

The variables will be used for point and change estimation, such as current volume and volume removed, respectively. Point estimation is made from the annual PSU and FSU. Change estimation is made from the subsample of FSU points that are randomly selected for re-sampling. Permanent plot information from FSU that were established prior to this new strategic design will be incorporated in these estimates so that their valuable change information is used.

Data Analysis

Quality control, data transformation, American Standard Code for Information Interchange (ASCII) file production and geographic information system (GIS) layers formation are data processing tasks that will be performed on PSU and FSU data. All the raw data will be stored in a national, common format and maintained on FTP sites for accessibility. User friendly programs written in ‘R’ will be provided that combine raw data into summary datasets to facilitate public user analyses (R, 2004). FIA staff will develop equations from PSU and FSU variables that estimate tree conditions, such as gross volume (Aldred and Sayn-Wittgenstein, 1972), (Grotefendt and Pickford, 1998), (Timberline, 1993). PSU measurements will be used to compute direct estimates (for example, crown closure equals sum of plot tree crown areas divided by fixed plot area). Change or trends will be computed from FSU plot re-measurement differences. Adjustment factors (AF) will be developed from FSU only variables for application to PSU estimates for items that are hidden such as understory shrub composition and fine woody debris. Spatial data will be derived from GIS algorithms (for example, distance and azimuth of trees from the plot center or to the nearest stream bank). Standard analyses and reports that are mandated, such as change detection, by the Farm Bill of 1998 will be major products of NFI (USDA, 2001). Extrapolation of the PSU and FSU data and plot characteristics (for example, volume) to national estimates will be based on PSU classification and the number of acres each sample represents until a validated method of stratification is proven. The use of PSU to validate the stratification tools of small scale aerial photos and satellite imagery will be studied.

Costs

The cost savings that PSU collection provides is one of NFI's main advantages. An indication of this is illustrated by using known costs for PSU collection (Grotefendt and Light, 2004), (Grotefendt and Fairbanks, 1996), (Grotefendt and Martin, 2003) and Forest Service FSU cost estimates by Czaplewski (Czaplewski, 1998b). The cost estimate to collect, measure, interpret, and produce raw data files nationally is $349 per PSU. The cost estimates for the collection of one FIA plot ranged from $600 to $1,240 per plot. This was dependent on whether it was a one day plot (One-Day), a wilderness plot (WP), or a forest health monitoring plot (FHM). The Forest Service Strategic Plan (FSSP) (Gillespie, 1998) specifies a total of 15,124 field plots in the southern Pacific Northwest Region (i.e., Oregon, Washington, California, and Hawaii). If 7 percent, 10 percent, and 83 percent of these were FHM, WP, and One-Day plots, respectively with 10 percent of the total being subsampled as FSU, the NFI would save 37 percent over the USDA Forest Service strategic plan (FSSP) when overhead cost differences are not included in the comparison.

The NFI national annual total plot cost is $10,132,334 using our PSU and Czaplewski's FSU cost estimates with the same ratio of field plot types given in the southern Pacific Northwest Region example above. The FSSP national annual total plot cost is $45,252,000 (see tables 3 and 4 in (USDA, 1999)). Using these two annual plot cost estimates without overhead NFI would save 78 percent. The average savings of the NFI may be over 50 percent based on these southern Pacific Northwest Region and national annual estimates.

A NFI overhead item not borne by the FSSP would be the additional cost of one to two million dollars for a research proposal to fine-tune its sampling approach. This research would determine: the number of FSU needed to calibrate PSU in different forest types; the amount of PSU interpretation and measurement training required; methods to reduce photo interpretation fatigue; and what kind of plots are best for calibration.

Results

These NFI methods have been partially implemented in Alaska and Washington for forest inventory and riparian buffer monitoring. Remote areas of rough topography were accessed and photographed even under adverse weather conditions. For forest inventory, fixed area PSU were collected from a random list chosen from a superimposed systematic grid overlaid upon 80,000 acres. PSUs of riparian buffers along streams were collected from the western half of Washington state and southeast Alaska extending from Juneau to Ketchikan. Photo measurements were comparable to field measurements (Grotefendt and others, 1996), (Grotefendt and Pickford, 1998). The correlation of photo measurements of individual tree dimensions to tree volume in old growth forest predicted average plot volume to within 10.9 percent of actual volume as determined from ground plots (Grotefendt and others, 1996). The absolute average tree height difference between photo and field clinometer measurements was 6.1 ft (s.d. = 4.7 ft, n=214). The absolute average difference between photo predicted and field measured diameter at breast height (DBH) was 2.3 in (s.d. = 2.2, n=109) (Grotefendt and Pickford, 1998). These and other applications provided cost information and an indication of the potential of the NFI (Grotefendt and Light, 2004).

Discussion

The proposed new FIA-Type Strategic Inventory (NFI) is designed to reduce costs, increase amount and timeliness of information, and will promote an increased user base. New ecological sampling needs, such as riparian, are met by NFI as well as timber inventory requirements. Flexibility in plot size and shape ensure adaptability to specific variables and plot locations are known. Flexibility in intensity of sample size from the fine grid improves detection of small area ecotypes. Timely annual results are achievable with reduced field effort.

NFI is untested in a national inventory and will require a major change in current techniques. Nonetheless, it has been applied across large areas which indicate its potential. Exploratory research will be required to better understand relationships between PSU variables and desired FSU variables across a broader geographic extent.

There also are conditions, such as dense forest stands, where currently a PSU may be unable to collect the needed information and a FSU will still be required.

The potential 50 percent field sampling cost savings that NFI may provide over the USDA Forest Service Strategic Plan (FSSP) costs make its proven methodology an attractive alternative and can be readily adapted to changes in funding. It is less dependent on owner goodwill, weather conditions, budgeting, and it has been applied in wilderness and remote Alaska sites. If catastrophic storms or suspected environmental concerns arise, a sample can be quickly collected and analyzed for the problem area. Interpretation and measurement of PSU can employ FSU field staff in the winter when field work is inefficient. This can increase employee retention and continuity of skilled data collectors.

Larger quantities of data, such as tree heights, can be collected more cost effectively. Information from PSU are more directly comparable to that from other remote sensing techniques, such as Lidar, small scale aerial photography, and satellite visible-infrared remote sensing, and can be used as validation for these techniques. This will improve reliability of area estimates. The PSU may be re-evaluated without field work if new questions arise, which is not possible with FSSP field plots.

Further research in the use of LSP with other techniques could provide potential enhancements such as development of Lidar or interferometric synthetic aperture radar (IFSAR) relationships; automation of individual tree assessment using LSP by Gong (Gong and others, 2002); and incorporation of small scale photography to automate facets of individual tree and crown assessments (ITC) (Gougeon and Leckie, 2003).

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The Use of Open Source Software in the Global Land Ice Measurements From Space (GLIMS) Project, and the Relevance to Institutional Cooperation

Christopher W. Helm is a Research Assistant at the University of Colorado, Boulder, The National Snow and Ice Data Center, Boulder, CO

Abstract—*GLIMS is a NASA funded project that utilizes Open-Source Software to achieve its goal of creating a globally complete inventory of glaciers. The participation of many international institutions and the development of on-line mapping applications to provide access to glacial data have both been enhanced by Open-Source GIS capabilities and play a crucial role in the success of the project.*

Thousands of the world's glaciers have seen a steady reduction in size over the past several decades, a trend that is representative of the recent warming temperatures of the world's climate (fig. 1). Because of this strong correlation between the health of glacial systems and corresponding weather patterns, glaciers can provide a great amount of understanding towards the world's changing environments (Kargel and others 2002). Though we cannot change these current patterns, we can strive for a better understanding of the causes behind the increases in glacial melting, hoping that we may become more thoroughly prepared for the changes we face in the future. Because of these reasons it is of great importance that there be created a global inventory of glacial ice that contains the current extent and present location of all the world's numerous glacial resources. The creation of such a database would help us to clearly understand current glacial behaviors, and provide a stronger foundation for the future monitoring and studying of glacial activities.

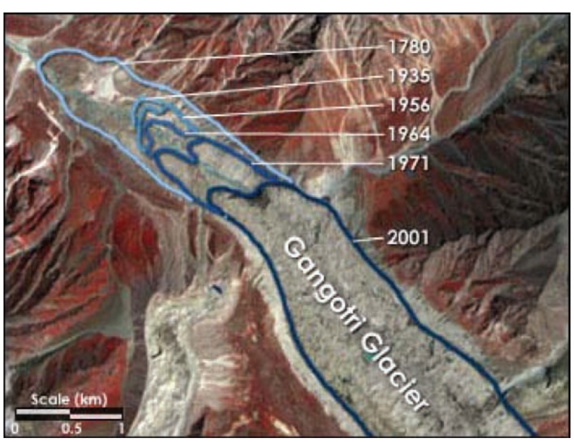

Figure 1. ASTER image showing the receding terminus of the Gangotri Glacier in central Asia (Image by Jesse Allen, Earth Observatory).

The Global Land Ice Measurements from Space (GLIMS) project was founded by a group of researchers in the United States, most namely are Hugh H. Keiffer, who first conceived the project, the Principal Investigator, and Coordinator, Jeffrey S. Kargel of the USGS Astrogeology Research Program in Flagstaff, Arizona, and Bruce H. Raup of the National Snow and Ice Data Center in Boulder, Colorado. Bruce is the lead technical coordinator of the data archiving processes needed to build the foundation of the GLIMS database and serve the data to the public. The NASA funded project's primary goal is to provide the world with a complete inventory of glaciers, making the data available to the public through the collaboration of a host of international institutions and new developments in the use of Open-Source Software (www.glims.org). Open-Source GIS tools are a free, cross-platform, and efficient method of ensuring that GLIMS completes the objective of obtaining the first-ever global glacier database. The utilization of this technology is a fundamental aspect in the success of a project that has grown to encompass the participation and coordination of sixty-seven different institutions from twenty-three countries.

Each institution that is participating in the project is referred to as a GLIMS Regional Center (RC) and is responsible for the creation and analysis of glacial data for its associated region, a region that contain amounts of glacial ice and of which the RC has particular knowledge. The GLIMS Coordination Center at the USGS in Flagstaff has developed and distributed to each RC an application called GLIMSView, a specifically designed, free, and cross-platform digitizing application. GLIMSView was developed specifically for GLIMS, and for the purpose

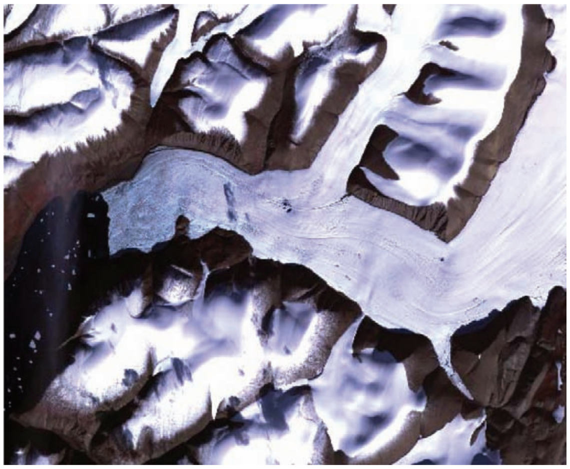

Figure 2. Example of an ASTER Image showing clearly defined glacial extents (Image courtesy of NSIDC).

of viewing Advanced Space-borne Thermal Emission and Reflection radiometer (ASTER) images (fig. 2) as well as other types of satellite imagery. Each ASTER image covers a sixty square kilometer region at a fifteen meter resolution. The ASTER Science Team, a division within GLIMS, has received over two-thousand ASTER images covering the world's approximate 170,000 glaciers (Raup, B. H. and others 2000). It is expected that GLIMS will receive updated ASTER images on a yearly basis to be distributed for analysis by the RCs. GLIMSView allows the RCs to easily view ASTER images, from which the RCs digitize glacier outlines, attach GLIMS specific attributes, and prepare data to be exported and ingested to the GLIMS database. Though it is not required of the RCs to use GLIMSView, the software ensures that the creation of data is based on the same set of standards. However, an RC can choose to use which ever type of software it desires for the production of its data as long as the data is submitted in the proper GLIMS format. More information about ASTER images, GLIMSVIEW, GLIMS data attribution standards, and the GLIMS data submission format are available at http://www.glims.org.

The glacial data created by each RC is submitted to NSIDC where it's ingested into the existing database of information. The database, also a form Open-Source Software (PostgreSQL and its spatial extension PostGIS) has been structured to organize incoming data into several tables comprising of two major types of information, dynamic and static. This makes it possible for data pertaining to changes in the shape and extent of the same glacier to be stored chronologically. Meaning that as a glacier changes, the database becomes updated with a new analyses of dynamic information, using the static attributes to link different sets of data with information that always remain the same, such as a glacier's name and a glacier's ID. The monitoring of changes in glacial extents on a global basis enhances the ability to study glacial activity in different regions on an annual basis. It provides a stable ground for studying the relationships between glaciers that are changing at different rates and helps to identify the reasons why these change are occurring. The data stored in the database contains a variety of glaciological data and contains attributes that are spatial in nature, in other words each record in the database can be visually represented by the outline of its glacier's extent in the real world. A unique aspect of this database is that the Open-Source database package PostGIS allows spatial data types to be stored in the form of geometries (points, lines, and polygons), and also allows a number geo-processing functions to be applied to this type of data. These capabilities allow the GLIMS data to be integrated into existing GIS projects and analysis in a number of different ways. The functionality of GLIMS data being GIS compatible, is being accomplished through the use of the University of Minnesota's MapServer, an Open-Source, on-line mapping utility.

MapServer is an Open-Source GIS tool that is distributed free of charge by the University of Minnesota. It is an interoperable and innovative GIS package, providing the capability for large amounts and types of spatial data to be interactively mapped over the Internet. Using MapServer, GLIMS will be able to export its data to the public, making the data easily viewed and retrieved by anyone who wishes to use it. MapServer operates based on a set of Open-Specifications designed by the Open GIS Consortium that detail the requirements for the creation of Web Feature Services (WFS). In other words, a WFS is a new type of interface that utilizes the Internet to serve GIS compatible features to the public. NSIDC, who is in charge of maintaining the database, is also designing the interface for the WFS to serve out the glacial data created from GLIMS. The construction of the WFS is currently under development and it will continue to grow as more data is received and the GLIMS database becomes more complete.

A total of three Open-Source GIS utilities are being used to fulfill GLIMS' goals of a geographically complete glacier inventory. Currently the project is in the stage of receiving data from the different RCs and will continue to move toward a complete database in the coming months. The use of Open-Source Software is what makes the cooperation and participation of the GLIMS RCs possible. Without such software and capabilities the goals of GLIMS would not be as easily accomplished. It is the hope of GLIMS that glacial data will continue to be received and updated for many years into the future, creating a greater wealth of information and increasing our knowledge about the ways in which glaciers interact with the world's climate and the effects they have on local environments. For a more in depth discussion of threats of glacier melting and the history of the GLIMS project please visit the GLIMS website (www.glims.org).

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Forest Canopy Heights in Amazon River Basin Forests as Estimated with the Geoscience Laser Altimeter System (GLAS)

E. H. Helmer, Research Ecologist, International Institute of Tropical Forestry, USDA Forest Service, Jardín Botánico Sur, Río Piedras, PR
M. A. Lefsky, Assistant Professor, Department of Forest, Rangeland and Watershed Stewardship, Colorado State University, Fort Collins, CO

Abstract—*Land-use change, mainly forest burning, harvest, or clearing for agriculture, may compose 15 to 40 percent of annual human-caused emissions of carbon (C) to the atmosphere. Spatially extensive data on forest C pools can validate and parameterize atmospheric and ecosystem models of those fluxes and quantify fluxes from forest change. Excellent evidence exists that light detection and ranging (lidar) waveforms can be scaled to estimate forest biomass and aboveground C pools. The Geoscience Laser Altimeter Systmem (GLAS) instrument provides satellite-based continuous return lidar data and may provide a way to inventory forest C pools globally. It was launched aboard the Ice, Cloud and Land Elevation Satellite (ICESat) on January 12, 2003. Here we explore whether GLAS data may support global inventory of forest C pools using the Amazon river basin as a study area. Forest C budgets in Amazonia are globally significant. However, globally-derived and validated Amazonian forest biomass-waveform relationships are not yet available. Consequently, here we address only vegetation canopy height. Over the Amazon basin, lands with at least 75 percent tree cover had GLAS-measured canopy heights averaging 30.48 ± 0.35 m (N = 2127). Fifty percent of measurements ranged from 25-35 m, agreeing with ground-based measurements in tierra firme forest. Lands with at least 60 percent tree cover had average canopy heights of 29.69 ± 0.10 m (N=2734). Regression-based mapping models relating waveform widths to data from maps of tree cover and elevation, or those variables plus generalized soil type, explain 36 to 47 percent of observed variation in mean vegetation canopy heights where tree cover is at least 20 percent. Finally, secondary forest age, as mapped with time series data over an area spanning three adjacent Landsat scenes in Rondonia, Brazil, was significantly related to GLAS-derived height. These results provide evidence that GLAS waveforms can contribute to global inventories of forest C pools.*

Introduction

Increases in atmospheric concentrations of CO2 and other greenhouse gases (GHGs) are projected to cause global average surface temperatures to rise 1.4 - 5.8 ºC over the next 100 years, which is rapid compared with climatic changes Earth has previously undergone (IPCC, 2001). Land-atmosphere carbon (C) fluxes are the most uncertain ones in the global atmospheric C budget, adding uncertainty to estimates of future levels and impacts of atmospheric GHGs (Prentice and others 2001; Houghton, 2003). Forest soils and woody biomass hold most of the carbon present in Earth's terrestrial biomes. Land-use change, mainly forest burning, harvest, or clearing for agriculture, may compose 15 to 40 percent of annual human-caused emissions of C to the atmosphere. Terrestrial ecosystems may absorb nearly as much C annually, with forest growth and expansion most important. Consequently, the levels, mechanisms and spatial distribution of forest land-atmosphere C fluxes are an important focus for reducing uncertainties in the global C budget (Fan and others 1998; Holland and others 1999; Pacala and others 2001; Schimel and others 2001). Spatially extensive data on forest C pools and net fluxes can parameterize and validate atmospheric and ecosystem models and quantify C fluxes from land-use change, which dominates land-atmosphere fluxes over longer periods. Such data are also necessary to monitor the differential impacts on forest ecosystems of global changes like increases in atmospheric CO^2, temperatures, nitrogen deposition, solar radiation, or cloud heights (Braswell and others 1997; Potter, 1999;

Pacala and others 2001; Schimel and others 2001; Houghton, 2003).

Forest C budgets in the Amazon river basin, the focus region of this study, are globally significant. Annual C fluxes from forest burning, clearing and regrowth in the Brazilian Amazon alone may vary from a net atmospheric C sink to a net source of about 0.2 Pg C yr –1, and logging in the region may add 5-10 percent to this estimate (Nepstad and others 1999; Houghton and others 2000). A further complication is that undisturbed forests appear to vary annually from a net C source to a sink (Saleska and others 2003). A net source of 0.2 Pg C yr-1 is equivalent to 6 to 12 percent of net C release via land-use change of 2.2 ± 0.8 Pg C yr-1 (Fan and others 1998; Pacala and others 2001). It also amounts to about 3 percent of the 6.3 ± 0.4 Pg C yr-1 of annual C emissions from fossil fuel burning and cement production during the 1990s. Yet estimates of forest C pools and fluxes in the region vary widely, and extensively-based estimates of forest biomass are probably more accurate than scaling from intensive ones (Houghton and others 2001; Saleska and others 2003). Although ground-based inventory of forest C pools is expensive, forest reflectance saturates space-based passive remote sensors at relatively low levels of aboveground biomass (Steininger, 2000; Foody and others 2003). Light detection and ranging (lidar) from satellites may, however, permit precisely located, global inventories of forest C pools in the near future. Accurate forest biomass estimates are possible with continuous return laser systems by combining waveform-measured height estimates with waveform-derived canopy-height profiles (Drake and others 2002; Lefsky and others 2002).

The Geoscience Laser Altimeter System (GLAS) is a lidar instrument that was launched aboard the Ice, Cloud, and Land Elevation satellite (ICESat) on January 12, 2003. The GLAS laser transmits short pulses (4 nano seconds) of infrared light (1064 nanometers wavelength) and visible green light (532 nanometers). Waveform returns are digitized at 15-cm intervals. As originally designed, laser pulses at 40 times per second illuminate 70-m diameter footprints that are spaced at 170-meter intervals along Earth's surface. Problems with the second laser have resulted in elliptical laser footprints of about 50 x 120 m (ICESat Land Working Group, 2004).

The goals of this study are to assess whether GLAS data have potential for monitoring forest structure across Amazonia and whether proportional forest cover may help scale GLAS-measured forest C storage from isolated waveforms to maps. Excellent evidence exists for cross-biome relationships that scale laser waveforms to forest biomass (Lefsky and others 2004). However, globally-derived and validated biomass-waveform relationships are not yet available. Consequently, in this paper we address only forest canopy height. Secondly, we estimate mapping models that relate existing geospatial datasets, like maps of proportional tree cover, to waveform height, as a rough proxy for forest C storage over an area. Thirdly, we explore the relationship between lidar-derived canopy height in Rondonia, Brazil and second growth forest as identified with Landsat data from multiple years. Excellent evidence exists for cross-biome relationships that scale laser waveforms to forest biomass (Lefsky and others 2004). However, globally-derived and validated biomass-waveform relationships are not yet available.

Consequently, in this paper we quantify only forest canopy height and mean vegetation height of partially forested land.

Methods

Lidar Waveforms and Processing

A geographic information system (GIS) coverage of Amazon basin boundaries (Mayorga and others 2002) subset GLAS waveforms collected over the region to those located within the river basin. For the basin-wide analysis, we sampled a subset of all waveforms available. Waveform processing began with characterizing background noise, which is the power that instrument noise and ambient light contribute to laser returns. Because background noise precedes and follows surface returns, its power values are the most common ones in any waveform. Consequently, fitting a Gaussian model to a histogram of power values for each waveform effectively determines a waveform-specific distribution of background noise, which yields the background noise mean and standard deviation. Multiplying the standard deviation of the background noise by a constant, in this case 5, and adding the mean noise level, estimates maximum noise level. Subtracting this maximum noise level from each waveform, and setting any resulting negative values to zero, yields a waveform of surface returns.

Both the intended and effective footprint sizes of GLAS waveforms are large enough to cause positive bias in estimates of forest canopy height on sloping land. Regressions to correct for this bias related waveform widths over presumably bare land to locationally correspondent slope indices for each study region:

$$\text{widths} = a(\text{slope index}) + b \qquad (1)$$

In Equation 1, widths is the fifth percentile of the range of waveform widths that occurs for each slope index value, which was assumed to indicate relatively bare land. All other waveform widths for a given slope index were assumed to have vegetation or other land cover above ground elevation and eliminated from the regression. Slope index is the maximum difference among all elevations in a 90-m window surrounding each waveform, which is a 3x3-pixel window for 30-m elevation data. The variables a and b are the regression slope and intercept, respectively. Elevation data derived from the Shuttle Radar Topography Mission (SRTM). Because the minimum available resolution of SRTM data outside the U.S. is 90 m, one-third of the maximum difference among pixels in the 270-m window surrounding each waveform center estimated an equivalent 90-m slope index. The resulting regression models for each study region calibrated waveform widths to remove any slope-related contribution. Corrected waveform width, widthi, was calculated from the processed waveform width (width) as follows:

$$widthi = width - widths \quad (2)$$

Mapping Models for Forest Canopy Height

We used multiple regression to estimate mapping models that relate GLAS waveform-widths, which are average heights from forested and non-forested lands for each footprint, to spatially continuous data. The mapped data included 1) percent tree cover at 500-m resolution derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery (Hansen and others 2003), 2) elevation from SRTM digital elevation models, and 3) for the Brazilian Amazon only, generalized soil type (EMPRABA, 1981). We assumed that such mapping models might be applied to lands with at least 20 percent tree cover.

Forest Age and GLAS-Derived Canopy Height

Land-cover maps for three adjacent time series of Landsat scenes over southwestern Amazonia (Rondonia, Brazil) (Roberts and others 1998; Roberts and others 2003) provided source data to evaluate canopy heights of secondary forest of various ages. Each single date of land-cover classification distinguished between second growth forest and closed upland forest that presumably was uncut and mostly old growth. The data had a 30-m pixel size. Spatial overlays for each time series yielded land cover maps of closed upland forest and median age of second growth forest for the most recent date of Landsat imagery. Where time between Landsat scenes in a time series was more than one year, the interval midpoints were used in estimating age of second growth forest. The earliest dates for the three scene footprints were 1975, 1978 and 1986. The most recent dates were 1998 or 1999, which is about four years earlier than the dates of the GLAS waveforms. After using each time series to map old-growth forest and secondary forest age, we mosiacked the three scenes. Recoding all secondary forest to one class and all non-forest to a third class, and mapping the standard deviations of class values over 90-m windows surrounding each pixel, permitted us to identify secondary forest pixels that were only surrounded by other secondary forest pixels. For each such pixel, we then calculated an average forest age from the median forest ages over 90-m windows. We then determined which of these secondary forest pixels were locationally correspondent with the center coordinates of GLAS waveforms and used linear regression to examine the relationship between lidar-derived canopy height and secondary forest age.

Results

Amazon River Basin Closed Forest Canopy Heights

Over the entire Amazon river basin, on those lands with at least 75 percent tree cover, lidar-measured canopy heights average 30.48 ± 0.35 m (N = 2127) (table 1), and 90 percent of measurements range from 14.08 to 42.23 m. Lands with at least 60 percent tree cover over this same extent have average canopy heights of 29.69 ± 0.10 m (N=2734), with 90 percent of measurements ranging from 11.68 to 42.12 m. The distribution of canopy heights (figure 1) for closed forest canopies in the basin is slightly skewed toward taller heights; 50 percent of stands have a mean canopy height between about 25 and 35 m.

Mapping Models for Average Canopy Height

Amazon River-wide, percent tree cover and SRTM-derived elevation relate to strongly to lidar height measurements for all lands with at least 20 percent tree cover, explaining 36 percent of variation in a highly significant relationship. The same variables explain somewhat more variation, 43 percent, in lidar heights over the Brazilian Amazon (table 2). Adding soil type to elevation and tree cover as explanatory values for height over the Brazilian Amazon improved the predictive model slightly, to an R-square of 47 percent. A one-way analysis of variance (ANOVA) suggests that where tree cover is at least 60 percent, forest on podzols (spodosols) (Beinroth, 1975) is significantly shorter than closed forest on other soil types (table 3). Where tree cover is at least 75 percent, canopy height on podzols is only significantly shorter than certain soil types, including alluvial soils,

Table 1. Summary statistics for lidar-derived canopy height, SRTM-derived elevation and tree cover for lands in the Amazon River basin with at least 60 percent or 75 percent tree cover and height at least 2 m.

	Waveform height meters	Elevation meters	Tree cover percent
Tree cover at least 75%, N = 2127			
Mean	30.448	191.6	82.8
Standard deviation	8.160	170.5	4.2
Range	2.083 – 46.350	4 – 3085	75 – 100
Tree cover at least 60%, N = 2734			
Mean	29.687	198.1	80.9
Standard deviation	8.750	190.4	6.2
Range	2.050 – 46.350	1 - 3085	60 – 100

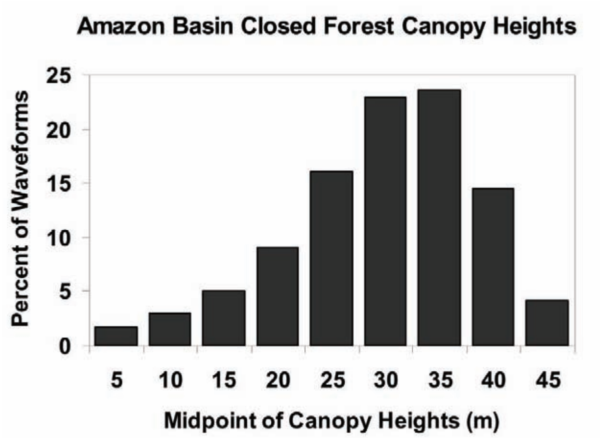

Figure 1. Frequency distribution of forest canopy heights over the Amazon River basin where tree cover is at least 75 percent and height is at least 2 m. Horizontal axis gives midpoint of heights for each bin.

Table 2. Relationships predicting height from tree cover, SRTM-derived elevation, or soil type for lands with at least 20% tree cover.

Multiple Regression Mapping Model	N	R-square	p-value
Amazon River Basin-wide			
1. HEIGHT = 1.60* + 0.350*** TREECOV + 0.00238 ELEV* – 0.0000738*** TREECOV x ELEV	3828	0.36	< 0.0001
Brazilian Amazon			
2. HEIGHT = 1.87* + 0.354*** TREECOV + 0.00420 ELEV* – 0.000154*** TREECOV x ELEV	2892	0.43	< 0.0001
3. HEIGHT = -6.22*** + 0.336*** TREECOV + 14E-5*** TREECOV x ELEV + mSOILi2	2886	0.47	<0.0001

[1] Asterisks indicate probabilities of erroneously rejecting the null hypothesis that coefficient estimates are zero, based on a two-sided t-distribution, ***p<0.0005, **p<0.005, *p<0.05.
[2] Coefficients for each soil type are given in table 3. All but four soil types had coefficient estimates that were significant at p<0.0001.

Table 3. Significant coefficient estimates for soil types in equation 3 of table 2.

Class No.	Generalized soil type	U.S. Soil Taxonomy[1]	Coefficient ± one standard error[2]
1	Alluvial soils	-	11.5 ± 2.2***
3	Cambisols	Inceptisols	14.4 ± 1.7***
5	Hydromorphic, lateriric soils	-	6.4 ± 1.4***
6	Gley soils	Inceptisols	6 ± 1.5***
9	Latosols	Oxisols	10.3 ± 1.2***
11	Podzolic soils	Ultisols	10.3 ± 1.3***
12	Deep sand soils	Entisols	9.4 ± 1.5***
13	Lithosols	Entisols	9.4 ± 1.4***
17	Planosols	Mollisols	8 ± 2.7**
19	Podzols	Spodosols	8.3 ± 1.6***

[1] Beinroth (1975) compares the Brazilian soil classification with that of the U.S. The summary does not explicitly relate hydromorphic and alluvial soils to any single U.S. soil order.

[2] Astersiks indicate probabilities of erroneously rejecting the null hypothesis that coefficient estimates are zero, based on a two-sided t-distribution, ***p<0.0005, **p<0.005, *p<0.05.

Table 4. Mean canopy heights (m) and lidar-derived elevations (m) for various soil types in the Brazilian Amazon.

Class No.	Generalized Soil Type	Mean Elevation (m)	N	Mean Height (m)	Significantly different from	Standard Deviation (m)	Range (m)
				Tree cover at least 75%			
1	Alluvial soils	17.461	13	35.394	19	4.215	29.5 - 43.4
3	Cambisols	375.530	9	35.744	19	9.878	12.2 - 45.5
5	Hydromorphic, lateriric soils	41.924	55	28.556	None	6.667	8.4 - 38.9
6	Gley soils	33.168	60	28.824	None	8.352	0.8 - 43.9
9	Latosols	122.443	767	30.809	19	8.155	1.3 - 45.6
11	Podzolic soils	184.425	383	29.732	19	8.653	0.2 - 46.4
12	Deep sand soils	246.671	34	28.985	None	7.356	14.7 - 43.1
13	Lithosols	240.907	66	30.779	None	8.637	1.7 - 45.2
19	Podzols	28.756	31	24.359	1,3,9,11	6.076	11.5 - 38
				Tree cover at least 60%			
1	Alluvial soils	17.772	15	34.983	6, 19	4.088	29.5 - 43.4
3	Cambisols	591.898	20	28.603	19	12.248	4.2 - 45.5
5	Hydromorphic, lateriric soils	41.897	66	27.849	11,6,9,19	7.701	4.5 - 41.8
6	Gley soils	33.764	84	26.608	6,19	8.912	0.8 - 43.9
9	Latosols	126.529	1000	30.192	19	8.887	0.8 - 45.9
11	Podzolic soils	193.912	467	28.968	19	8.992	0.2 - 46.4
12	Deep sand soils	256.012	43	27.027	19	8.366	7 - 43.1
13	Lithosols	250.976	79	30.342	19	8.458	1.7 - 45.2
19	Podzols	27.416	40	20.625	All	8.912	5 - 38

cambisols (inceptisols), latosols (oxisols), podzolic soils (ultisols) and lithosols (entisols). Where tree cover is at least 75 percent, the tallest forest canopies occur on alluvial soils and cambisols (table 4).

Age of Second Growth Forest and Lidar-Derived Canopy Heights

After excluding areas of mixed land cover in 90-m windows, secondary forest age in 1998-99 was significantly related to lidar-derived height in 2003 ($p < 0.005$) (figure 2). The relationship between median age of second growth forest in 1998-99 and lidar-derived canopy height in 2003 is Log10(age) = 0.349 + 0.0161(height) (R-square = 0.40, N = 22, $p < 0.005$). Assuming that all second growth forest was 4 yr older in 2003, the following equation results: Log10(age) = 0.778 + 0.0905(height) (R-square = 0.39, N = 22, $p < 0.005$).

Discussion

Canopy height measurements from GLAS agree with previous ground-based studies in the Amazon region. In Paragominas, Pará, Brazil, upland seasonal evergreen old-growth forest on latosols (oxisols) and podzolic soils (ultisols), the most common soil types in the region, are 2535 m tall (Uhl and others 1988). They correspond well with the average closed canopy height of about 30 m from

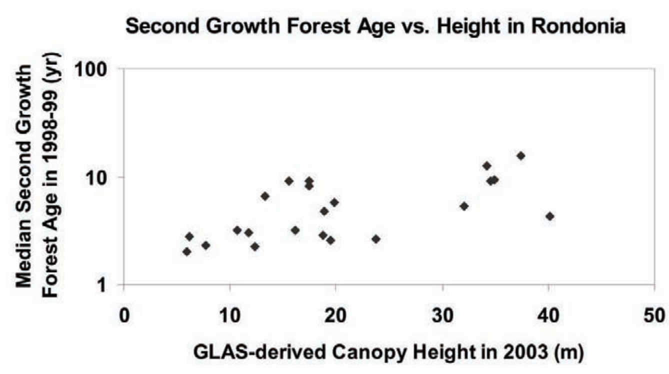

Figure 2. Relationship between median age of second growth forest in 1998-99 and lidar-derived canopy height in 2003.

GLAS measurements and a distribution of canopy heights in which 50 percent of measurements range from 25-35 m. The average canopy height of forest on podzols (spodosols) of 24 m, with 90 percent of measurements between 12 and 33 m, also corresponds well with forest height observed on those soils of 20-30 m for Caatinga forest and 5-10 m for Bana forest (Kauffman and others 1988).

Regression-based mapping models relating GLAS-derived mean canopy heights to data from maps of tree cover and elevation explain 36 to 47 percent of observed variation in waveform widths over the Amazon basin and the Brazilian Amazon. Insofar as GLAS-derived mean heights over lands with 20 percent or more tree cover serve as a proxy for forest-related C storage over a given 500m pixel, the geospatial layers that we used can contribute to scaling estimates of forest C storage globally. Based on results in the Brazilian Amazon, global geospatial data on soil types might further improve such mapping models. Identifying soil type with the less generalize 70- or 249class versions of the Brazilian soils map might also enable soil type to explain more of the variability in waveform width. Clay content of terra firme forest latosols, which is related to several soils fertility parameters, explained one-third of the variability in biomass of those forests (Laurance and others 1999).

Finally, the significance of the relationship between second growth forest age in 1998-99 and GLAS-derived canopy heights in 2003 demonstrates that GLAS data are sensitive to age-related differences in forest canopy height. This result provides further evidence that GLAS waveforms can contribute to global inventories of forest C pools.

Conclusions

Apparently valid height estimates of closed forest canopies are derivable from GLAS waveforms for both the Amazon River basin and by generalized soil type for the Brazilian Amazon. In addition, maps of proportional tree cover, elevation, and soils are likely to contribute to scaling GLAS-based estimates of forest C pools to spatially continuous data.

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Aerial Detection Surveys in the United States

E. W. Johnson, USDA Forest Service, Rocky Mountain Region, Golden, CO
D. Wittwer, USDA Forest Service, Alaska Region, Juneau, AK

Abstract—*Aerial detection surveys, also known as aerial sketchmapping, is a remote sensing technique of observing forest change events from an aircraft and documenting them manually onto a map. Data from aerial surveys have become an important component of the Forest Health Monitoring, a national program designed to determine the status, changes, and trends in indicators of forest condition. Aerial surveys are an effective and economical means of monitoring and mapping insect, disease and other forest disturbances. Information from aerial surveys can be considered the first stage in a multi-stage or multi-phase sampling design. Aerial skecthmap surveys have been utilized in the United States since the 1950s. Today, USDA Forest Service, State & Private Forestry, Forest Health Protection, together with other federal, state, and county cooperators conducts annual sketchmap surveys across all land ownerships. In 2002, approximately one million square miles were surveyed in the United States alone. Traditionally, forest damage has been sketchmapped on USGS base paper maps. Recently, the USDA Forest Service's Forest Health Technology Enterprise Team has developed a Digital Aerial Sketch Mapping system which automates this process allowing users to digitize polygons directly onto a touch-screen linked to a Global Positioning Unit (GPS) unit and computer or onto a tablet PC with an integrated GPS.*

Introduction

Forest health has gained popular attention in recent years because of environmental concerns about air pollution, acid rain, global climate change, population growth, and long-term resource management. In response to these environmental concerns and to legislative and policy direction, Federal and State agencies have been working together to develop a program for forest monitoring and reporting on the status and trends of forest health. The national Forest Health Monitoring (FHM) program has been established to accomplish this objective.

The FHM program is comprised of three interrelated monitoring activities: Detection Monitoring (Plot and Survey Components); Evaluation Monitoring; and Intensive Site Ecosystem Monitoring. A fourth, related activity is Research on Monitoring Techniques. Each monitoring activity provides a different level of information and each has specific, complementary goals.

Detection Monitoring consists of two components: the Plot Component and the Survey Component. The Plot Component of Detection Monitoring employs a set of plots systematically distributed across the entire United States providing data on forest mensuration, tree crown condition, tree damage, ozone injury to vegetation, soil chemistry and erosion, vegetation diversity, lichen diversity, coarse woody debris, and fuel loading. The Survey Component of Detection Monitoring makes use of both ground surveys and *aerial surveys* to collect data on the occurrence of some insects, diseases, and other forest health stressors. Both Plot Component and Survey Component information, in combination with data on weather and climate change, fire incidence and damage, and observations on shifts in land use, are required to interpret forest condition. This paper describes aerial surveys, how aerial survey data is collected, and how aerial survey programs are managed.

What are Aerial Detection Surveys?

Aerial survey, also known as aerial sketchmapping, is a remote sensing technique of observing forest change events from an aircraft and documenting them manually onto a map. The observer views a particular forest change event, such as mortality caused by bark beetles or defoliation caused by gypsy moths, and delineates the affected area onto a map to record its size, shape, and location as accurately as possible. Attributes, such as host, causal agent, symptom, and an estimate of intensity or number of trees affected, may also be recorded.

Aerial surveys have been recognized for over fifty years as an efficient and economical method of detecting and monitoring forest change events over large forested areas. It is a relatively low cost remote sensing method that provides a coarse, landscape-level overview of forest conditions. Today, USDA Forest Service, State & Private Forestry, Forest Health Protection (FHP), together with other federal, state, and county cooperators conducts annual sketchmap surveys across all land ownerships. Approximately one million square miles were surveyed within the United States in 2002.

Aerial surveys can be used as the first step of a multi-tiered process of detection, monitoring, and evaluation, utilizing other remote sensing and ground sampling techniques to gather additional data on significant forest events or change. As with all remotely sensed data, some amount of ground-truthing is required before the data can be considered reliable.

How is Aerial Survey Data Collected?

In order to collect aerial survey data, the following elements are needed: a high-winged aircraft providing good visibility and capable of flying at relatively slow speeds, a pilot who has a sincere interest in safety and is motivated to perform at a high level, and a sketchmapper who has the ability to relate forest damage observed on the ground to features on a map without experiencing the debilitating effects of motion sickness. The map base onto which the sketch-mapped information is recorded varies from sketchmapper to sketchmapper and from program to program. For the more general "overview" surveys, the map base will often be of the 1:100,000 scale topographic or satellite image variety. For more intensive "special" surveys, using 1:24,000 scale maps is common. The data from the maps is then digitized and entered in a national Geographic Information System (GIS) database using common standards that are required for Forest Health Monitoring reporting efforts.

Since forest pests and the damage they cause are dynamic and highly variable, the resulting data will also be highly variable. No two sketchmappers will or can be expected to record the same outbreak in exactly the way. For this reason, sketchmapping should be regarded more as an art than an exact science. It is important at the outset that this be understood, not only by conscientious sketchmappers who find that their data may not be in close agreement with their peers or with a subsequent statistically reliable aerial photo survey, but also by the forest manager, who may want to put the information to use. Sketchmapping is highly subjective, and the resulting data can be no more accurate than the competence of the sketchmapper and the conditions under which the data was obtained (Klein and others (1983).

As the preceding passage implies, there are certain limitations as to how the data obtained from aerial sketchmap surveys can be used. During a typical aerial survey mission, the survey plane speed is approximately 100 knots (115 MPH) flown at an altitude from 1,000 to 3,000 feet above ground level. Observers on average are evaluating a swath of about 1.5 miles wide at any one time, which only gives them about 30 seconds per mile to recognize, classify, and record all of the activity they see. Because of these circumstances, aerial sketchmap data should only be regarded as a coarse "snapshot" of landscape level forest health and/or forest change condition. Spatially, the data is best displayed at small scales such as 1:100,000, 1:250,000 or 1:500,000. The data is better used for demonstrating trends rather than exacting precise measurements.

How are Aerial Survey Programs Managed?

There is much more to aerial sketchmapping besides looking for damaged trees from an aircraft; a great deal of preliminary work must be done before anyone is sent up in the air to do this type of work. Some of this work includes developing an aviation management plan and an aviation safety awareness program; providing for suitable, safe, cost-effective aircraft; and ensuring the availability of trained, qualified personnel to do the work, including experienced, qualified pilots.

Aviation Management Plans

An aviation management plan provides all of the program participants with information about the nature and intent of the mission and the program. It includes: a description of the program along with its purpose and scope; the personnel involved and their responsibilities; and a definition of all of the pertinent policies, procedures, operations, safety plans, and documents that apply to the program. By reading the aviation management plan, anyone unfamiliar with the program should be able to quickly grasp the intent, authority, and extent of the program.

Aviation Safety Awareness Program

The purpose of an aviation safety awareness program is to ensure that all participants understand the importance of conducting an aerial survey program safely. It is the responsibility of management to provide adequate safety awareness training. It is the responsibility of all participants to be aware of all safety implications in an aviation program. Proper training includes formal aviation safety and management courses, which should be repeated every few years. Approaching and solving problems through continual training ensures a high standard of job performance where instilled safety practices are an integral part.

Suitable Aircraft

Having the right tool for the right job also applies to aerial surveys. Aircraft specifications can vary depending on many factors, some of which include: terrain, number of observers, flying altitude, flight speeds, flight patterns, size of survey area, ferry distance to the survey area, and expected accuracy levels. With increased horsepower comes an increased cost. A mission should never be flown with an underpowered airplane. Finding the appropriate aircraft is a matter of weighing the benefits with the costs yet never compromising safety.

Personnel

The most critical element in aerial sketchmapping is also the most variable: the sketchmapper. Conducting an aerial survey with a trained, experienced sketchmapper is the best way to assure a quality aerial survey. Although it helps that a sketchmapper is good with maps, is able to endure riding in an aircraft without experiencing motion sickness, has a background in forestry and an interest in aviation, and has had some form of aerial sketchmapping training; there is no substitute for experience. An individual cannot be expected to collect quality aerial survey data without receiving months, perhaps even years, of on-the-job training.

A good pilot contributes greatly to the safety and quality of the survey. A well-qualified pilot works as a team player to position the aircraft at the appropriate altitude, speed, and location to give the observer the best view. An aerial survey program benefits greatly by using stringent requirements for pilot qualifications.

Along with personnel flying the aerial survey, the survey team includes someone on the ground responsible for "flight following": that is, monitoring the location of the aircraft through regular radio contact. The flight follower, or dispatcher, maintains radio contact with the flight crew in case of an emergency or the need to pass along important information. A good dispatcher is diligent about constantly monitoring the aircraft's position and follows proper procedures in the event of an emergency.

New Technologies

New technologies are constantly being sought after and integrated into aerial surveys. The USDA Forest Service's Forest Health Technology Enterprise Team has recently developed a digital aerial sketchmap system (DASM), where observed forest damage polygons can be directly recorded onto a touch-screen linked to a Global Positioning Unit (GPS) unit and computer, or onto a tablet PC with an integrated GPS. This eliminates the need for using pencils to draw on paper maps and the ensuing lengthy process of post processing the maps into a digital format. The DASM also helps the observer to stay on course via an aircraft icon linked to a GPS receiver that flashes on the screen across a moving map display.

Automated flights following systems have now been established in many aerial survey programs nationally. A GPS unit installed in the aircraft transmits position locations to a centralized dispatch center responsible for following the aircraft's route. In the event of an emergency, help can be immediately dispatched to the incident's exact location.

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Small Area Variance Estimation for the Siuslaw NF in Oregon and Some Results

S Lin, D.Boes and H.T. Schreuder

***Abstract**—The results of a small area prediction study for the Siuslaw National Forest in Oregon are presented. Predictions were made for total basal area, number of trees and mortality per ha on a 0.85 mile grid using data on a 1.7 mile grid and additional ancillary information from TM. A reliable method of estimating prediction errors for individual plot predictions called the semi-parametric bootstrap is given too. Prediction errors were quite large. Suggestions on how to improve such necessary predictions for small areas are given.*

Introduction

Management agencies need reliable spatial information for decision making. In the past foresters and other land managers cruised or sketch mapped an area usually to decide what is where. Managers were contemptuous of statistical sampling because it might give reliably data on how much was there but not where. Frequent legal challenges changed this. Now interest is in obtaining reliable (defensible) mapped and statistical data together. For example Forest Inventory and Analysis (FIA) of the USDA Forest Service has made this one of the high priority research efforts for their national program. One such area of current research is referred to as small area estimation, basically a model-building approach using statistical data in combination with ancillary data such as from the satellite thematic mapper ™, geographic information systems (GIS), topographic maps and other helpful information.

Small area estimation techniques represent a substantial improvement in terms of quality of data and, especially in defensibility of data based management decisions relative to what used to be done when managers relied on subjective information. As so many new developments, the techniques are oversold as a panacea. This is because estimates generated by such techniques are claimed to have standard errors similar to those for classical sampling. The trouble is the comparison is made for the entire population of interest whereas managers are primarily interested in predictions for much smaller areas such as polygons used as a basis for management. Standard errors for individual predictions can be large, as one would expect, given the variability encountered on the ground in forests.

Considerable work in small area estimation of forest resources is now being done in many parts of the world. Multiple imputation methods (including regression models) and k-nearest neighbor techniques have been proposed for continuous variables. In these techniques, field sample information is extrapolated to the entire population where information on sample locations is input to non-sampled locations by some criteria such as similar TM readings for the sampled and non-sampled locations. In multiple imputations for each unit without sample data, a series of ℓ predictions are made using randomly selected data and an underlying model and database. Then the data sets are analyzed separately and pooled into a final result, usually an average of the results.

Brief Review of Literature

Franco-Lopez (1999) reviews methods for projecting and propagating forest plot and stand information. As he notes, considerable effort has been extended in Nordic countries combining forest monitoring information, remote sensing and geographic information systems (GIS) to develop maps for forest variables such as cover type, stand density and timber volume with emphasis on the k-nearest neighbor technique. He confides that while his results are imprecise for Minnesota, they are comparable to those obtained by other methods in this region.

Methods

An objective in Lin (2003) was to predict mortality, total basal area and number of trees on 1-ha plots at a 0.85 mile grid given data collected on a 1.7 mile grid. These variables were selected for their economic and ecological importance. The sampling design used on the latter grid was the CVS plot design (Max et al. 1996) consisting of a set of a circular 1-ha plot subsampled at 5 locations with subplots of different sizes for different sized trees. Ancillary data used was plot information for plots in the neighborhood of the prediction locations and TM data using bands 1-5 and 7 from TM 5.

Results and Conclusions

In this study: (1) the predictions errors for predictions were derived based on transformed and non-transformed data for non-sampled locations using only field sample plot or subplot information, (2) prediction errors for predictions were derived based on spatial multivariate regression models with distance-related correlation functions, (3) spatial zero-inflated models were used to handle the numerous zeros in the data, (4) the normal approximate and bootstrap-t prediction intervals were compared for the predictors with coefficients based on distance-related correlation functions with and without auxiliary information, and (5) reliable bootstrap methods were developed for different situations.

The semi-parametric bootstrap method is the best method currently available to estimate prediction errors. It works as follows (Lin, 2003 pp 97-98): If we denote $\underline{Y}$ as the vector of the variable of interest, $\underline{\mu}$ as the vector of its mean at the i=1, …,N locations, B the vector of regression coefficients, ε an Nx1 vector of random variables with mean 0 and NxN dispersion matrix σ^2 I, the correlation matrix of Y, I the identity matrix, with H and V the corresponding (0,1) matrices with 1's for the horizontal and vertical neighbors respectively, $C^{(1)}$and $C^{(2)}$the corresponding (0,1) matrices with 1's for corner neighbors in the directions {(1,1), (-1,-1)} and {(1,-1), (-1,1)} respectively and zeroes elsewhere in all matrices. Then suppose the spatial data follows the linear model:

$\underline{Y}=\underline{\mu}+B\varepsilon$ where $\underline{Y}=(Y_1,...,Y_N)'$,$\underline{\mu}=(\mu_1,...,\mu_N)'$,$\underline{\Gamma}=I+\rho_1 H+\rho_2 V+\rho_3 C^{(1)}+\rho_4 C^{(2)}\equiv B'B,\varepsilon\ \ MVN(\underline{0},\sigma^2 I)$
or more simply:

$$Y_i=\mu+\sum_{j\neq i}^{N}(Y_j-\mu)+\varepsilon_i i=1,...,N$$

where $B^{-1}\equiv I-M$ and $\underline{M}=(m_{ij})$.

For a symmetrical and positive-definite estimator $\hat{\Gamma}$ of Γ, decompose it as:

$\hat{\Gamma}=\hat{B}'\hat{B}$ and define $(\hat{\varepsilon}_1,...,\hat{\varepsilon}_N)\equiv\hat{B}^{-1}(\underline{Y}-\underline{\mu})$ and $\tilde{\varepsilon}_i=\hat{\varepsilon}_i-\sum_{j\neq i}^{N}m_{ij}\hat{\varepsilon}_i/N,i=1,...,N.$

Then the assumed i.i.d. $\tilde{\varepsilon}_i$ are bootstrapped.

For each bootstrap sample $\underline{\varepsilon}^*$ calculate $\underline{Y}^*=\hat{\mu}+\hat{B}\underline{\varepsilon}^*$.

Then refit the model to each of the bootstrap samples and predict for each of the samples at the desired locations. The variability between the estimates for the predicted location(s) is then used for the bootstrap variance estimate for that location.

We conclude that prediction models developed are quite unreliable for this data set. For prediction purposes a simple model that assumes a spatial correlation structure without any distributional assumptions worked as well as any other. The specific spatial correlation structure was selected by minimizing an overall mean squared error. Our recommended predictor is a linear combination of measurements at neighboring sites. The coefficients in the linear combinations are functions of the estimated neighboring correlations. These simple predictors have an analytical formula for the prediction errors and these too can be estimated using the estimated correlations. These predictors work for any of the response variables total basal area, number of live trees and mortality. The semiparametric bootstrap method is recommended for computing the reliability of the plot predictions.

The overall results were quite disappointing. There is little spatial dependence among the response variables at the 1.7-mile grid scale and consequently such dependence is of little use in making predictions at non-sampled plots. Also, there is little useful correlation between our response variables and the many available auxiliary variables, including those from satellite imagery (™). Auxiliary data contributed little to improving predictions in our study. The following shows the results for six plots, similar results were found for other plots.

For total basal area we found that certain auxiliary data were useful in reducing prediction errors. To illustrate as to the size of the errors involved for this variable, we predicted the value at each of six sites on the 0.85-mile grid. Predicted total basal area range from about twenty to sixty m^2 per ha. If the sample mean was used as a predictor and independence among sites assumed, the prediction error is estimated to be 24.38. The estimated prediction errors using our simple predictors at the six sites are, respectively, 24.23, 24.22, 24.21, 24.24, 24.11, and 24.12. Clearly there is little improvement over the nominal 24.38. On the other hand, the corresponding estimated prediction errors for the same six sites, when one incorporates aspect and band 4 (representing active vegetation) as auxiliary variables, are, respectively, 18.54, 18.64, 18.53, 18.47, 18.59 and 18.44 showing a nearly twenty-five percent improvement.

For number of live trees/ha, predictions are between above three hundred and five hundred trees per ha. The respective estimated prediction errors at the six sites are 264.81, 264.56, 264.52, 264.70, 264.53, and 264.55 without auxiliary data, and 258.52, 258.14, 258.62, 257.74, 259.87 and 258.25 with auxiliary data. The overall reduction in prediction errors is less than five percent.

For mortality per ha, predictions are between about forty and a hundred and thirty. The nominal estimated prediction errors range from 52.71 to 52.76 without auxiliary data. The estimated prediction errors using auxiliary data ranged from 53.19 to 54.08 so for M, auxiliary data provides no improvement in prediction.

We are not ready for prime time in FIA (except perhaps in some very homogeneous parts of the country), i.e., we should not be publishing results on small area estimates at this time unless quite reliable estimates were generated for the area involved. For successful small area estimation, three conditions need to be met. First of all there should ideally be a good correlation between sampled and non-sampled areas nearby or similar to the ones sampled. This usually requires a much more intensive grid than the 5000 m grid now used by FIA. Secondly, there should be a close relationship between spatial characteristics of a location and plot information and the spatial locations need to be accurate.

Research should be pursued further in this field. We need to use data from an improved resolution remote sensor relative to TM and/or photography as used by the National Resources Inventory (NRI) of the Natural Resources Conservation Service. This improved ancillary information may yield better information for better predictions. Also: there is a need to think about generating estimates emphasizing different sources for different variables and redefinition of some variables could be useful too. For some variables remote sensing alone (including photography) may do better than ground sampling, for others we have to continue to rely on ground sampling primarily.

For management purposes we really want mapped or very detailed local information at least for percent cover, cover types (about 30), and stand structure. Percent cover can probably be obtained as well from remote sensing as from ground sampling. Cover type definitions are actually still quite fluid. In a simple case: some people argue that a mixed pine/hardwood stand has to have at least 40 percent of each, the remainder in the other. Others might argue for a 30/70 percent split. It seems reasonable to use definitions on what remote sensing can objectively give us in that regard. Stand structure on the other hand will probably always have to be obtained from ground sampling. Other examples abound. Large tree mortality and certain types of old growth can probably be best estimated from remote sensing whereas lower vegetation will have to be sampled on the ground usually. In this regard different plots may need to be used for different variables too at the same grid locations.

To obtain reliable predictions today, additional information is required such as that available from improved remote sensors or large- scale photos combined with expertise from local ecologists. Also, at present it is still necessary to correct for location errors with models. Making such corrections requires considerable information on the extent and location of the errors. Hopefully, improvements in GPS-type sensors will allow us to ignore location errors in the future.

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Aerial Sketchmapping for Monitoring Forest Conditions in Southern Brazil

Y. M. Malheiros de Oliveira , M. A. Doetzer Rosot and N.B. da Luz, researchers, Brazilian Agricultural Research Company – Embrapa, Colombo-PR, CEP 83400-000, Brazil
W. M. Ciesla, owner, Forest Health Management International, Fort Collins, CO
E.W. Johnson, Aerial Survey Program Manager, USDA Forest Service, Rocky Mountain Region, Forest Health Protection, Denver, CO
R. Rhea, entomologist, USDA Forest Service, Southern Region, Forest Health Protection, Asheville, NC
J.F. Penteado Jr., technician and aerial observer, Brazilian Agricultural Research Company – Embrapa, Colombo-PR, CEP 83400-000, Brazil

Abstract—*Aerial sketchmapping is a simple, low cost remote sensing method used for detection and mapping of forest damage caused by biotic agents (insects, pathogens and other pests) and abiotic agents (wind, fire, storms, hurricane, ice storms) in North America. This method was introduced to Brazil in 2001/2002 via a USDA Forest Service/EMBRAPA technical exchange program, which included demonstration flights, a feasibility study, workshops, production of satellite maps, observer training and operational flights, primarily for assessment of damage caused by European wood wasp (*Sirex noctilio*), monkeys (*Cebus nigritus*), armillaria root disease (*Armillaria *spp.), and other damaging agents in pine plantations in Southern Brazil. New applications have been investigated in the most recent campaigns, carried out in 2003 and 2004. These include the use of this technique to monitor land use changes, evaluate the accuracy of classifications from satellite imagery, and to classify successional phases in remnants of *Araucaria angustifolia *forests in Southern Brazil. The operational flights have demonstrated that clearcuts, land use change detection, and other anthropogenic activities may be suitably mapped and monitored from the air. Future activities are aimed at consolidation of this technique in Brazil, the identification of other damage signatures, such as those caused by the eucalyptus red gum lerp psyllid (*Glycaspis brimblecombei*), and the use of digital aerial sketchmapping methods.*

The Aerial Sketchmap Program in Brazil

Aerial sketchmapping is the oldest and most widely used remote sensing tool for forest health assessment in North America (CIESLA, 2000). This is a relatively simple and low cost method of monitoring forest condition. Trained observers, working in low-flying aircraft generally at a flying height between 300 and 800 meters above ground level, locate areas of tree mortality or foliar injury and "sketch" those locations onto maps as coded points or polygons according to predetermined classification schemes. Resultant data are used to monitor pest damage, initiate salvage harvesting, plan pest management operations and develop historic databases on the occurrence and severity of forest insect and disease outbreaks (CIESLA and others, 2002).

This approach to forest health assessment has potential value in southern Brazil, due to the existence of large areas of pine and eucalyptus plantations (about 2.7 million acres), where the presence of an insect or disease might cause widespread damage. These fast growing forests provide raw material for pulp, paper and wood products industry, supplying both domestic and export markets and thus play a key role in the regional economy.

The first infestations by the European wood wasp (*Sirex noctilio*) were reported in 1988 (IEDE and others, 1988) in Rio Grande do Sul – the southernmost State – and presently the insect is known to have spread also to Santa Catarina and Paraná States (DISPERATI and others, 1998). In 1998 a technical exchange agreement was celebrated between USDA Forest Service and the Brazilian Agricultural Research Agency (EMBRAPA), thus providing the basis for the development of an aerial sketchmap program oriented primarily to assessment of damage caused by *S. noctilio*, but also for other forest pests in pine plantations in Brazil's three southernmost states: Paraná, Santa Catarina and Rio Grande do Sul. The following activities have been carried out:

Demonstration flights—About 2,400 hectares of *Pinus taeda* plantations were flown over by an Aero Boero 115 aircraft, from which the mapping of various levels of tree mortality caused by *S. noctilio* was done (CIESLA and others 1999).

A feasibility study—The study concluded that aerial sketchmapping was indeed feasible in southern Brazil due to: low costs (similar to those in North America); aerial visibility of damaging agents; availability of satellite maps for aerial sketchmap surveys; an interest on the part of EMBRAPA and representatives of forest industry to look into the implementation of this technology; and a potential capability to detect and map damage caused by forest pests other than the European wood wasp.

Production of aerial survey maps—The traditional topographic maps used in North America were substituted by satellite maps in Brazil, produced from Landsat 7 ETM data with varying scales (1: 100,000; 1:50,000; 1:25,000), printed in a band 543 (RGB) configuration, which resembled a natural color image or in 453 (RGB) – false color. The maps were overlaid with a 4 km UTM grid, major roads, drainages and the polygons of pine plantations.

Training of aerial observers—During the period 8-12 April 2002, in Brazil, twelve trainees, representing EMBRAPA (6 trainees), private industry (3), a non-government organization (NGO) (1), Universidade Federal do Paraná (1) and a pilot attended aerial sketchmap classes and took part on training flights, mapping damage caused by several damaging agents. On July of the same year a member of the Embrapa team was trained in USA, taking part ion a 2-week aerial survey to detect forest insect and disease damage in Colorado State.

Workshop—A technical workshop held in Curitiba, Brazil, on November 22 – 23, 2003, brought together USDA Forest Service aerial sketchmappers, the Embrapa team and the Paraná State Government staff in order to discuss the potential use of aerial sketchmapping techniques and other remote sensing approaches in the so called "Paraná Biodiversity Project," which is related to the conservation of native forests in Paraná State.

Operational flights—Operational flights were conducted immediately after the first training period and since then many flight campaigns have been carried out. The approaches, objectives, and results of these surveys are described and discussed in this paper.

Operational Flights

Three operational flight campaigns were carried out by the USDA Forest Service/Embrapa team during the years 2002, 2003 and 2004 (table 1). In 60.5 hours of flight, the surveys covered an area of more than one million hectares, which, in fact, corresponds to 5 percent of the area of Paraná State (Fig. 1). The same Cessna 185 aircraft used for the observer training was also used for operational aerial sketchmap surveys (Fig. 2). All surveys were flown using the grid method. Flight lines were established at 4 km intervals and observers mapped a 2 km wide swath. A Garmin GPSMAP 295 Global Positioning System (GPS) receiver (Fig. 3) was used to help the pilot keep the survey aircraft on the flight lines and to facilitate location of beginning and ending points of flight lines.

Surveys for Forest Damage Detection and Thematic Accuracy Assessment

In surveys whose objectives were the assessment of forest damage in pine plantations and also the accuracy of satellite imagery visual interpretation, flight lines were established in such a manner as to include all areas classified as pine plantations and eliminate non-pine-forested areas (Fig. 4). Universal Transverse Mercator (UTM) coordinates of each flight line beginning and end point were entered into the GPS.

CIESLA and others (2002) describe a number of damage signatures detected and mapped in the 2002 flight campaign:

- Scattered tree mortality in pine plantations suggestive of infestations of *Sirex noctilio*.
- Top kill in both pine and Araucaria plantations suggestive of damage caused by indigenous monkeys. This is a relatively new problem in southern Brazil.
- Yellowing or chlorosis in pine plantations. This may be associated with either soil nutrient deficiencies and/or root disease caused by a species of Armillaria.
- Small group kills of 5-20 trees in pine plantations. These resemble the classic signature associated with bark beetle infestations in North America.

A provisional coding system was developed for the prevailing forest damage types in Brazil and included host, damage type and intensity of damage. This system was slightly modified during the 2003 surveys as Brazilian aerial sketchmappers gained more experience and became more familiar with conditions in their country (table 2). Future modifications may include a new code for the eucalyptus red gum lerp psyllid.

Table 1. Characterization of aerial sketchmapping flight campaigns in Southern Brazil.

Flight region	Area (ha)	Objectives	Flight duration (hours)	Date
Palmas/União da Vitória - PR	379,200	Forest damage assessment (wood wasp, monkey); accuracy assessment of satellite imagery visual interpretation	32	April, 2002
Pitanga - PR	35,200	Forest damage assessment (wood wasp, *Armillaria* spp); accuracy assessment of satellite imagery visual interpretation	3	April, 2002
Caçador - SC	57,600	Classification of *Araucaria angustifolia* (Parana-pine) cover classes in remnants of Araucaria angustifolia forests	3	April, 2002
Abapã - PR	108,800	Forest damage assessment (wood wasp); accuracy assessment of satellite imagery visual interpretation	5	June, 2003
Rio Branco do Ivaí - PR	41,600	Forest damage assessment (wood wasp); accuracy assessment of satellite imagery visual interpretation	3.5	June, 2003
Rio dos Touros - PR	48,000	Discrimination of different successional phases in remnants of *Araucaria angustifolia* forests; accuracy assessment of satellite imagery classification	3	June, 2003
Mangueirinha Indian Reserve - PR	64,000	Discrimination of different successional phases in remnants of *Araucaria angustifolia* forests; accuracy assessment of satellite imagery classification	2	June, 2003
São Mateus do Sul - PR	216,000	Detection of afforestation in remnants of *Araucaria angustifolia* forests; forest damage assessment (wood wasp, monkey); accuracy assessment of satellite imagery visual interpretation	4.5	April, 2004
Guarapuava - PR	216,000	Detection of afforestation in remnants of *Araucaria angustifolia* forests; forest damage assessment (wood wasp, monkey); accuracy assessment of satellite imagery visual interpretation	4.5	April, 2004
Total	**1,166,400**		**60.5**	

Following the completion of the aerial surveys, damage polygons were transferred to mylar overlays, which were scanned, georeferenced and vectorized for entry into the EMBRAPA Geographic Information System (GIS), including the damage signature information as tabular data.

The results of the aerial surveys regarding forest damage were checked through ground surveys. Table 3 shows omission and commission errors found for the flights over the region of União da Vitória and Pitanga, in Paraná State. The general accuracy for the survey achieved 91.43 percent. However, about 40 percent of the stands damaged by monkeys could not be detected by the aerial survey. The same happened to the stands injured simultaneously by monkey and wood-wasp, fifty percent of them being omitted. All the stands attacked by the wood-wasp have been discriminated, while 10.71 percent of the stands annotated as damaged by wood-wasp belonged, actually, to other damage classes.

A final forest damage map for the region of União da Vitória, Paraná State, is shown in Figure 5. The GIS environment allows the selective display of all information collected during the aerial survey. As new flights are performed, one can add new information to the database. Further spatial analyses may help develop a spatial distribution pattern for certain forest pests, as well as risk maps.

Although the visual interpretation of satellite imagery has proved to be the most efficient method of mapping pine plantations in Southern Brazil (ROSOT and others, 2003), the assessment of thematic accuracy demanded heavy economic and personal resources due mainly to the need of several trips in order to get reliable ground data in forest plantations. As the Embrapa team decided to produce satellite maps for the training of aerial observers, they realized that the aerial sketchmap survey could be used as an opportunity to check the accuracy of the pine classification. The sketchmapper should, thus, be responsible for the observation of forest damage as well as for the checking of forest type, which was easily done. The most frequent classification errors included:

- omission errors: non-classified young plantations, less than 8 years old; non-classified small pine plantations (1 to 5 years old);

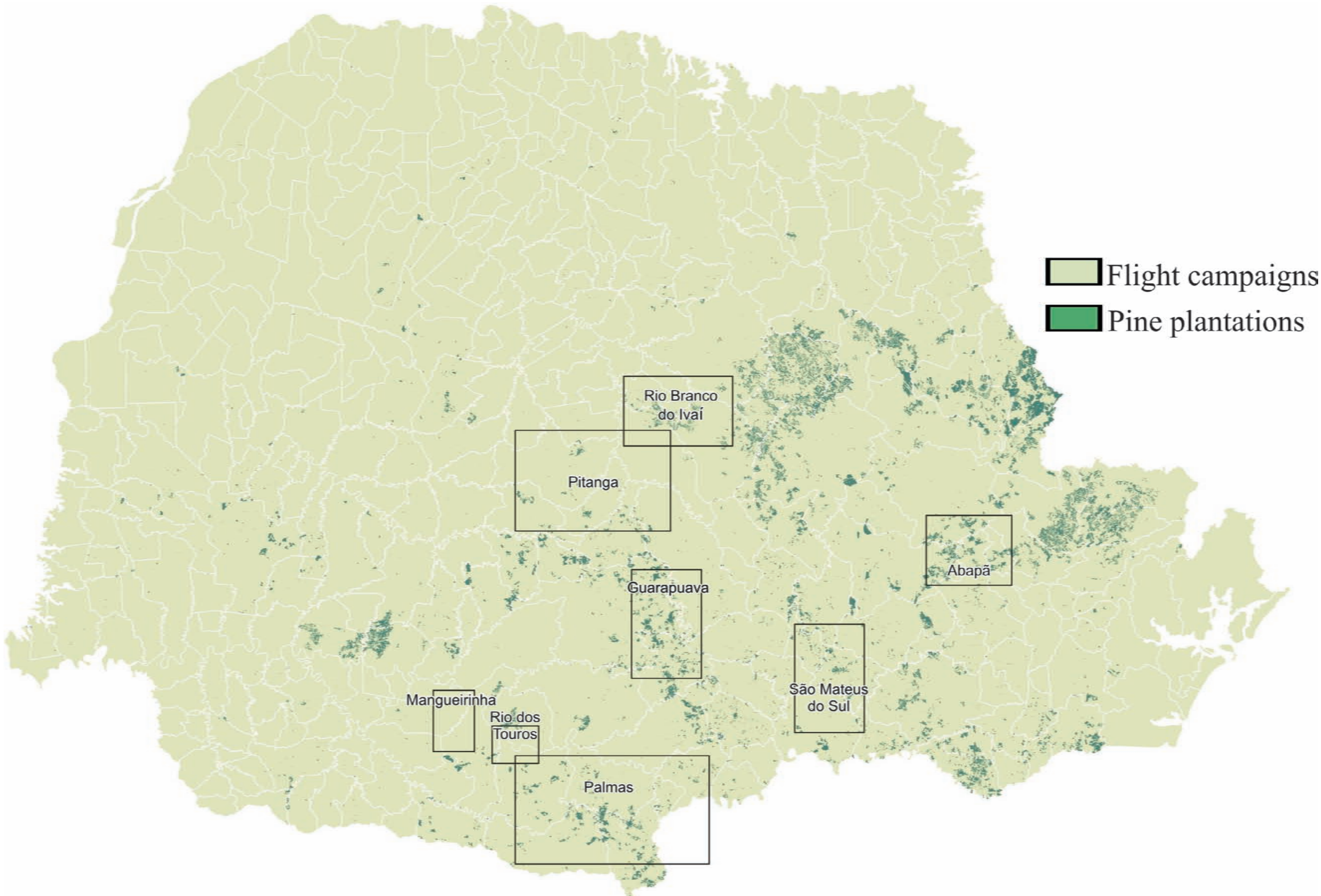

Figure 1. Flight Campaign Areas in Parana State.

Figure 2. Cessna 185 Aircraft Used for Both Observer Training and Operational Aerial Sketchmap Surveys in Southern Brazil.

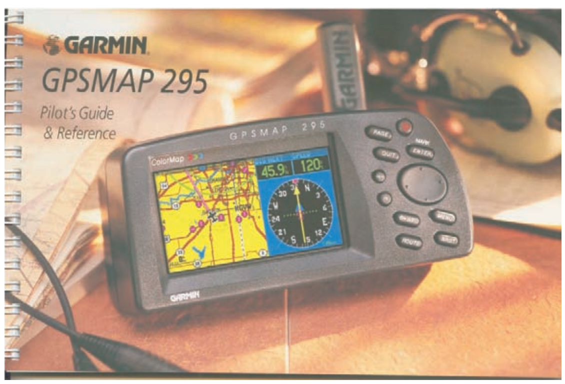

Figure 3. The Garmin GPSMAP 295 Global Positioning System (GPS) Receiver Used in Aerial Sketchmap Surveys.

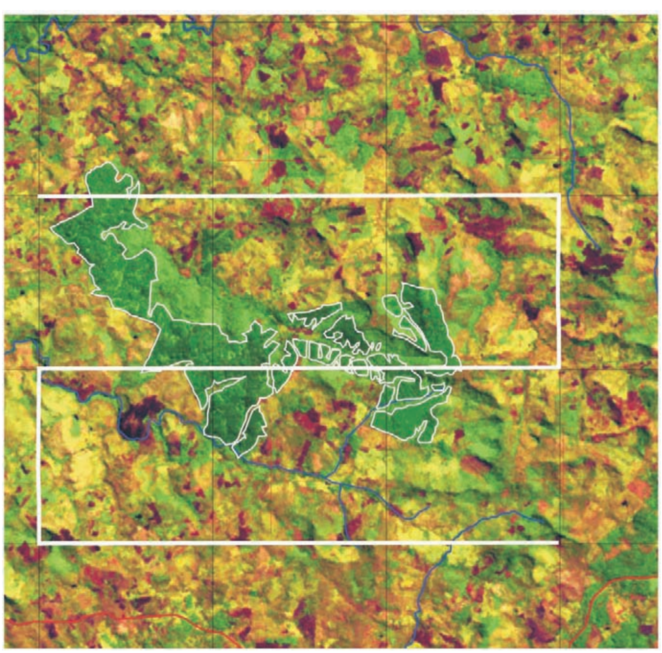

Figure 4. Flight Lines Established on Satellite Map.

- commission errors: natural and planted Araucarian forests; eucalyptus plantations.

The accuracy assessment was performed in GIS environment on a polygon basis, i.e., the ground control points were represented by the centroids of "ground truth" polygons. For the region known as Abapã it was found that the visual interpretation of satellite imagery omitted 10.74 percent of the existing pine stands. On the other hand, 2.4 percent of the polygons assigned to the "pine class" belong actually to other vegetation classes on the ground. For this region the overall accuracy equaled 87.46 percent, which is rather good considering average accuracies around 80 percent for automatic classification of Landsat imagery (COLEMAN and others, 1990; CAMPBELL, 1996).

Surveys for the Discrimination of Different Successional Phases in Remnants of Araucarian Forests in Southern Brazil

In the year 2000 the Paraná State Government has mapped all the remnants of Araucarian forests present in the State (PROBIO Project) using automatic digital classification of Landsat TM imagery. The classification results, which included five forest types, were refined by ground checks and ancillary data. In 2003, as a part of the aerial sketchmapping program, an aerial survey was conducted over a sample area in remnants of the Araucarian Forest with two main objectives:

- To develop an aerial signature for the classes considered in the previous mapping.
- To update the year 2000 classification.

For this type of survey the satellite maps were overlaid with a 4 km UTM grid, major roads, drainages and the polygons resulting from the final digital classification made by the Government staff. Before the operational flight actually took place, the USDA Forest Service/Embrapa team and the government staff have flown over a demonstration site so that the sketchmappers could be trained in recognizing the different forest types.

After the survey was done the first thing to be pointed out was the indubitable richness of details one can gain from a 300-meter-high flight perspective. Not only the forest remnants could be mapped, but also different land cover classes such as bare soil and row crops (Fig. 6). Depending on the scale of the base map (in this case, 1:25.000) even the presence or absence of riparian forests could be annotated.

The sketchmappers also discussed the benefits and trade-offs of superimposing the previous classification results on the satellite maps. Due to the dynamic changes

Table 2. Coding system for Aerially Visible Forest Damage Signatures in Southern Brazil.

Host/code	Damage type/code	Damage intensity (% of trees affected in plantation or polygon)/code
Araucaria angustifolia/Au	Monkey/2	Light (<5%)/L; Heavy (≥ 5%)/H
Pinus spp/Pi	Wood wasp/1	Same as above
	Monkey/2	Same as above
	Armillaria/3	Same as above
	Cinara spp/4	Same as above
	Defoliation/5	Same as above
	Chlorosis or yellowing/6	Same as above
Eucalyptus spp/Eu	Chlorosis or yellowing/6	Light (<5%)/L; Heavy (≥ 5%)/H

Table 3. Omission and Commission Errors Related to the Causal Agent as Determined by Aerial Sketchmapping Surveys.

Causal agent	Omission error (%)	Commission error (%)
Wood wasp	0	10.71
Monkey	40	0
Wood wasp/monkey	50	0
Chlorosis	0	0

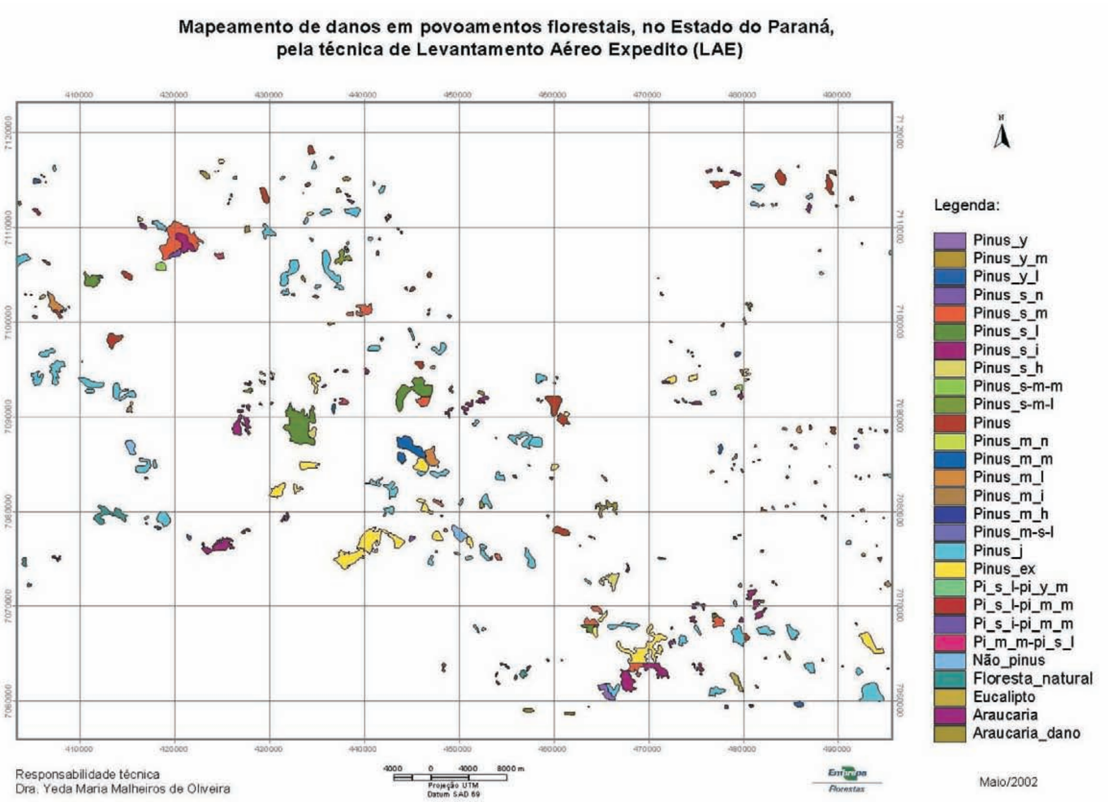

Figure 5. Forest Damage Map Resulting from an Aerial Sketchmap Survey Over the Region of União da Vitória – Paraná State.

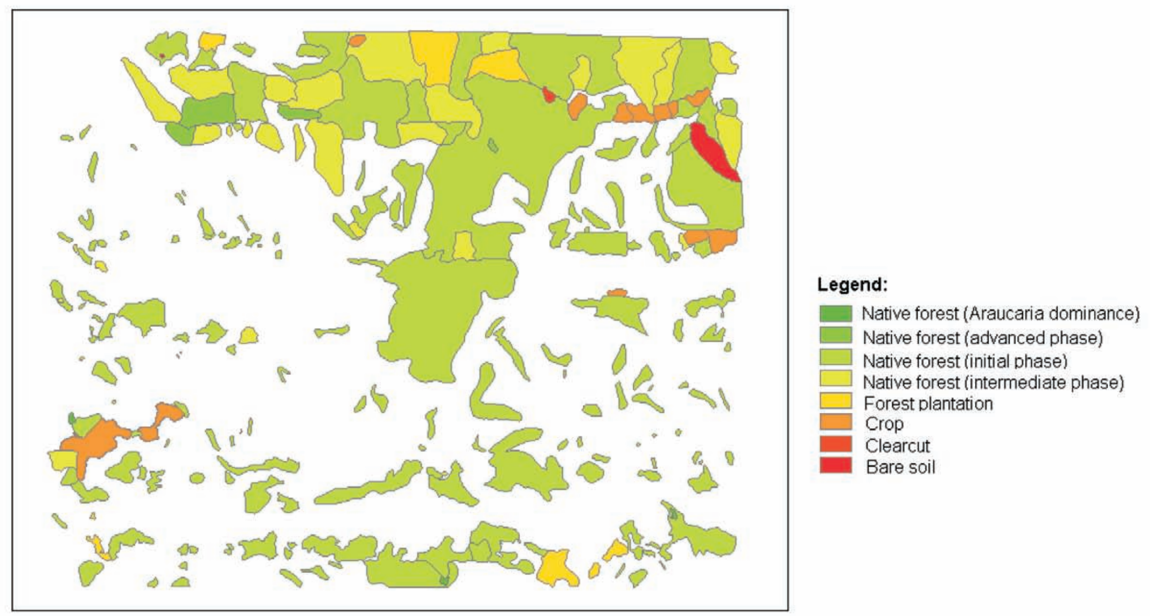

Figure 6. Results of the Aerial Sketchmap for the Region of Rio dos Touros Showing Land Use and Native Forest Classes.

of land cover classes and also to the subjectiveness in defining the forest types it would sometimes be recommended not to overlay any polygons on the base map. In fact, the classes considered for the digital classification represented three different successional phases of secondary native forest, a forest plantation class and a native forest class with 80 percent or more of Araucaria trees cover. Excepting the forest plantation class, the four other classes resemble so much each other that it is rather difficult to perform even a regular classification. Many differences concerning location and classification of forest types were found in the two survey approaches. When considering solely the "native forest" and "non-native forest" classes, the agreement between the two approaches could reach 49 percent in terms of the total surveyed area.

The aerial sketchmapping of the Mangueirinha Indian Reserve (fig. 7) presented similar results to those obtained by the digital classification only for the polygons representing the "intermediate stage" and "araucaria dominance," whose calculated areas differ in about 30 percent. Major differences between the survey and the classification are related to the class "initial stage," which seems to be represented in a larger extent in the aerial survey than in the PROBIO classification results. Many areas recognized (from the air) as "initial stage" has been misclassified as "araucaria dominance." Confusion arose also in the class "advanced stage," with differences in measured areas around 90 percent between the Probio and the aerial survey results.

The aerial survey was also concerned with other land use classes, such as "bamboo," which occurs often in Araucarian Forests and has lately been considered as a threatening factor to the natural regeneration of the species *Araucaria angustifolia* (parana-pine).

The Forest Reserve of Caçador, in Santa Catarina State, was also flown during the 2002 campaign. The main objective was to classify the remnants of Araucarian Forest inside and outside the Reserve in three *Araucaria angustifolia* (parana-pine) cover classes, which can be seen on the resulting map, showed in figure 8. "Au1" labels represent forest patches with more than 80 percent of araucaria cover, while "Au2" represent classes between 80 percent and 20 percent of araucaria cover, and "Au3," less than 20 percent. Pine (Pi) and Eucalyptus (Eu) plantations, as well as exploited areas (Ex), were also mapped. These results provided the basis for further research involving landscape analysis approaches and the visual interpretation of high resolution satellite imagery.

Surveys to Monitor Deforestation in Remnants of Araucarian Forests

The most recent campaign carried out by the Embrapa team was a survey requested by the Brazilian Environmental and Renewable Natural Resources Agency (IBAMA) to monitor anthropogenic deforestation in remnants of Araucarian Forests in two different areas in Paraná State. The low-altitude flight allowed the mapping of 48 points of varying intensities of deforestation, including areas where the process has just begun ("deforestation traces").

The observers used the same flight to check the forest plantations for accuracy assessment as well as for the

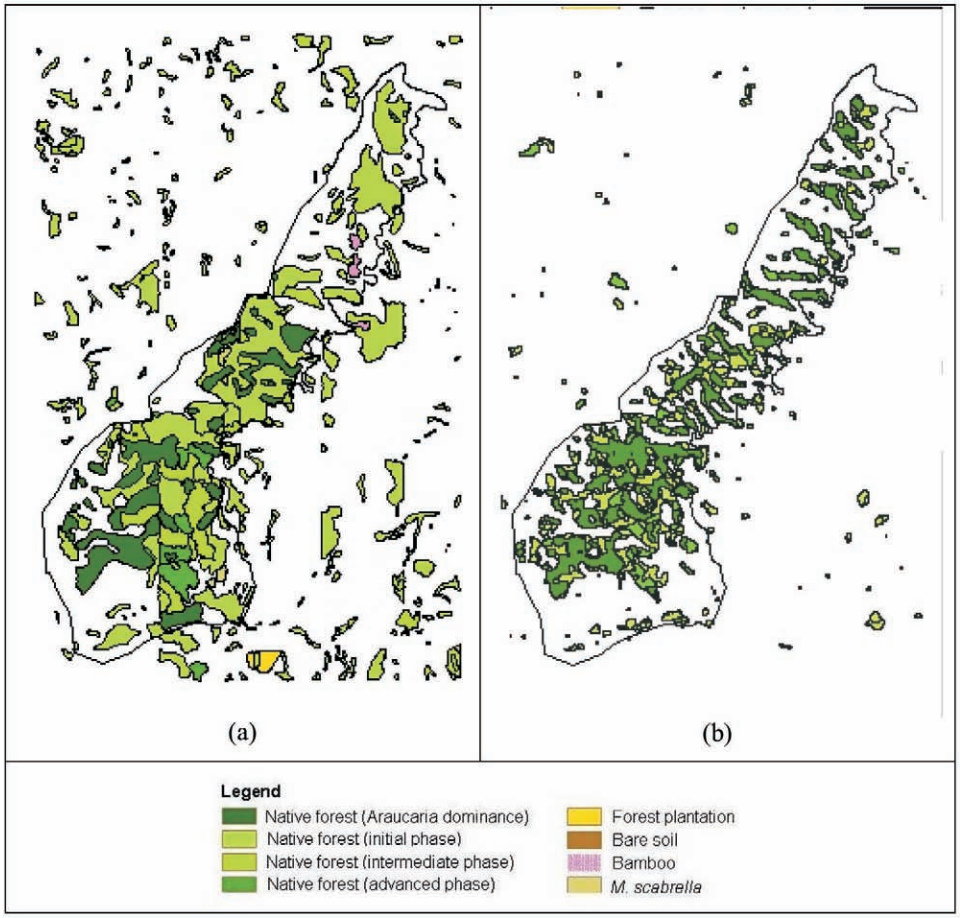

Figure 7. Results of Aerial Sketchmap Survey (a) and Digital Classification (b) for the Mangueirinha Indian Reserve, Paraná State.

detection of woodwasp infestations (fig. 9). The IBAMA staff is now engaged in ground checking operations using data (maps, reports and tables) generated by the Embrapa GIS.

This last campaign (April, 2004) provided also the opportunity for two additional Embrapa employees to be trained as aerial observers, thus contributing to the consolidation of the technique in Brazil.

Future Steps

Until now four major approaches were identified for the use of aerial sketchmap surveys in Southern Brazil:

- the detection and mapping of forest damage, mainly in – but not limited to – forest plantations;
- the assessment of thematic accuracy of other remote sensing techniques, like, for instance, digital classification or visual interpretation of satellite imagery; the updating of existing forest maps;
- the mapping and classifying of forest remnants and other environmentally relevant features such as riparian forests, wetlands, etc.

As annual flight campaigns are being carried out, the Embrapa aerial observer team is becoming more proficient at identification of damage types typical of Southern Brazil and is now able to expand the provisional coding system developed during the first years of this project.

Forest health researchers are concerned with recent infestations of the eucalyptus red gum lerp psyllid in Eucalyptus stands located in Paraná and São Paulo States. The detection and mapping of forest damage caused by this insect seems to be a new challenge for the aerial sketchmap surveys in Southern Brazil.

Another important aspect of full-scale implementation is prompt ground checking of damaged areas detected from the air. In this regard Embrapa is expecting to develop partnership with forest plantation owners, who would be able to give field support for ground checking as well as to provide silvicultural and management information related to the forest stands for which damage has been reported.

An interesting issue has arisen after the 2003 flights over the Araucarian Forest regions and it is related to the need of recording some kind of imagery during the flight. When analyzing the survey results, the sketchmappers and the government staff pointed out that it would be very useful to have some video imagery or aerial pictures to help them characterize and identify the aerial signature of the feature,

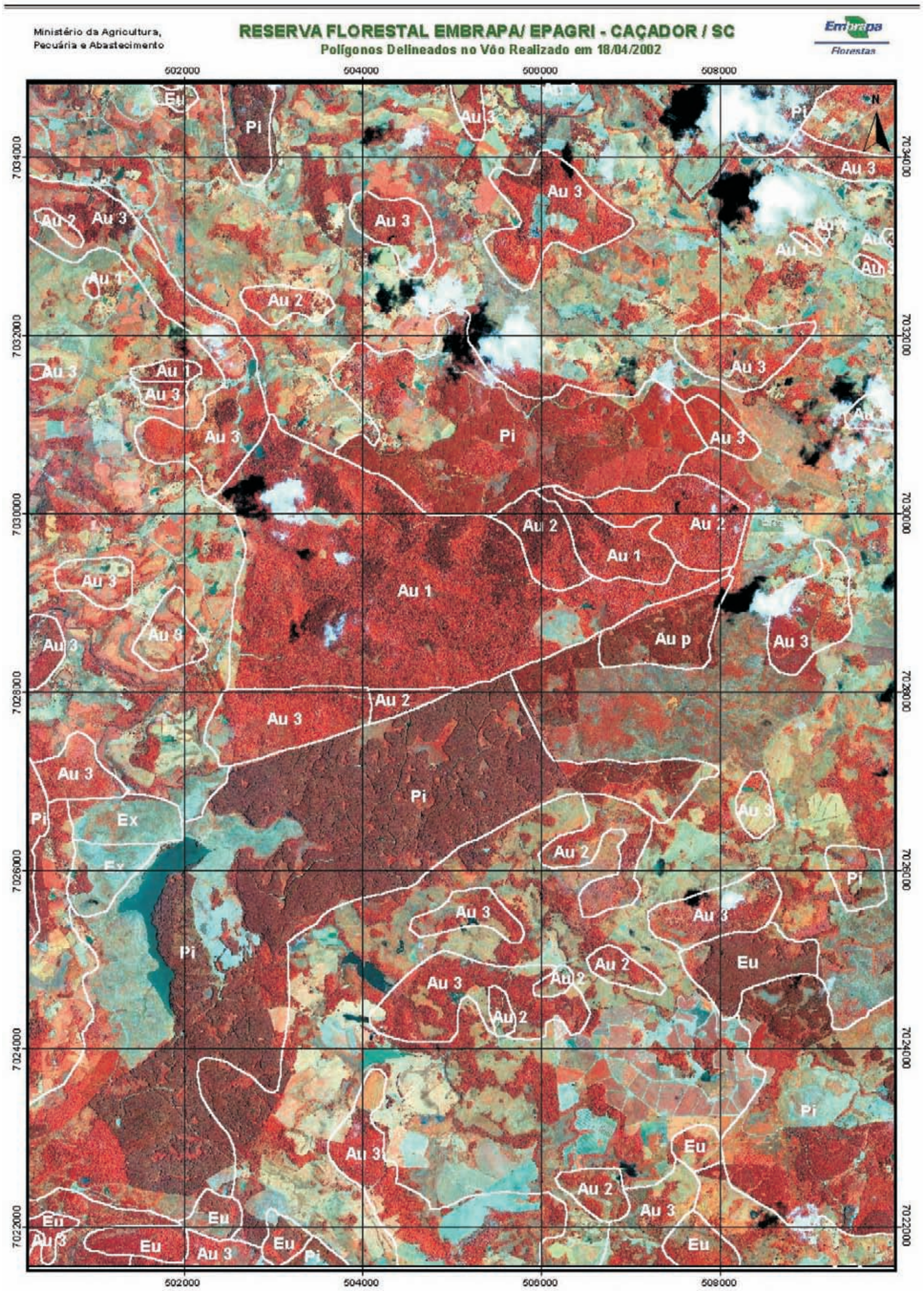

Figure 8. Results of the Aerial Sketchmap Survey for the Forest Reserve in Caçador, Santa Catarina State, Overlaid on an IKONOS (NIR-G-B) Composition.

vegetation class or phenomenon being studied. This topic was discussed during the workshop held in Curitiba, in November 2003 and the sketchmap team decided that it is worth testing different methods of image acquisition in future steps of the aerial sketchmap program.

Significant advances in computer technology, GPS, and GIS have led to the interest in the development of electronic enhancements, both in Canada and the U.S., to allow direct recording of forest damage on maps stored in a laptop computer during aerial sketchmap surveys (CIESLA, 2000). The USDA Forest Service/Embrapa team is now planning to introduce the digital aerial sketchmap system in Brazil. Previous feasibility studies concluded that the application of this new technique would pose no difficulties for the Brazilian conditions, since the base maps used in the surveys are already composed and stored in digital format and that the USDA Forest Service Forest Health Technology Enterprise team can provide some of the software and other equipment necessary for the system to operate. It should, thus, be tested and implemented in future flight campaigns.

Conclusions

The aerial sketchmap program in Brazil is in full development and some facts that have contributed to its successful implementation are:

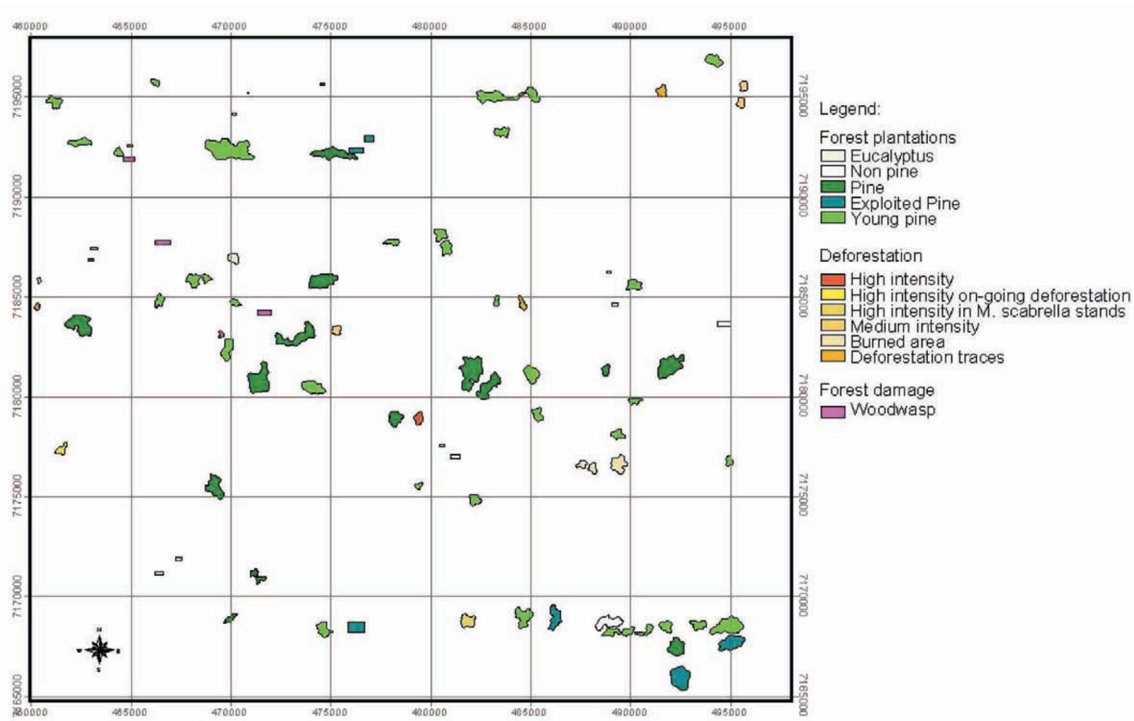

Figure 9. Partial Results of the Aerial Sketchmap Survey for the Monitoring of Deforestation in Remnants of Araucarian Forests (Region of Guarapuava – Parana State).

- the constant support of USDA Forest Service Forest Health Technology Enterprise Team;
- through its members, who introduced the aerial sketchmapping in Brazil and who were always eager to adapt the technology to Brazilian environmental and working conditions;
- the great extent of forest (natural or planted) present in Southern Brazil and the land use dynamics which demand new methods for forest monitoring;
- the interest of forest owners and public agencies in applying the new technology for various purposes;
- the interest of Embrapa – being a public research agency – in developing and adapting techniques that will contribute to the sustainable use of forest resources.

Flight campaigns in Brazil have demonstrated that clearcuts, land use change detection, and other anthropogenic activities in Araucarian Forests may be suitably mapped and monitored from the air. The aerial sketchmapping technique represents, therefore, an inexpensive and effective alternative to the monitoring and conservation of this endangered biome in Southern Brazil.

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Naturalness as a Paradigm for Environmental Services Assessment

Martín Alfonso Mendoza B., Ana Lid del Angel P., and Gabriel Díaz

Abstract—*The municipality of Coatepec, Veracruz, Mexico, has been the first in Mexico to set up a purse and a payment scheme to pay for environmental services. The scheme at Coatepec focuses on water resources, though many other similar programs exist throughout the world. Here a theoretical analysis permits to study and understand the dominant effect that position and arrangement play in the relevance of specific forms of land cover and stand structure in regard to a differential importance to overall level of environmental quality that society enjoys. The driving force that makes a difference in the importance of a specific stand is the degree of resemblance to pristine conditions in its structure and functions, modified by the strategic position on the ground respect resource position and users location in the watershed. Attributes of natural conditions were inferred from landscape ecology theory, and from historic records from the region. These attributes are then converted to importance values for a catalog of current conditions present in the region, and applied over a land classification map. Value estimates are drawn from an arbitrary scale that can be translated into a certain payment for environmental services rendered. These latter translation requires a definition of a specific purse of public money, or else, a theoretical estimate of service demands from stakeholders and affected regional population. The estimate of environmental services value is presented in a map and a payment scale in tabular form, for conditions in the Coatepec municipality in 2002.*

Introduction

This paper deals with the relative importance that position provides to environmental relevance of cover types and structure. Although it is natural to accept that spatial arrangement is an important factor that modifies the role and weight of those elements that constitute environmental quality, applications such as valuation of environmental services generally portray poorly this hierarchic strategic importance. Using a case study, a specific instrumentation is presented. This design uses a measure of naturalness weighted by public preferences and relative position to segregate which areas contribute the most to environmental quality.

Environmental quality, in the context of this paper, is the subjective perception about personal welfare associated with human environmental condition. As such, a hierarchic scale derived from public preferences is a suitable device to generate a value scale to use in land classification.

Forest continuity as measured by fragmentation statistics is one of the principal expressions of geographic differentiation. Feasibility of self-sustaining populations requires sufficiently large gene pools that move around genes freely. Considering trees as the most demanding of populations, it is convenient to think about genetic feasibility in terms of terrain covered by a continuous tree canopy. Besides serving as a proxy for most species genetic pool, continuity in canopy also represents a number of important ecological functions and environmental influences, such as watershed regulation of water flow, and soil stability.

Edge effects also have been a matter of attention in landscape ecology because they are seen as detrimental of the productive performance of timber stands. However, edges between wooded areas and open ground are gradients that create an interphase between contrasting environments, and as such, they represent a valuable storage of opportunities and diversity in wildlife habitat, and ecological influences in the interface between forested and open ground. Careful handling of opportunities and hazards in edge environments is one new priority in forest management that resulted from advances in landscape theory.

The global trend to achieve social efficiency in environmental services markets has developed in Mexico into a scheme where government sets up arbitrary sums of money to allocate as subsidy for those landowners whose properties contain specific vegetation covers in good natural condition. Since stocking, composition and other spatial independent attributes are used as criteria in selecting whose land deserves subsidy, no consideration is given to landscape factors such as fragmentation, connectivity, edges, and strategic position. In this paper a contention is made that similar pieces of land will have contrasting weight over the amount and quality of the most important environmental services, depending on its position, extent, amount of edges, and chances for connectivity. Water is the resource that this study uses as example because it is also the resource whose services are the foremost presence in the public mind, and in the government declarations.

The design presented is a scheme that assesses environmental quality of pieces of land judging the presence of characteristic elements expected in natural conditions, weighted by position in the watershed (highlands being more influential), nearness to water and riparian zones, continuity in canopy (best if <10 000 ha, and >50 ha), minimal edge condition, near other wooded blocks (<200 m). Weights are defined subjectively, following hierarchic preferences of the local public.

One study case, the municipality of Coatepec, Veracruz, is presented as example, and as a means to explain the scheme and its properties and capabilities. Coatepec is a small municipality (around 14 000 ha), just 20 km away from the state capital of Xalapa, is part of the most important coffee producing region of Mexico. The mountain range of Sierra Madre Oriental gives Coatepec a mountainous setting with steep valleys descending on the Golf of Mexico's coastal plains. Coatepec is the first place in Mexico to introduce a program of subsidies for environmental services, and its peculiarities are favorable to research because they display many different vegetation types, degrees of land development, and steep topography that offers varied resource scenarios, from supply of water for cities, an irrigation district, water sports and fishing, channel stability upstream, and flood hazards downstream.

Methods

A land elevation model and vegetation classification was taken from INEGI. Public opinion was gathered though a survey of random interviews using a fixed response questionnaire. The questionnaire uses non monetary valuation questions to elicit the interviewee choice of preferences regarding environment, and public spending on environment related programs. Finally, description of current structures and condition for all cover types present was obtained by sampling random points along regional transects, and measuring and registering specific attributes of natural and developed conditions for a given land cover type.

Definitions

Natural cover types:

- Temperate mixed conifer forest
- Cloud forest
- Medium tropical forest
- Low tropical forest.

Developed conditions and transformed cover types:

- Temperate forest: prairie, grassland, homestead
- Cloud forest: coffee plantation, cultivated grassland, city, town, rustic residential area
- Medium tropical forest: fruit orchard
- Low tropical forest: intensive cropping (sugar cane, produce), annual cropping (corn), grassland, town

Seral stages of natural vegetation:

Mapping criteria adapted from Oliver and Larson (1990):

- Initiation – One story, no crown differentiation, any age, but usually young pre-reproductive, little or no fuel load.
- Exclusion – One story, crown dominance, some density related mortality, some fuel load of fine fuels, any age.
- Reinitiation – Two stories, some medium to large openings, some fuel load, some snags.
- Diversification – More than two stories, all sorts of openings in diverse stages of regeneration, considerable levels of fuel, some large woody debris but seldom fully degraded, many snags, rare catastrophic events but many and frequent small disturbances, many large trees, some reaching maximum longevity.
- Old growth – Large and old trees, numerous small disturbances with regeneration of every possible age, large accumulation of sizable woody debris, all fully decayed including large snags heart rotten, topped.

Special Conditions

- Riparian zone
- Roads, trails, highways

Assessment

Transects across the region permitted sampling of all cover types and the variability of their conditions. Area contains not enough repetitions or ample zones of a single cover and condition, so sampling was selective with criteria emphasis on representivity, spread of distribution, and the inclusion of as much variability as it could be detected during a preliminary survey.

After selective choice of a location in a given transect, sample point was randomly selected within the apparent extent of continuous cover of the same kind. All conditions of the cover present at the sampled location were sampled, whether they were seral stages, defining attributes for the cover and condition, and special conditions such as houses, cities, or other man made structures, stretches of dirt or paved roads, and segments of channel and riparian conditions. When more than one special condition was present, or if enough length of linear conditions, randomization defined the sample position.

Point variables were measured or registered at the sample point. Area measurements were taken from a relaskope plot centered at the sample point. Length observations and measurements were taken in stretches of 20 m of road or stream.

Field data was summarized. The list of values in a cover and condition combination constituted its description for purposes of land classification and assessment of environmental quality. Each polygon with a given cover and condition was given a relative value of 1 if it were in a natural condition, more than 50 ha in area, less than 2 times the perimeter of an equivalent circle in edges, had at least 5 % of small openings inside, was inside a riparian area, and in the upper third of the watershed in elevation. Weights reducing the initial value were added for each factor missing. Weight value sought to create a spread of values representative of the observed variation in that criterion during the field transects. Developed and damaged sites were evaluated according to the apparent suitability of the current condition for providing a similar effect as the natural covers; for instance, city environment is judged as an efficient cover for regulating the water resource, while annual crops are highly ineffective in the same way.

Valuation

A photo mosaic with images depicting characteristic elements of most local cover types and conditions was presented to a random sample of persons in the locality. Randomization was done by home or work location. Control responses were taken from a set of scientists and government officers, and a set of persons randomly selected at the state capital of Xalapa, a large city 20 km away of the study area, and a community with extraordinary leverage in land management policies and decisions in the region. Sampled individuals were asked to identify which images are the most natural, which they felt provided the most environmental services, and which of the environments represented they liked best, or would like to see in their region. Then, they were asked their opinion and assessment of government spending in environmental programs. This question was paired to the respondent's expressed need for a better environment, if any.

Considering that the local and national government already is allocating a certain budget for environmental programs, the relative share for Coatepec can be considered as a purse that is to be divided among those landowners possessing land that provides or protects environmental quality. With this thought in mind, the level of public funding could be divided by the study area and then multiplied by the relative worth factor previously estimated.

Results

Survey results indicate that there is an overwhelming satisfaction with the current level of environmental quality in Coatepec, and therefore, the public sees no need to increase government spending, nor pass on the cost of environmental services and externalities to businesses, farms, nor consumers. Additional verbal comments from some interviewees explain that the only environmental concern at this point is the need for government to assure no additional environmental degradation, nor land development of any sort. These results can be interpreted as an unwillingness to pay for additional environmental services or quality. See the geographic distribution of cover classes in figure 1.

The total study area involves 69223 ha, practically all of them in a single watershed drained by La Antigua river. Forested area is 4452 ha, split into 1004 fragments of up to 214 ha; only 31 fragments (998 ha) can be considered functionally as forests. Coffee plantations and other orchards with forest like functionality occupies 5111 ha, while other agriculture and animal production uses 22204 ha. Urban development has used an additional 3793 ha. Considering a 200 m buffer zone, riparian conditions add up to 1857 ha, but only 727 ha are forested and they contain.

In all the study area only one polygon had a relative worth of one, and two had a greater than 0.9. The rest are fragments of vegetation away from riparian or highland conditions, and therefore unlikely to seriously enhance the region's environmental quality, therefore, it would be socially inefficient to pay subsidies to these landowners until they, could change their land management to a more socially responsible manner.

Persons interviewed were asked if they could identify the cover type, assess the degree of good or bad environmental condition, and finally, express their relative personal preference.

Data sampled included verification of cover indicators, as defined above. Then elements defining naturality were listed in each locality.

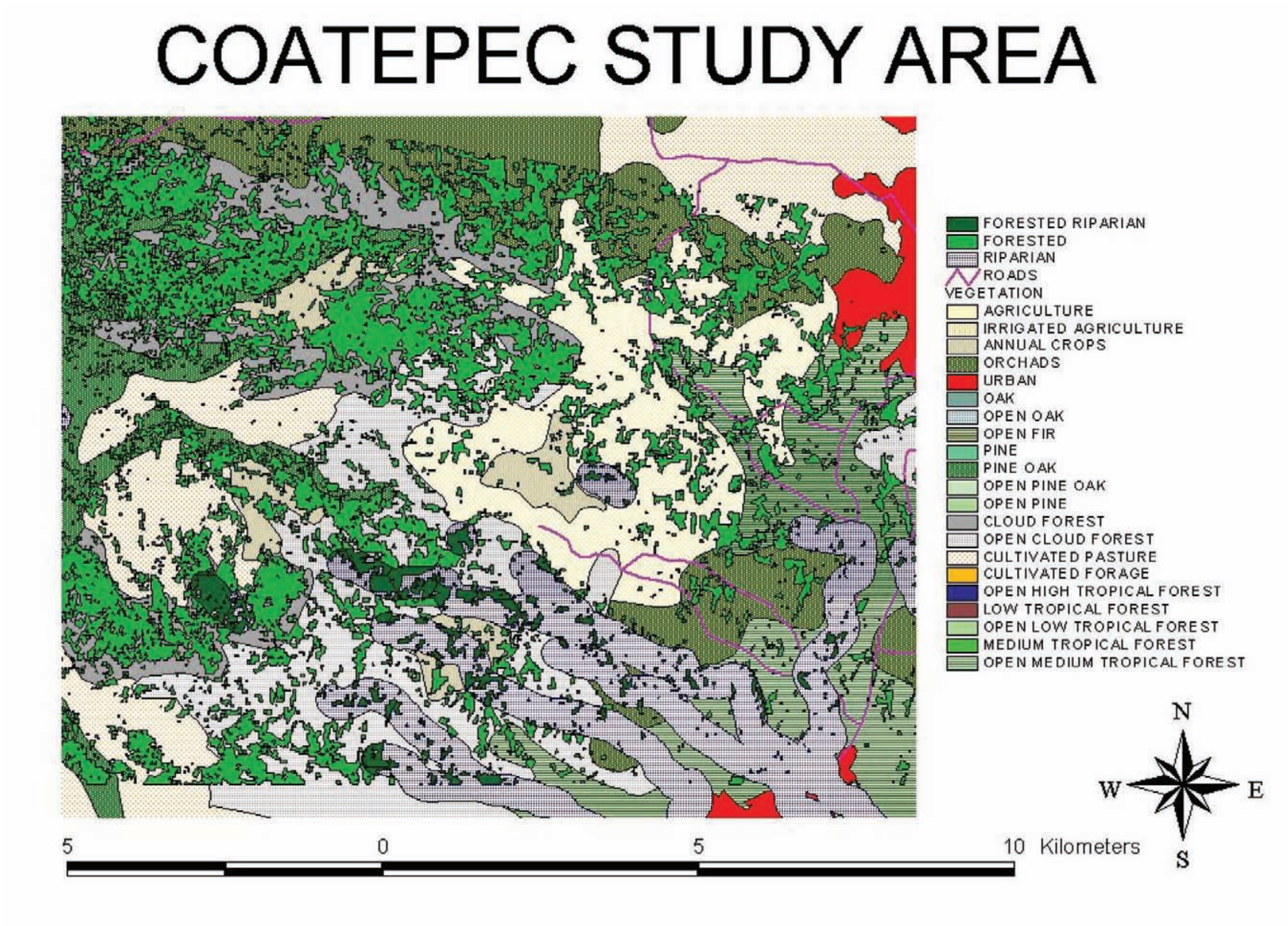

Figure 1. Coatepec study area forested fragments and vegetation cover types.

Cover Distribution

Potential cover (natural) is assumed to be as defined by INEGI (map of veg. cover).

For each polygon in the map was estimated area, net area deducted from edge effects (a 30 m buffer was assumed), and distance to the closest polygon of the same cover type. Valuation in the previous phase was weighted subjectively in a 0 to 1 scale to consider deductions if polygon net area were less than 50 ha. If a polygon had less than 50 ha, the area of all polygons of the same kind within a 200 m distance were added before deducting the weight.

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A Heuristic for Landscape Management

Martín Alfonso Mendoza B., FIPRODEFO, Bruselas 626 Col. Moderna, 44190 Guadalajara, Jalisco, México
Jesús Zepeta S. and Juan José Fajardo A., Consultoría Ambiental SC, Emiliano Zapata 96, 46900 Mascota, Jalisco, México

Abstract—*The development of landscape ecology has stressed out the importance of spatial and sequential relationships as explanations to forest stand dynamics, and for other natural ambiences. This presentation offers a specific design that introduces spatial considerations into forest planning with the idea of regulating fragmentation and connectivity in commercial forest stands when these stands are subject to silvicultural regimes for conversion to a condition similar to pristine. El Llanito, a group of forest tracts privately owned in Atenguillo, Jalisco, Mexico, is under a forest plan that will serve as an example of landscape management. In this plan, the harvest schedule from SICODESI, a traditional Mexican forest management method, is used as the initial feasible solution in a heuristic that introduces successive changes in prescription, and timing of treatment, to improve the solution features, considering fragmentation and connectivity specs, and the proportional balance of successional stand structures. Results in the example case show a clear trend towards a more balanced distribution of successional stages, and a harvest level comparable to historic levels. There is a slight decline in fragmentation and connectivity goals, much of which can be explained by the sizable amount of area damaged by pests and fire in the previous cycle. This outcome is a welcomed improvement over the features displayed by the SICODESI solution, which could have been chosen if landscape management were not available.*

Introduction

Landscape ecology has brought attention to spatial relationships that explain many of the most important ecological processes. Keeping track of disturbance patterns is one recurrent theme in spatial studies within landscape ecology. Introducing these advances into forest management planning is the purpose of this paper.

The particular case of Mexican forestry favors one particular design of landscape management. After almost a century of harvesting in commercial timberland stand structure has changed in a way that characteristic elements of late successional stages have been drastically reduced, while the simpler and younger stand structures typical of early succession predominate. Fragmentation and connectivity have steadily worsened. Stand structure demands specific silvicultural regimes, known as biopaths, to gradually replenish elements that define mature and old stages and functions. Meanwhile, adjacency and time sequence in treatments need to keep tabs on fragmentation and connectivity. Designing a form of forest planning that will fulfill both aims is requires the use of a specific heuristic such as the one presented here.

Case Study

El Llanito is a forest comprising a set of five contiguous forested tracks controlled by a single timber company, Sánchez Monroy Cia. S. de R.L. de C.V., and managed by a single consulting firm, Servicios Forestales Profesionales Mascota S.C. The 3357 ha of El Llanito contains 2017 ha of commercial timber land covered with mixed conifers. These biological and socioeconomic conditions are representative of many other forest in the southwest of Jalisco.

In 2002, a new forest plan was needed to guide the fourth entry in the forest. The steady hand of a

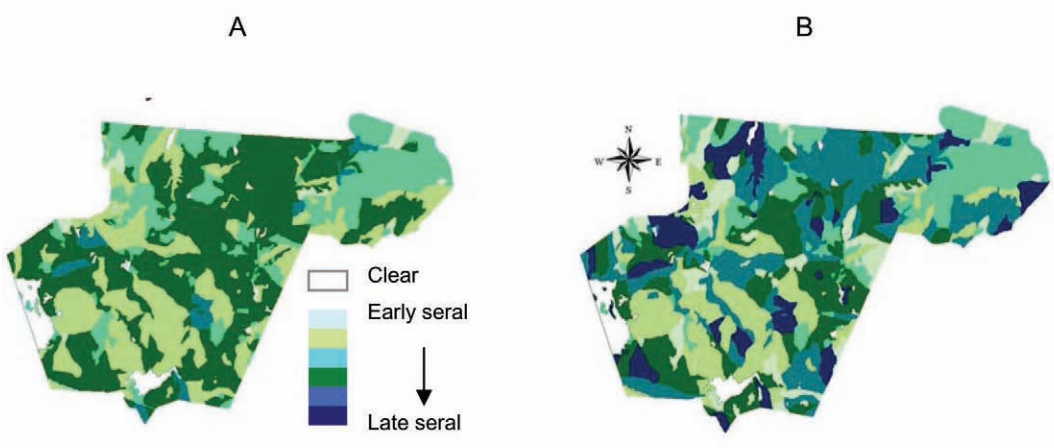

Figure 1. Current stand conditions (A), and landscape management expected stand structures (B). El Llanito, Jalisco, México 2002-2011 forest plan.

professional forester has conducted a careful and continuous, long term operation in El Llanito. The residual forest structure still contains considerable stocking and opportunities for silviculture, hence offering a benevolent setting where new ideas such as landscape forest management, can be tested with ease.

Silvicultural Regimes

Background

The initial entries in El Llanito followed selective criteria that fostered liquidation of old-growth elements, but retained most of the former structural diversity and canopy stories. Difficulties with diminishing regeneration was one factor in a policy change in 1992 towards even-aged silviculture. For a decade these efforts advanced in developing high yield, young, single story stands, and solved the regeneration concerns of the past through applying seedtree cuts to the most mature stands.

In the previous cutting cycle catastrophic events impacted a third of the forest area, reducing 9 percent standing volume in the commercial portion of the forest. Neither selection nor even-aged regimes were prepared to handle recurring considerable pests and fire damages, because both assume no catastrophic events. They only deduce a small penalty to adjust standing volume estimates. However, the whole region is prone to serious fire and pest incidents that reach El Llanito, even though it is located at the top of the mountain range known as Sierra Occidental.

Timber Regimes

Under the new landscape management, each stand is visited by a professional silviculturist and prescribed. Mature one story stands generally are assigned for final harvest. Natural regeneration is obtained from seedtrees. Sites with slope or erosion potential receive a lighter cut similar to protection cut. Areas with multiple canopy stories, and low productivity stands are regenerated using selection cut. All other stands are prescribed thinning, except if stocking is so low that it would be uneconomic to log.

Special Regimes

Crests and riparian zones are prescribed special biopaths that pretend to reconstruct natural conditions. Presence of very large trees with long crowns, plenty of large woody debris in advanced decay, minimal organic matter and small fuels, dense understory with visibility under 50 m are desirable attributes that are retained when present, and fostered when absent.

Best Management Practices

Road network was carefully surveyed to define stretches of road that could be closed and vegetated, specially shortcuts and roads near riparian conditions. Some of the access roads had small portions in need of realignment, but most were prescribed a set of improvements in line with FAO's low impact logging specifications (Dykstra and Heinrich 1996).

Forest Planning and Regulation

Net revenue optimization was the initial approximation to a harvest schedule for the planning cycle 2002-2011. This criterion is in line with the private nature of forest ownership, and interests of the logging firm. Maintaining an even flow of harvest similar in amount to the previous cycle was a second level screening criterion. Last, feasible combinations of stand, treatment and annual cutting area allocation were required to follow a rule that every annual cutting area should at least maintain fragmentation and connectivity stats.

Results

Figure 1 depicts graphically differences between unconditional revenue maximization, and the final round of choices in harvest schedule. A total of 300 stands (93.5 %) received regimes different from the unconditional recommendation prescribed by the silviculturist. Most changes were from options where those that allowed the revised prescription to be coherent with the current stand condition. This meant to induce an accelerated change to latter seral structures in 119 stands, and move to early successional stages the other 181 stands.

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Distributed GIS Systems, Open Specifications and Interoperability: How do They Relate to the Sustainable Management of Natural Resources?

Rafael Moreno-Sanchez, Department of Geography and Environmental Sciences, University of Colorado at Denver, Denver, CO

Abstract—*The aim of this is paper is to provide a conceptual framework for the session: "The role of web-based Geographic Information Systems in supporting sustainable management." The concepts of sustainability, sustainable forest management, Web Services, Distributed Geographic Information Systems, interoperability, Open Specifications, and Open Source Software are defined and their relevance and relationships are explained. The potential contributions of web-based GIS systems to natural resources sustainable management is highlighted.*

Introduction

The aim of this is paper is to provide a conceptual framework for the session: "The role of web-based Geographic Information Systems in supporting sustainable management." The concepts of sustainability, sustainable forest management, Web Services, Distributed Geographic Information Systems, interoperability, Open Specifications, and Open Source Software are defined and their relevance and relationships are explained.

Due to the multi-faceted role of the natural resources, and more specifically of the forest resources, sustainable forest management necessitates decision-making which recognizes and incorporates: a) diverse ecological, economic, and social processes; b) a multitude of variables; and c) conflicting objectives and constraints. Furthermore, all these elements most be considered at different spatial and temporal scales.

One thing is to clearly defined sustainability and sustainable forest management and other is to make these concepts operational through decision-making processes, decision support systems, and management strategies. Most studies have focus on either the ecological, economic, or social aspects of the forest management. Few have aimed to address these three aspects at the same time into specific decision-making processes or support systems (Varma, Ferguson and Wild, 2000). Also, if Communication and Information Technologies (CIT) such as the World Wide Web (WWW or the web), Geographic Information Systems (GIS), or computer based decision support systems, are part of the tools used in the implementation of the concept of sustainability, the sustainability of these tools should also be addressed as part of a comprehensive sustainable management approach.

The ability of Geographic Information Systems (GIS) to deal with spatial and non-spatial information has long be recognized as a notable feature that can contribute significantly to deal with the complexity of diverse information sources, information management activities, and analyses required to develop sustainable management alternatives (Cowen, 1990; Varma, Ferguson and Wild, 2000; Wing and Bettinger, 2003).

The geo-processing principles and functionality found in GIS systems are moving out of a tightly defined niche into the information technology (IT) mainstream. Isolated, standalone systems are being replaced by integrated components, and large applications are being replaced by smaller, more versatile applications that work together transparently across networks. Of these, the World Wide Web (WWW or the web) is becoming the core medium for distributed computing in IT generally and in the geo-processing domain specifically (Hecht 2002a). In other words, GIS systems, once focused on data and tools implemented with client-server architecture, now are evolving to a Web Services model (Dangermond 2002). In this new architecture the web is used for delivering not just data, but geo-processing functionality that can be wrapped in interoperable software components called Web Services. These components can be plugged together to build larger, more comprehensive services and/or applications (Hecht 2002b). Interoperability between heterogeneous environments, systems and data is fundamental for the implementation of this Web Services model. Interoperability is achieved by complying with Open Specifications (OS).

The remainder of this paper will present each of the previously mentioned concepts and how they relate to each other. The importance of web-based GIS systems is highlighted. Finally, future directions for development and research are suggested.

Defining Sustainability and Sustainable Forest Management

Sustainability has been defined in many different ways. The fuzziness associated with its various definitions is typical of a "young paradigm" (Bosshard, 2000). Sustainability can be understood more as a journey rather than a destination. As managers aim to make the concept operational they learn from their experiences and adjust not only the methods used but the concept itself. A broad definition of sustainability is: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Sustainable forest management involves managing forests as ecosystems, and it involves an integration of: a) environmental benefits and values: b) socio-economic and cultural benefits to meet human needs; and c) institutional arrangements to formulate and implement appropriate policies and programs and to monitor their effectiveness. These three elements are dynamic and change over time. (Canadian Council of Forest Ministers, 1997).

Defining Open Specifications (OS), Interoperability, and Open Source Software (OSS)

Open Specifications (OS) provide software engineers and developers information about a given specification as well as specific programming rules and advice for implementing the interfaces and/or protocols that enable interoperability between systems. The Open GIS Consortium Inc. (OGC) (http://www.opengis.org) defines interoperability as "the ability for a system or components of a system to provide information portability and interapplication cooperative process control. In the context of the OGC specifications this means software components operating reciprocally (working with each other) to overcome tedious batch conversion tasks, import/export obstacles, and distributed resource access barriers imposed by heterogeneous processing environments and heterogeneous data."

Herring (1999) and Kottman (1999) present an in depth discussion of the OpenGIS Data Model and the OGC process for the creation of OS respectively. Software products can be submitted for testing their interfaces for compliance with OGC OpenGIS Implementation Specifications (see http://www.opengis.org/techno/implementation.htm for the most recent approved and in process specifications). Initially, the only OpenGIS Specifications that products could conform to were the OpenGIS Simple Features Specifications for CORBA, OLE/COM and SQL (McKee, 1998), now there are eleven. Within computer environments there are many different aspects of interoperability (Vckovski, 1998): a) Independent applications running on the same machine and operating system, i.e., interoperability through a common hardware interface; b) application A reading data written by another application B, i.e., interoperability through a common data format; and c) application A communicating with application B by means of interprocess communication or network infrastructure, i.e., interoperability through a common communication protocol. Besides technical issues, there are also interoperability topics at higher levels of abstraction such as semantic barriers (Harvey, 1999; Seth, 1999). A system based on the OS later described would be able to achieve a level of interoperability of the second type above described.

According to Hecht (2002a) interoperability is desirable for the following reasons: a) it allows for communication between information providers and end users without requiring that both have the same geo-processing or viewer software; b) no single Geographic Information System (GIS), mapping tool, imaging solution or database answers every need; c) there are large amounts of database records with a description of location that have the potential to become spatial data, and also, advances in several technologies (e.g. GPS integrated into mobile devices) are increasing the amount of database records with location information; d) the number of software companies offering components to deal with geographic information is growing; e) it is more efficient to collect data once and maintain them in one place. (This is particularly cost effective if communities of users can find, access and use the information online, so they don't need to access, retrieve and maintain whole files and databases of information for which others are responsible); f) the ability to seamlessly combine accurate, up-to-date data from multiple sources opens new possibilities for improved decision making and makes data more valuable; and g) the ability for multiple users, including non-GIS experts, to use a particular set of data (perhaps at different levels with different permissions) also makes the data more valuable. Gardels (1997) discusses how compliance with OGC's OpenGIS specifications and the resulting interoperability can contribute to integrating distributed heterogeneous environments into on-line environmental information systems (EIS). He points to three technical strategies (federation, catalogs, and data mining) for the integration of these systems, and how they are heavily depended on interoperability among diverse data sources, formats, and models. He concludes that properly designed geodata access and analysis tools, combined with open environmental information systems, can provide sophisticated decision support to the users of geographic information.

Two organizations have been coordinating the development of the most relevant open specifications used in creating web-based GIS systems: The OpenGIS Consortium Inc. (OGC) (http://www.opengis.org), and the World Wide Web Consortium (W3C) (http://www.w3.org). To this date the W3C has created more than forty technical specifications (http://www.w3.org/TR/). As of January 2002, the OGC has adopted nine OpenGIS Implementation Specifications and 11 candidate specifications are in the works (Hecht 2002c; a roadmap to the specifications work is presented at http://www.opengis.org/roadmap/index.htm).

Briefly, Open Source Software (OSS) are programs whose licenses give users the freedom to run the program for any purpose, to modify the program, and to freely redistribute either the original or modified program without further limitations or royalty payments (http://www.opensource.org/docs/definition.php). Among the most well known OSS projects there are the Linux operating system and the Apache web server. Some times the term Open Technologies is used to refer to these projects and others such as XML, HTML, TCP/IP, and Java technology. A comprehensive list of GIS-related OSS can be found at http://opensourcegis.org/. According to Wheeler (2002) OSS reliability, performance, scalability, security, and total cost of ownership are at least as good as or better than its proprietary competition, and under certain circumstances, they are a superior alternative to their proprietary counterparts.

Defining Web-based GIS, Web Services and Distributed GIS Systems

The Internet has changed how GIS data and processing are accessed, shared, and manipulated. Internet GIS or web-based GIS (we will use both terms interchangeably, although strictly they are not the same) is a research and application area that utilizes the Internet and other internetworking systems (including wireless communications and intranets) to facilitate the access, processing, and dissemination of geographic information and spatial analysis knowledge (Peng and Tsou, 2003).

Web Services are interoperable, self-contained, self-describing, module components that can communicate with each other over the WWW (Peng and Tsou, 2003). The OGC envisions that Web Services will allow future applications to be assembled from multiple, network-enabled geoprocessing and location services. The GIS Web Service is a vendor-neutral interoperable framework for web-based discovery, access, integration, analysis, exploitation, and visualization of multiple online geodata sources, sensor-derived information, and geoprocessing capabilities (OGC, 2001).

The development of GIS technology has closely mirrored the development of computer technologies. It has evolved from mainframe GIS, to desktop GIS, to client/server GIS architectures, to the most recent paradigm Distributed GIS or Distributed GIServices. Distributed GIServices are Web Services, they represents a dramatic departure from the traditional client/server model. Rather than relying on desktop GIS programs, Distributed GIS, when fully implemented, does not necessarily require the user to install GIS programs on the user's desktop. Distributed GIServices are built using distributed-component technology, which can connect to and interact with multiple and heterogeneous systems and platforms without the constraints of traditional client/server architectures (Montgomery, 1997). Distributed-component frameworks break up the client and server sides of an application into smart components that can interoperate across operating systems, networks, languages, applications, tools, and multi-vendor hardware. Currently there are three major infrastructures for distributed-component technology: CORBA, DCOM and .NET, and Java technology. Under a Distributed GIServices architecture, there is no difference between a client and a server. Every GIS node embeds GIS programs and geodata and can become a client or a server based on the task at hand. Furthermore, in this architecture components are interoperable and can be downloaded to create adhoc GIS system to satisfy specific users' needs. These systems rely on the Internet and wireless networks for data and processing communication. Users can access the GIS analysis tools and data from anywhere with Internet access or wireless data service coverage. The client could be a desktop computer, a laptop computer, a Personal Digital Assistant (PDA), or a mobile phone (Peng and Tsou, 2003). A Distributed GIS is defined as a network centric (wired or wireless) GIS tool that uses the Internet or a wireless network as a primary means of providing access to distributed data and other

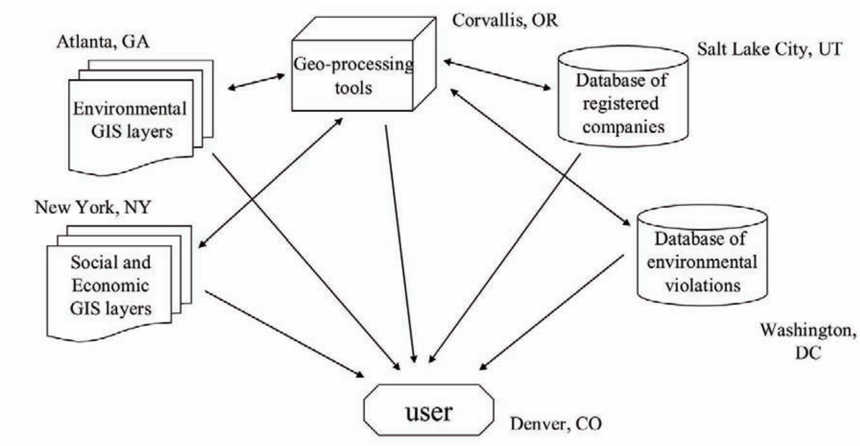

Figure 1. Example of a Distributed GIServices system. Each node in the system can serve as a client or a server and they are dynamically linked. The nodes in the system can be distributed in different geographical locations. Each data set or application is maintained in one place, any changes to them are immediately available to all the other nodes or users. All communications take place over the WWW.

information, disseminating spatial information, and conducting GIS analysis (Peng and Tsou, 2003).

Distributed GIS systems have the following characteristics: a) they make use of integrated dynamic client/server architecture, i.e. every node in the system can behave as a server or a client depending on the task at hand; b) they are web-based; c) they are composed of several nodes found in different locations, and these nodes are dynamically linked (data and applications are kept current because they are maintained at one location in the network); d) they are cross platform (not limited to any kind of machine or operating system), and interoperable (they can work transparently with other components that comply with the same Open Specifications); and e) ideally, they do not need locally installed data and GIS software. Figure 1 presents a hypothetical Distributed GIS system.

The Relevance of the Previously Presented Concepts to the Sustainable Management of Natural Resources

The evolution of GIS towards a Web Services architecture is moving us closer to the delivery of the full potential of GIS technology to contribute to address some of the most challenging informational needs for making the concept of sustainability operational. GIS has long be acknowledged as a key tool to deal with the large amounts of spatial and non-spatial data from different sources, at different spatial and temporal scales, and to carry out the analyses required to support the creation of sustainable management alternatives.

How do the technologies described in the previous sections relate to each other? Anderson and Moreno-Sanchez (2003) make a detailed presentation of these relationships. Briefly, compliance with Open Specifications enables interoperability of data and applications. Let's talk first about OS that enable interoperability at the data level. One of the most important Open Specifications (OS) for the development of web-based information systems is the Extended Markup Language (XML). XML is a World Wide Web Consortium (W3C) OS and a subset of the Standard Generalized Markup Language (SGML) [ISO 8879] (http://www.w3.org/TR/1998/). XML uses pairs of text-based tags, enclosed in parentheses, to describe the data. These tags make the information passed across the Internet "self describing" (Waters 1999). XML satisfies two compelling requirements, firstly it separates data from presentation, and secondly, it transmits data between applications. XML is a metalanguage, for example, a language that describes other languages (Boumphrey et al. 1998; http://www.xml.com). These languages are called XML schemas.

The OGC has developed the Geographic Markup Language (GML) specification (http://www.opengis.net/gml/02-069/GML2-12.html). This Open Specification is an XML schema for the encoding for the transport and storage of geographic information, including both the spatial and non-spatial properties of geographic features. In GML the geometries and attributes of geographic layers are represented within XML tags, again, this brings forth all the advantages of XML's openness, transportability, and interoperability. GML is designed to support interoperability and does so through the provision of basic geometry tags (all systems that support GML use the same geometry tags), a common data model (features/properties), and a mechanism for creating and sharing application schemas (GML 2.1.2 specification at http://www.opengis.net/gml/02-069/GML2-12.html).

GML will become the dominant format for the distribution of geographic data. For example, in Europe the British Ordnance Survey is using GML to deliver the Digital National Framework on the web and to mobile devices (Holland 2001; http://www.ordinancesurvey.co.uk/dnf/home.htm). In the hypothetical Distributed GIS system in figure 1 all geographic data would be in GML format. All non-spatial data contained in Database Management Systems (DBMS) would be input and output in XML format. All the distributed components of the system would be able to read and write GML and XML hence creating interoperability at the data level among the components.

To enable interoperability between the applications in the system, each of the distributed components in the system would have to be developed complying with OS for interprocess communication. For example, the following OS are important when developing interoperable web-based functionality (http://www.opengis.org/specs/). The Web Map Services (WMS) OGC Open Specification provides three operations protocols (GetCapabilities, GetMap, and GetFeatureInfo) in support of the creation and display of registered and superimposed map-like views of information that come simultaneously from multiple sources that are both remote and heterogeneous. The Web Map Features (WMF) OGC Open Specification describes data manipulation operations on OpenGIS® Simple Features (feature instances) such that servers and clients can "communicate" at the feature level, i.e. individual feature instead of "pictures" (like in the case of WMS) can be transferred between clients and servers. The Web Map Coverage (WMC) OGC Open Specification extends the WMS interface to allow access to geospatial "coverages" (in OGC terminology these are raster layers) that represent values or properties of geographic locations, rather than WMS generated maps (pictures).

Open Source Software (OSS) offers an alternative to proprietary web-GIS, DBMS, and web server software. The advantages and disadvantages of using these OSS to create web-based spatial information systems are detailed in Anderson and Moreno-Sanchez (2003).

A Distributed GIS system would offer the characteristics and advantages of interoperability listed by Hecht (2002a) in section three of this paper. Specific data sets (spatial and non-spatial) could be maintained in one location with the benefits of increase consistency, easy of maintenance, and security. Specific GIS geo-processing functionality could be offered as Web Services, for example a buffer function, an overlay function, or more complex spatial modeling procedures could be invoked or downloaded to integrate an adhoc GIS system to support a specific decision-making process. Individuals or companies, by simply complying with OS could develop very specific or sophisticated modular functionality that could be easily and transparently integrated into a Distributed GIS system. Up-to-date data and functionality could be seamlessly integrated from multiple sources without the need for import/export processes, download of data, or software extensions. Finally, in an ideal Distributed GIS implementation, end users would not need GIS software or data installed locally in their machines.

We can easily imagine how all the above-mentioned capabilities would be relevant for supporting sustainable natural resources management approaches. Instead of creating large decision support systems developed by a single agency, company or group of individuals, the Web Services and distributed systems approach leverages the resources (data sets, Information Technology know-how, and specific expertise) and the creativity of the whole community of interested parties in the problem. Different federal, state agencies, or private companies, would maintain specific spatial and non-spatial data sets, as well as geo-processing functionality and make them available as Web Services. For example, WMS, WFS, or WCS would be used for the distribution of spatial data. If necessary, these organizations could send or receive geographic data in GML format (or non-spatial data in some XML schema) to other nodes in the system, or authorized end users. Metadata for spatial and non-spatial data sets would be kept in XML format and would integrate a searchable directory of resources available to any of the distributed GIS system components and end users. Individuals, public and private organizations could develop interoperable components to address specific analytical or processing needs, and these components, once accepted, could be made immediately available to all the nodes in the distributed system as well as to end users. End users would not need high-end computers or expensive GIS or DBMS software to interact with the distributed system. In and ideal distributed system deployment they would not need local specialized software (a web browser would suffice) or local data.

Much work has been done on the development of web-based participatory planning systems to incorporate stakeholders input into natural resources management decision-making processes (Kangas and Store, 2003; King, 2002; Kingston, Carver, Evans and Turton, 2000; Laukkanen, Kangas and Kangas, 2001;Varma, Ferguson, and Wild, 2000). The systems created through these efforts could be redesigned to interoperate with the rest of the components in a distributed system. They could take advantage of the rest of the resources available in the system, and through their output provide input to other components such as optimization routines to generated management plans. In other words, the integration of more powerful decision-support systems would be easier in distributed-components architecture.

Conclusions

To this day all the above-mentioned capabilities have not been fully implemented in a Distributed GIS system, however, constant technological developments, and the spread of the necessary technical knowledge will make this possible in the very short term. The most popular commercial GIS software vendors are incorporating plug-ins to be able to read and write data in GML format, make use of WMS, WFS, and WCS. Sooner rather than later federal and state agencies will start to use GML as the dominant format for their data.

There is a need to develop small prototype Distributed GIS implementations to demonstrate the capabilities of this architecture, expose some of its limitations, and point to the areas that need more research to create the large distributed systems that are required to address sustainability problems at different spatial and temporal scales.

If tools such as Distributed GIS systems and Decision Support Systems are used in developing sustainable natural resources management approaches, the sustainability of these tools also must be addressed as part of the whole sustainable management approach. Little research has been done on this regard.

Finally, as for any web-based information tool, broader issues of equality, accessibility, and environmental, social and economic impacts of these technologies need to be evaluated. It has been suggested that the birth of Information Societies brought about by the use of Communication and Information Technologies could lead to new approaches to sustainability and sustainable growth (Bohlin, 2001; Ducatel, 2001). These issues are becoming of strategic importance and fundamental to long-term prosperity and security for any nation or region of the world seeking to have influence in the 21st century.

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Spatial Statistical and Modeling Strategy for Inventorying and Monitoring Ecosystem Resources at Multiple Scales and Resolution Levels

Reich, Robin M, Professor of Forest Biometry and Spatial Statistics, College of Natural Resources, Colorado State University
Aguirre-Bravo, C., Research Coordinator for the Americas, Rocky Mountain Research Station, USDA Forest Service
Williams, M.S., Mathematical Statistician, Rocky Mountain Research Station, USDA Forest Service

Abstract—*A statistical strategy for spatial estimation and modeling of natural and environmental resource variables and indicators is presented. This strategy is part of an inventory and monitoring pilot study that is being carried out in the Mexican states of Jalisco and Colima. Fine spatial resolution estimates of key variables and indicators are outputs that will allow the modeling of complex ecological conditions relevant to resource planners and managers for supporting decision making processes at multiple scale levels. Several procedures for model evaluation and multiscale spatial estimation are also key components of this strategy. Point and spatial statistical estimates will be evaluated so that issues of accuracy and precision can be properly addressed. Products from the application of this strategy will be reported at multiple scales. Final recommendations for field implementation will be made in light of the evaluations of the study results.*

Introduction

Growing demands for geospatially explicit information are emerging as a result of complex sustainability challenges. This plus the technological changes that are taking place are accelerating the rate at which traditional approaches to statistical estimation and modeling are being transformed to meet the new needs of the Geospatial Information Age. Driven by these trends, experts and institutions everywhere are continuously reassessing and redirecting their programs and technical capabilities. Institutions that have relevant research and monitoring programs for the assessment and sustainable management of ecosystem resources are at the forefront of implementing the necessary technological transformations.

Over the years, data and information for land management and environmental protection applications have been generated by a variety of means to meet institutional needs for planning and decision making processes. In forestry and natural resources, for example, institutions in most countries have a variety of research and monitoring programs, several with long operational histories. Different sampling strategies (Frayer and Furnival 1999) using various remote sensing technologies (Holgren and Thuresson 1998) and field measurement protocols are common among these institutional programs. Typical outputs include national and state tabular statistics for describing specific target populations and their related cartography. Now that geographical information systems are widely available, assessment results and a variety of information from these programs have the potential of being reported within a geospatial framework for large-scale strategic applications.

While the intent of national inventory and monitoring programs is to generate statistical summaries and cartography for strategic purposes, it is clear that this information has limited value for tactical and operational applications. These programs, being content-biased due to the nature of their systematic sampling design, can not account for the variety of spatial pattern and ecological conditions that exist at small scales of spatial resolution. For local spatial contexts, where humans interact with ecosystem resources and make a variety of management decisions, it is critical to know where the resources are located, their extent and condition, and the intensity and direction of their ecological change. To effectively address these and other related questions, the data and information provided to local planners and decision makers must be available at multiple levels of spatial resolution (Aguirre 2001).

In light of the above, a spatially balanced estimation and modeling strategy is required to generate geospatial data and information that meet local stakeholder expectations. Pixel-level statistical modeling opens new opportunities for describing the complexity of ecosystem resource attributes at multiple resolution levels and for advancing the designs of current inventory and monitoring programs. Outputs from spatial statistical models can also be used to develop estimates of population attributes and their measures of central tendency at multiple geographic scales. Due to these and other advantages, spatially explicit products have a very high potential utility for supporting planning, management and decision making processes. Generating these products and making them available may be one of the most defining technological innovations for land management and environmental protection of institutions in the 21st century.

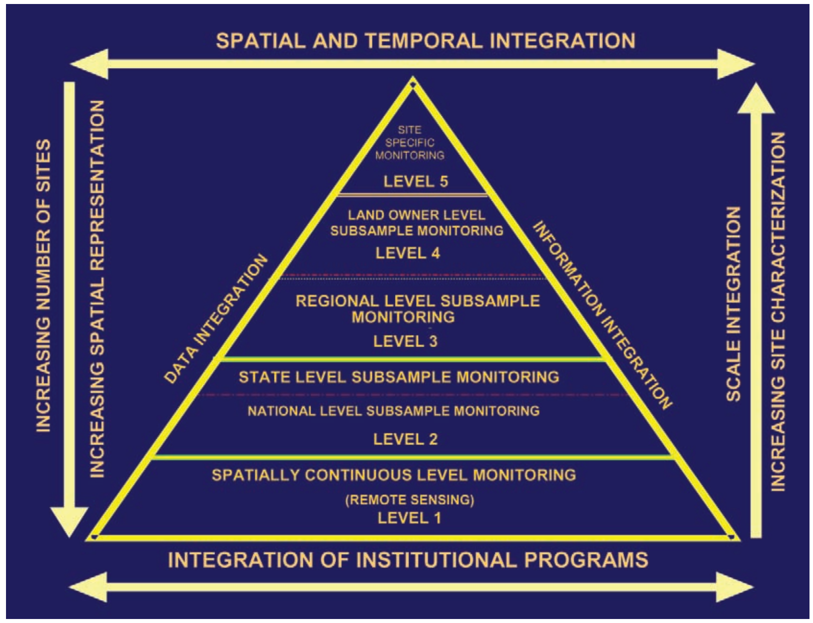

Figure 1. Conceptual model for integration of monitoring design and institutional processes.

The objective of this paper is to present a spatial statistical modeling approach for inventorying and monitoring ecosystem resources so that the resulting outputs can be used for a variety of multi-scale applications, particularly for local operational contexts. In addition, the paper documents the spatial statistical modeling approach recommended for the Mexican states of Jalisco and Colima's pilot study project on monitoring and assessment for the sustainable management of ecosystem resources.

Integrated Monitoring Framework

In designing an integrated multi-resource inventory and monitoring system to evaluate the condition and change of variables and indicators for sustainable ecosystem resource management (for example, forest, rangeland, agriculture, wildlife, water, soils, biodiversity, etc.) one needs some baseline data for comparison. Given that we are dealing with complex systems, it is not wise to select one or two variables for ecological monitoring purposes. Also, analyzing variables independently of one another may lead to incorrect conclusions because of their spatial inter-dependencies. Statistical estimates and modeling processes are significantly influenced by the spatial patterns of relationships between and among variables. The spatial variability and arrangements of attributes to be measured are important factors to consider in choosing the proper sampling strategy. Techniques commonly used in describing spatial relationships between two or more variables include regression analysis and a variety of geostatistical procedures that take into consideration spatial and temporal dependencies (Cliff and Ord 1981).

The proposed framework for integrated ecosystem resource monitoring will rely on information collected at different spatial scales of resolution and sampling intensities and designs to provide detailed information for regional state and local levels for ecosystem resource planning and management purposes (fig. 1). At each monitoring level, particularly at the local levels (Level 4-5), field measurement protocols and plot designs must be compatible with those used at state and regional geographic scales (Levels 2-3). Remote sensing data from high resolution sensors cuts across all possible monitoring scales (Level 1). National level monitoring assessments will be generated using statistical procedures that are compatible with spatial modeling at smaller scales. Central to this integrated approach is its advantage for optimizing the use of field data from multiple sources when meeting interoperability criteria, thereby minimizing cost and maximizing utility of products from inventory and monitoring programs.

An important feature of this integrated framework is the products and outputs that will be developed at each level and their uses at higher levels of the inventory. At the lowest level, a land cover map will be generated for the entire study area. This map will be constructed from the combination satellite imagery, digital elevation models and a large data set of inexpensive ground information (Level 1). This map will provide general information on the extent and spatial location of the major and minor cover types found in the study area. This map will also be used in Level 2 for area frame construction and as a tool to post-stratify data derived from a systematic sample of permanent ground plots that are collected for the purpose of long-term monitoring and estimating forest resources at the National and State level (Level 2). While the estimates derived from Level 2 will be design-unbiased and efficient, the small sample size and systematic spacing of ground plots is generally poor for spatial modeling purposes. To address these deficiencies, Level 3 of the inventory will use a stratified sampling scheme to ensure that ground data will be collected in all of the land categories of interest. The Level 2 and 3 ground data will be used, in conjunction with the Level 1 map to develop spatial models that describe the land resources structure of the study area. The goal of Level 4 is to identify areas where the spatial models are not performing well and to collect additional data for the purpose of refining the models in these locations. Thus, the Level 4 data will be a purposive sample of ground plots for the purpose model refinement. Level 5 is reserved for special studies. This may include intensively sampled monitoring locations, but little can be said about the types of analyses performed at this level due to the unknown nature of the issues.

Pilot Study Area

The Pilot Study Area consists of the Mexican southwestern states of Jalisco and Colima with a continental area of approximately nine million hectares (twenty million acres). Though Jalisco is larger in area (90 percent), the state of Colima (10 percent) plays a very distinctive role in the economy of the whole region and diversifies the Pilot Study Area considerably. Four major ecological regions provide the natural resources and environmental conditions that make this region one of the most prosperous in Mexico (fig. 2). The eco-regions are the transversal neo-volcanic system, the southern Sierra Madre, the Southern and Western Pacific Coastal Plain and Hills and Canyons, and the Mexican High Plateau. Linked to these ecological regions, there are several important Hydrological Regions (HR) that drain to the Pacific Ocean (HR12 Lerma-Santiago, HR13 Huicicila, HR14 Ameca, HR15 Costa de Jalisco, HR16 Armeria-Coahuayana;, HR18 Balsas, and HR37 El Salado). One of the watersheds, the Lerma-Santiago Hydrological Region is connected to Chapala Lake, the most important source of water for the City of Guadalajara.

Precipitation ranges from roughly 300 mm/year in some locations to more than 1200 mm/year in the higher elevations, with the principal precipitation coming in summer monsoons. The ecological systems of this region cut across the boundaries of other Mexican states. For example, several major watersheds drain through the tropical and subtropical forests of the state of Colima.

Figure 2. Location of the states of Jalisco and Colima, Mexico.

Mostly in the state of Jalisco, water from surface and underground sources is heavily used for agriculture and industrial activities, though a significant portion goes to meet the domestic needs of approximately ten million people. While on average Colima is humid, water in the state of Jalisco is a critically limiting resource that threatens the sustainability of urban and rural ecological and economic systems. Most of the land (85 percent) in the state of Jalisco is privately owned. Small private landowners are the main driving force of economic development in agriculture, forestry, and rangeland economic activities. In contrast to Colima, for example, a small portion of Jalisco's land is owned by ejidos (10 percent), communities (3 percent), and the government (2 percent). Recently, as a result of trade liberalization brought about by NAFTA policies, new industries have been established in these two states and natural resource utilization has increased due to higher population growth rates.

The region's biophysical heterogeneity blends itself to bring about unique habitat conditions for a large diversity of plant and animal species. Within its boundaries, there are a significant number of species of mammals and birds, many of which are severely threatened by human activities. Some of the plant and animal species are endemic to specific locations within the ecological regions that comprise the Pilot Study Area. Extensive areas of pine-oak forest are home to "specialty" birds such as the thick-billed parrot, the Mexican-spotted owl, and woodpeckers. It is thought that habitat loss is the single most important element affecting bird populations in this ecosystem complex. Not much is known about how (in other words, what, when, where, why) plant and animal species are being impacted by human activities. Water and other biological resources are an integral part of these ecological regions whose services transcend geopolitical domains and jurisdictions.

Data Sources and Description

Data are derived from various sources and using a number of different sampling protocols. One common feature is that data collection and analysis will be designed for a 10 m spatial resolution, meaning that all data will be scaled and stored on a 10 m grid system covering the study area.

GIS Data

GIS grids of elevation, slope, and aspect will be developed from digital elevation models. Grid coverages for each topographic variable will be resampled (Resample function, nearest neighbor, Grid Module (ARC/INFO®, ESRI 1995) to provide a 10 m spatial resolution.

Landsat TM Data

Landsat Thematic Mapper (TM) data contains 8 spectral bands. The data comprise 11 Landsat scenes that are radiometrically and geometrically corrected. Grids of spectral bands 1-8 of a cloud-free, 2002 and 2003 Landsat TM image will be resampled to a 10-m spatial resolution as above and averaged by moving a 3 x 3 pixel window (FOCALMEAN, Grid Module; ARC/INFO®, ESRI 1995) over the resampled grids. Each 10 m x 10 m pixel of resampled Landsat data will therefore represent an average of the surrounding 30 m x 30 m pixels, except for the central 10-m pixel of the original 30 m Landsat pixel, whose value will not change. Resampling is important because not all of the sampling units will fall within spectrally distinct areas; some plots may land in transition zones between spectral classes. Averaging of the Landsat information reduces potential registration errors and better reflects changes in forest structure and vegetative types measured on the ground. Use of other remote sensors (for example, SPOT, MODIS, IKONOS, etc.) will also be investigated as part of this study.

Landcover Point Data

To develop a detailed vegetation map of the pilot study area, point data will be collected throughout the two states to identify major vegetation types. To date, approximately 750 points have been visited. Field crews will identify land areas that clearly meet the definition of each cover type. At the location of each sample point, a Global Positioning System (GPS) is used to obtain the UTM coordinates of the sample points as well as information on the dominant vegetation type. The accuracy of the GPS coordinates is approximately 3 m.

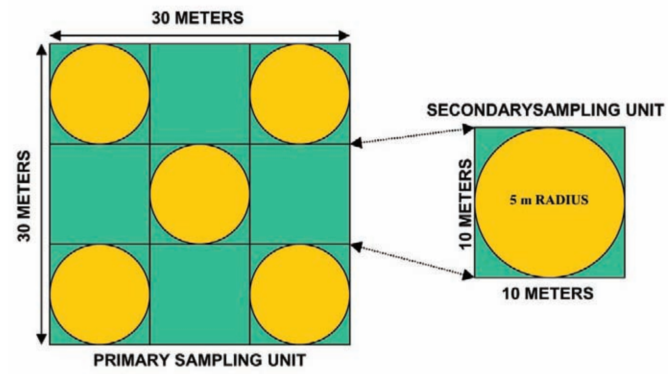

Figure 3. Plot Layout for Primary and Secondary Sampling Units.

Ground Plot Data

The primary sampling unit (PSU) is 30 m x 30 m (fig. 3) square plot corresponding to the size of an individual pixel on a Landsat TM image and consists of nine 10 m x 10 m secondary sampling units (SSUs). Each primary sampling unit will be centered on the coordinates assigned to it and will be laid out in a north-south, east-west manner. The location of each PSU will be verified using a GPS with an estimated accuracy of within 3m.

Because these will be permanent plots, the PSU center will be monumented on the ground. Five of the nine SSU's will be selected for detailed measurement, using a circular plot of 5 meters radius. SSU-1 will be located at the PSU center. The other four SSUs will be located in the four corners of the PSU (fig. 3).

The decision to use a 100 m^2 SSU is based on study by Reich and others (1992) to determine the optimal plot size for measuring coniferous forests (in other words, tree diameters and tree heights) in El Salto, Durango, Mexico. Results suggest that in highly aggregated stands (c = 0.052, table 1) in which individual trees occur in clumps, it is better to sample a small number of trees on each plot by using a small plot size and spreading the plots over a large proportion of the forest, rather than sampling fewer number of plots using a larger plot size (table 1). As the spatial distribution of trees approaches that of a random spatial pattern (c = 0.5) the optimal plot size increases. Similar results were observed by Reich and Arvanitis (1992). Both of these studies suggest that the spatial distribution of trees is the most important factor influencing the selection of an optimal plot size. Because of the difficulty in determining the spatial distribution of individual trees, Reich and Arvanitis (1992) developed a technique for estimating the spatial distribution of various stand characteristics

Table 1. Optimal plot size that minimizes total survey time with an allowable error of 10 percent at the 95 percent confidence level, by stand type near El Salto, Durango, Mexico (Reich and others 1992).

Spatial Distribution	Degree of Aggregation (c)	Stocking Level	Number of Stands	Trees/ha	Optimal Plot Size (m²)
Single Storied Stands					
Aggregated	0.292	Low	1	65.1	115
Aggregated	0.054	Medium	8	762.6	15
Aggregated	0.292	Low	3	268.6	250
Two Storied Stands					
Aggregated	0.054	Low	12	327.2	10
Aggregated	0.054	Medium	23	1085.2	10
Aggregated	0.292	High	11	2478.2	205
Aggregated	0.054	Low	1	647.7	25
Aggregated	0.292	Medium	4	1244.1	31

using simple counts of "in" trees on either variable or fixed area plots.

Several kinds of subplots will be located within each of the 5 m radius plots (fig. 4) and different measurements will be made on each plot type. All large trees (>12.5 cm DBH) will be measured on each of the 5 m plots. Observed attributes will be specified in the field sampling and indicators measurement manuals. Saplings (2.5 cm < DBH < 12.5 cm) will be measured on a circular plot (3m radius) co-located at the center of each tree subplot. Within each of the 5 m radius plots will be 3 square plots, each measuring 1 m x 1m. The first 1 m^2 quadrat will be located at the center of the 5 m radius plot. The remaining two 1 m^2 are located 6 m from the center plot, on a diagonal of the 5 m radius plot (fig. 4). Seedlings (height > 30 cm and DBH < 2.5 cm) will be sampled on the three 1 m^2 quadrats. In addition to counting seedlings, the percent cover of herbaceous plants, shrubs, and tree species < 30 cm tall will be recorded.

On all nine of the SSUs, a spherical densiometer will be used to estimate canopy closure while an angle gauge will be used to estimate basal area by species. This information will be used to correlate the detailed vegetation and soils data collected on the five SSUs.

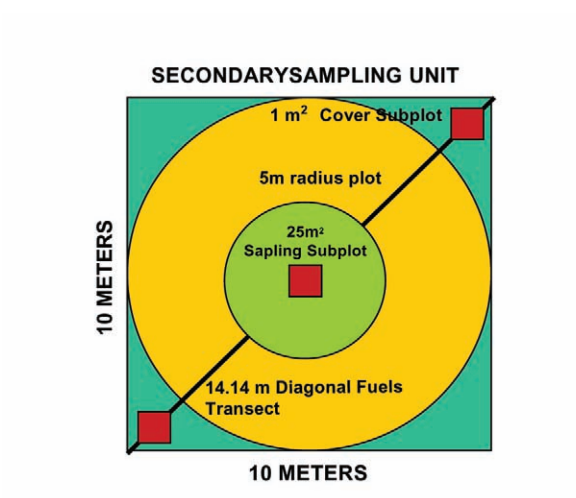

Figure 4. Layout of Tree and Cover Subplots of SSUs.

To estimate fuel loadings, a 14.14 m transect will be established diagonally across each of the 5 m radius plots, proceeding at 45 degrees (fig. 4). This will be referred to as the 14 m transect. Line intersect techniques will be used to estimate fuel loadings of large woody material (sound and rotten) > 7.5 cm in diameter. All large woody material intersecting the 14 m transect will be counted and their cross-sectional areas measured by genus. Small woody material (0-0.6 cm, 0.6-2.4 cm, 2.4-7.5 cm) will be counted on a diagonal transect on the three 1 m^2 plots. In each case, the mean height of fuels in each sampled diameter class, as well as the slope of the diagonal transect will be measured, and reported, respectively. Soils attributes will be observed on each 5 m radius plot. Any destructive soil samples will be collected outside the west side (270 degree Azimuth) of the primary sampling unit and at a distance of 5 meters of the plot boundary line.

Most of the indicator variables are compatible with those used by the USDA Forest Service and Canadian ecosystem resource monitoring programs. Other indicator variables can be integrated into this pilot study as resources become available and the need dictates to ensure comparability and interoperability of indicators with participating government agencies from the USA and Canada.

Sampling Design

The development of the sampling and plot designs is complicated by the diversity of variables and indicators to be assessed, and the need to assess the ecosystem resources at a range of scales, the need to monitor the indicators over time, and the need to do so efficiently. To meet national and state level objectives for ecosystem resource assessments while providing information needed to develop geostatistical models to estimate key attributes at local scales, a stratified random sampling design will be employed. Stratification generally provide more precise estimates compared to a simple random or systematic sample of the same size, while providing estimates of population parameters for individual strata (Schreuder and others 1993).

In the first phase, the pilot study area will be stratified by vegetation type (for example, temperate forest, tropical forests, grasslands, mesquite forests, agricultural lands, etc.). Strata will be defined using a detailed vegetation map of the pilot study area developed using the independent set of point data. Each stratum will have a known size and will be used as weights to obtain area-wide estimates. The number of sample plots within stratum will be allocated proportional to the size of the stratum and the variability within stratum. In the second phase, Landsat TM data will be used to obtain an unsupervised classification of the spectral variability associated with each of the dominant vegetation types, or stratum identified in phase one. The number of spectral classes, or strata in the second stage, will vary, depending on the spectral variability observed within each stratum. An equal number of sample plots will be randomly located within each spectral class. This will ensure that the sample plots will cover the spectral variability associated with the Landsat TM image which is essential for spatially interpolating the sample data. The field crews will locate the plots at the UTM coordinates given to them – accurate location of the points is important both for spatial modeling as well as to future relocation of these permanent plots. Plot locations will be kept secret. The opportunity also exists to intensify for local areas within land tenure units, MAUs, or administrative units, as budgeting allows.

Modeling Methods

Vegetation Map

The vegetation map of the pilot study area will be constructed using the Landsat TM, climatic data, vegetation point data, and field sample data. A stepwise decision tree (Breiman and others 1984, Friedl and Brodley 1997, De'Ath and Fabricus 2000) will be used to identify independent variables (Landsat TM bands, elevation, slope, or aspect) that are important in discriminating among vegetation types. The decision tree uses a binary partitioning algorithm that maximizes the dissimilarities among groups to compare all possible splits among the independent variables and splits within each independent variable to partition the data into new subsets. Once the algorithm partitions the data into new subsets, new relationships are developed to split the new subsets. The algorithm recursively splits the data in each subset until either the subset is homogeneous or the subset contains too few observations (< 5) to be split further. To prevent over fitting the data, a pruning algorithm (Friedl and Brodley 1997) will be used to eliminate subsets that were fit to noise in the data. Decision tree criteria will then be used as 'training' statistics to classifying the 2002 and 2003 Landsat image (fig. 5).

Spatial Modeling

Ecosystem resource attributes and indicators measured on the sample plots (in other words, canopy closure, basal area, fuel loadings, soil texture, understory vegetation, density of seedling/saplings, etc.) will be modeled to a 10 m spatial resolution using procedures developed by Joy and Reich (2002). Multiple regression analysis will be used to develop a trend surface (TS) model to explore the coarse-scale variability (in other words, non-stochastic mean structure) in continuous measures of forest structure as a function of elevation, slope, aspect, landform, and Landsat TM bands. To account for interactions between vegetation types and other independent variables, dummy variables will be introduced in the models as interactions with elevation, slope, aspect, landform, and data from the eight Landsat bands. For each component of forest structure modeled, a stepwise procedure will be used to identify the best subset of independent variables (main effects and interactions) to include in the TS models.

To describe the fine-scale spatial variability (in other words, residuals associated with the TS models) in ecosystem resource attributes and indicators will be modeled using binary regression trees (RT). The RT is a non-parametric approach to regression that compares all possible splits among the independent (continuous) variables using a binary partitioning algorithm that maximizes the dissimilarities among groups. Once the algorithm partitions the data into new subsets, new relationships are developed, assessed, and split into new subsets. The algorithm recursively splits the data in each subset until either the subset is homogeneous or the subset contains too few observations (for example, < 5) to be split further. Interpolation using RTs is relatively insensitive to sparse data (Joy and Reich 2002). Independent variables considered in the RT will include elevation, slope, aspect, landform, Landsat TM band readings, and vegetation type, the latter being treated as a categorical variable. To avoid over-fitting the RTs, a 10-fold cross-validation procedure (Efron and Tibshirani 1993) will be used to identify the tree size (in other words, number of terminal nodes) that minimizes the total deviance (in other words, error) associated with the trees.

Semi-variograms which describe how the sample variance changes as a function of distance will be used to evaluate spatial dependencies among the residuals from the various models. If the residuals exhibited

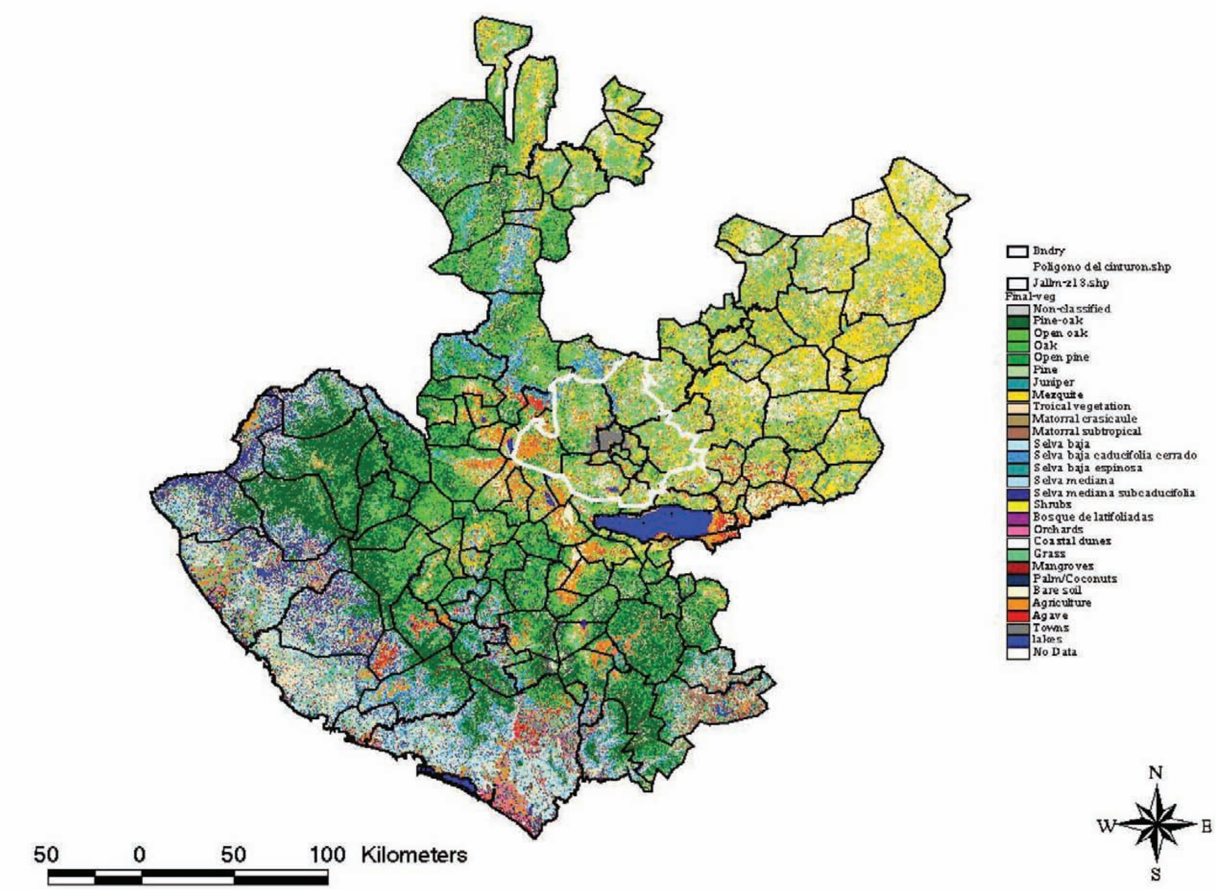

Figure 5. Preliminary vegetation map of the states of Jalisco and Colima, Mexico. The vegetation map is based on point data collected at 2000 locations and a 2002 Landsat TM imagery. The missing Landsat TM images for 2002 will be acquired and used in developing the final vegetation map of the study area.

spatial dependencies, a spatial autoregressive (SAR) model will be used to obtain generalized least squares (GLS) estimates of the regression coefficients associated with the TS model (Upton and Fingleton 1985). The model residuals will be reevaluated to ensure the removal of the spatial dependencies. In fitting the SAR models, a spatial weight matrix (in other words, a block diagonal matrix) based on inverse distance weighting will be used to represent the spatial dependencies among the PSUs and SSUs.

Grids representing the various components of forest structure will be generated for the best fitting TS model using the model's parameter estimates. Similarly, grids representing the error in each TS model will be generated by passing each grid for the appropriate independent variable through the RTs. The final predicted surfaces for each component of forest structure will be obtained from the sum of the TS and RT grids.

Model Evaluation

The effectiveness of the final models will be evaluated using a goodness-of-prediction statistic (G) (Agterburg 1984, Guisan and Zimmermann 2000, Kravchenko and Bullock 1999, Schloeder and others 2001). The G-value, measures how effective a prediction might be relative to that which could have been derived by using the sample mean (Agterburg 1984):

$$G = \left(1 - \left\{ \sum_{i=1}^{n} \left[z_i - \hat{z}_i \right]^2 \Big/ \sum_{i=1}^{n} \left[z_i - \bar{z} \right]^2 \right\} \right), \qquad [1]$$

where Z_i is the observed value of the ith observation, $\hat{Z}_i$ is the predicted value of the ith observation, and $\bar{Z}$ is the sample mean. A G-value equal to 1 indicates perfect prediction, a positive value indicates a more reliable model than if one had used the sample mean. A negative value indicates a less reliable model than if one had used the sample mean, and a value of zero indicates that the sample mean should be used to estimate Z.

A 10-fold cross-validation (Efron and Tibshirani 1993) will be used to estimate the prediction error for each variable modeled. The data will be split into K=10 parts consisting of approximately 15 sample plots. For each kth part, the TS and RT models are fitted to the remaining K-1=9 parts of the data. The fitted model is used to predict the kth (in other words, removed) part of the data. This process is repeated 10 times so that each observation is excluded from the model construction step and its response predicted.

To evaluate the effectiveness of the models, we will compute various measures of the prediction error. Prediction bias (Williams 1997) will be calculated for each validation data set as a percentage of the true value. Accuracy (Kravchenko and Bullock 1999) will be measured by the mean absolute error (MAE), which is a measure of the sum of residuals (in other words, actual minus predicted) and the root mean squared error (RMSE), which is a measure of the square root of the sum of squared residuals. Small MAE values indicate models with few errors, while small values of RMSE indicate more accurate predictions on a point-by-point basis. To assess the estimation uncertainty in the models (Isaaks and Srivastava 1989) the estimation error variance (EEV), $\hat{\sigma}_i^{2(-k(i))}$ for each observation in the kth part of the data will be calculated:

$$\hat{\sigma}_i^{2(-k(i))} = MSE^* \left[\left(X_i^{-k(i)}\right)' \left(X^{*\prime} X^*\right) \left(X_i^{-k(i)}\right) + 1 \right] + 2MSE(RT) + 2COV(\hat{Y}, \hat{\eta}) \quad [2]$$

where MSE* is the regression mean squared error for the TS model fitted using K-1 parts of the data, X* is a matrix of independent variables associated with the K-1 parts of the data, $X_i^{-k(i)}$ is a vector of independent variables associated with the ith observation in the kth part of the data, $\hat{Var}(RT)$ is the mean squared error of the RT used to describe the error in the TS model, and $Cov(\hat{Y}, \hat{\eta})$ is the covariance between the estimated values, $(\hat{Y})$, from the TS model and the predicted residuals, $(\hat{\eta})$, from the RT for the K-1 parts of the data. The consistency between the EEV, $\hat{\sigma}_i^{2(-k(i))}$, and the observed estimation errors (in other words, true errors), $e_i^{-k(i)} = (Z_i - Z_i^{-k(i)})$, will be calculated using the standard mean squared error (SMSE) (Havesi and others 1992):

$$SMSE = \frac{1}{n} \sum_{i=1}^{n} \frac{\left(e_i^{-k(i)}\right)^2}{\hat{\sigma}_i^{2(-k(i))}}. \quad [3]$$

EEVs are aSSUmed consistent with true errors if the SMSE falls within the interval $\left[1 \pm 2(2/n)^{-1/2}\right]$ (Havesi and others 1992). Paired t-tests ($\alpha = 0.05$) will be used to test for differences between the mean estimation errors and zero.

Data Collection and Model Building Phases

Data collection and model building will be carried out simultaneously to ensure the development of the most reliable models.

Phase I. In this phase, point data will be collected throughout the pilot study area to identify both the major and minor vegetation types. This information will be used to develop a preliminary vegetation map of the pilot study area (see section on Vegetation Map). The preliminary vegetation map will be used to identify strata for the purpose of locating sample plots in the field (fig. 5).

Phase II: In this phase, one-third of the sample plots will be located in the field and measured. In addition, point data will also be collected. The point data along with the classification of the field plots will be used to update the vegetation map of the pilot study area. Preliminary models will be developed for key indicator variables such as canopy closure to identify geographical regions or vegetation types within the pilot study area that have large errors associated with their estimation. This information will be used to allocate the next group of sample plots to various strata.

Phases III and IV: The steps outlined in Phase II will be repeated until all of the sample plots have been located in the field and measured.

Phase V: The point data collected in Phases I-IV along with the classification of the sample plots measured in Phases II-IV will be used to develop the final vegetation map of the pilot study area. Also during this phase, spatial models will be developed for all of the ecosystem resource attributes and indicators variables measured on the sample plots (see section on Spatial Modeling).

Multi-Scale Estimation (Model-Based)

In addition to being able to assess the level of uncertainty associated with the spatial models, it is also important that the models are capable of providing estimates at any spatial scale or level of support. It is also important that we are able to place bounds on the error of estimation. To accomplish this it is important that the PSU remain intact as much as possible by not splitting them in half. This may not be possible near boundaries, and in such cases, the formula presented below will have to be modified to take into consideration PSU of unequal sizes. To demonstrate this concept, assume one is interested in estimating the mean (for example, canopy closure, basal area, height understory vegetation etc.) per SSU within a specified geographical unit and place a bound on the error of estimation. Assume the area of interest contains n PSUs consisting of m = 9 SSU's. The modeled surfaces are used to provide an estimate ($\hat{\hat{Z}}$) on each of the nm SSU's, along with the model prediction variance ($\hat{\sigma}^2$) using Eq. 2. An estimate of the mean value per SSU ($\hat{\hat{Z}}_{sp}$) is given by:

$$\hat{\hat{Z}}_{sp} = \frac{1}{nm}\sum_{i=1}^{n}\sum_{j=1}^{m}\hat{Z}_{ij} = \frac{1}{n}\sum_{i=1}^{n}\hat{\hat{Z}}_{i} , \qquad [4]$$

where $\hat{\hat{Z}}_{ij}$ is the estimated value on the jth SSU from PSU i, and $\hat{\hat{Z}}_{i}$ is the average for the ith PSU. If PSUs of the same size are sampled, the total sum of squares associated with estimating the mean can be partitioned into the within-PSU sum of squares (SSW) and the between-PSU sum of squares (SSB) (Scheaffer and others 1996). With appropriate divisors, these sum of squares become the usual mean squares of an analysis of variance. The within-PSU mean square (MSW) is given by

$$MSW = \frac{SSW}{n\,(m-1)} = \frac{1}{n\,(m-1)}\sum_{i=1}^{n}\sum_{j=1}^{m}\left(Z_{ij}-\overline{Z}_{i}\right)^2 \approx \frac{1}{nm^2}\sum_{i=1}^{n}\sum_{j=1}^{m}\hat{\sigma}_{ij}^2 , \qquad [5]$$

where $\frac{1}{n(m-1)}\sum_{i=1}^{n}\sum_{j=1}^{m}\left(Z_{ij}-\overline{Z}_{i}\right)^2$ is the MSW one would typically use in cluster sampling and $\frac{1}{nm^2}\sum_{i=1}^{n}\sum_{j=1}^{m}\hat{\sigma}_{ij}^2$ is its equivalent using the EEV formula (Joy and Reich 2002). The between-PSU mean square (MSB) is given by:

$$MSB = \frac{SSB}{n-1} = \frac{m}{n-1}\sum_{i=1}^{n}\left(\overline{z}_{i}-\overline{z}_{sp}\right)^2 \approx \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{m}\hat{\sigma}_{ij}^2 , \qquad [6]$$

where $\frac{m}{n=1}\sum_{i=1}^{n}\left(\overline{z}_{i}-\overline{z}_{sp}\right)^2$ is the general formula for calculating the MSB and $\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{m}\hat{\sigma}_{ij}^2$ is its equivalent using the EEV formula (Joy and Reich 2002). The MSB can be used to calculate the variance of $\hat{\hat{z}}_{sp}$ as follows:

$$\hat{V}\left(\hat{\hat{z}}_{sp}\right) = \frac{MSB}{nm} . \qquad [7]$$

Using these relationships it is possible to obtain local estimates of any of the modeled variables to any spatial scale along with their corresponding estimates of the variance.

Global Estimation (Sampling Design-Based)

The field data may also be used to obtain global estimates of the mean and variance for the states of Jalisco and Colima for individual vegetation types. Within a given vegetation type, i (i=1,2,…,L) an estimate of the mean and variance of some attribute, z, can be obtained using the formula for a stratified random sample (Cochran 1977, Schreuder and others 1993):

$$\overline{z}_{i} \frac{1}{N_i}\sum_{j=1}^{C} N_{ij}\overline{z}_{ij} \qquad [8]$$

$$\hat{V}\left(\overline{z}_{i}\right) = \frac{1}{N_i^2}\sum_{j=1}^{C} N_{ij}^2\left(\frac{N_{ij}-n_{ij}}{N_{ij}}\right)\frac{s_{ij}^2}{n_{ij}} \qquad [9]$$

where Nij is the number of PSUs in the jth spectral class (j = 1, 2, …, C), $N_i = \sum_{j}^{C} N_{ij}$ is the number of PSUs in the ith vegetation type, nij is the sample size in the jth spectral class in the ith vegetation type, s_{ij}^2 is the sample variance of the jth spectral class in the ith vegetation type, and $\overline{z}_{ij}$ is the sample mean for the jth spectral class in the ith vegetation class.

The state-wide estimates of the mean and variance of the variable of interest are again obtained using the formula for a stratified random sample (Cochran 1977, Schreuder and others 1993):

$$\overline{z} = \frac{1}{N}\sum_{i=1}^{L} N_i\overline{z}_i = \frac{1}{N}\sum_{i=1}^{L}\sum_{j=1}^{C} N_{ij}\overline{z}_{ij} \qquad [10]$$

$$\hat{V}\left(\overline{z}\right) = \frac{1}{N^2}\sum_{i=1}^{L} N_i^2\left(\frac{N_i-n_i}{N_i}\right)\hat{V}\left(\overline{z}_i\right) = \frac{1}{N^2}\sum_{i=1}^{L}\left(\frac{N_i-n_i}{N_i}\right) \sum_{j=1}^{C} N_{ij}^2\left(\frac{N_{ii}-n_{ij}}{N_{ij}}\right)\frac{s_{ij}^2}{n_{ij}} \qquad [11]$$

where N is the total number of PSUs in the states of Jalisco and Colima and $n_i\sum_{j=1}^{C} n_{ij}$ is the sample size in the ith vegetation class.

These formula can be modified to provide estimates of the mean and variance for the SSUs.

Plot Remeasurement

Sample plots will be remeasured on a cycle of a one-to-five years with an average of 25 percent of the plots being remeasured in a given year. The rate of remeasurement will be based on the temporal variability associated with the various vegetation types. For example, agricultural areas would be expected to change very rapidly from one year to the next, as compared to the mesquite forests which are very stable over time.

In the second year, a new cloud free, Landsat TM imagery will be acquired of the pilot study area. The Landsat imagery will be normalized with respect to the Landsat imagery used in the initial survey. The two Landsat images will be differenced to identify areas in which the spectral characteristics have changed. Cluster analysis will be used to stratify the pilot study area into five to ten strata with similar changes in the spectral variability. Based on their spectral properties, the sample plots will be assigned to one of the five to ten strata representing changes in the landscape. Within each stratum, sample plots will be randomly selected, without replacement, for remeasurement. The proportion of sample plots selected from each stratum will depend on the number of sample plots assigned to a given stratum. If there are no sample plots assigned to a particular stratum, there is an opportunity to establish new sample plots to expand the database used to make inferences about the resources within the pilot study area.

Spatial-Temporal Modeling

To model the changes in ecosystem resource attributes and indicators over time, first order differencing will be used (Brockwell and Davis 1991). This first order difference is defined as

$$\Delta z_t = z_t - z_{t-1} \qquad [12]$$

where z_t describes the process at time t. The changes observed on the remeasured sample plots will be modeled as a function of changes in the spectral bands associated with the sample plots, elevation, slope, aspect, and vegetation type. The approach used in the modeling will be similar to the one used in developing the original models. An estimate of the process at time t will be obtained by adding the predicted surface of change to the predicted surface of the process at time t-1:

$$\hat{z}_t = \hat{z}_{t-1} + \Delta\hat{z}_t \, . \qquad [13]$$

In subsequent years, it may be necessary to use higher order differences to eliminate quadratic or higher order trends.

Identifying Micro-Ecological Management Units

Resource managers are constantly trying to improve the way they manage the natural resources under their care. Typically, the area of interest is sub-divided into management units, or stands, based on certain characteristics, such as canopy closure and/or species composition, and then each area is managed on an individual basis. Unfortunately, the definitions used in the creation of these management units, or stands, may not be compatible with different management objectives.

Using the techniques discussed earlier, resource managers can generate response surfaces representing important resource attributes (in other words, canopy closure, basal area, volume growth, fuel loadings, biomass, understory vegetation, etc.) under their management. Using a collection of these surfaces to represent certain ecological or management conditions (in other words, diversity of resident and migratory birds, species richness, wildlife habitat suitability, volume production, fire hazard, etc.) one can apply a multivariate spatial clustering algorithm to identify "micro-ecological" units that have similar spatial characteristics. Thus, the management units identified for the production of volume may be different from those identified to maximize the diversity of resident and migratory birds, and so on. The algorithm applies a k-means clustering algorithm to the selected response surfaces, and clusters the individual pixels of the response surfaces into k clusters. K-means is a nonhierarchical clustering method that uses nearest centroid sorting to iteratively minimize the Euclidian distance between cluster means (Hartigan 1975).

Conclusions

The science and art of spatial statistics and modeling open new opportunities to advance the systems for inventorying and monitoring ecosystem resources and the environment. In research and other applications, these technologies provide a flexible framework for integrating multiple sources of data and information for spatial modeling at multiple scales and resolution. Integrating field data and remote sensed data through a geostatistical-based approach brings about significant gains in statistical and economic efficiency. However, for the achievement of successful results, it is essential to take into account a variety of technical considerations when using these technologies for practical applications.

Statistical estimates and modeling processes are significantly influenced by the spatial patterns that exist between and among variables of interest. The spatial variability and arrangements of these attributes are important factors to consider in choosing the proper sampling strategy. If the sampling design does not capture the spatial variability in the data it may not be possible to spatially interpolate the field data. It is also important that the field data be collected at the desired spatial resolution. For example, if the field data is collected on a systematic grid, it may not be possible to spatially interpolate the data to a finer spatial resolution, especially, if the scales of pattern are smaller than the grid spacing used to collect the data. If Landsat imagery is being used in the interpolation process, it is also important that the sample plot corresponds as closely as possible to the size and shape of the pixels in the imagery. This tends to minimize the errors associated with what is being measured on the ground and what the satellite senses.

In addition to be able to spatially interpolate the field data, it is important to evaluate the individual models as to their predictive performance. This provides useful information to the users in terms of the accuracy and precision of estimates in areas not sampled.

The Jalisco-Colima Pilot Study constitutes a test-bed for using and learning about the application of these new technologies. While these techniques have been applied to smaller areas (< 370,000 ha) their performance when applied to more diverse and larger geographical areas is generally unknown.

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Statistical Strategy for Inventorying and Monitoring the Ecosystem Resources of the State of Jalisco at Multiple Scales and Resolution Levels

Robin M. Reich, Professor, Forest Biometry, Colorado State University, Ft Collins, CO
Hans T. Schreuder, retired Mathematical Statistician Rocky Mountain Research Station, USDA Forest Service, USA

Abstract—*The sampling strategy involving both statistical and in-place inventory information is presented for the natural resources project of the Green Belt area (Centuron Verde) in the Mexican state of Jalisco. The sampling designs used were a grid based ground sample of a 90x90 m plot and a two-stage stratified sample of 30 x 30 m plots. The data collected were used to present strategic information for the green belt area as well as mapped information on crops and forest conditions. The experience gained in this study will be used to plan a statewide inventory for the states of Jalisco and Colima, Mexico and ultimately for the entire country of Mexico.*

Introduction

In Mexico, individual agencies address the extent, status, and trends of selected natural resources in response to their specific missions. No agency, or group of agencies, examines the interactions and interdependence among multiple natural resource components from an integrated ecosystem perspective. Available information often is at scales that have limited value for state planning and policy-making. While useful for strategic national level planning, this information has limited use for supporting regional and local decision-making resource applications. Similarly, there is no integrated program to periodically assess multiple natural resources at regional and local scales, and at multiple resolution levels. Accordingly, the ecosystem resource monitoring initiative, of which this document is a part, will enable comprehensive assessments of Jalisco's natural resources for the management of their sustainability.

This ecosystem resource monitoring initiative addresses a number of critical issues that stakeholders in the states of Jalisco and elsewhere in Mexico are facing to insure the environmental sustainability for present and future generations. Land management agencies charged with this responsibility have come to the realization that current data and information available are insufficient to confront successfully the ecological and economic challenges of ecosystem resource sustainability. In light of the above, the purpose of this technical document is to describe the statistical approach for inventorying and monitoring the ecosystem resources of the Mexican state of Jalisco at multiple scales and resolution levels. Design-based inference is used to ensure a minimum number of assumptions.

Overview of the Sampling Designs

Unlike many National level inventories, such as the US Department of Agriculture, Forest Service Forest Inventory and Analysis program (FIA), the goal of the Jalisco pilot project (JCPP) is to design an integrated inventory system that provides both traditional assessments of population totals and means as well as spatially realistic maps that describe the location and distribution of various attributes of the population. In other words, an inventory is designed that meets strategic, management, and local needs. The products produced by the inventory include reliable estimates of means and totals for important ecosystem characteristics and maps describing the spatial and temporal properties of the ecosystem.

In designing an integrated multi-resource inventory and monitoring system to evaluate the condition and change of variables and indicators for sustainable ecosystem resource management (forest, rangeland, agriculture, wildlife, water, soils, biodiversity, etc.) one needs some baseline data for comparison. Because one is generally dealing with complex systems, it is not wise to focus on only one or two variables for ecological monitoring purposes. Also, analyzing these variables independently of one another may lead to incorrect conclusions because

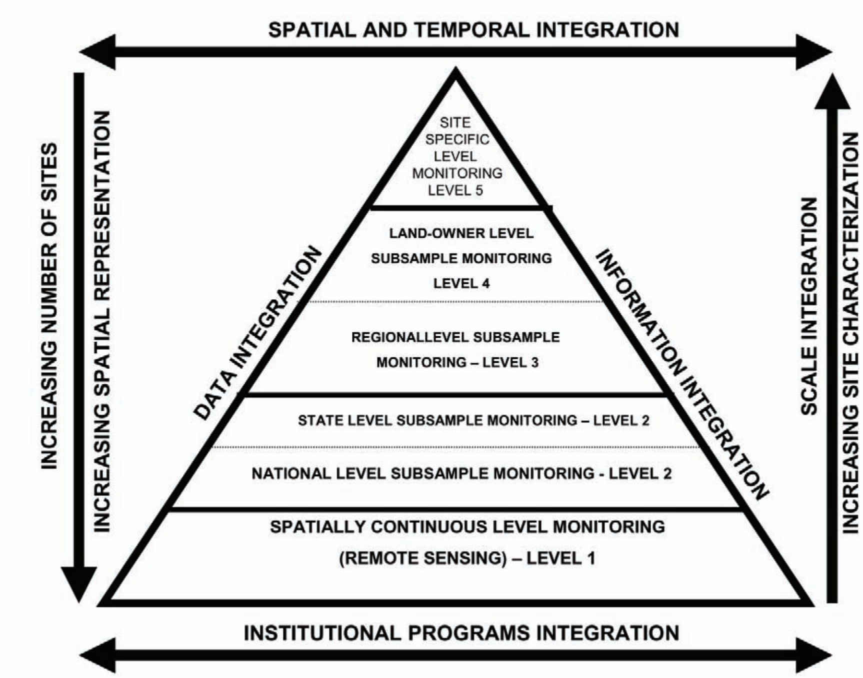

Figure 1. Conceptual model for integration of monitoring design and institutional processes.

of their inter-dependencies. One approach is to model the spatial relationship between key indicator variables. In ecosystem resource management, for example, this information can then be used to identify forest habitats that are either conducive or a deterrent to the presence of ecologically important plant and/or animal species. Techniques commonly used in describing spatial relationships between two or more variables include regression analysis and a variety of geo-statistical procedures that take into consideration the spatial dependency (Cliff and Ord 1981). The proposed ecosystem resource monitoring system will rely on information collected at different spatial scales of resolution and sampling intensities (fig. 1) to provide detailed information at the local level for ecosystem resource planning and management purposes.

The JCPP is an integrated inventory and monitoring program that is designed to address numerous objectives at different spatial scales. The components of the inventory are broken down in 5 components, which are referred to as 'levels', each addressing different spatial scale and information needs. This document provides a brief overview of all five levels of the inventory and a detailed description of Levels 1 and 2. Other documents will address Levels 3, 4 and 5 in more detail.

Spatially Continuous Monitoring (Level 1)

Landsat Thematic Mapper (TM) data will be used to provide a complete and uniform census of individual Environmental Accounting Units (EAU) across jurisdictional domains (i.e., private lands, federal and state lands, ejidos, communities, municipalities, regions, etc.). An EAU is a watershed used to assess ecological and human activity assessment as well as for resource decision making and planning applications This approach will provide data, or measurements collected as a series of contiguous and simultaneous measures across land tenure units. It will also provide the capability of monitoring EAU's for changes in spectral and spatial characteristics that can be applied over a range of spatial and temporal scales appropriate for addressing specific ecosystem resource issues.

Remote sensing data have been used primarily to develop static maps of vegetation cover or land use to guide management decisions in planning applications. However, a current component missing in ecosystem resource monitoring is its use for change detection and spatial modeling of ecosystem properties. When compared to traditional plot data, remotely sensed data can be quite helpful in detecting changes in the land base. Many critical indicator variables such as site productivity, presence or absence of threatened or endangered species, and biological diversity are simply not being measured with sufficient spatial coverage and frequency to allow evaluation of current and future trends. Unlike previous applications of remote sensing in monitoring ecosystem resources in which remote sensing imagery is treated as the primary variable of interest, we propose a slightly different approach. In our approach, Landsat TM data is treated as an auxiliary variable while the field data is treated as the primary variable of interest in describing specific properties of the region at any desired spatial scale (i.e., 1 to 30 m). Appropriate use of the approach can greatly increase the value of outputs from monitoring programs (Metzger 1997).

The decision to use Landsat TM data over other remote sensors (e.g., SPOT (10 m resolution), LEWIS (5 to 300 m resolution), Space Imaging (1 to 4 m resolution), Earthwatch (3 to 15 m resolution), Earthwatch Quickbird (1 to 4 m resolution), OrbView 2 (1100 m resolution), OrbView-3 (1 to 8 m resolution), SPOT 4 Vegetation Sensor (1000 m resolution), MODIS (250 to 1000 m resolution)) is based on the following reasons. The cost of acquiring data from these high resolutions sensors is significantly higher than what it currently costs to acquire Landsat TM data. Users of these sensors have shown that in terms of modeling large-scale spatial variability (Metzger 1997), Landsat TM data is superior to currently available SPOT data even though the latter has a finer resolution, but is also more expensive. Also the resolution associated with some of these new sensors are not the same across different spectral bands making it difficult to integrate with field data with the same level of precision. For this approach to work, it is important to have a wide range of spectral data at a consistent resolution. An additional benefit is that the spatial modeler involved in this work has considerable experience in working with TM. Therefore, Landsat TM data will be used as the remote sensing sensor of choice until some of these other sensors have been thoroughly evaluated.

In addition to the Landsat data, GIS grids of elevation, slope, and aspect will be developed from digital elevation models. Grid coverages for each topographic variable will be resampled (Resample function, nearest neighbor, Grid Module (ARC/INFO®, ESRI 1995) to provide a 30 m spatial resolution so that an average elevation, slope and aspect can be assigned to each pixel

A separate ground sampling effort was also undertaken to collect data that will be used to construct a classified map of the cover types of Mexico. These ground data comprise approximately 2600 purposively chosen points. At each point, the GPS coordinates and the cover type are recorded. These data were used to determine the spectral signature of the TM data and landscape characteristics associated with each cover type. This will allow us to generate a preliminary land cover map.

Design-based Inference for Inventory and Monitoring (Level 2)

The development of the sampling and plot designs is complicated by the variety of indicators to be assessed, the need to assess the ecosystem resources at a range of scales, the need to monitor the indicators over time, and the need to do so efficiently. To meet national level objectives for ecosystem monitoring and large-scale assessments, a traditional grid-based sampling design is used. The plot locations are treated as a simple random sample of the landscape and post-stratification is employed as a variance reduction technique. This will be referred to as the Tier 1 inventory.

The next level of the survey is designed to meet State level inventory objectives. This is referred to as the Tier 2 inventory. The only feature that distinguishes the Tier 1 and 2 inventories is the increased sampling intensity in Tier 2.

Model-based Inference for Monitoring and Inventory (Levels 3-4)

For the remaining objectives involving estimation at local scales (levels 3 – 4), the plot data from the Tier 1 and 2 inventories will be enhanced with additional ground plots to provide information needed to develop geostatistical models. These models will be used to describe the location and distribution of various resource attributes and to estimate key attributes at all locations within the sampled population.

To ensure that the spatial variability in the study area is captured, additional sample plots will be located to enhance the spatial models for use in local management applications. The location of these plots can be based on a pre-stratification scheme that locates plots in areas with the highest errors in the spatial models or where the spectrally-derived strata may not capture all of the unique spatial features on the landscape. The primary sampling unit (psu) is a 30 m x 30 m square.

Analytical Issues

The analysis of the Tier 1 and 2 inventory data is straightforward once the data have been edited and stored in an electronic file. An analysis program for Level 1 and 2 data incorporating the estimators discussed later in this paper is now being developed in the computer language R. Analytical techniques for Levels 3 and 4 of the inventory is more complicated, but software and training is available.

Study Area

The Pilot Study Area consists of the Mexican southwestern states of Jalisco and Colima with a continental area of approximately nine million hectares (twenty million acres). Though Jalisco is larger in area (90 percent), the state of Colima (10 percent) plays a very distinctive role in the economy of the whole region and diversifies the Pilot Study Area considerably. Four major ecological regions provide the natural resources and environmental conditions that make this region one of the most prosperous in Mexico (fig. 2). The eco-regions are the transversal neo-volcanic system, the southern Sierra Madre, the Southern and Western Pacific Coastal Plain and Hills and Canyons, and the Mexican High Plateau. Linked to these ecological regions, there are several important Hydrological Regions (HR) that drain to the Pacific Ocean (HR12 Lerma-Santiago, HR13 Huicicila, HR14 Ameca, HR15 Costa de Jalisco, HR16 Armeria-Coahuayana;, HR18 Balsas, and HR37 El Salado). One of

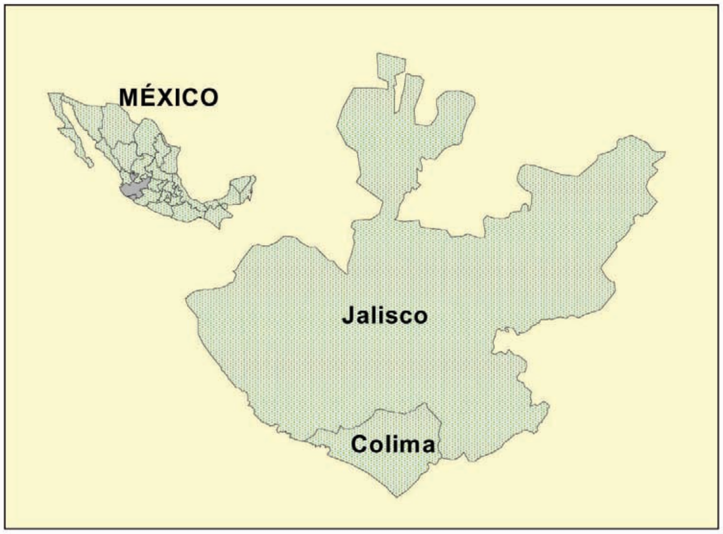

Figure 2. Geographic Location of Pilot Study Area in Mexico.

the watersheds, the Lerma-Santiago Hydrological Region is connected to Chapala Lake, the most important source of water for the City of Guadalajara.

Precipitation ranges from roughly 300 mm/year in some locations to more than 1200 mm/year in the higher elevations, with the principal precipitation coming in summer monsoons. The ecological systems of this region cut across the boundaries of other Mexican states. For example, several major watersheds drain through the tropical and subtropical forests of the state of Colima. Mostly in the state of Jalisco, water from surface and underground sources is heavily used for agriculture and industrial activities, though a significant portion goes to meet the domestic needs of approximately ten million people. While on average Colima is humid, water in the state of Jalisco is a critically limiting resource that threatens the sustainability of urban and rural ecological and economic systems. Most of the land (85 percent) in the state of Jalisco is privately owned. Small private landowners are the main driving force of economic development in agriculture, forestry, and rangeland economic activities. In contrast to Colima, for example, a small portion of Jalisco's land is owned by ejidos (10 percent), communities (3 percent), and the government (2 percent). Recently, as a result of trade liberalization brought about by NAFTA policies, new industries have been established in these two states and natural resource utilization has increased due to higher population growth rates.

The region's biophysical heterogeneity blends itself to bring about unique habitat conditions for a large diversity of plant and animal species. Within its boundaries, there are a significant number of species of mammals and birds, many of which are severely threatened by human activities. Some of the plant and animal species are endemic to specific locations within the ecological regions that comprise the Pilot Study Area. Extensive areas of pine-oak forest are home to "specialty" birds such as the thick-billed parrot, the Mexican-spotted owl, and woodpeckers. It is thought that habitat loss is the single most important element affecting bird populations in this ecosystem complex. Not much is known about how (what, when, where, why) plant and animal species are being impacted by human activities. Water and other biological resources are an integral part of these ecological regions whose services transcend geopolitical domains and jurisdictions.

The Design and Estimation for the Tier 1 and 2 Inventories

There is no "perfect" solution for the sample design and estimators for a large-scale inventory. Limitations associated with remote sensing, GPS, and the amount of time required by the field crews for data collection influence the design of the survey (Williams and Eriksson 2002, Overton and Stehman 1996). The sampling strategy chosen for the JCPP is an efficient and flexible strategy.

An efficient sampling design for collecting information over large geographical areas is a systematic grid with equal spacing and a random start. It has the advantage of spreading the sample units uniformly throughout the population. However, the systematic grid design tends to be the least efficient for spatial modeling because the equal spacing between plots provides less information for modeling purposes than a design with uneven spacing. In order to avoid periodicity in the resource and to permit plots to occur at random distances for spatial modeling, the plots will be located randomly within hexagonal cells formed by a triangular grid. This grid of hexagon cells for the Tier 1 inventory will uniformly cover all of Mexico with the size of each hexagon being approximately 900 km^2. To facilitate across border assessments, the grid for Mexico is an extension of the one developed for the FIA inventory in the U.S. The triangular grid can be used to intensify the Tier 1 sample for meeting State level inventory needs. This State level intensification is the Tier 2 component of the inventory. For the pilot study, the Tier 2 inventory is a 36-fold intensification of the Tier 1 grid.

A ground plot is located within each hexagon cell in accordance with a uniform distribution. The field crews will locate all of the ground plots at the UTM coordinates at the center of the TM pixel given to them – accurate location of the points is important both for spatial modeling as well as future relocation of these permanent plots. The grid density will be set first to meet state needs. It will then be intensified to meet other multiple scale needs, based on available funding. The intensity can also be altered in each of the main hydrological regions or municipalities. Plot locations will be kept secret. The opportunity to intensify also exists for local areas within land tenure units, EAUs, or administrative units, as funding is made available.

The other major advantage of using Landsat TM data is that the pixels can be used to construct an area frame comprised of equal area sample units. The advantage of this area frame approach (Husch and others 1982, Eriksson 1995) is that it is a true equal probability sample regardless of the type of stratification used, with the inclusion probabilities of the sample units (e.g., trees, CWD, and other vegetation) along the boundaries of different subpopulations not needing adjustment. This is especially advantageous when the sample data will be post-stratified, because every division (stratification) of the population creates new subpopulations with new boundaries. These new boundaries would require adjustments to the inclusion probabilities of all population elements (trees) along the new boundaries and it is unlikely the data needed for these could or would be collected (see Williams and Eriksson 2002 for a discussion of this topic).

For estimation, the plots will be post-stratified using the classified Level 1 Landsat TM data. At a minimum, the entire population and each EAU will be stratified into areas that are predominantly forest or non-forest. The plots will also be assigned to these strata, and then the appropriate results for post-stratified random sampling will be applied (Cochran 1977, Schreuder and others 1993). The estimators are given below. For large areas, the sample size in each stratum will be approximately proportional to the size of each stratum.

Description of the Ground Sample Units

The primary sampling units (psu) are a 90 m x 90 m (fig. 3) and a 30 m x 30 m (fig. 4) and are constructed with 3 x 3 blocks of Landsat TM pixels. Both psus will be sub-sampled by five 10m x 10m secondary sampling units (ssus). Each primary sampling unit will be centered on the coordinates assigned to it and will be laid out in a north-south, east-west manner. PSU locations will be verified using a Global Positioning System (GPS) with an estimated accuracy of within 3m.

In order to maintain an equal probability sample design and because the locational and registration errors in remote sensing and GIS technologies prevent an accurate subdivision of a pixel, a psu is considered either totally within a population or totally out of a population (or stratum). Thus the population boundaries are redefined

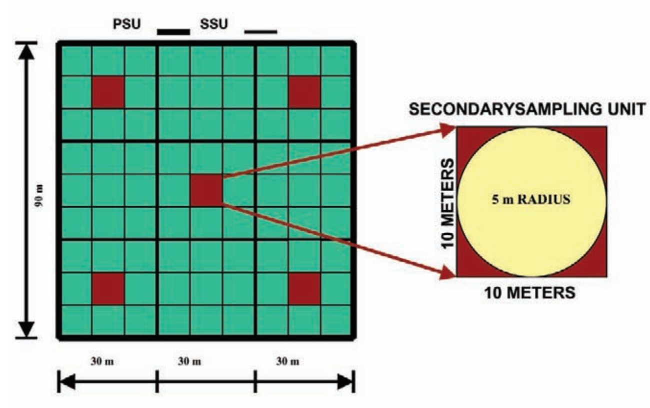

Figure 3. Plot Layout for the 90 m x 90 m Primary (PSU) and Secondary Sampling (SSU) Units.

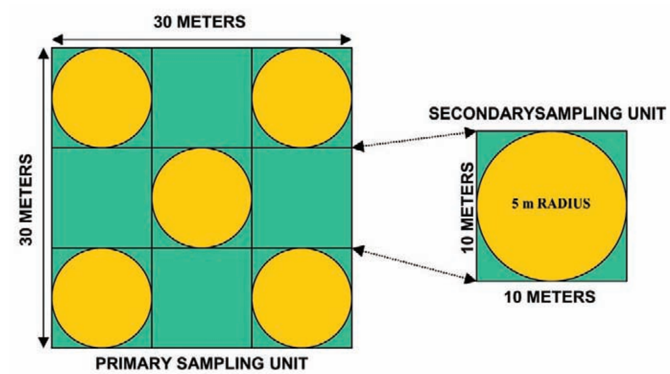

Figure 4. Plot Layout for the 30 m x 30 m Primary (PSU) and Secondary Sampling (SSU) Units.

to follow the area frame population boundaries created by the edges of the psus. A psu is ``in" when the center of the psu falls inside the population or stratum boundary. This creates a jagged stair stepped edge along the population boundaries, so a small portion of the actual landmass of an area segment will lie within the boundary of another area segment. The size of the difference should be minimal, generally less than 0.05 percent for the water sheds in the Green Belt.

Because these will be permanent plots, the psu center will be monumented on the ground. A sample of five of the 81 ssus will be selected for measurement, using a circular plot of 5 meter radius. This plot will be referred to as the 5 m plot. One 5m plot will be located at the psu center. The other four 5 m plots will be located at fixed angle directions and constant distance with respect to the psu center (fig. 3).

Several kinds of subplots will be located within each of the 5 m plots (fig. 5) and different measurements will be made on each plot type. All large trees (>12.5 cm DBH) will be measured on each of the 5 m plots. Observed attributes will be specified in the field sampling and indicator measurement manuals. Saplings (2.5 cm < DBH

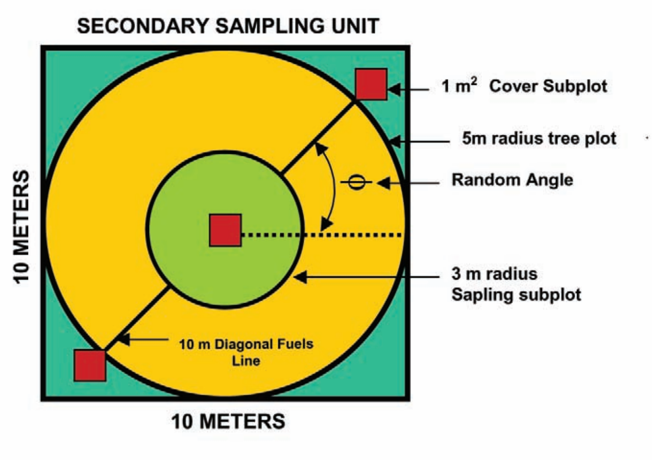

Figure 5. Layout of Secondary Sampling Unit.

< 12.5 cm) will be measured on a circular plot (3m radius) co-located at the center of each tree subplot. The term '3 m plot' will be used to denote this plot. Within each of the 5 m plots will be 3 square plots, each measuring 1 m x 1m. These will be referred to as 1 m quadrat. The first 1 m quadrat will be located at the center of the 5 m plot. The remaining two are located 6m from the center plot, on a diagonal of the 5 m plot (fig 4). Seedlings (height > 30 cm and DBH < 2.5 cm) will be sampled on three 1m quadrats. In addition to counting seedlings, the percent cover of herbaceous plants, shrubs, and tree species < 30 cm tall will be recorded.

To estimate fuel loadings, a 10 m transect with a random orientation will be established. This will be referred to as the 10 m transect. Line intersect techniques will be used to estimate fuel loadings of large woody material (sound and rotten) > 7.5 cm in diameter. All large woody material intersecting the 10 m transect will be counted and their cross-sectional areas measured by genus. Medium size woody materials (2.5 to 7.4 cm in diameter) that are intersecting the first 5 m of the transect will be counted. In addition, the first, center, and last 1m of the diagonal transect will be used to count fine woody materials (0.01-2.4 cm in diameter). In each case, the mean height of fuels in each sampled diameter class, as well as the slope of the diagonal transect will be measured and reported, respectively.

Soil attributes will be observed on each 5 m radius plot. Any destructive soil samples will be collected on the west side (270 degree Azimuth) of the primary sampling unit at a distance of 5 meters of the plot boundary line.

Most of the indicator variables are compatible with those used by the USDA Forest Service and Canadian ecosystem resource monitoring programs. Other indicator variables can be integrated into this pilot study as resources become available and the need dictates to ensure comparability and interoperability of indicators with participating government agencies from the USA and Canada.

Selection of the Ground Plot Locations and the Assignment of Measurement Periods

Two procedures were used to locate the sample plots in the field. In the first procedure, plot locations were arranged on a triangular systematic grid with a random start, with plot locations falling at the intersection of a triangular grid with approximately 27 km point spacing. This grid allows for a four-year time span between remeasurement of each ground plot on an interpenetrating rotating panel design. Thus, the entire grid and each individual panel is evenly distributed within the area, with a sampling intensity of approximately one ground plot for every 6800 hectares (167,000 acres) for the FHM program.

The JCPP will adopt the same sampling intensity as FIA with one ground plot for every 2400 hectares and maintain across border consistency by meshing the hexagon grid covering Mexico with the existing grid covering the U.S. However, with the increased focus on spatial modeling, the placement of ground plots within each hexagon will not be on the systematic grid. Instead, the plot location within each hexagon will be completely random. This is done by generating a random (x, y)-coordinate that falls within each hexagon. The justification for this practice is that the estimation of correlograms and variograms is difficult when ground plot locations are equally spaced, especially when the scale of spatial patterns is expected to be much finer than the spacing of the grid. For the purpose of estimating population means and totals, this sample is still treated as a simple random sample of the land base, as is common with most environmental surveys. The justification for this practice is summarized by Ripley (1981. pp. 19-21).

The purpose of the hexagon grid is two-fold. In the first place it is used to establish a pseudo-systematic sample (with a random start) of ground plots across the JCPP study area. Secondly it is used to allocate ground plots to each yearly panel so that a good spatial representation of all conditions is represented in each panel. The hexagon grid has no other use in the estimation process. The resulting sample can be best described as a hybrid of centric- and nonaligned-systematic sampling (Ripley 1981, pp.19-21).

The assignment of each plot to a panel is loosely based on the original design used by Forest Health Monitoring (FHM) and the current FIA design (fig. 6). The EMAP grid was developed for interpenetrating rotating panels of 3,4,7,9, and 11 years or any multiple. The FIA design is designed for sampling periods of 5, 7 or 10 years. The state of Jalisco tentatively plans a five year period of remeasurement.

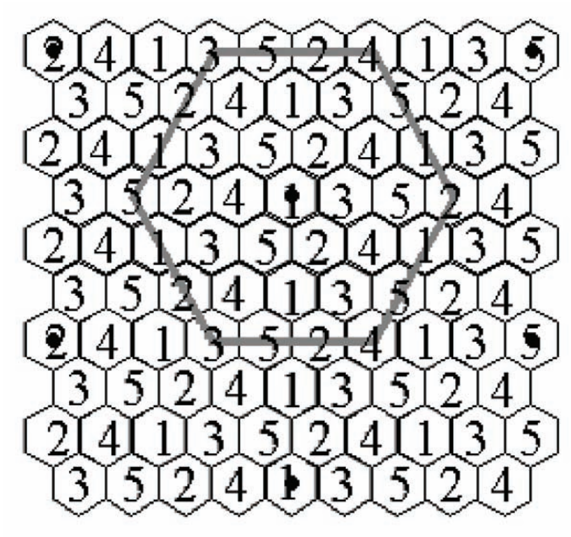

Figure 6. Numbering of each hexagon for the panel assignment.

In the second approach, A two-stage sampling design is employed. In the first stage, the pilot study area was stratified by vegetation type (e.g., temperate forest, tropical forests, grasslands, mesquite forests, agricultural lands, etc.). Strata were defined using a detailed vegetation map of the pilot study area developed using an independent set of point data. Each stratum has a known size and is used as weights to obtain area-wide estimates. The number of sample plots within each stratum were allocated proportional to the size of the stratum and the variability within stratum. In the second phase, Landsat TM data was used to obtain an unsupervised classification of the spectral variability associated with each of the dominant vegetation types, or stratum identified in phase one. The number of spectral classes, or strata in the second stage, will vary, depending on the spectral variability observed within each stratum. An equal number of sample plots were randomly located within each spectral class. This ensures that the sample plots will cover the spectral variability associated with the Landsat TM image, which is essential for spatially interpolating the sample data.

Estimators for the TIER 1 and 2 Inventories

The estimators for the Tier 1 and 2 inventories are simple. The purpose of this section is to present the estimators in detail. This allows the readers to progress only as far into the notation as necessary. Further justification for this approach and simulation results can be found in Williams and Patterson (2003).

One topic that will not be discussed in detail is the method used to assign stratum values to each 90 m X90 m psu. Instead, it is assumed that an effective stratification algorithm will be developed for various regions that will combine the individual pixel attributes, cover map information, and other auxiliary information contained within the area frame. The algorithm may reflect regional forest and landscape characteristics and may depend on the type of analysis being preformed. However, at this point in time there is too little known about available information to define a single technique for the study area.

Slightly different approaches are used to derive the estimators of various cover types versus the estimators associated with vegetation. Thus, these topics will be treated separately.

Estimators for total area of land by cover type or condition classes

To estimate the total area of forest or other condition class, the five 5 m plots of the psu are viewed as the second stage of a two-stage cluster sample. Multistage cluster plot sampling results are used to divide each psu into M=81 secondary sampling units, from which a sample of size m=5 is chosen (fig. 3).

While the estimators derived from the smaller plots sizes (e.g., the 3 m and 1 m plots) can be combined with the one derived from the 5 m plots, the nested structure of the these plots will produce highly correlated estimates. This correlation between the estimators of forest area is such that essentially no reduction in variance exists when estimating forest areas on anything other than the largest plot used (Williams and Patterson 2002). Thus, the area of forest or condition class is estimated using only the information from the largest plot size implemented.

Regardless of the plot size or the method of assignment to a stratum for each psu, the goal is to estimate the proportion of specific condition classes in each stratum. To accomplish this, the n ground plots are treated as a post-stratified sample with a random sample size of n_h in each stratum. For each ground plot, the proportion of the psu covered by forest is either estimated by a subsample of ssus or by measuring the proportion of the psu covering the condition class of interest. Thus, given that the assumptions are reasonable, the estimator of the area of forest is a post-stratified, two-stage cluster sample (Cochran 1977), given by

$$\hat{A}_F = A\hat{p}_F = A\sum_{h=1}^{H}\frac{N_h}{N}\left[\sum_{i=1}^{n_h}\sum_{j=1}^{m}\frac{p^F_{hij}}{mn_h}\right] \qquad (1)$$

where p^F_{hij} is the proportion of forest in the j^{th} 5m subplot of the i^{th} PSU within the h^{th} stratum.

Since the variance of $\hat{A}_F$ is equal to $A^2 Var\left(\hat{p}_F\right)$ suffices to determine $Var\left[\hat{p}_F\right]$. The derivation of the variance combines results from the variance of a simple random post-stratified sample and the variance of a stratified two-stage sample (Cochran (1977), §5A.9 and §10.9). Conditioning on the n_h's, $Var[\hat{p}_F]=Var[E[\hat{p}_F|n_h]]+E[Var[\hat{p}_F|n_h]]$. Since for fixed stratum sample sizes, $\hat{p}_F$ is an unbiased estimator of p_F, the first term is zero. For fixed n_h,

$$Var(\hat{p}_F)=\sum_{h=1}^{H}\left(\frac{N_h}{N}\right)^2\left[\left(\frac{1}{n_h}-\frac{1}{N_h}\right)S_{1h}^2+\frac{1-m/M}{mn_h}S_{2h}^2\right]$$
$$=\sum_{h=1}^{H}\frac{1}{n_h}\left\{\left(\frac{N_h}{N}\right)^2\left[S_{1h}^2-\left(\frac{1}{m}-\frac{1}{M}\right)S_{2h}^2\right]\right\}-\frac{N_h}{N^2}S_{1h}^2 \qquad (2)$$

(Cochran 1977). The next task is to find the expectation of $1/n_h$. Assuming the sample size is sufficiently large to preclude n_h=0 then to order n^{-2},

$$E\left[\frac{1}{n_h}\right]=\frac{1}{n(N_h/N}+\frac{1-N_h/N}{n^2(N_h/N)^2}$$

Using results derived in Cochran (1977) it can be shown that an unbiased estimator for the above approximation of $Var[\hat{p}_F]$ is given by

$$\text{var}[\hat{p}_F]=\sum_{h=1}^{H}\frac{1}{n}\frac{N_h}{N}\left[\left(1-\frac{n}{N}\right)s_{1h}^2+\frac{n}{N}\left(\frac{1}{m}-\frac{1}{M}\right)s_{2h}^2\right]$$
$$+\left(1-\frac{N_h}{N}\right)\frac{1}{n^2}s_{1h}^2 \qquad (3)$$

where s_{1h}^2 and s_{2h}^2 are the between cluster and within cluster sample variances for stratum h (Cochran 1977). Due to the large number of psus (N) in comparison to sample size (n) the second term within the square brackets is small relative to the first term for both the Tier 1 and 2 inventories.

Vegetation or tree estimators

In this section, the estimator that utilizes the tree information from the entire ground plot is given. Unlike the estimator for forest area, where the assumption is made that the psu is divided into M secondary sampling units, a different approach is taken. This is because the tree and other vegetation attributes are gathered from transect samples and across the 1 m, 3 m, and 5 m plots, which would require different M values and the calculation of the correlations between the estimators derived from each of the plot sizes. Thus, the proposed estimators of tree and other vegetation attributes within each psu are expressed as a triareal sampling design comprised of three different sized subplots (Husch and others 1982). The estimator for the total within each psu is expressed using a Horvitz-Thompson estimator. Two assumptions are necessary. The first is that systematic nature of the three subplots within each psu is equivalent to having the points randomly located within the psu. In the literature, this assumption has been justified by assuming that the location of trees in the forest has a random pattern within the psu (de Vries 1986). When this assumption is not realistic the variance estimator tends to over-estimate the variance. The second assumption is that none of the points falls close enough to the boundary of the psu so no adjustments to the inclusion probabilities of trees are required. This allows a constant inclusion probability to be assigned to all trees tallied on each of the three types of subplots. This assumption is necessary because it is impractical to obtain the actual probabilities of selection for border trees.

The n ground plots are treated as a post-stratified sample of psus, with a random sample size n_h in each stratum. Within each psu, a tree-centered circle, or 1 m quadrat in the case of seedlings, (Husch and others 1982) is placed about each tree, the size of the circle is determined by the diameter at breast height limits, which in turn determine the inclusion probabilities. Then a tree is included in a sample drawn by a single point if the point lies within the tree-centered circle. Let a^{1m}, a^{3m}, and a^{5m} denote the area of the 1m quadrat-, 3 m-, and 5m radius plots respectively and let $a_{psu}=8100m^2$ denote the area of the psu. The probability that a tree is included in the sample drawn by a single point within the psu depends on the size of the tree and is defined as:

$$\pi = \begin{matrix} a^{1m}/a_{PSU} \\ a^{3m}/a_{PSU} \\ a^{5m}/a_{PSU}\,, \end{matrix}$$

where a^{1m} is the area of the 1 m quadrat, a^{3m} is the area of the 3 m radius plot, and a^{5m} is the area of the 5 m radius plot.

The estimator given here is for the 3 m and 5 m radius plots, where m=5 plots are sampled within each psu. The estimator for the 1 m quadrats is defined analogously with the exception being the change in sample size to m=15. Estimation for the psu is based on the selection of 5 points within the psu and measurements of the subplots of 3 m and 5 m radius respectively centered at these points. Let T_{hij} be the number of trees tallied at the j^{th} point of psu i in stratum h. Then the estimator of the total of the tree attributes within the psu for the j^{th} point of psu i, in stratum h, is given by

$\hat{Y}_{hij}=\sum_{t=1}^{T_{hij}}\frac{Y_{hijt}}{\pi_{hijt}}$ with and respectively the value of interest and the probability of selecting tree t at point j, psu i, in stratum h.

with the estimator for the total of the PSU derived from the m=5 points being

$$\tilde{\hat{Y}}_{hi} = \frac{1}{m}\sum_{j=1}^{m}\hat{Y}_{hij}.$$

An unbiased estimator of $Var\left[\tilde{Y}_{hi}\right]$ is given by

$$var\left[\tilde{Y}_{hi}\right] = (m(m-1))^{-1}\sum_{j=1}^{m}(\hat{Y}_{hij} - \tilde{Y}_{hi})^2.$$

This estimator is derived by summing across the psus and strata. Then the estimator is

$$\hat{Y} = \sum_{h=1}^{H} N_h \frac{1}{n_h}\sum_{i=1}^{n_h}\tilde{Y}_{hi} \qquad (4)$$

An approximation of the variance of the estimator is given by

$$Var\left[\hat{Y}\right] \approx \sum_{h=1}^{H} N^2\left[\frac{N_h}{N}\frac{1}{n} + (1-\frac{N_h}{N})\frac{1}{n^2}\right]\bar{V}\left[\tilde{Y}_{hi}\right] + N^2\left[\frac{N_h}{N}(\frac{1}{n}-\frac{1}{N})(1\text{-}\frac{N_h}{N})\frac{1}{n^2}\right]S_h^2 \qquad [5]$$

where $\bar{V}\left[\hat{Y}_{hi}\right] = \sum_{i=1}^{N_h} Var\left[\tilde{Y}_{hi}\right]/N_h$ and

$$S_h^2 = \sum_{i=1}^{N_h}(Y_{hi} - \bar{Y}_h)^2/(N_h - 1).$$

An unbiased estimate of the above approximation of $Var[\hat{Y}]$ is given by

$$\text{var}[\hat{Y}] = \sum_{h=1}^{H} N^2\left[\frac{N_h}{N}\frac{1}{n} + (1-\frac{N_h}{N})\frac{1}{n^2}\right]\text{var}[\tilde{Y}_{hi} + N^2 \left[\frac{N_h}{N}(\frac{1}{n}-\frac{1}{N}) + (1-\frac{N_h}{N})\frac{1}{n^2}\right]\tilde{s}_h^2 \qquad ,[6]$$

where $\text{var}[\hat{Y}_{hi}] = \sum_{i=1}^{n_h}\text{var}\left[\tilde{Y}_{hi}\right]/n_h$ and

$$\tilde{s}_h^2 = \sum_{i=1}^{n_h}(\tilde{Y}_{hi} - \tilde{\tilde{Y}}_h)^2/(n_h - 1).$$

The above estimation assumes that there are no plots or subplots that cannot be measured. A nuisance that arises with almost any type of field sampling with plots is that parts of the psu or subplots will fall outside the population of interest or are inaccessible to sampling either because of difficulty of terrain or to reach part of the sample in a practical manner we need to trespass on private land. Not all landowners will allow the crews on or across their land even to measure other lands. How to treat inaccessible plots or subplots is described in the appendix. The following estimator deals with the situation of missing plots or subplots. Post-stratification, as considered above, is not shown in the below formulation since it is a straightforward extension of what is given by simply applying the estimator shown to each stratum.

The most appropriate estimator to be used in estimating population totals with missing subplots is:

$$\hat{Y}_s = A\left[\sum_{i=1}^{n}\sum_{j=1}^{n_s}\sum_{k=1}^{n_{ss}}\hat{A}_{ijk}Y_{ijk}\right] / \left[\sum_{i=1}^{n}\sum_{j=1}^{n_s}\sum_{k=1}^{n_{ss}}\hat{A}_{ijk}\right] \qquad (7)$$

and

$$\hat{Y} = A\left[\sum_{i=1}^{n}\sum_{j=1}^{n_s}\hat{A}_{ij}Y_{ij}\right] / \left[\sum_{i=1}^{n}\sum_{j=1}^{n_s}\hat{A}_{ij}\right] \qquad (8)$$

where $\hat{A}_{ij}$ and $\hat{Y}_{ij}$ are the estimated sampled area and value of interest respectively in subplot j of plot i, n is the number of plots in the sample, n_s is the number of subplots in the sample for plot i where $\hat{Y}_s$ is the estimator for subplot size s and subplot ss ,and m_i is the number of subplots in the sample for plot i (Max and others 1996). We recommend the use of bootstrap variance estimators here as discussed in Schreuder and others (1993).

Line intersect sampling estimators

The line intersect sample (LIS) is drawn using m=5 randomly oriented lines with the centers covering each of the 5 m plots. The estimator employed is the LIS estimator as described in Kaiser (1983) and Gregoire (1998), with the key difference being that the sample locations are a systematic sample subsample of the psu rather than five random locations. There should be little if any detectable bias in the resulting estimators, but the variance estimator should over-estimate the true sample variance. The LIS estimator for the amount of woody debris on the psu estimated from the m=5 L=10m lines with random orientation is given by

$$Y_{hi} = \frac{1}{m}\sum_{j=1}^{m}Y_{hij} = \frac{1}{m}\sum_{j=1}^{m}\frac{a_{PSU}\pi}{2L}\sum_{k=1}^{P_j}\frac{g_{hijk}}{\cos\delta_{hijk}}$$

where g_{hijk} is the cross-sectional area of the log measured perpendicular to the long axis of the log (m^3) for the k^{th} piece of debris on the j^{th} transect, P_j is the number of pieces of debris intersected by the j^{th} line, and δ_{hijk} is the slope of the log. In relatively flat terrain, δ_{hijk} , may be set to zero. However, a bias in excess of 10 percent can occur whenever the slope exceeds 25 percent. The derivation and further details for this estimator can be found in Kaiser (1983 example 2c).

The variance estimator given in eq. [6] applies.

Other estimators

While area and vegetation totals are the primary forest attributes that are estimated, other estimators are also of interest. The first class are mean per tree estimators (average number of conks or disease agents per trees). The form of this estimator is $\bar{\hat{Y}} = \hat{Y} / \hat{N}$, where $\hat{N}$ is the estimator of the number of trees (eq. [4] with Y_{hijt}=1). Another class of estimators is used to assess change. These have the form where and are the estimators at times 2 and 1, respectively.

Variance estimators for the mean per tree and difference estimators are

$$\mathrm{var}(\bar{\hat{Y}}) \approx \frac{1}{\hat{N}}\left[\mathrm{var}(\hat{Y}) + \frac{\hat{Y}}{\hat{N}}\mathrm{var}(\hat{N}) - 2\frac{\hat{Y}^2}{\hat{N}^2}\mathrm{cov}(\hat{Y},\hat{N})\right] \quad (10)$$

and

$$\mathrm{var}(\Delta\hat{Y}) = \mathrm{var}(\hat{Y}_2) + \mathrm{var}(\hat{Y}_1) - 2\,\mathrm{cov}(\hat{Y}_2,\hat{Y}_1) \quad (11)$$

Alternative estimators

At this point in time there are a number of alternative estimators that may offer advantages over the estimators given above.

In various circumstances we may have complete knowledge on a covariate associated with the variable of interest for which we know all the values in the population or we can get those with relative ease. Usually this information is combined with the information on the variable of interest measured on a sub-sample of the units in the population. Denoting by y= variable of interest and x= covariate, numerous estimators are possible. We focus only on the generalized regression and the ratio-of means estimators, the others are generally not desirable.

A very general, efficient estimator is the generalized regression estimator developed by C.E. Sarndal:

$$\hat{Y}_{gr} = \sum_{i=1}^{n} y_1 / \pi_i + a_{gr}(N - \sum_{i=1}^{n} 1/\pi_i) +$$

$$b_{gr}(X - \sum_{i=1}^{n} x_i / \pi_i) = \sum_{i=1}^{N} \hat{y}_i + \sum_{i=1}^{n} e_i / \pi_i \quad (12)$$

where

$$\hat{y}_i a_{gr} + b_{gr} x_i, e_i = y_i - \hat{y}_i ,$$

$$\hat{y}_i = a_{gr} + b_{gr} x_i,\ e_i = y_i - \hat{y}_i,$$

$$a_{gr} = \{\sum_{i=1}^{n} 1/(\pi_i v_i) - b_{gr}\sum_{i=1}^{n} x_i / (\pi_i v_{i)}\}$$

$$/\sum_{i=1}^{n} 1/(\pi_i v_i)$$

$$b_{gr} = \{\sum_{i=1}^{n} 1/(\pi_i v_i)\sum_{i=1}^{n} x_i y_i / (\pi_i v_i) - \sum_{i=1}^{n} y_i$$

$$/(v_i\pi_i)\sum_{i=1}^{n} x_i/(v_i\pi_i)\}/\{\sum_{i=1}^{n} 1/(\pi_i v_i)\sum_{i=1}^{n} x_i^2/(v_i\pi_i) -$$

$$[\sum_{i=1}^{n} x_i/(v_i\pi_i)]^2\}$$

with variance:

$$V(\hat{Y}_{gr}) = (1/2)\sum_{i \neq j}^{N}(\pi_i\pi_j - \pi_{ij})(e_i/\pi_i - e_j/\pi_j)^2 \quad (13)$$

with 2 possible variance estimators given in Schreuder and others (1993) but we recommend using a bootstrap variance estimator here. This is the estimator to be used when possible.

Another estimator that is not a special case of the above is called the generalized ratio of means estimator:

$$\hat{Y}_{rm} = (\sum_{i=1}^{n} y_i / \pi_i / \sum_{i=1}^{n} x_i / \pi_i) X = (\hat{Y}_{HT} / \hat{X}_{HT}) X \quad (14)$$

with approximate variance

$$V(\hat{Y}_{rm}) = V(\hat{Y}_{HT}) - 2RCov(\hat{Y}_{HT}, \hat{Y}_{HT}) + R^2 V(\hat{X}_{HT}) \cdot \quad (15)$$

There is a good discussion in Schreuder and others (1993) but again, we recommend using a bootstrap variance estimator. Both the generalized regression and the ratio-of-means estimator are asymptotically unbiased.

There will be opportunities to use $\hat{Y}_{gr}$ in the pilot study. With the heavy emphasis on remote sensing platforms we will examine what we can do with that in relation to the ground sampling to obtain improved estimates for some parameters.

Variance estimators can also be derived that utilize re-sampling techniques, with the most common being bootstrap and jackknife estimators. Bootstrap samples are generated by repeating the sampling design with replacement at the same sample sizes as the actual sample design and then generating estimates for each bootstrap sample. The variance between those estimates is the variance estimate for the estimator of interest. Usually 2000 bootstrap samples are generated. This is applicable for all estimators above.

Summary and Recommendations

The statistical strategies presented in this document significantly benefit from the experience that exists in Canada and the United States. In light of how rapid technology has been evolving, these strategies incorporate new design elements so that remote sensing and land measurement protocols processes can be unified for purposes of making reliable statistical inferences. Consistency of data collection protocols at national and state levels is essential for this strategy to work properly and generate estimates of known confidence. Its implementation on the Pilot Study Area produced valuable information for improving design elements and data analysis approaches. How the two strategies can be integrated even better and to determine what would be the best plot to use to constitute some of the questions to be addressed after the full analyses of the data from this project.

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The FIA Panel Design and Compatible Estimators for the Components of Change

Francis A. Roesch, Mathematical Statistician, Southern Research Station, USDA Forest Service, Asheville, NC

Abstract—*The FIA annual panel design and its relation to compatible estimation systems for the components of change are discussed. Estimation for the traditional components of growth, as presented by Meyer (1953, Forest Mensuration) is bypassed in favor of a focus on estimation for the discrete analogs to Eriksson's (1995, For. Sci. 41(4):796-822) time invariant redefinitions of the components of change, as evaluated in Roesch (2004), and Roesch (in review). A simple extension of the mixed estimation framework for forest inventory trends presented in Van Deusen (1996, Can. J. For. Res. 26: 1709-1713.) and Van Deusen (1999, Can. J. For. Res. 29(12): 1824-1828) is used to unify estimation of the individual components.*

Introduction

The USDA Forest Service's Forest Inventory and Analysis Units (FIA) report on the condition of forests within the United States and its territories. To this end, the Forest Service recently initiated an annualized forest inventory sampling design in order to improve estimation of both the current resource inventory and changes in the resource. Roesch (in review) gives the theory for a generalized three-dimensional explanation of the current sample frame. In two dimensions, the sample plots are located relative to a systematic triangular grid consisting of *k* mutually-exclusive interpenetrating panels. If the number of sample plots equals *n*, then each panel consists of approximately *n/k* plots. Time is the third dimension, incorporated by measuring one panel per year for *k* consecutive years, after which the panel measurement sequence reinitiates. That is, if panel 1 was measured in 1997, it will also be measured in 1997+k, 1997+2k, and so on. Panel 2 would then be measured in 1998, 1998+k, 1998+2k, etc. (Figure 1.) The panels are assigned to previously measured and new plots in a spatially systematic manner.

The sample is drawn from a three-dimensional cube, two dimensions constitute the land area and the third dimension is time. Roesch (in review) describes the two areal dimensions of the design as the joint selection of previously existing and new sample points by a randomly applied triangular grid. It is assumed that the sample points from the entire collection of previous periodic inventories constitute a random sample from the infinite set of points within the geographically-defined population described above. The sample unit is a series of line segments, linear in time. That is, when the time dimension is collapsed down onto the area dimensions, each series of line segments collectively appear as a single point on the area. Each line segment within a series is of an approximate length of 1 day. Individual segments occur every (k +/- 1) year, within each series. Within a sufficiently small segment of time, all points within the land area dimensions of the volume common to each area segment created by the overlapping inclusion areas of all possible subsets of trees occurring on the land area (sensei Roesch et. al. 1993) could be viewed as a temporally-specific sampling unit. However, because these segments change as time progresses, the sample unit appears as a point in the temporally-specific land area dimensions of the volume. That is, if the population is sliced into, say, annual volumes, and then the annual sub-population is viewed from the top, a set of N/k points on the land area base will be observed. The thinner the temporal slice, the smaller the sample per land area of interest and the wider the slice, the fuzzier the segment

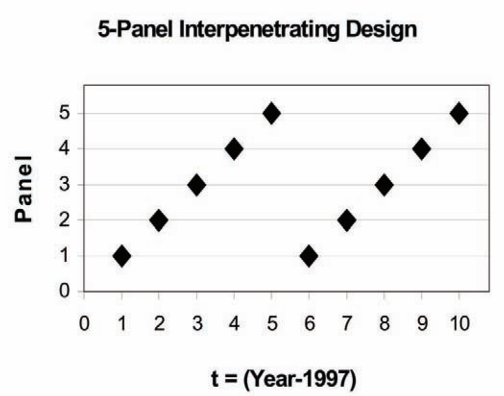

Figure 1. A rotating panel design with 5 panels and a five-year remeasurement period.

boundaries, due to changes in both the land area and the subpopulations of trees within the land area. The temporal slices should be thin enough that all daily line segments (sample units) associated with a point on the land area can be considered exchangeable. We usually (but not always) assume that the assignment of measurement day within panel (slice) is ignorable. When we can make this assumption, the plot measurements support the entire line segment within the panel volume (that is all days constituting the slice.) For most forestry purposes, annual slices will constitute the minimum height that forms a reasonable compromise between temporal specificity and land area generality.

Below, I briefly review the traditional components of growth as presented by Meyer (1953) and subsequently show the intuitively appealing redefinition of the components of change given by Eriksson (1995). I then discuss how discrete analogs to Erickson's components could be estimated from the annual inventory design.

Components of Growth

Meyer (1953) expressed the components of forest growth as:

$$V_2 - V_1 = S + I - M - C, \qquad (1)$$

where:

V_i = the total value at time i, i=1,2,
S = survivor growth,
I = ingrowth,
M = mortality, and
C = cut.

Estimators for the components of growth are considered compatible if they can replace the population parameters in equation (1) without destroying the equality.

Roesch (2004) and Roesch (in review) claim that the weakness of the traditional definitions of the components of growth lies in their inherent dependence on the length of the measurement interval because the definition of the components of growth for the population is dependent upon the time that the relative sample stages are executed. By these definitions, the components are not strictly population parameters to be estimated. Rather, they were a convenient marriage of a population and its sample. Unfortunately, the marriage ceased to remain convenient when the sample design changed in a significant way.

Components of Change

Eriksson (1995) recommended a new set of definitions, labeled the components of change, that were applicable over a temporal continuum, as opposed to the traditional growth component definitions that were not time-additive over multiple period lengths. For example, over a ten-year period in which all plots are measured in years 0, 5, and 10, the sums of the expected values of the estimators of each component over the two intervals (years 0-5 and 5-10) would not equal the expected value of the estimators sans the year 5 measurement. The components of change given by Eriksson (1995) are defined by population attributes and are therefore not sample dependent. Non-additivity is a valid concern due to a fundamental flaw in the original definition of the components of growth. Additionally, the redefinitions become extremely compelling in the realm of annual inventories. The discussion above at least suggests that the original definitions are inadequate for time-interpenetrating sample designs, such as this rotating panel design.

Eriksson (1995) noted that the traditional component of ingrowth consists of both the value of the trees that attain the minimum merchantability limit and the growth in value subsequent to attaining the minimum merchantability limit. Obviously, the later should actually be attributed to survivor growth. Paraphrasing the definitions of Eriksson (1995), live tree growth is the growth in value that occurs on trees after the minimum merchantability limit has been achieved. Entry is the value of trees as they attain the minimum merchantability limit. Mortality is the value of trees as they die, and Cut is the value of trees as they are harvested. Roesch (2004, in review) used discrete analogs to Eriksson's (1995) definitions with a small (1 year) interval length for two reasons, (1) an assumption that 1 year is about the minimum interval length required for the growth signal to overpower measurement error, and (2) to facilitate a tractable temporal partitioning of the observations.

Implicit in the use of the discrete definitions is the assumption that no growth occurs on mortality and cut trees during year of death or harvest. During the time interval of interest, a tree can contribute to multiple components of change. For example, an individual may enter the population, live for two years and then die in between observation instances.

The discrete intervals allow the definition of a set of indicator matrices, one for each component, having one row for each tree in the population during the forest inventory. For example, the indicator matrix for the entry component:

time = P P-1…1 tree

$$\mathbf{I}_{E=} \begin{bmatrix} 0 & 0 \cdots 1 \\ 0 & 0 \ddots .0 \\ 0 & 1 \ddots .0 \\ 1 & 0 \cdots 0 \end{bmatrix} \begin{matrix} 1 \\ \vdots \\ \vdots \\ N \end{matrix} .$$

In $\mathbf{I_E}$, the first column is for the most recent year of the inventory, and each successive column is one year prior to the previous column. For each tree, all columns are zero except for the year of entry, which would contain a 1. Analogous indicator matrices for tree mortality, $\mathbf{I_M}$, and for tree harvest, $\mathbf{I_C}$, are defined. The indicator matrix for the live category contains a 1 for each year that a tree is alive subsequent to its entry year and prior to its year of harvest or death, and a 0 otherwise:

$$\mathbf{I_L}= \begin{bmatrix} 0 & 0\cdots 0 \\ 1 & 1\ddots 1 \\ 0 & 1\ddots 0 \\ 1 & 1\cdots 1 \end{bmatrix} \begin{matrix} 1 \\ \vdots \\ \vdots \\ N \end{matrix}$$

The four indicator matrices are of equal dimension and sum to the population indicator matrix, $\mathbf{I_P}=\mathbf{I_E}+\mathbf{I_L}+\mathbf{I_M}+\mathbf{I_C}$. Likewise, we form a value matrix of the same dimension:

$$\mathrm{v}= \begin{bmatrix} v_{1,P} & v_{1,P-1} \cdots & v_{1,1} \\ v_{2,P} & v_{2,P-1} & \\ \vdots & \ddots & \vdots \\ v_{N,P} & \vdots & v_{N,1} \end{bmatrix},$$

and an (Nx1) entry value vector: $\begin{bmatrix} v_1^E \\ v_2^E \\ \vdots \\ \vdots \\ v_N^E \end{bmatrix}$

The period of interest of length t beginning in year h ($h\geq 1, h+t\leq P$) is selected by defining a column vector $\mathbf{Y_{h+t,h}}$ in which rows represent time in reverse annual order. A row contains a 1 for a year of interest and a 0 otherwise.

Additionally, we define the first difference matrix with P-1 columns and P rows, such that the ordered pair $\begin{bmatrix} 1 \\ -1 \end{bmatrix}$ appears once and only once in each column and all other entries are zero. The ordered pair occupies the first two positions in the first column, and moves one position down in each subsequent column:

$$\mathbf{d}^1= \begin{matrix} & \begin{matrix} P\text{-}1 & P\text{-}2\cdots\cdots & 1 \end{matrix} & \\ & \begin{bmatrix} 1 & 0\cdots 0 & 0 \\ -1 & 1\cdots 0 & 0 \\ 0 & -1\ddots\vdots & \vdots \\ 0 & 0\cdots -1 & 1 \\ 0 & 0\cdots 0 & -1 \end{bmatrix} & \begin{matrix} P \\ P-1 \\ \vdots \\ \vdots \\ 1 \end{matrix} \end{matrix}$$

The change components are represented as:

Entry: $\mathbf{E_{h,h+t}}=(\mathbf{I_E}'\mathbf{v^E})'\mathbf{Y_{h+t,h+1}}$,

Live growth: $\mathbf{L_{h,h+t}}=(\mathbf{I_L}'(\mathbf{vd^1}))'\mathbf{Y_{h+t,h+1}}+[\mathbf{I_E}'(\mathbf{v}-\mathbf{v^E})]'\mathbf{Y_{h+t,h+1}}$,

Merchantable Mortality: $\mathbf{M_{h,h+t}}=(\mathbf{I_M}'\mathbf{v})'\mathbf{Y_{h+t-1,h}}$, and

Merchantable Cut: $\mathbf{C_{h,h+t}}=(\mathbf{I_C}'\mathbf{v})'\mathbf{Y_{h+t-1,h}}$.

We also estimate Merchantable Volume at times h+t to h: $\mathbf{V_{h+t,h}}=(\mathbf{I_P}'\mathbf{v})'\mathbf{Y_{h+t,h}}$.

It is important to clearly distinguish the attributes that truly belong to the population from those that are artifacts of the sample design. My suggestions for estimation recognize (1) a measurement interval length (say five years) that is longer than the minimum growth interval of one year, and (2) annually overlapping measurement intervals that result from the rotating panel design.

Mixed Estimator

The components of change definitions are superior to the traditional components of growth for a number of reasons, the time additivity advantage pointed out by Eriksson (1995) being the most obvious. However, that does not necessarily translate into a stronger argument for forcing compatibility of the estimates of the components. Suppose that our sample design consists of five overlapping continuously remeasured panels, one panel measured each year and then remeasured five years hence. The strongest signal for value during any particular year will come from the panel actually measured in that year, while the strongest signal for the live growth component will come from the panel with a remeasurement interval centered on that year. A mixed estimator would seem to be a good way to balance the desire for the "best" estimate for each component with a desire for compatible estimates. The mixed estimator draws strength from overlapping panels. It's a generalized least squares estimator in which model constraints are appended to the data matrices. Van Deusen (1996, 1999, 2000) showed mixed estimators for successive annual estimates. Roesch (2001) tested mixed estimators using both real and simulated data, finding the mixed estimators to perform quite well relative alternative techniques. Roesch (in review) argues for an approach that involves building compatibility constraints for the components of change into a mixed estimator after noting that compatibility requires, for any i and any t, the strict equality: $\hat{V}_{i+t}-\hat{V}_t=\hat{L}_{i,i+t}+\hat{E}_{i,i+t}-\hat{M}_{i,i+t}-\hat{C}_{i,i+t}$.

Consider a model in which the observed midpoint values are used to constrain the component estimates. That is, for k, an integer, and $t\geq k+1$ let

$$\delta_t^k=\begin{cases}(V_{t-(k-1/2)}-V_{t-(k+1/2)}), \text{ if k is odd:} \\ (V_{t-(k-2/2)}-V_{t-(k+2/2)}), \text{ if k is even;}\end{cases}$$

and form a four-column row vector of components such that:

$$\chi_t^k = \begin{cases} \frac{L_{t-k,t}}{k} | \frac{E_{t-k,t}}{k} | \frac{-M_{t-k,t}}{k} | \frac{-C_{t-k,t}}{k}, \text{ if k is odd;} \\ \frac{2L_{t-k,t}}{k} | \frac{2E_{t-k,t}}{k} | \frac{-2M_{t-k,t}}{k} | \frac{-2C_{t-k,t}}{k}, \text{if k is even;} \end{cases}$$

Assume an observation model at each time t: $\delta_t^k = \chi_t^k \beta_t + e_t$,

where β_t is a vector of coefficients with a row for each component and e_t is iid (0, σ^2_t/m_t), and combine it with a reasonably constrained transition model.

Form a vector from the, δ_t^k's, $\Delta = [\delta_{k+1}^k, \ldots, \delta_T^k]'$, a matrix **X**, from the χ_t^k's, having ((T-k)*4) columns. The vector χ_t^k is placed in row i beginning in column ((i-1)*4)+1). The rest of the elements in the row are zeros. Concatenate successive elements of the column vectors β_t into the column vector $\beta = \begin{bmatrix} \beta_{k+1} \\ \vdots \\ \beta_T \end{bmatrix}$, having ((T-k)*4) rows. Form vectors from the error terms **e**=$[e_{k+t}, \ldots, e_T]'$ and $\varepsilon = [\varepsilon_{k+t}, \ldots, \varepsilon_T]'$. Represent equation (3) with:

$$\Delta = \chi\beta + e \quad (4)$$

Represent the covariance matrix of Δ with Σ. The temporal constraints can be re-expressed as:

$$\mathbf{R}\beta = \varepsilon \quad (5)$$

where **R** is the appropriately sized matrix of constraints for the transition model.

Combining the observation model with the transition model:

$$\begin{bmatrix} \Delta \\ 0 \end{bmatrix} = \begin{bmatrix} X \\ R \end{bmatrix} \beta + \begin{bmatrix} e \\ \varepsilon \end{bmatrix} \quad (6)$$

Following Van Deusen (1999), the error vectors **e** and ε are assumed to have independent multivariate normal distributions. ε represents random deviations applied to the beta coefficients, which should be independent of the sampling errors represented by **e**. Theil's (1963, 1971) mixed estimator for β, is:

$$\hat{\beta} = \left[X'\Sigma^{-1}X + \frac{1}{p} R'\Omega^{-1}R \right]^{-1} X'\Sigma^{-1}\Delta$$

The transition covariance matrix Ω is assumed to be a scaled submatrix of Σ, allowing us to adapt a maximum likelihood estimator of the parameter p given by Van Deusen (1999), which determines the strictness of the constraints.

Conclusion

In this paper and the previous ones cited, I attempted to clearly distinguish the effect of scale in the definition of the components of change from the effect on our ability to estimate the components of change at different scales caused by the sample design. Once this distinction has been made, it is clear that the annual estimates of the components of change desired by users of FIA data can only be obtained through the use of models applied to the sample design. That is, there are no strictly design-unbiased estimators for the annual components of change available for this rotating panel design. The mixed estimation technique allows us to use simple models to make well-supported estimates at varying scales by drawing strength from measurements made on temporal "neighbors".

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1872 vs 2004: Mining Claim Meets the World Wide Web

Edward Russell, computer scientist, Computer Terrain Mapping, Inc., Boulder, CO

Abstract—*Inappropriate development or land use on private inholdings in a matrix of predominantly public land have the potential to profoundly impact backcountry landscapes. Beyond damage to natural systems and cultural resources, ramifications include impacts on neighboring communities dependent upon tourism and backcountry recreation for their economic vitality. Limited financial resources make geotechnologies an ideal tool for prioritizing inholdings for land conservation acquisition or other means of protection. The World Wide Web holds tremendous promise for distributing geographic information and applications for use in conservation planning by local governments, land managers, and conservation professionals. Two example projects in the rugged San Juan Mountains of southwestern Colorado illustrate the potential and challenges that these technologies hold for rural communities.*

Introduction

Land ownership patterns around many of Colorado's mountain communities reflect the legacy of the region's mining past. While visitors see forested hillsides and high mountain tundra, an unseen world of jumbled private inholdings within a matrix of public land exists beneath this alpine landscape. A remnant of 19th century legislation intended to help settle the sparsely inhabited and mineral rich west; this ownership pattern presents significant 21st century challenges for surrounding mountain communities. The General Mining Law of 1872 provided for "patenting" open public land – a process in which public land is converted to private ownership. Figure 1 shows the chaotic ownership pattern of patented mining claims in the northern San Juan Mountains in southwestern Colorado.

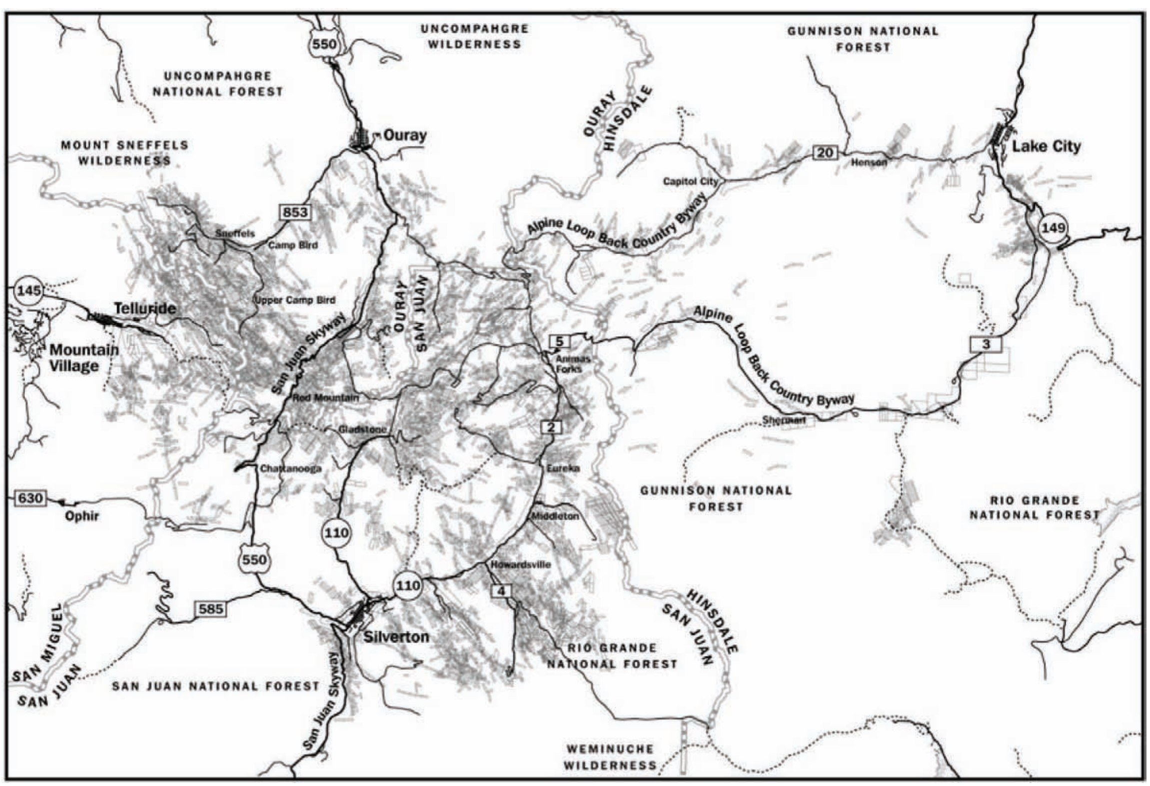

Figure 1. Patented mining claims in a portion of the northern San Juan Mountains.

Managing the landscape to preserve natural values, historic resources, and recreational access is a daunting challenge within this incoherent ownership framework. Construction of second homes and vacation cabins - "backcountry sprawl" - further fragments wildlife habitat, compromises scenic vistas and strains local government's ability to provide services and infrastructure. Furthermore, drainage from open adits and runoff from tailings piles can create downstream water quality problems with consequential environmental liability issues for organizations that seek to mitigate these negative impacts.

For workers concerned with conservation-oriented land management alternatives, the magnitude of the inholding problem can be overwhelming. To make the problem more manageable, we've developed a methodology that ranks private parcels according to their conservation priority. This methodology takes into account both the intrinsic conservation resource values associated with each parcel along with an estimate of the likelihood of (residential or commercial) development based upon physical constraints present on the property. The highest ranking properties are those with the greatest occurrence of conservation resources and the highest development potential based upon physical constraints. Conservation workers can then design management or acquisition scenarios based upon available financial resources matched with critical priority parcels.

With many land managers located in dispersed, rural locales, internet-based technologies have become an important distribution vehicle for geospatial data and services. Cash strapped local governments, federal agencies and nonprofits need only an internet connection and web browsing software to access capabilities that typically costs thousands of dollars a "seat" for desktop licensing. Two projects – the Red Mountain component of the San Juan Skyway Spatial Analysis and Mapping Project and the Alpine Loop Back Country Byway Spatial Analysis and Mapping Project – in portions of Hinsdale, Ouray, San Juan and San Miguel counties utilized the conservation priorities methodology to rank private inholdings within the area illustrated in figure 1. References to the "northern San Juan" area that follow indicate the area of figure 1 and the two projects mentioned above.

Economics, Demographics and Politics

Figure 2 shows the change in the number of jobs in different industries over time for Ouray County. This chart illustrates the decline of mining as an employment base and the ascendance of recreation / tourism related jobs in the retail and service sectors. It also depicts the increasing importance of the construction and real estate industries for this county. These trends are fairly typical of other northern San Juan counties. The recreation and tourism industries are highly dependent on the region's natural and cultural amenities. Consequently, protecting the region's natural and cultural resources also helps to protect the region's economic vitality.

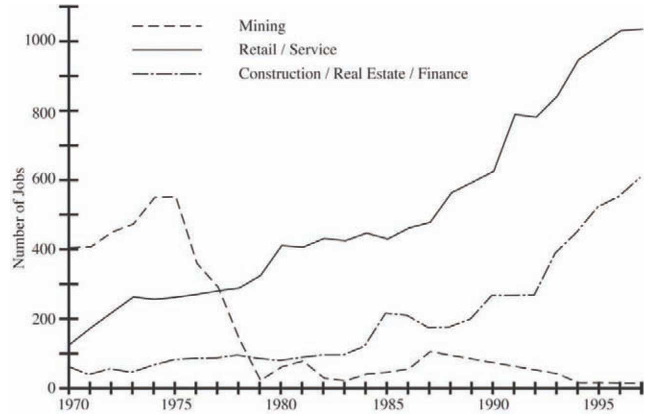

Figure 2. Economic profile for Ouray County, Colorado. This graph illustrates the number of jobs in selected industries as a function of time. Large scale mining ended with the closure of the Idarado mine in 1978 (adapted from The Wilderness Society 2000).

The outdoor amenities offered by the San Juan region have made the area desirable for part-time residents. Table 1 shows the percentage of second or seasonal homes for counties within the northern San Juan area determined from the 2000 Census. The table also gives the county's second home ranking within the state. Seasonal activities such as winter skiing, fall hunting and high country summer recreation are major draws to the mountainous counties including those in the San Juans. The second home industry contributes significantly to local economies through jobs in construction, real estate, and finance (fig. 2).

Many San Juan Mountain counties have very high levels of public land ownership. Table 2 shows the land stewardship breakdown for four northern San Juan counties. The percentage of land in public ownership is particularly high for San Juan and Hinsdale counties (~89

Table 1. Percentage of second or seasonal homes for 4 northern San Juan counties. The rank is within 63 Colorado counties in 2000 (Bureau of Census 2000).

County	2nd Homes (%)	Rank in Colorado
Hinsdale	61.3	1
San Juan	49.4	4
San Miguel	33.5	10
Ouray	12.7	24

Table 2. Percentage of land in public ownership (undifferentiated). The rank is within 63 Colorado counties (Division of Wildlife, NDIS web site).

County	Total Public Land (%)	Rank in Colorado
Hinsdale	95.5	1
San Juan	88.9	3
San Miguel	62.2	23
Ouray	45.5	33

percent and ~96 percent respectively). As a consequence, acquisition of private land and subsequent transfer to public ownership frequently meets significant political opposition. Reasons for opposition include decreased property tax base, restriction of residential and commercial growth opportunities, and a general distrust of federal government intentions. This presents an added challenge to those interested in land conservation in these counties. Other land management alternatives such as land exchanges, recreational easements, or transfer of development rights should be considered in this political context.

Significant Resources

Several significant natural and cultural resources draw visitors to the region and add to the quality of life for local residents. These resources have been identified by project stakeholders for preservation and enhancement and were included as components in the GIS modeling process.

Recreation

Recreational activities in the area are numerous and include hiking, biking, off highway motorized use, mountaineering, rock climbing, skiing, snowshoeing, snowmobiling, camping, horseback riding, fishing, rafting and kayaking. As mentioned above, recreation and tourism have become the major components of the region's economy.

Recreational elements included in the GIS analysis were roads, trails, campgrounds and huts, trail heads, ski areas and historic railroads.

Historic

The northern San Juans contain an outstanding record of Colorado's hard rock mining era. Beyond a snapshot of life of a bygone time, the region's historical resources provide an important record of innovation in mining technology. The Red Mountain Pass area has been referred to as a mining "Silicon Valley" for the technical advancements that the area produced (Clifton 2003). Along with outdoor recreation, these historical resources provide a significant visitor draw.

The Colorado Historical Society (CHS) maintains a database of inventoried historic sites that were used in the spatial modeling exercise.

Ecological

The montane, subalpine, and alpine environments found in the northern San Juans provide habitat for a number of economic species and species of special concern, including elk, mule deer, boreal toad, ptarmigan, lynx, and moose. A number of potential conservation areas identified by the Colorado Natural Heritage Program (CNHP) occur within the northern San Juan region.

Important habitat and ecological areas from a variety of data sources were used in the GIS modeling.

Scenic

The San Juan region is renowned for its scenic splendor. The San Juan Skyway, which runs through the western portion of the study area, is referred to as the "most scenic drive in America." The City of Ouray uses the moniker of "Switzerland of America" for its scenic character.

Visual resources were modeled through viewshed mapping and skyline analysis (areas where structures would break the skyline) from designated roadways within the study area.

Watershed

Four significant drainages have their headwaters in the northern San Juan project area. The Lake Fork of the Gunnison and the Uncompahgre River are major tributaries to the Gunnison River. The San Miguel River is a major tributary to the Dolores River; the Animas River is a major tributary to the San Juan River. These watersheds provide source water for numerous downstream communities. Healthy watersheds result in healthier ecosystems and higher water quality for drinking water, recreation, and agricultural operations.

Buffers around streams and water bodies were used in the modeling.

Threats to Resource Integrity

Reliable recreational access to the region's "magnet" locations becomes especially important in the currently prevailing economic climate. While the vast majority of recreational destinations are located on public land, backcountry access roads and trails frequently cross private inholdings. Conflict arises when public access through these inholdings is challenged by private landowners. In San Miguel County, access along the standard route up Wilson Peak, one of Colorado's popular "14ers" (peaks over 14,000 ft in elevation) has been blocked by the owner of a private inholding in U.S. Forest Service land. Since these 14ers are destinations for many thousands of hikers a year, closures of this type can have local economic ramifications.

With each passing year, the harsh high country conditions take their toll on historic structures. Stabilization and restoration efforts on private property cannot take place without landowner permission and adequate funding. While this "passive destruction" slowly degrades the structural integrity of historic sites, deliberately destructive acts can have an immediate and devastating impact. In August 2002, a Red Mountain Pass landowner destroyed historic structures on his property that had been built over a hundred years earlier (Greenhill 2002). Ostensibly to eliminate "attractive nuisance" liability, some felt that this destruction, together with the "for sale" signs on the property, were a form of blackmail to set a higher-than-market-rate price.

An owner of a patented mining claim has the same rights as owners of other private parcels, including the right to construct a home or cabin. In sensitive high country environments, construction of homes and access roads often fragments wildlife habitat, impacts scenic vistas and creates demand for new local government services, such as winter road maintenance and remote emergency services. In addition, for privacy, safety and liability reasons, new mountain residents may block recreational routes that have traditionally, though unofficially, crossed their property.

The area's mining heritage has a downside as well. Mining's legacy extends beyond historic structures and the record of hard rock mining innovation to draining adits, tailings piles and downstream pollution. Researchers investigating frail-boned white tailed ptarmigan have linked this condition to elevated cadmium levels in willows, a primary ptarmigan food source (Larison and others 2000). Fish populations have been impacted for tens of miles and water quality standards have not been met for the Animas River, which provides drinking water for the communities of Silverton and Durango (Robinson and Odell 2002). Short term gain was emphasized at the expense of long term unintended or ignored consequences. It's worth reflecting on our actions today and their potential impact on future generations.

Conservation Priorities Methodology

To address the issues of land conservation within the context of these resources and threats, we've developed a methodology to prioritize lands based upon their conservation resource values and likelihood of development (fig. 3). The "Landscape-Based Conservation Priorities" section of the figure illustrates two vital components: "Resource Value" (or conservation resource value) and "Development Potential." This section is referred to as landscape-based because it focuses predominantly on the naturally occurring systems – in other words., topographic, vegetative, geologic, etc. - largely separate from the human imposed land ownership pattern.

Resource value is the combination of spatial factors that contribute to the intrinsic conservation value of the area. These conservation resources include scenic vistas, critical wildlife habitat, historic resources, recreational amenities, and areas important for watershed health.

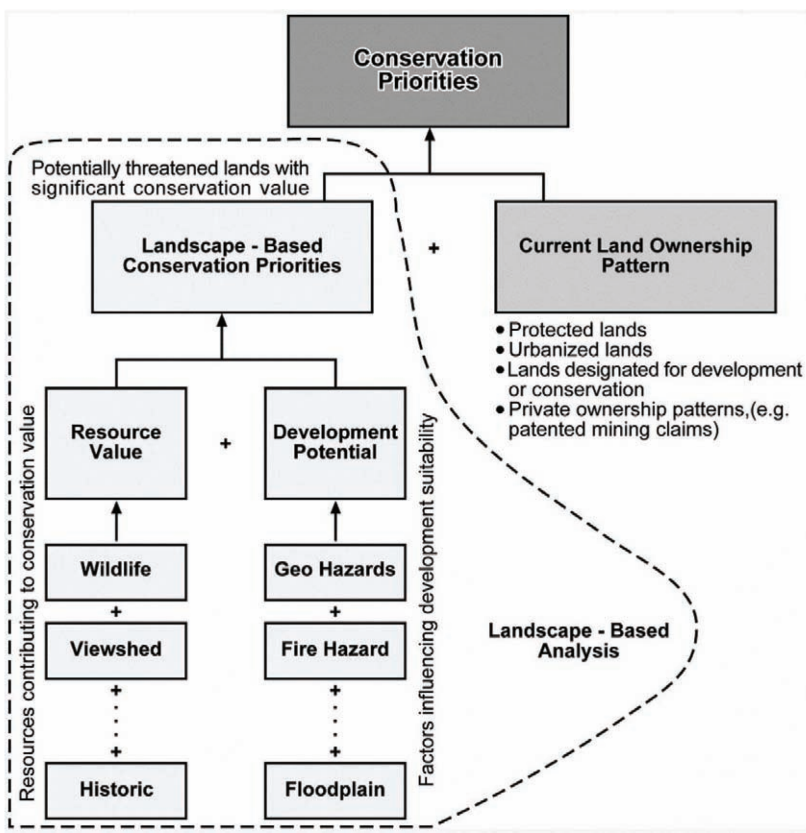

Figure 3. Conservation priorities methodology (Computer Terrain Mapping and others 2004).

Development potential combines factors that constrain the "buildability" of a parcel. These constraints include steep slopes, geologic hazards, avalanche hazard, proximity to existing roads (to access a property), floodplains, environmental constraints and wildfire hazard.

Resource value and development potential are combined to form the landscape-based conservation priorities. These are areas with high conservation value that are likely to be developed based upon building constraints. At this point, development potential has not been restricted to private parcels. The results of the landscape-based analysis are combined with the private land ownership pattern to produce the overall conservation priorities.

There are advantages to decoupling the landscape-based computations from the human imposed land ownership pattern. First, the digital representation of a parcel's location may involve considerable uncertainty. If this digital representation shifts due to a more accurate set of locational parameters, the parcel's value and priority status can easily be recalculated. Another advantage allows public agencies to assess the conservation priority of a potential trade parcel that is currently in public ownership. If only private parcels are evaluated, then a separate analytical exercise would need to occur to similarly assess the conservation value of a potential publicly-owned trade parcel.

Challenges

This prioritization process provides a useful framework for evaluating and ranking parcels for land conservation purposes. However, a variety of factors present challenges in the data acquisition, analysis and interpretation stages. Familiar issues such as spatial accuracy and data completeness tend to be amplified in these more remote regions.

Many of the surveys for patented mining claims are over 100 years old and some reference locational monuments that have been destroyed. Wherever possible, GPS coordinates for locational monuments were utilized for locating parcels from mineral survey plats and "rubber-sheeting" surrounding claims.

Our analyses show a positive conservation bias toward roads – a somewhat unexpected result. Roads are viewed as a conservation positive in the recreational access they provide. Since roadways were the viewing platforms for the visual analysis, areas proximal to these roadways were more likely to be visible and thus have a higher visual resource value. Finally, close proximity to access roads increases development potential and consequently raises the conservation priority value for a parcel. Areas farther from roads tend to be less disturbed and have higher ecological value, however. This may be indirectly included in the analysis in the form of potential conservation areas and other areas of high natural values. In future projects it may be worthwhile considering "unroaded" areas as conservation resources.

Establishing a reasonable context for point data continues to be a struggle. Among project stakeholders, historic resources were considered to be at or near the top of the list in importance. Our source data consisted of individual sites or points. Determining an appropriate spatial context for a historic site, which could be translated into a buffer around the point data, is a problem that we have not adequately solved. BLM and USFS regulations typically forbid camping within a 50 to 100 ft buffer from the site, but a site's visual context may extend for hundreds of feet. So, for example, a parcel containing a significant historic structure may be conserved, but residential development on an adjacent parcel could greatly impact a visitor's experience.

Finally, some areas that are considered to be of great importance by stakeholders just don't show up as significant in the analysis. Whether this is due to inaccurate or incomplete source data, flaws in the modeling process, or the overall subjectiveness of the values that we're attempting to model, it's important to ultimately rely on "carbon-based" (rather than "silicon-based") thinking.

Internet Applications

The land managers, local governments, and conservation workers who are the ultimate users of the analytical results of these projects are located in dispersed sites, often in rural locales. Access to GIS capabilities and expertise vary widely among the different user groups. These reasons, together with the ubiquitous presence of the World Wide Web, make the internet a highly desirable venue for distributing data and capabilities. Both the northern San Juan projects made web-based mapping and geospatial applications an important task within the overall work scope.

A number of precepts guided development and component integration for the web-based applications:

- Minimal client-side software and hardware should be required. The current applications require only web browser software (with free plug-ins) and an internet connection.
- Most data and applications will reside on the server side of the connection. This will insure that users access the most current datasets available.

- Applications should be geared toward non-expert GIS users, but additional capabilities should be available for those with the expertise.
- Capabilities should be customized for land conservation / land management uses.
- The applications should be built primarily on open source components. Where in-house, proprietary components are used, they should be OGC-compliant to enable easy integration of future application and extensions.
- Because of the sensitive nature of some of the data and results, access to the applications should be password protected. Some real estate speculators in the area specialize in selling inholdings to the federal government; discouraging this type of use was important among project stakeholders.
- The resulting systems enable the user to perform a variety of GIS-based functions including basic raster and vector mapping capabilities, database querying, display of results in map or report form, polygon or point based raster queries (raster values that occur within a polygon or at a point), viewshed analysis and point-to-point line-of-sight analysis.

More advanced users develop conservation scenarios highlighting different resources and parcel selections. For example, a scenario could be developed highlighting the top 50 parcels based on visual resource value within BLM-managed lands. Just a few years ago, these types of capabilities were restricted to the realm of the "white lab coat" crowd.

Conclusions

The conservation priorities methodology provides land managers and conservation workers with a GIS-based guide to ranking private parcels for varying acquisition or management scenarios in inholding-riddled public lands. This process takes into account (1) an estimate of the occurrence of conservation resources within a parcel and (2) an estimate of the development potential of the parcel.

Web-based technologies, requiring minimal client-side investment in hardware and software, are delivering on the promise of putting the analytical power of geographic information systems into the hands of non-expert workers.

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Spatial Modeling of Industrial Windfall on Soils to Detect Woody Species with Potential for Bioremediation

S. Salazar, Colegio de Postgraduados, Campus Veracruz, Carretera Federal Veracruz-Xalapa km 26.5. Mpio. Manlio Fabio Altamirano, Veracruz, C. P. 91690

M. Mendoza, FIPRODEFO, Jalisco, México, A. L. del Angel Perez, Instituto Nacional de Investigaciones Agropecuarias, Campo Cotaxtla, Veracruz, Ver.

A. Tejeda M, Facultad de Ciencias Atmosféricas, Universidad Veracruzana. Xalapa, Ver. México

Abstract—*A spatial model is presented to explain the concentration of heavy metals (Fe, Cu, Zn, Ni, Cr, Co and Pb), in the soils around the industrial complex near the Port of Veracruz, Mexico. Unexpected low concentration sites where then tested to detect woody plant species that may have the capability to hiperacumulate these contaminants, hence having a potential for dendroremediation.*

The study case circumstances are conducive to test this hypothesis because of the radial nature of the industrial sprawl, and the rural surroundings, where low presence of heavy metals is expected. Contaminants selected are common in the sort of industrial outfits in the region, most of which are involved in metal manufacturing.

Results show levels of Cu, Zn, Cr, Co, and Pb in soils exceeding the reference threshold concentration in a fanshaped pattern downwind, with peak values for Fe. At least four species had no damage symptoms: guácimo, Guazuma ulmifolia*; roble,* Tadelobuia pentaphylla L.*, cocuite,* Gliricidia sepium *and* palo mulato, Bursela simaruba L. *This suggests these materials are resistant to metal pollution at the concentration levels seen in the region.*

Analysis of woody and bark tissue is underway, and it is expected to confirm the potential of the four species as pollutant accumulators suitable for bioremediation. If such were the case, they should they be propagated and placed all through out the downwind side of the industrial complex in a large scale trial. The up wind concentrations were not a concern from the point of view of environmental regulations, and the effect of accumulator species already present resulted not statistically significant, except cocuite.

Introduction

Spatial modeling of airborne contaminants on soils is an approach capable of identifying woody species with potential capability for remediation and reclaiming. There are two direct benefits from this type of result, a) assess the soil health condition, and b) identify native species suitable for clean up.

In the Mexican scene, 21 out of 32 states comprises 166 illegal toxic dump sites abandoned. An assessment in 1995-1997 reported: heavy metals, dust, smelter residues (scum), mining debris, oils, hydrocarbons, organoclorides, muds, Pb, cadmium, niquel, cianure, silic sand (EMA 1999). Consider in addition that industry continuously disposes this and other contaminants.

Nowadays there is a recent body of regulatory legislation concerning toxic emissions into the atmosphere, and heavy metals are a matter of concern in this regard. Tools to locate and spatially analyze hot spots are therefore urgently needed. Screening up locations where contaminants represent a hazard to population is an activity of major priority. In a similar fashion, modeling the fallout patterns creates the opportunity to detect species with potential capability to accumulate these metallic contaminants.

The municipality of Veracruz (latitude 19º 16´ y 19º 06´ N, longitude 96º 07´ y 96º 20´ W) includes the city of Veracruz (pop. 457 377), and a considerable industrial infrastructure including the Port of Veracruz, and Bruno Pagliai industrial park (FIBP), (INEGI 2000).

Climate in the study region is tropical semidry, with summer rains. Weather is strongly influenced by trade winds. Natural vegetation cover in Veracruz has declined historically, temperate forests dropped from 18 percent to 4 percent, and tropical forests from 66 percent to 24 percent, in the 1800 to 1900 time span (INEGI 2000). The main cover type is low tropical forest, which involves wooded areas of up to 15 m in height, growing in a climate with 25.3 ºC mean temperature, and 1669.2 mm annual rainfall (SEFIPLAN 2002). This vegetation responds to xeric site conditions imposed by the sandy, poorly developed soils usually found in coastal dunes such as in the study region. Local species are well adapted to these environments produced by the fast drainage, occasional gusty winds, heavy showers, and high salt content in the water.

This research has an appeal and relevance given by the evolving conditions of reduced tree cover, loss of natural landscape, increasing population and industrial development, and rising emission levels (EMV 1998).

Materials and Methods

The study area is defined by a 5 km radius centered at FIBP, at 16 km west from the city and port of Veracruz. FIBP began with the first facility, Tenaris Tamsa, opening in 1958. Tenaris is a steel mill and pipe manufacturer that is the largest (185 ha) and dominant tenant in the park. Today there are 157 industrial outfits in FIBP, 48 of them are metal-mechanic manufacturers, and 44 are chemical industries. Other businesses in FIBP involve food and beverages, electric and electronic components, glass, construction materials, and some other products (CFBP 2002).

The federal highway Veracruz-Jalapa divides by half the study area. This road is used by over 2000 vehicles, many of which are heavy trucks.

Industrial facilities are surrounded by farms with cropping and grazing plots, though these activities are declining because of new housing developments. The largest of these housing projects is Valente Díaz (pop. 13765), which is the second largest population in Veracruz municipality, just surpassed by Veracruz city itself. One more factor of relevance for Valente Díaz is that it borders with the Tenaris steel mill (SEFIPLAN 2002).

A network of sampling points were subjectively chosen to supply information from different distances and orientation respect the center point of the study area. Sampling points necessarily must be near a native tree of sufficient age as to expect to have received the effect of pollutants and reacted to it. From this tree, a sample of bark and wood was taken at 1.3 m in heigth. Two soil samples from the tree crown cover area were also taken, one at 10 cm in depth, and another one at 20 cm. For each soil sample, total concentration of Fe, Cu, Zn, Mn, Ni, Cr, Co, Cd, Pb, and extractable concentration of Fe, Cu, Zn and Mn were determined with procedures indicated in the official Mexican norm about sampling and analysis of soils NOM-021-RECNAT-2000 (SEMARNAT 2002). Tissue analysis was done through atomic absorption using a solution of ashes from tissue sample incinerated at 550 ºC.

Complementary soil data sought included pH, electric conductivity, cation exchange capacity organic mater, total nitrogen, assimilable phosphorous, exchangeable bases, and texture.

Climate data was provided by Centro de Previsión del Golfo de México. Wind speed and direction, temperature, relative humidity, global solar radiation, cloud cover, and barometric pressure were variables selected to model atmospheric dispersal. The local cartography was digitized, and fed to software Archie (FEMA/USEPA 1993), and Surfer (Golden Software, Inc). Isoconcentration digital maps for each contaminant were produced with the ground and atmosphere modeled features, plus contaminant values recorded in field samples of soil, bark and wood. Scenarios of interest to model included:

- the annual cycle, represented by weather and contaminant fallout patterns in January, April, July, and October (featuring seasonal conditions for winter, spring, summer, and fall), gusty wind days (synoptic weather systems from higher latitudes descending on to the tropics; also, stormy conditions associated to anticyclonic circulation producing winds over 30 m s-1)
- steady days with high temperature (maximum hourly temperatures each month)

Results

Soils presented an average pH of 5.95 at the 0-10 cm depth, and 5.79 at 10-20 cm (±0.69 and ±0.79 standard deviation, respectively). Mean electric conductivity was 0.142 dS.m-1, a value within acceptable range (United States Salinity Laboratory of Riverside, USA). Organic mater contents in the soil was >3.01 percent at 10-20 cm deep, and still very high at 2.01 percent to 3.0 percent in the top layer, at 0 cm to10 cm. Soils were coarse in texture, ranging from sandy loam to loamy sand. Exchangeable cations were also high, ranking Ca >Mg >K>Na.

Soil total heavy metals (Fe, Cu, Zn, Mn, Ni, Cr, Co, Pb), resulted over the reference tolerance (table 1). Of

Table 1. Average of total heavy metals in soils 0-10 cm, 10-20 cm, mg.kg-1 (dry weight).

	0-10cm	10-20cm				
Fe	This study	This study	(1)	(2)	(3)	(4)
average	45372.9	40411.7	-	-	-	-
range	17520-161590	20740-116550				
Cu						
average	67.3	78.87	100	60	26	100
range	9.7-468.8	11-437.5				
Zn						
average	193.8	163.7	400	70	73.5	300
range	39-1550	38-1240				
Mn						
average	1036	957.5	1500	3000	490	-
range	374-3950	298-3831.5				
Ni						
average	42.9	43.16	100	-	18.5	100
range	20-234	20-204.8				
Cr						
average	112.3	105.7	75	-	50	100
range	18-675	18-675				
Co						
average	35.3	35.3	25	30	10.5	-
range	31.7-63.5	31.7-63.5				
Cd						
average	2	-	8	-	-	5
range	0-2	-				
Pb						
average	105.2	111.9	200	-	26	100
range	26-250	20-440				

particular concer was total and extractable Fe, where records show elevated concentrations >25.0 mg.kg-1, while Cu averaged a high >1.2 mg.kg-1, Zn was also beyond toxic levels (>8.0 mg.kg-1), and so was Mn too (>29 mg.kg-1)

A total of 13 tree species were tested (table 2).

Concentrations of Fe, Cu, Zn, Mn, Ni, Cr, Co, and Pb in bark and wood tissues are presented at table 3.

Cu bioacumulation index by species was oustanding, and statistically significant for cocuite (Gliricidia sepium) and roble (Tadelobuia pentaphylla L). Three other species also displayed a satisfactory bioacumulation potential (index>1).

Table 2. Trees sampled in the study site. FIBP, Veracruz, Mexico.

Nombre común	Nombre científico*
Almendro	*Terminalia catappa L.*
Cedro	*Cedrela odorata*
Cocuite	*Gliricidia sepium*
Ciruelo	*Spondias mombin L.*
Flamboyán	*Delenox regia*
Guácimo	*Guazuma ulmifolia*
Higuera	*Ficus carica*
Mulato	*Bursela simaruba L.*
Jobo	*Spondias purpureas*
Nacastle	*Enterolobium cyclocarpum*
Palo dulce	*Achatacarpus nigricans*
Roble	*Tadelobuia pentaphylla L.*
Uvero	*Coccoloba barbadensis*

(Martínez 1994)

Discussion

This first evaluation assessed heavy metals in the study area soils. The key finding is the expected behavior of sandy and loamy soils. Coarse soils like these have a low retention of heavy metals. Therefore, these contaminants seep through down into the water table. The ample empty spaces inside sandy soils provide fast movement of air and water, and therefore, quick movement of metals carried as particles or dissolved.

Now considering the current trend towards industrial and housing development in the region, significant increase of paved ground and artificial structures (houses, buildings), will make contaminant drift even faster. In this scenario, current environmental regulations might be excessively lenient in protecting public health.

Should any of the species studied turn out as good bioaccumulators, they could be a valuable means to clean up medium level brown soils. Moreover, the spatial model used to identify bioaccumulators is also capable of identify priority areas to be forested with those species found, and the minimum and maximum area and planting density can be calculated too.

Table 3. Heavy metals in bark and wood, study site, Veracruz, México. mg.kg-1 (dry weight).

	Bark								Wood			
	Fe	Cu	Zn	Mn	Ni	Cr	Co	Pb	Fe	Cu	Zn	Mn
Roble	407	28.7	26	56.9	5.9	11.3		7.8	36.8	6.25	8.68	98.7
Cocuite	329	37.5	31	23.7		9			358		6.2	23.7
Jobo	486	18.8	31	134	5.9	18	6.35	5.2	329		18.6	7.9
Ciruelo	408	28.1	31	79	5.9	13.5		5.2	53.6	6.25	6.2	
Nacastle	677	12.5	24.8	120	5.9	18		5.69	52.7	6.25	18.6	43.15
Nopillo	475	24.2	29.5	89.2	5.9	14.6	6.35	5.36	198	6.25	12.4	24.92
Mulato	511	20.9	29.1	106	5.9	16		5.36	158	6.25	13.95	25.32
Almendro	207	18.8	24.8	39.5	5.9	13.5		5.2	28.6	6.25	12.4	
Palo Dulce	129	12.5	49.6	15.8	5.9			5.2	50.1		12.4	
Guácimo	168	15.6	37.2	27.7	5.9			5.2	39.3	6.25	12.4	38.4
Uvero	54.7	6.25	12.8	82.4					34.2	6.25	8.4	53.7
Cedro	78.7	6.25	12.4	92.4					48.2	6.25	12.4	68.6
Higuera	68.5	6.25	12.8	79.8					36.2	6.25	8.78	58.4
Flamboyán	67.3	6.25	12.7	84.9				5.5	39.5	6.25	9.86	60.23

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On-Line Analysis of Southern FIA Data

Michael P. Spinney, Quantitative Forestry Analyst, and Paul C. Van Deusen, Principal Research Scientist, National Council for Air and Stream Improvement, Lowell, MA
Francis A. Roesch, Mathematical Statistician, USDA Forest Service, Southern Research Station, Asheville, NC

Abstract—*The Southern On-Line Estimator (SOLE) is a web-based FIA database analysis tool designed with an emphasis on modularity. The Java-based user interface is simple and intuitive to use and the R-based analysis engine is fast and stable. Each component of the program (data retrieval, statistical analysis and output) can be individually modified to accommodate major additions or changes. This modular structure fosters a flexible architecture to encourage outside development of analysis algorithms. SOLE produces statistical tables, figures, maps, and PDF reports based on user selected area and variables.*

Introduction

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service has been collecting forest inventory data since 1930. Database structure and inventory design have evolved over time to satisfy user demand. The most recent revision of the FIA database (FIADB) has created new ecological variables and changed the definition of others. The sheer size of the FIADB can be intimidating to some users, and the database structure can confuse others. Readily accessible, easy to use tools are necessary to ensure proper analysis of FIA data.

FIA data is periodically analyzed by the Forest Service and published for the public as a standard suite of tables for a state or region. With the adoption of the annual inventory system, published reports are produced on a 5 year period. The length of this period may not be adequate for users who require more timely reports or are interested in a spatial scale different than the state or region level. These users must download data, replicate the relational database then correctly query and summarize the data. Not all users with these data needs are willing to invest this amount of effort.

Internet based FIA analysis tools bridge the gap between periodic state level reports and customized analysis by the user. Without understanding underlying database structure, users can tailor their analysis by choosing a certain area and selecting specific variables. Internet-based tools correctly analyze the data regardless of the current state of the database. FIA's MapMaker is the Forest Service's official web-based analysis tool which utilizes standardized FIA analysis algorithms. Other online tools are available.

The Southern On Line Estimator1 (SOLE http://ncasi.uml.edu/SOLE) has been cooperatively developed by the Forest Service and NCASI. It is a web-based annual FIA data analysis tool that uses a JAVA-based user interface and an R-based analysis engine. The user selects an area and variables of interest, and analysis output comes in the form of tables, charts, maps, and PDF files.

Background

SOLE Structure Overview

SOLE's structure has been developed with flexibility as the top priority. Each of the three main components of the program (data retrieval, statistical analysis, and output) have been developed to be independently modified. This open architecture facilitates outside development of analysis algorithms.

The user can specify a geographical region of interest and initiate a query by sequentially selecting tabs at the top of the interface. After choosing states in the State Selection window, the user progresses through the SOLE Map, Variable Selection, Filters (optional), Analysis and/or Mapping tabs. Once the user satisfies the requirements of each tab, SOLE makes the next tab available. Detailed instructions can be found in the help files linked to each tab.

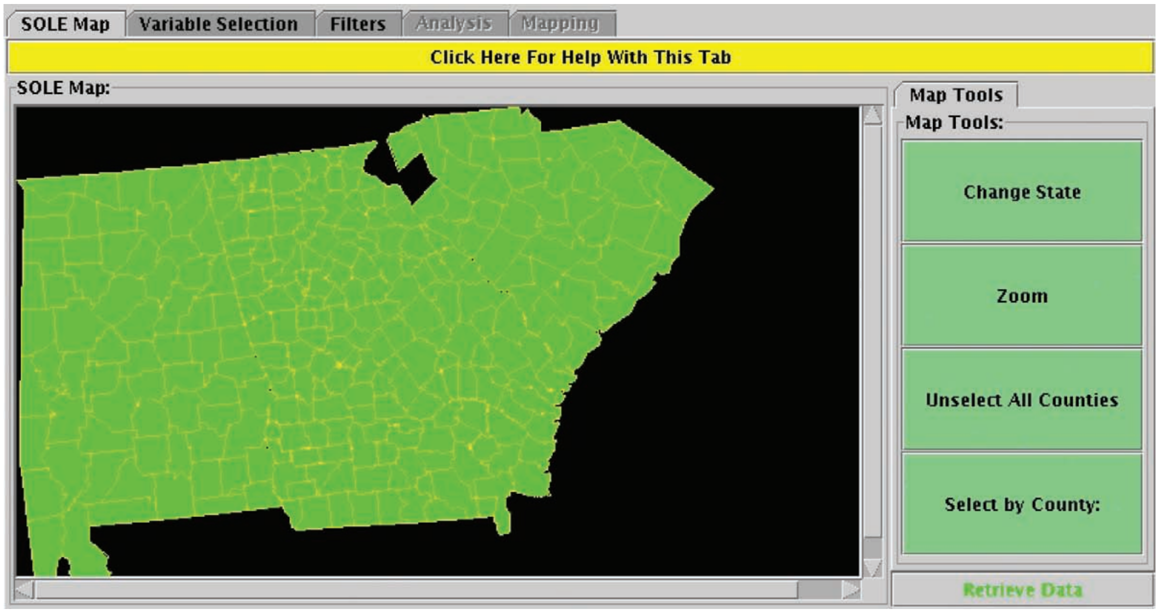

Figure 1. SOLE map tab, for county selection and data retrieval.

Using the Program

State Selection

The first window a user sees is the State Selection screen. States with annual data have black backgrounds, and states with periodic data (currently not available for analysis in SOLE) are gray. When a state is selected, the state name pops up and the state is highlighted green. When the user is satisfied with their state choices, they click the bottom of window and are brought to the SOLE Map tab.

SOLE Map

Here the user selects the counties they wish to work with (fig. 1). Individual counties can be chosen with the Select by County button, or select all counties in the state using the Select All Counties button. Clicking on the red Retrieve Data button loads the necessary data files into the statistical program, R (R Development Core Team 2003). Once the data files have been loaded, the next group of tabs, Variable Selection and Filters are made available.

Variable Selection

Currently, only FIADB volume variables are available for analysis. These are grouped in two ways. The first is Quantitative (continuous data, for example, any volume/biomass estimate) or Qualitative (categorical data, such as productivity class). In addition, Quantitative variables are grouped based on diameter greater or less than 5 inches. This preserves the precision of volume estimates by ensuring that no trees less than 5 inches d.b.h. are included in sawtimber estimates (fig. 2). For all analyses, one Quantitative and one Qualitative variable are required. Tabular analyses will examine one Quantitative and several Qualitative variables.

Filters

This tab is optional, but can be useful to select only a specific subset of data. Data availability varies by state, so we recommend determining the range of values for an analyses before setting filters. The status of a filter is displayed at the top of an analysis.

Analysis

Charts and tabular analyses are launched from this tab (fig. 3). The header of each analysis indicates which filters (if any) were used, the analysis and variable names.

Tabular analysis

There are currently two methods in SOLE for determining the mean: moving average and mixed estimators. The 5-year moving average (MA) is the default estimation method for FIA analysis; it provides a complete estimate for that 5-year period. A moving average analysis will result in the following seven tables:

1. Moving average (per acre), over measurement year or by cycle.
2. Standard error of each element of table 1.
3. Area (acres) represented by the plots used in the calculation of table 1. Summarizes EXPCURR.

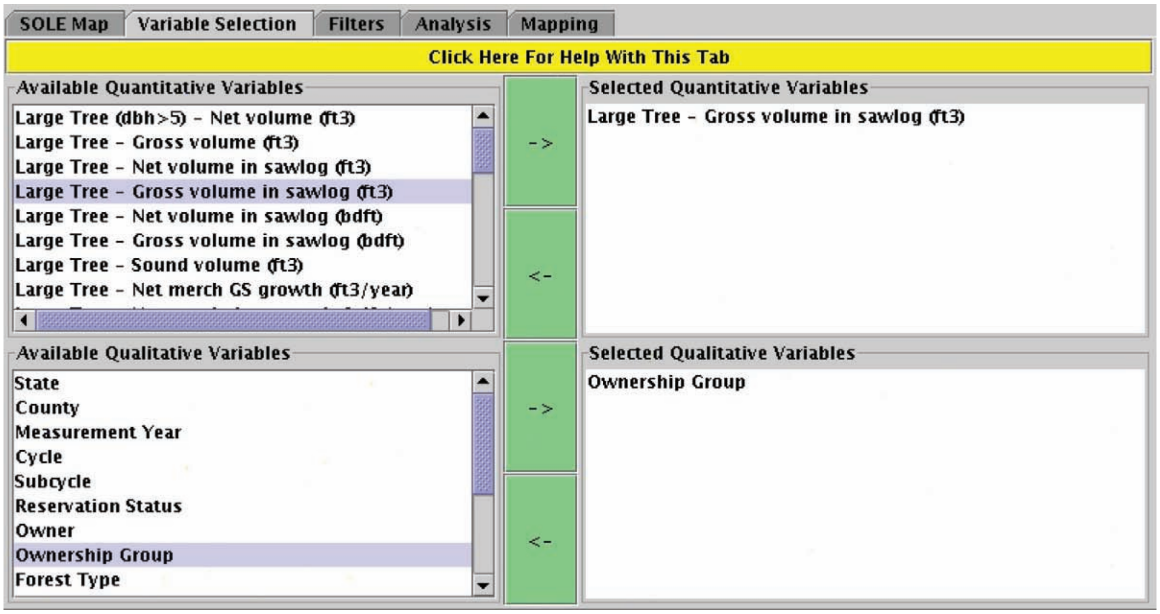

Figure 2. SOLE variable selection tab.

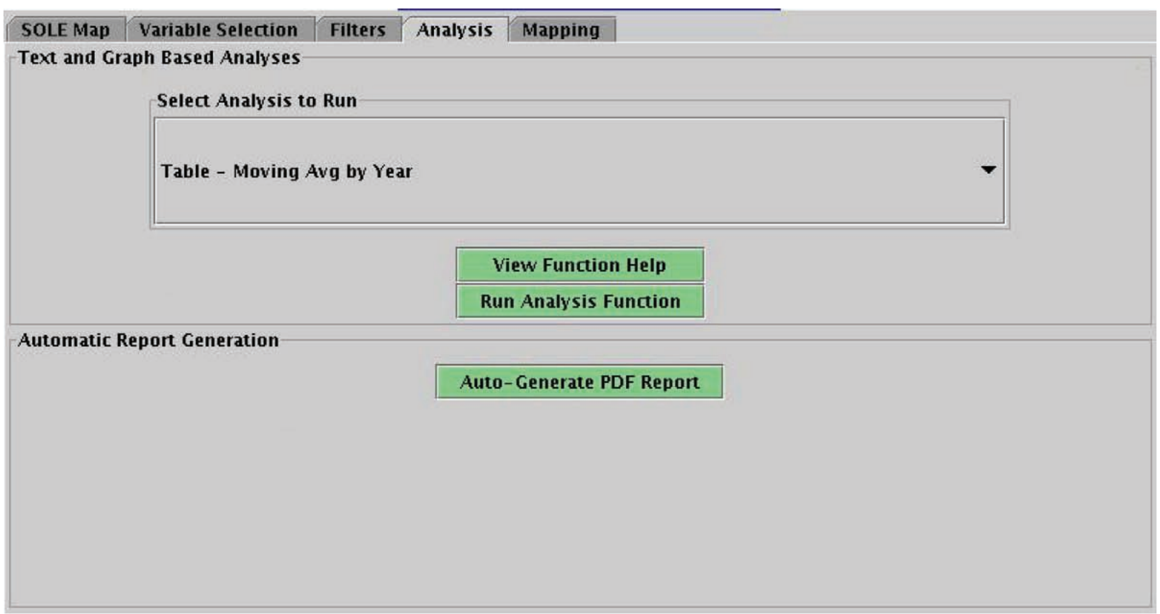

Figure 3. SOLE analysis selection tab.

4. Total estimate for the area sampled. Equals moving average multiplied by area.
5. Standard error of the total estimate.
6. Total number of plots used in calculation, broken down by each level of the Qualitative Variable.
7. Number of plots by measurement year.

The MA provides a complete estimate for each specific 5-year period. Using the MA as the standard estimate, change can be determined after a second MA can be calculated, in year 6. In this case the data from panel 1, measured in year 1, is dropped from the estimator, and the data from panel 1, measured in year 6, is added. Eighty percent of the data is common to the two consecutive MA estimates. Therefore, if the user wanted to compare estimates for two consecutive years, only 20 percent of the data would not be self-canceling (Van Deusen 2000). After 10 years, both the MA and mixed estimator (ME) can provide full-data change estimates, however, it is not obvious to which years the MA difference estimator should be applied. Conversely, the alternative method of mixed estimation incorporates an explicit trend model while using 100 percent of plots to determine change between any 2 years in the most efficient manner.

The mixed estimator analysis results in six tables that have measurement year as columns:

1. Mixed estimator mean by year (per acre)
2. Standard error per year
3. Acres
4. Total estimate for the sampled area
5. Standard error or the total
6. Adjusted sample size by year

Graphical analysis

Often the simplest way to visualize data characteristics is through a graph-based analysis. SOLE offers bar charts, box plots, pie charts, and XY plots. Bar and pie charts show a basic distribution of the Quantitative Variable by each level of the Qualitative Variable. XY plots offer some insight into the data distribution and frequency based on the number and dispersion of points along the axis. Box plots convey the most statistical information about the data because they show the mean, interquartile range, and outliers for each level of Qualitative Variable.

Map analysis

County-level maps can be created from the Mapping tab. Basic maps of the mean and median are supplemented by more complex ratio maps, which display the ratio of filtered to unfiltered data. For example, the user could filter for a specific ownership group and then view a map of the proportion of volume on land owned by that group to the volume on all land collectively owned by all groups.

PDF report

Any combination of tabular, graphical or map analyses; or text can be included in the PDF report. At the simplest level, the report could be completely contained such that the user only selects an area of interest, or it could be customized with the user's choice of variables. Potentially, this feature could be developed to produce an array of standard FIA report tables at the click of a button, giving the user the ability to produce real-time reports at each FIADB17 update.

Conclusions

Web based FIA analysis tools are essential for proper analysis of FIA data. SOLE provides a simple interface to allow users of all levels to obtain custom analytical results. The SOLE graphical user interface (GUI) is written in Java, and the analytical components are written in the S programming language as implemented in the OpenSource R statistical analysis program. SOLE is written in a modular fashion that makes it easy to add new capabilities. SOLE provides a wide range of options for users who wish to analyze FIA annual inventory data and obtain graphical and tabular results. Flexibility in each component of SOLE ensures that it remains highly adaptable to changes in both database structure and user needs.

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Remote Sensing, Sampling and Simulation Applications in Analyses of Insect Dispersion and Abundance in Cotton

J. L. Willers, Research Entomologist, J. M. McKinion, Electronics Engineer, and J. N. Jenkins, Geneticist, USDA-ARS Genetics and Precision Agriculture Research Unit, Mississippi State, MS

Abstract—*Simulation was employed to create stratified simple random samples of different sample unit sizes to represent tarnished plant bug abundance at different densities within various habitats of simulated cotton fields. These samples were used to investigate dispersion patterns of this cotton insect. It was found that the assessment of spatial pattern varied as a function of sample unit size and was independent of large pest densities. Using this knowledge, it was demonstrated how remote sensing assists field scouts in estimating pest abundance and the pattern of dispersion within commercial cotton fields. For the majority of pest management decisions in commercial fields, both the simulation data and field results supported the robust assumption that cotton pests are randomly dispersed at different densities within homogenous habitats. Therefore, it was possible to estimate the boundaries of different pest densities by mapping habitat variability within cotton fields using high resolution, geo-referenced, remotely sensed imagery. Once boundaries for various densities of the pest were established, site-specific prescriptions of pesticides were implemented, reducing pest management costs and the amount of pesticide applied to the environment.*

Introduction

Analyzing the dispersion of many cotton insect pests in large commercial cotton fields is a challenging problem in applied ecology. Pest dispersion impacts sampling (Davis 1994; Trumble 1985), analysis of population ecology (Banerjee 1976; Dalthorp and others 2000; Fleischer and others 1999), the establishment of economic thresholds or injury levels (Byerly and others 1978; Stern and others 1959; Wilson 1994), the rate of habitat colonization (Southwood and others 1983), and the building of spatially-based prescriptions (Dupont and others 2000; Fleischer and others 1999; Seal and others 2001) to control cotton pests. The need to create efficient maps describing cotton pest dispersion patterns in commercial cotton fields provided the motivation for this study.

A simulation approach was stressed to avoid effects due to discrepancies in observer abilities, sampling error, management practices, location effects, or lack of enough sample time, all of which arise in field conditions and influence conclusions. Simulation methods to investigate relationships among sample unit size, clustering and infestation rate have already been described (Willers and others 1990). These initial results are built upon in this work, where simulation methods now explore the relationship between infestation rate and measures of dispersion for sample units of different sizes if pests are randomly dispersed. Knowledge of these relationships is necessary in order to employ (Willers and others 1999) remote sensing to stratify cotton fields into various habitats according to the phenology of the crop. Willers and others (1999) have previously found that tarnished plant bugs (TPB; *Lygus lineolaris* [P. de B.] (Heteroptera: Miridae)) distribute themselves at different infestation rates in these habitats. Information about how dispersion patterns relate to sample unit size, pest density, and habitat quality therefore creates the foundation for spatial approaches toward cotton insect control. These simulation results are applicable to the tarnished plant bug. Results are relevant to field data and can apply to other pest species (Willers, unpublished), particularly for pests that attack the floral structures of the cotton plant.

The various methods utilized in the analysis of spatial patterns have been presented by Dalthorp and others (2000), Davis (1994), Kuno (1991), Ludwig and Reynolds (1988), Patil and Stiteler (1974), Pielou, (1977, 1978), Southwood (1978), Taylor (1984) and Waters (1959). The analysis approach employed here does not follow the traditional testing of the goodness of fit of sample data to expected frequencies estimated from the Poisson, or any other probability distribution (Davis 1994; Ludwig and Reynolds 1988; Poole 1974; Steel and Torrie 1960). The reason for choosing to not use this classical approach was the deliberate choice to study estimator performance and assessment of dispersion when the sample size is usually small (< 30 sample units/sample). The goodness of fit test does not apply when sample size is small. Therefore, use is made of Lloyd's mean crowding and patchiness indices (Lloyd 1967) to test for random dispersion. Also, choices for sample unit size are known to influence the assessment of dispersion, particularly when artificial (as opposed to natural (see Ludwig and Reynolds 1988)) units are employed (Davis 1994; Ludwig and Reynolds 1988; Pielou 1977, 1978; Poole 1974). The indices developed by Lloyd (1967) are not influenced by sample unit size.

The information discovered through use of simulation was used to assess pest dispersion in large commercial cotton fields during the production season.

Methods and Materials

The sample design used in the simulations has been previously described (Willers and others 1999; Willers and Akins 2000) and a sensitivity analysis has been presented in Willers and others (2000). However, several points must be recalled from these previous studies. The first is that the fundamental sample unit size is a quadrat (cell) with a length of 0.9144 m and a width equal to half the row spacing (commonly, 1.016 m) between rows of cotton. Therefore, 0.404 ha (or 1 land ac) of field area will contain 4,359.526 units of this size (at 0.9290 m^2 each). These units provide the main link between the simulated system and field conditions. Specifically, the total number of these units (or small areas centered upon the crop row) in a cotton field is the finite population size (Thompson 1992) at risk to be sampled, and can be apportioned amongst one or more habitats (Willers, unpublished). Also, the individual pixel in a geo-registered, high spatial resolution (1 m^2), multi-spectral image of the field of interest conceptually corresponds to one of these quadrats.

The second point is that these quadrat sampling units can be arranged into a series of consecutive units to span the cotton rows at right angles to the row direction, and form a larger sampling unit called a belt transect (Ludwig and Reynolds 1988; Thompson 1992; Willers and others 1999; Willers and Akins 2000). A single transect constitutes a sample and a diagram of a transect is provided in Willers and Akins (2000). In the field, the number of insects of a particular species are counted, along with ancillary data (such as the size or age of each individual observed), within each quadrat sample unit. The quadrat sample unit results are totaled for each transect sample. In the simulated system the model generates and tallies these counts.

The third point is that these transects (using a simple random sampling strategy) are placed at consultant/producer determined locations within habitats based upon maps derived by classified imagery (Richards and Jia 1999; Willers and others 1999; Willers, unpublished) of the cotton field. In the simulated system, different habitats are modeled by changing the infestation rate parameter (see below).

Simulation Model Development and Assumptions

The development of the simulation model to study dispersion in the presence of different pest densities and sample unit sizes was based upon the negative binomial distribution (NBD) (Anscombe 1949; Davis 1994; Ludwig and Reynolds 1988; Pielou 1977, 1978; Southwood 1978). Willers and others (1990) describe most modifications necessary to simulate impacts of different sample unit sizes, densities, and dispersion patterns using the NBD. Counts of numbers of insects per row for simulated belt transects of different lengths (L) and infestation rates (λ) were obtained using the NBD with its dispersion parameter (k) set to 50 so that random variates could be generated at different pest infestation rates and sample unit sizes, under the assumption of a Poisson (random) dispersion pattern. The simulated sample unit size for each quadrat (or crop row length) of the belt transect was fixed at 10 plants/quadrat (Willers and others 1990; Willers, unpublished). The number of insects (events) per quadrat for a belt transect of length L was generated by the inverse transformation method (Pritsker and Pegden 1979) and used to sample a simulated area of field having a particular mean infestation rate (or number of insects/100 plants, λ). To create transect lines of different lengths (or a sample unit of length L) a 'do-loop' was employed to repeat the process and simulate the sample results for a specified number of 'crop rows'. The simulation model was programmed in SAS® (SAS Institute 1990).

The question in this study was to determine how assessment of dispersion differs with changes in (1) the pest density (infestation rate) and (2) the length of the primary sample unit within a cotton habitat class. Therefore, various lengths (L = 4, 8, 16, 24, or 396 rows) of belt transects were employed and the dispersion pattern of insect pests at different densities was investigated. Comparisons of simulated results with actual TPB counts were obtained by comparison with transect lines sampled in a commercial cotton field (Willers and others 1999; Willers, unpublished). This published data set can be examined and compared to these simulated results (available online at http://www.jcotsci.org).

Analysis of Dispersion

Lloyd's indices of patchiness and mean crowding (Lloyd 1967) judged performance of the random dispersion assumption for simulated combinations of different infestation rates (densities) and transect sample unit sizes. The index of patchiness is a measure of random dispersion when equivalent to unity (Davis 1994; Lloyd 1967; Southwood 1978). The index of mean crowding (Lloyd 1967; Pielou 1977) is a description of the mean number of individuals occupying the same habitat space as another individual. In this study, this index applies to the quadrat sample unit and not the belt transect sample unit.

Results

The various combinations of pest density and transect length were studied using 10,000 simulation runs. Estimates of mean crowding and patchiness were obtained for each combination and summarized by histograms. Figs. 1 through 3 show results for estimates of Lloyd's index of patchiness at several infestation rates and several different (short) transect lengths. Simulation results where the transect length is fixed for a long distance (396 crop rows) while varying the infestation rate (λ = 0.01, 0.08, 0.16, 0.24, and 0.40) are presented in figures 4 (mean crowding) and 5 (patchiness).

Analyses of Simulation Data Using Lloyd's Indices

The index of patchiness is derived from the mean crowding index (Davis 1994; Lloyd 1967). This index indicates random dispersion for values equivalent to 1. Patterns of results are shown for λ = 0.01, 0.08 and 0.24 (figs. 1 through 3). For brevity, only a few of the many possible graphs from simulation runs estimating dispersion statistics are shown. For patchiness, as belt transect length and infestation rate increased, the index decreases in multi-modality and increasingly centers about a modal value of 1. This index is sensitive to choices for sample unit size, but not to values for infestation rate, once the rate departs from small values close to zero. Despite this sensitivity, the convergence of results about a mode of 1 supports the assumption that a random dispersion pattern is plausible for most densities estimated with a belt transect sampling technique. Consistency in estimating this index is most doubtful if too short of a transect was employed and the density was close to zero, which means that field samples would most likely be so variable as to obscure any discernment of relationships. Trends are most clear if very long transects are utilized; however, very long transects require too much time in commercial fields.

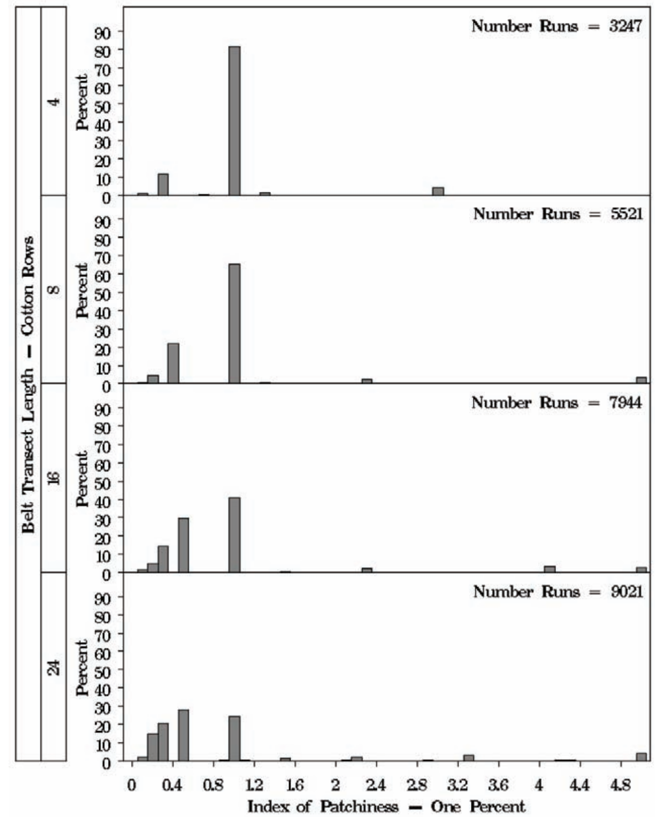

Figure 1. Histograms of results for Lloyd's (1967) index of patchiness for 4 different transect lengths at a simulated infestation rate of 1 percent. The index has a value < 1 for regular dispersion patterns.

Analysis of Simulation Data Using A Long Transect

The pattern of response between pest density and very long transects is presented in figs. 4 and 5. While many lengths could be chosen, we selected one that was ca. 0.4 km (0.25 mi) long. This distance is often encountered in large fields and within similar habitat classes of cotton growth and phenology as captured by remote sensing imagery.

The analysis of results at this large size (or distance) of sample unit reveals an interesting finding about increases in pest numbers per unit area. Mean crowding is a noisy parameter when belt transects increasingly shorter than 24 rows are employed and lower infestation rates exist (data not presented). Mean crowding estimates for long transects (L = 396 rows), on the other hand, are well separated with increases in density (fig. 4). This result is reasonable and could be important for assisting the development of better logic for spatial simulation

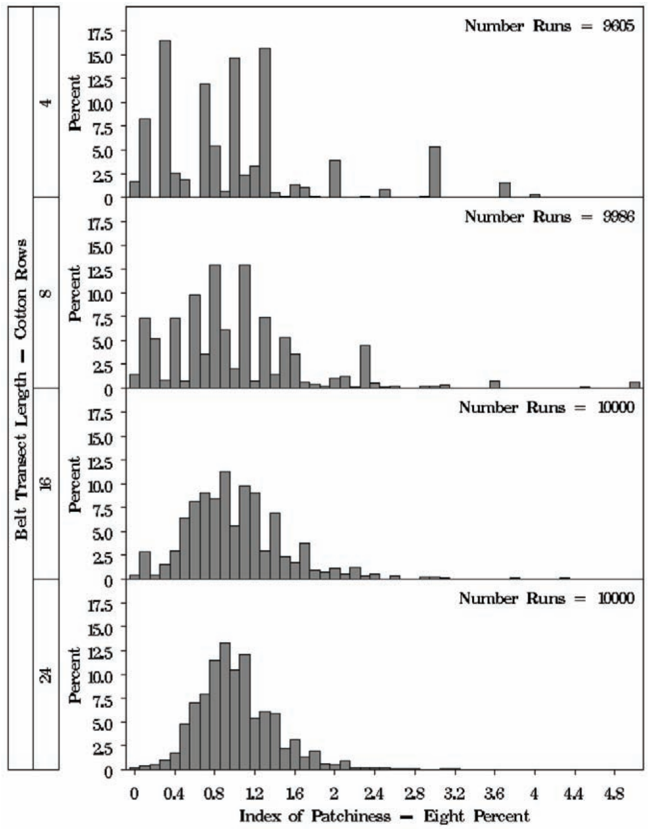

Figure 2. Histograms of results for the index of patchiness for four different transect lengths at a simulated infestation rate of 8 percent. The index has a value > 1 for aggregated dispersion patterns.

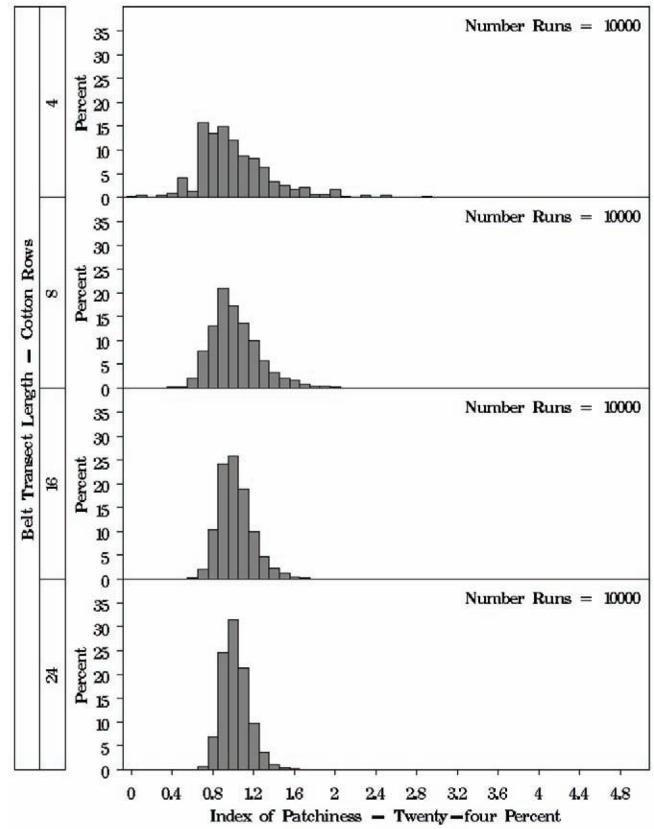

Figure 3. Histograms of results for the index of patchiness for four different transect lengths at a simulated infestation rate of 24 percent. The index is equivalent to one for random dispersion patterns.

models of pest damage to cotton. Wagner and others (1996) reviewed many models of damage to plants by cotton pests. A flaw of many was the failure to correctly model pest damage at high densities. The mean crowding value could provide a metric to better allocate damage amongst groups of plants in simulation models, especially if spatial allocations of different pest densities (within an individual simulated field) were also incorporated.

For all densities, except $\lambda = 0.01$, the index of patchiness for the longest transect converged about a value of 1 (an indicator of random dispersion) (fig. 5). The lack of stability at low densities (as shown in the top panel of fig. 5) was previously found by Byerly and others (1978; p. 262). The effect was attributed to the proportionately large effect that errors in estimating the standard error of a small mean could cause. Similar effects are likely to be at work for the index of patchiness when a short belt transect samples a habitat having a low pest population. The effect is particularly obvious when smaller lengths (recall figs. 1 through 3 and compare across increasing densities at similar transect lengths) are used to sample simulated populations in homogenous habitats. Furthermore, for low population densities there may not be enough individuals to occupy all available habitat spaces, which also would cause deviations from a random dispersion index of 1. However, the patchiness index is independent of density (fig. 4) once there is a departure from very low infestation rates (fig. 5) (Myers 1978).

The behavior of convergence about a patchiness of 1 for large sample unit sizes (fig. 5) shows most clearly the validity of a random dispersion pattern over a large spatial extent (or distance), particularly for increases in infestation. While it is impractical to sample large sized sample units, it is practical to apply simple random sampling within homogenous habitat classes and select widely spaced sample sites. If the estimate of pest density is similar at the widely spaced sites within a habitat class, it is reasonable to infer that other unsampled locations between these sites are also infested at a similar rate. Therefore, a habitat classification map derived from imagery can effectively be used to estimate pest severity in commercial fields without large sample sizes, because the pest is most likely randomly dispersed throughout the habitat. Other works are in preparation to verify with field observations this conclusion derived by use of simulation.

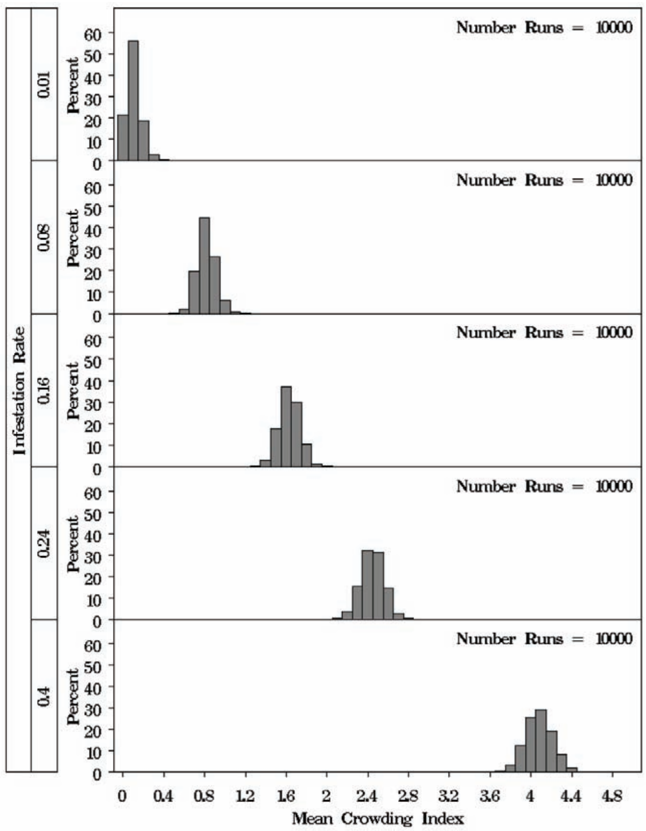

Figure 4. Histograms of results for Lloyd's (1976) mean crowding index for 5 different simulated pest densities where the belt transect length is 396 crop rows.

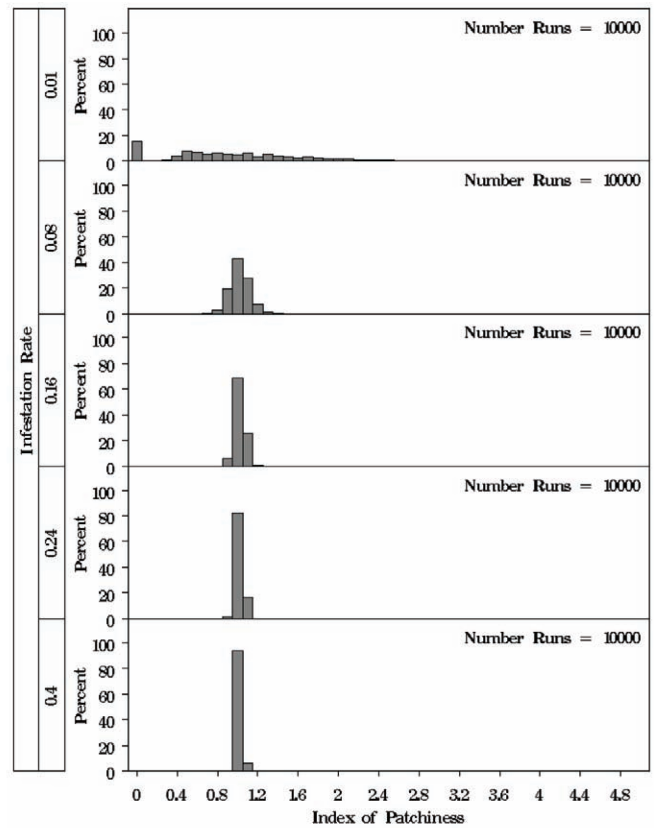

Figure 5. Histograms of results for the index of patchiness for five different simulated pest densities across a belt transect length of 396 crop rows.

Discussion

Stern and others (1959) first presented the concept of an economic threshold (ET), or economic injury level (EIL). They discussed several ecological concepts and considered the impact of changes in pest density in both space and time (Fleischer and others 1999). It is reasonable to consider that the ET and EIL strongly imply the presence of a consistent density on a spatial scale until an edge of a habitat class is encountered. Across this edge, the pest density will decrease or increase as the habitat and/or environmental conditions within these other additional regions vary. These effects will persist during a small increment of time so that management decisions can be made. Remote sensing can provide the delineation of edges of cotton habitats (Willers and others, 1999; Willers, unpublished). These technologies, along with the use of appropriate ecological assumptions combined with density estimates (with small sample sizes) and experience (Willers, unpublished), permit the building of plausible maps of pest density in cotton. The five key concepts driving the creation of these pest density maps are (1) the assumption of a random dispersion pattern amongst (2) small units of area for (3) characteristic densities occurring within (4) different habitats in cotton fields over (5) time.

Many investigators consider regular and random dispersion patterns to be rare in natural contexts (Dalthorp and others 2000; Ludwig and Reynolds 1988; Taylor 1961; Wilson 1994). For insects that are distributed across natural units (Ludwig and Reynolds, 1988) such as a plant, a leaf, or a cotton bud (square, flower, or boll) one can easily envision (in fact, demonstrate) that an aggregated dispersion pattern is common. Using sample units that are small in size, we can, in these cases, agree with traditional thinking. In this study, a measure of dispersion examined the assumption that a random dispersion pattern could be assumed for many fruit feeding cotton insect pests when large arbitrary (rather than natural (Ludwig and Reynolds 1988)) sampling units are employed. Based upon the use of these practical, but arbitrary, sampling units, we disagree with traditional thinking that random dispersion patterns are rare. Furthermore, the conclusion of random dispersion found amongst belt transects should apply to other sampling techniques (for example, whole plant visual samples, drop cloth, or sweep net) provided that sample units are constructed to constitute more than a single plant. The intent should be to focus searching within 'small' sizes of area, rather than over a wide scattering of individual plants across a large area or along a single, short length of row (Willers, unpublished) as traditionally done in cotton.

Several authors have used simulation as a tool to answer various questions about either aggregation or dispersion (Myers 1978; Pielou 1960; Sawyer 1989). The findings of this simulation study have also produced useful results. Obtaining a field data set as comprehensive as those obtained here by use of simulation would have been quite expensive. The customized form of the NBD that generated much of the data used in this study has been quite useful in cotton sampling research (Willers and others 1990, 1999; Willers and Akins 2000; Williams and others 1995). The results provided insight useful for the application of site-specific approaches to cotton insect control. The assumption that a random dispersion pattern occurs within large sized sample units (fig. 5) (also found by Sawyer (1989)) derived from a series of contiguous, secondary sample units placed in homogenous habitats has value. The finding can be exploited for (1) redefining economic injury levels (EILs), (2) simulating pest damage to the crop, or (3) refining sample design efficiency. All these goals have relevance for additional discoveries that provide decreases in sample size or sampling time in commercial cotton applications. In commercial applications, it is not possible to satisfy the sample number sizes often required by theory (Karandinos 1976); therefore, discovering new estimators accurate at low densities and small sample sizes is desirable. The utilization of information from remote sensing imagery along with the simulation and sampling methods described here can reduce sample time in commercial cotton fields. The same information provides the template for spatial applications of pesticides, reducing costs and providing environmental benefits (Dupont and others 2000; Frigden and others 2002; Seal and others 2001; see also www.gointime.com).

Summary

The simulation analyses indicate that the assumption of random dispersion of a pest within crop habitats occupied at different characteristic densities is useful for commercial scouting and decision making purposes. The assumption strengthens continued use of simple random sampling (SRS) or line-intercept (LIS) estimators (Thompson 1992; Willers and others 1999; Willers and Akins 2000) for pest or plant densities within habitats. Boundaries (or edges) of different pest densities in commercial fields can be determined from appropriately classified (Richards and Jia 1999), high resolution, remotely sensed imagery to create a mosaic (Pielou 1977, 1978) of habitat classes. The pest density estimate for a habitat stratum geographically applies to each class within the mosaic (whether sampled or not) if other conditions such as planting date or other agronomic influences are also similar.

Acknowledgments

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Global Cooperation and Security

Planning Quality for Successful International Environmental Monitoring

George M. Brilis and John G. Lyon, U.S. Environmental Protection Agency, National Exposure Research Laboratory, Las Vegas, NV
Jeffery C. Worthington, U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC

Abstract—*Federal, State, and municipal government entities are increasingly depending on geospatial data for a myriad of purposes. This trend is expected to continue. Information sharing and interoperability are in line with the Federal Executive Order 12906 (Clinton, 1994) which calls for the establishment of the National Spatial Data Infrastructure (NSDI). If other organizations voluntarily implement the U.S. Environmental Protection Agency's quality planning approach—or a similar approach that embraces the same critical quality elements—for projects that include geospatial data, then an increased level of confidence will be achieved for information that is shared between organizations and countries.*

Introduction

Within the Federal government, many agencies are developing, expanding and configuring their geospatial databases to facilitate data exchange and interoperability. These actions are in line with Federal Executive Order 12906 (Clinton, 1994. Amended by Bush, 2003) which calls for the establishment of the National Spatial Data Infrastructure (NSDI). The NSDI is defined as the technologies, policies, and people necessary to promote sharing of geospatial data throughout all levels of government, the private and nonprofit sectors, and the academic community.

When the applications of geospatial data and information have the same objectives, the NSDI appears to be a Amagic bullet;" however, some Federal agencies are apt to be involved in more litigation than others. This is especially true for regulatory agencies, such as the U.S. Environmental Protection Agency (EPA). EPAs mission is to protect human health and to safeguard the natural environment—air, water, and land—upon which life depends.

To accomplish its mission, EPA works to develop and enforce regulations that implement environmental laws enacted by Congress. EPA is responsible for researching and setting national standards for a variety of environmental programs, and, when appropriate, delegates to States and tribes the responsibility for issuing permits and for monitoring and enforcing compliance. Where National standards are not met, EPA can issue sanctions and take other steps to assist the States and tribes in reaching the desired levels of environmental quality.

Data, and the technology used to create them, are one of the primary drivers in the creation of space law and in many cases are the foundation upon which existing space law rests (Gabrynowicz, 1996). The technology involved in creating data may include, but not be limited to, one or more of the following:

- Remote sensing apparatus, such as satellites and aerial photographs, that are used to capture images
- Global positioning satellites, that are used to establish location
- Geographic information systems, a system of hardware, software, data, people, organizations, and institutional arrangements that are used to collect, store, analyze, and disseminate georeferenced information

Data may also originate from non-technological sources, such as:

- Mechanical or engineering drawings, used for many purposes such as depicting and envisioning structure
- Pre-existing (or archived) data, direct or transformed to be used as an integral part of the project at hand
- Text reports that may contain data such as chemical analyses

Because societies, technologies, cultures, and people are rapidly changing, definitions for key words and phrases used throughout this paper are addressed:

Technology is the combination of skills, knowledge materials, machines, and tools, that people use to convert, or change, raw materials into valuable goods or services—in the context of this paper, data are produced (De Sutter, J., 2003).

Information is the representation of data (or raw facts) to a receiver; it is the most important resource of a modern organization. Information is data in a usable form, processed in some way, it is data plus interpretation.

Data Package is the composite of the deliverable item(s) from producer to client. The data package may include, but not be limited to:

- Data
- Metadata (data about data)
- Information
- Conclusions

The process, progress, and closure of national and international space law cases that must consider geospatial data and concepts may become hindered by the lack of consistency in the formation and content of a data package (Lunetta and others 1991). At the time of this writing, geospatial data package content and structure are being submitted to clients in a manner that suits the creator (vendor) of the package, at times within consultation with the client. In other words, often there is no consistency in the way data packages are structured.

This inconsistency may require reviewers to take an inordinate amount of time searching the package to find case-relevant information, provided the information is available in the package. This problem is compounded when a reviewer must compare two packages, from two vendors (prosecution and defense) to determine consistency or points-of-departure. If the case-relevant information is contained in the packages, the reviewer may find it necessary to determine where this information is in the package, and how the vendors presented the information. In some situations, the reviewer may be required to normalize the data in each package in order to make a proper comparison (i.e., resolution).

The questions arise then: If parties are going to voluntarily create consistent data packages as deliverables, on what basis should the packages be structured? What element(s) crosses the real and imaginary borders of science and politics that would be palatable to all nations, data providers, clients, and stakeholders? The answer lies in the examination of processes common to companies throughout the world. Developed first as a means of efficiency, and to ensure continuity of production processes, Standard Operating Procedures (SOPs) have been written to ensure that if one employee departed, another could take his/her position and the production line would still operate relatively smoothly.

Another, primary, reason Standard Operating Procedures (SOPs) are written is to ensure that, within an organization, products have a consistent level of quality. Equally important, an organization must ensure that employees implement the SOPs; it is not enough to have them on the shelf. Over the centuries, companies have found, on an international level, that SOPs:

- Ensure smooth production
- Help to ensure consistent quality
- Demonstrate to clients that their concerns are addressed
- ....and more

"Error may be transferred from one data process step to the next unknown to the analysts until it manifests in the final product,..." (Lunetta, 1991). SOPs may facilitate tracking the source of errors and thereby reduce error propagation. The ability to reduce error propagation increases the overall quality of geospatial products. For more than a decade, the geospatial science community has been engaged in identifying potential sources of error, discussing the impact of the error and making recommendations to overcome error-related impediments. Vigilance is required because technology in general, and the tools used in geospatial analysis is always evolving. Therefore, SOPs need to be periodically reviewed and revised and appropriate in order to ensure the continual improvement of quality.

The link of SOPs to quality and the importance of following SOPs has been recognized and articulated by the scientific community. The impact of the "SOP to quality" link in the geospatial and space law arena is best exemplified by one case in which a private manufacturer of aeronautical products was not found liable for inaccurate data used in an aeronautical chart (*Brocklesby v. The United States and Jepperson & Co*). Jepperson had changed the chart format text to graphic form, and, the court said of Jepperson, "...in the process it had the ability and opportunity to detect the error." The court also held that the manufacturer had the right to seek indemnification against its co-defendant, the United States, who through the Federal Aviation Administration (FAA), supplied the information used on the chart. This decision resulted in passing a new law to provide indemnification by the United States in future cases (Gabrynowicz, 1996).

This particular case is important enough to be restated: Jepperson claimed they were not liable because the defective data came from the FAA. The court held that Jepperson could have verified the data by following the process in their own Standard Operating Procedures which required it to check the data to determine its validity and completeness.

The processes described in Jepperson's SOPs to check data validity and completeness are Quality Assurance (QA) and Quality Control (QC) procedures.

The NSDI and Global Spatial Data Infrastructure (GSDI) are conceptually sound and are making progress in their objectives; however, neither organization has fully addressed QA and QC procedures. Additionally, the Federal Geographic Data Committee (FGDC), though it factors QA and QC procedures into its products, has not separately and explicitly addressed QA and QC procedures – neither in its documentation nor its organizational structure.

Consistent means to share geographic data among all users could produce significant savings for data collection and use and could enhance decision making. Executive Order 12906 calls for the establishment of the National Spatial Data Infrastructure defined as the technologies, policies, and people necessary to promote sharing of geospatial data throughout all levels of government, the private and non-profit sectors, and the academic community. The goal of this Infrastructure is to reduce duplication of effort among agencies, improve quality, and reduce costs related to geographic information, to make geographic data more accessible to the public, to increase the benefits of using available data, and to establish key partnerships with States, counties, cities, tribal nations, academia and the private sector to increase data availability.

The NSDI has come to be seen as the technology, policies, criteria, standards, and people necessary to promote geospatial data sharing throughout all levels of government, the private and non-profit sectors, and academia (FGDC, 2004). NSDI provides a base or structure of practices and relationships among data producers and users that facilitates data sharing and use. NSDI is a set of actions and new ways of accessing, sharing, and using geographic data that enables far more comprehensive analysis of data to help decision-makers chose the best course(s) of action. Much has been accomplished in recent years to further the implementation of the NSDI, but there is still much to be done to achieve the vision: current and accurate geographic data that are readily available across the country (FGDC, USGS, 2004).

Cooperation and partnerships for spatial data activities among the Federal government, State and local governments, and the private sector will be essential for developing a robust infrastructure. The twenty-first century will see geographic information transported from remote nodes using computer networks to support decision making throughout the Nation. The National Information Infrastructure (NII) will provide the technology infrastructure to make this possible. The costs of creating and maintaining digital spatial data are high, so it is particularly important that spatial data collection not be duplicated, and that data be shared to fully realize its potential benefits. Largely for these reasons, the National Performance Review (prepared under the guidance of former Vice President Gore) urged the formation of spatial data partnerships between Federal agencies, State and local governments, and the private sector. After examining the pros and cons of several current spatial data programs that involve partnerships, the Mapping Science Committee (MSC) of the National Academies of Science (Mapping Science Committee, 1993) agreed that a partnership model, the subject of this report, is an excellent approach for enhancing the NSDI. The MSC serves as a focus for external advice to Federal agencies on scientific and technical matters related to spatial data handling and analysis. One of the Committee's roles is to provide advice on the development of the NSDI for making informed decisions at all levels of government and throughout society in general. Recently a number of State geographic information councils have been established to coordinate spatial data activities within the respective States. Such councils can also encourage partnerships between State and local government agencies, coordinate arrangements between State agencies and the private sector, and provide points of contact for partnerships with the Federal government organizations. The MSC agrees with the recommendation of the Federal Geographic Data Committee (FGDC) in its strategic plan to help form or strengthen these State geographic information councils (Mapping Science Committee, 1993).

The relationship of the FGDC and the NSDI is that the FGDC is responsible for steering the NSDI. A recent report form the US Government Accountability Office (GAO) clearly addresses the need for improvement in identifying and reducing duplicative investments (GAO, 2004a). In their report the GAO notes that the Federal Enterprise Architecture effort, and FGDC's reporting process - are insufficiently developed and have not produced consistent and complete information (GAO, 2004b). In addition to its other responsibilities, the Office of Management and Budget (OMB) Circular A-16 charges FGDC with leading the preparation of a strategic plan for the implementation of the NSDI. Such a plan could ensure coherence among the many geospatial coordination activities that are under way and provide ways to measure success in reducing redundancies. In 1994, FGDC issued a strategic plan that described actions Federal agencies and others could take to develop the NSDI, such as establishing data themes and standards, training programs, and partnerships to promote coordination and data sharing. In April 1997, FGDC published an updated planCwith input from many organizations and individuals having a stake in developing the NSDICthat defined strategic goals and objectives to support the vision of the NSDI as defined in the 1994 plan. Unfortunately, no further updates have been made (GAO, 2004c); the current work can be viewed at their website http://www.fgdc.gov/nsdi/nsdi.html. In addition, the current National Geospatial Strategy Document, FGDC's 1997 plan, is also out of date. (GAO, 2004d).

OMB Circular A-16 established the NSDI and the FGDC. OMB A-16 links the FGDC and NSDI to quality in the statement "A coordinated approach for developing spatial data standards that apply to collecting, maintaining, distributing, using, and preservation of data will improve the quality of spatial data and reduce the cost of derivative products created by federal and non-federal users" (OMB A-16, 2002a). Since the focus of the GAO report was on duplicative efforts, the GAO did not include a review of quality issues in their study of the FGDC and the NSDI geospatial information. A search of the GAO report for the word "quality," and phrase "information quality" confirms this suspicion because a word search of the study yielded nothing more than "quality of air...," "...water quality..," etc. Recognizing that the improvement of quality does not "just happen," OMB developed its own Information Quality Guidelines (IQGs), however OMB's IQGs have not "trickled-down" to the FGDC and NSDI. The authors anticipate that GAO may subsequently report on FGDC and NSDI quality issues, since the referenced GAO report does not include recommendations regarding the establishment and implementation of IQGs.

The authors of this paper believe that a consistent approach to quality planning, information technology, and information management, will provide the basis for solution of the issues identified by the US GAO, and more. In addition, it is critical that the information shared be of known quality. A baseline level of quality assurance, including adequate documentation, is required to ensure confident, interoperability of data.

Why is Planning for Geospatial Projects Important?

Planning is important in geospatial projects because it allows the project team to identify potential problems that may be encountered on a project and develop ways to work around or solve those problems before they become critical to timelines, budgets, or final product quality. Many examples exist of how a lack of planning impacts quality in geospatial projects. Lack of planning and detailed knowledge about data needs can cost a project a great deal of time and effort. Also the graded approach to developing QA Project Plans increases efficiency in that QA Project Plan elements are planned to be commensurate with the scope, magnitude, or importance of the project itself.

Developing and implementing a good QA Project Plan provides value to a geospatial project by:

- Guiding project personnel through the implementation process, helping ensure that choices are consistent with the established objectives and criteria for the project and providing material for the final report.
- Fostering project transparency, better communication among the project team members, and better results for the decision maker.
- Reducing the risk of schedule and budget overruns.
- Leading to a more defensible outcome than a project without proper planning documentation.
- Documenting the criteria and assumptions in one place for easy review and referral by anyone interested in the process.
- Providing consistency, making it easy for others to review the procedures and ensuring that individual steps are not overlooked in the planning phase.

In addition to these benefits, a project with a well-defined QA Project Plan often takes less time and effort to complete than a project without a planning document. Projects without planning documents are more likely to need additional money and time to correct or redo collection, analysis, or processing of data. The savings resulting from good planning typically outweighs the time and effort spent to develop the QA Project Plan. Poor quality planning often results in poor decisions. The costs of decision-making mistakes can be enormous and far outweigh the costs of proper planning for quality.

Quality Assurance Project Plan

The QAPP is a necessary and pivotal plan to guide and assure known quality in scientific and engineering projects. It is defined as a "document describing in comprehensive detail the necessary Quality Assurance (QA), Quality Control (QC), and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria" (EPA, 2001a), and it is composed of a number of elements.

What are the Characteristics of a Scientifically Sound Geospatial Data Project Plan?

A scientifically sound, quality-based geospatial QA Project Plan generally:

- Provides documentation of the outcome of the systematic planning process.
- Is developed using a process designed to minimize or control errors.
- Documents the standard operating procedures to be followed.
- Documents the data sources, format, and status of the existing (also called secondary or non-direct measurements) data to be used in the project [including topological status, accuracy, completeness, and other needed Federal Geographic Data Committee (FGDC) metadata].
- Is frequently updated as new information becomes available or as changes in methodology are requested.
- Provides for the documentation of any changes from the original plan.

Current Trends in Geospatial QA

Literature searches reveal that the geospatial science community continues to conduct research and promulgate guidance regarding spatial accuracy (Mower and Congalton 2000) (Lunetta and Lyon, 2004). However, spatial accuracy alone is not enough. Information Technology (IT) and Information Management (IM), provide the foundation of support for geospatial science. Ensuring that IT and IM are sound and minimize the chance of corrupting the data stored or passed through them is an essential step in handling any type of electronic data (Brilis, 2003a).

The U.S. Environmental Protection Agency has a Geospatial Quality Program (GQC) which guides the Geospatial Quality Council (GQC). Since its' formation in 1999, the GQC has developed numerous geospatial quality guidance documents and training courses to bridge the gap between the quality assurance community and the geospatial science community. The "Progress and Products" section of the GQC website contains downloadable QA guidance documents (Brilis 2003b).

In addition, the entire life cycle of geospatial information must be considered for a holistic approach to assuring quality. The life cycle consists of: Quality Planning; Data Acquisition; Data Input; Data Storage; Data Transformation; Data Output; and the often overlooked area of Data and Information Use and Misuse. This journal article focuses on the first step, Quality Planning.

Who Can Benefit from this Document?

Anyone developing geospatial projects or using geospatial data for EPA will benefit from this document. This document helps in the creation of a QA Project Plan that specifically addresses the issues and concerns related to the quality of geospatial data, processing, and analysis. This document also helps anyone who is:

- Creating geospatial data from maps, aerial photos, images, or other sources.
- Generating or acquiring the aerial photos or images.
- Using existing data sources in their geospatial projects.
- Generating new geospatial data from Global Positioning System (GPS) receiver data on horizontal and vertical positions.
- Developing complex analysis programs that manipulate geospatial data.
- Overseeing applications programming or software development projects—to understand how planning is related to developing software programs that use geospatial data.
- Reviewing QA Project Plans for geospatial data—to understand the steps and details behind the planning.
- Serving as a QA Officer for a group that creates or uses geospatial data.

The benefits of a QA Project Plan are to communicate, to all parties, the specifications for implementation of the project design and to ensure that the objectives are achieved for the project. It does not guarantee success every time, but the prospects are much higher with a QA Project Plan than without one (EPA, 2002a).

Graded Approach

Systematic planning for QA/QC is based on a common-sense, graded approach. The graded approach is the process of basing the level of application of managerial controls applied to an item or work according to the intended use of the results and the degree of confidence needed in the quality of the results. This means that the extent of systematic planning and the approach to be taken match the general importance of the project and the intended use of the data. For example, when geospatial data processing is used to help generate data either for decision making (i.e., hypothesis testing) or for determining compliance with a standard, EPA recommends that the systematic planning process take the form of the Data Quality Objectives (DQO) Process that is explained in detail within Guidance for the Data Quality Objectives Process (QA/G-4) (EPA, 2000a).

The Graded approach to QA Project Plans implies that, for projects of very limited scope, quality objectives, or size, a simple description of the use of weekly or monthly status e-mails may be appropriate. For more complex projects with many processing steps, data sources, and complex processing methods, more formal reports may be specified and documented.

Secondary Use of Data

Secondary use of data is the use of data collected for other purposes or from other sources, as distinct from the primary acquisition or purpose. Sources may include literature, industry surveys, compilations from computerized databases and information systems, and results from computerized or mathematical models of environmental processes and conditions.

Geospatial projects, almost always use existing data from a source external to the project. When designing a project and, in turn, developing a QA Project Plan, the question of which Geographic Information System (GIS) data sources to use is important.

Overview of the Components of a QA Project Plan

This section provides a list of the components of a QA Project Plan included in EPA Requirements for Quality Assurance Project Plans (QA/R-5) (EPA, 2001b). The components of a QA Project Plan are categorized into "groups" according to their function, and "elements" within each group that define particular components of each group and form the organizational structure of the QA Project Plan. QA groups are lettered and QA elements are numbered. The four groups are:

Group A—Project Management

The elements in this group address the basic area of project management, including the project history and objectives, roles and responsibilities of the participants, etc. These elements ensure that the project has a defined goal, that the participants understand the goal and the approach to be used, and that the planning outputs have been documented.

Group B—Data Generation and Acquisition

The elements in this group address all aspects of project design and implementation. Implementation of these elements ensure that appropriate methods for sampling, measurement and analysis, data collection or generation, data handling, and QC activities are employed and are properly documented.

Group C—Assessment and Oversight

The elements in this group address the activities for assessing the effectiveness of project implementation and associated QA and QC activities. The purpose of assessment is to ensure that the QA Project Plan is implemented as prescribed.

Group D—Data Validation and Usability

The elements in this group address the QA activities that occur after the data collection or generation phase of the project is completed. Implementation of these elements ensures that the data conform to the specified criteria, thus achieving the project objectives.

Table 1 shows a complete list of the QA Project Plan groups and elements. Subsequent sections of this paper provide more detail about the content of each section.

Suggested Content of QA Plan Elements

The QA Plan structure described in the groups above leaves the content of each section open to the discretion of the QA Plan author(s). There are a number of suggested contents for each of the groups. This content is "suggested" because each geospatial project is unique. The suggested content is not a "one-size-fits-all" scenario.

To exemplify the range of geospatial products, two types of projects are presented for illustrative purposes. Example 1: A hazardous waste site manager may need geospatial information to take an alleged violator to court Example 2: Geospatial projects - this may require near real-time satellite imagery. A researcher may be involved in evaluating the effect of city growth on the environment, therefore archived images of the site in addition to near real-time satellite images may be required to conduct this type of assessment.

Because of the wide-array of geospatial applications, the content for each QA Plan group is suggested. The QA

Table 1. Summary of QA Groups and Elements.

Group	Element	Title
A	1	Title and Approval Sheet
	2	Table of Contents
	3	Distribution List
	4	Project/Task Organization
	5	Problem Definition/Background
	6	Project/Task Description
	7	Quality Objectives and Criteria
	8	Special Training/Certification
	9	Documents and Records
B	1	Sampling Process Design
	2	Sampling and Image Acquisition Methods
	3	Sample Handling and Custody
	4	Analytical Methods
	5	Quality Control
	6	Instrument/Equipment Testing, Inspection, and Maintenance
	7	Instrument/Equipment Calibration and Frequency
	8	Inspection/Acceptance for Supplies and Consumables
	9	Data Acquisition (Nondirect Measurements)
	10	Data Management
C	1	Assessments and Response Actions
	2	Reports to Management
D	1	Data Review, Verification, and Validation
	2	Verification and Validation Methods
	3	Reconciliation with User Requirements

Plan author(s) should consider contacting the project manager, and/or the appropriate QA professional to ensure that critical quality items are addressed in the QA Plan.

The suggested content is presented in the next sections.

Group A—Positioning the Project in Earthly Perspective

Title and approval sheet

Suggested Content:

- Title of plan.
- Name of organization.
- Names, titles, and signatures of appropriate officials.
- Approval signature dates.

Table of contents

Suggested Content:

- Table of contents.
- List of tables, figures, references, and appendices.
- Document control format when specified by the Project Manager.

Distribution list

Suggested Content:

- Individuals and organizations who receive approved QA Project Plan.
- Individuals and organizations responsible for implementation.
- Individuals and organizations who receive updates.

Project/task organization

Suggested Content:

- Identified roles and responsibilities.
- Documentation of the QA Manager's independence of the unit generating the data.
- The individual responsible for maintaining the official QA Project Plan is identified.
- Organization chart showing lines of responsibility and communication.
- List of outside external organizations and subcontractors in the organization chart.

Problem definition/background

Suggested Content:

- The specific problem to be solved or decision to be made.
- Description of the project's purpose, goals, and objectives.
- Identification of programs this project supports.
- Description of the intended use of the data to be gathered or processed.

Project/task description

Suggested Content:

- Sufficient background for a historical and scientific perspective for project tasks.
- Schedule and cost.

Quality objectives and criteria

Suggested Content:

- The quality objectives for the project.
- The performance and acceptance criteria used to evaluate quality. (Use the systematic planning process to develop quality objectives and performance criteria [see EPA Quality Manual for Environmental Programs, Section 3.3.8.1 (EPA, 2000a), for more information]).

Special training/certification

Suggested Content:

- Any training or certification specifications for the project.
- Plans for meeting these specifications.

Documents and records

Suggested Content:

- Description of the mechanism for distributing the QA Project Plan to project staff.
- List of the information to be included with final products, including metadata records, calibration and test results (for GPS or remote sensing tasks), processing descriptions provided by data vendors (for example, address matching, success rate reports from address matching vendors).
- List of any other documents applicable to the project, such as hard-copy map source material, metadata provided with data from secondary data sources, interim reports, and final reports.
- All applicable specifications for the final disposition of records and documents, including location and length of retention period.

Group B—Data Generation and Acquisition

Sampling process design

Suggested Content:

- Description of the data or image acquisition design.
- For geospatial data to be collected, the design for acquisition (for example, how and where locational data will be acquired).

Sampling and image acquisition methods

Suggested Content:

- Description of data, photography, or imagery collection procedures.
- Methods and equipment to be used.
- Description of GPS equipment preparation.
- Description of performance criteria.
- Description of corrective actions to be taken if problems arise.

Sample handling and custody

Suggested Content:

- Description of needs for handling and transfer of hard-copy imagery or other hard-copy data inputs.

Analytical methods

Suggested Content:

- Image processing and/or photo-analysis methods to be used.
- List of method performance criteria, if applicable.
- QC activities needed for GPS measurements, field observations, map digitization, image acquisition, image processing, or image analysis.
- The frequency of each check and corrective action needed when limits are exceeded.

Quality control

Suggested Content:

- Develop QC checklist for each step of data collection, checking and assessing the quality of map digitizing or satellite ground-truthing results.
- Ensuring that the requested special bands have been delivered.
- Checking against independent data sets such as other images or vector products.
- Examining the cloud coverage of images to ensure that cloud coverage extent does not impede use of the data.
- Ensuring that the view angle of imagery is as specified.

Instrument/equipment testing, inspection, and maintenance

Suggested Content:

- Description of how inspections and acceptance testing of instruments, equipment, and their components affecting quality will be performed and documented.
- Description of how deficiencies will be resolved.

- Description of (or reference to) periodic preventive and corrective maintenance of measurement or test equipment.

Instrument/equipment calibration and frequency

Suggested Content:

- Instruments used for data collection whose accuracy and operation need to be maintained within specified limits.
- Description of (or reference to) how calibration will be conducted.
- How calibration records will be maintained and traced to the instrument.

Inspection/acceptance for supplies and consumables

Suggested Content:

- Description of how and by whom supplies and consumables will be inspected and accepted.

Data acquisition (nondirect measurements)

Suggested Content:

- Description of secondary data used.
- Description of the intended use of the data.
- Acceptance criteria for using the data in the project and any limitations on that use.
- Information Technology issues.
- Logistical consistency.

Data management

Suggested Content:

- Description of the project management or activities.
- Flow charts of data usage and processing.
- Description of how data will be managed to reduce processing errors.
- Description of the mechanism for detecting and correcting errors in data processing.
- Examples of checklists or forms to be used.
- Description of the hardware/software configuration to be used on the project.
- Description of the procedures that will be followed to demonstrate acceptability of the process.
- Description of the data analysis or statistical techniques to be used.
- Information Technology issues:
    - Security.
    - Electronic Exchange Formats.
    - Hardware/Software Configuration.

Group C—Assessment/Oversight

Assessments and response actions

Suggested Content:

- Description of each assessment.
- Information expected and success criteria.
- Assessments to be done within the project team and which are done outside the project team.
- The scope of authority of assessors.
- Discussion of how response actions to assessment findings are to be addressed.
- Description of how corrective actions will be carried out.

Reports to management

Suggested Content:

- Frequency and distribution of reports issued to management that document assessments, problems, and progress.
- Individuals or organizations responsible for preparing the reports and actions recipients would take upon receipt of the reports.

Group D—Data Validation and Usability

Data review, verification, and validation

Suggested Content:

- The criteria to be used to validate and verify the final product.

Verification and validation methods

Suggested Content:

- Description of validation and verification processes for the final products.
- Discussion of issues related to resolving problems detected and identification of individuals or authorities who determine corrective actions.
- Description of how the results of the validation will be documented for the product users.
- Definition of differences between validation and verification issues.

Reconciliation with user requirements

Suggested Content:

- Description of how the products or results will be reconciled with criteria defined by the data user or decision maker.

- Description of how reconciliation with user criteria will be documented and how issues will be resolved.
- Discussion of limitations on the use of the final data product and how these limitations will be documented for data users or decision makers.

Discussion

Application of a structured quality plan facilitates subsequent assessment, not only by scientists, but by courts. A structured quality plan communicates that the basic scientific method is being applied. This in turn ensures that judges have a basis that they can relate to. Specifically the U.S. Supreme Court's concept of "sound science," as related to environmental programs and their supporting data, requires an assessment of exactly what the legal concepts are and what are the actual processes to which they apply in an environmental program. The "Daubert Rule" looks specifically at the theory or technique and some areas associated with the theory or technique (for example, peer review, error rates, standards for control, and general acceptance) (Brilis, 2000).

A critical question might be, "What are the science-related theories or techniques involved in environmental programs?" Theories and techniques may be based on one or more disciplines, such as:

- experimental design
- engineering design
- sampling
- chemistry/biology
- quality assurance
- statistical analysis
- risk assessment
- risk management

When does the Daubert Rule come into play? Maybe not at all. The Daubert Rule would most likely apply to novel situations where a standard approach to performing the operation does not exist. For example, if the investigation activity is predetermined according to a known method and the analytical work is a known method (i.e., EPA and ASTM methods), then discussions about what might constitute needed proof for a hypothetical situation may be totally unnecessary.

For much of the environmental work performed on a routine basis, this approach is simply not necessary. However, when the activity requires the application of scientific expertise, the criteria outlined in the Daubert Rule makes sense when looking at admissibility of scientific evidence.

How should scientists respond to the complex implication of law on the process of science? Scientists should focus on the overlying charge that forms the basis for all credible work, that is, "to produce data of known and acceptable quality that is usable for its intended purpose." The intended purpose is key to the establishment of clear objectives for the project, the associated measurements, and their associated quality control criteria (Maney and Wait, 1991; Wait and Douglas, 1995). Each of the criteria mentioned here are not requirements and the end result is not good or bad, depending on the objective; the resulting information can be considered good, better, or best for assisting lawyers in using the overall result to support the original objectives.

From 1993 to 1999 more than 2000 cases cite the Daubert decision. As such, it behooves the scientist conducting defensible testing to consider the following:

Planning Criteria

- persons planning this work are knowledgeable (expert and trained)
- planning was performed
- planning was documented
- the plan was reviewed
- the plan included a clear objective(s)
- the plan included readily identifiable measurements to achieve the objectives
- the plan stated specific QC criteria for the measurements
- the plan referenced sampling and analytical procedures

Implementation criteria

- changes to the plan were noted and approved
- the activity was implemented as planned
- there was documented management overview of the implementation
- there was documented quality assurance overview of the implementation
- corrective action regarding problems noted during overview was taken and documented
- the personnel performing the work were trained
- the records that were kept were accurate
- the supplies used met requirements
- measurement devices were calibrated
- problems encountered were recorded
- problems were resolved (and documented)

The result and assessment criteria

- quality control criteria were met
- report conclusions are supported by data

- the data were validated
- the report was reviewed
- review comments were addressed
- results are comparable to results from similar work

Sample authenticity criteria

- chain of custody was maintained
- sample identity was maintained
- sample integrity was not compromised
- sample records are all consistent

Data integrity criteria

- data output records were well maintained
- computer hardware and software was controlled
- the quality of any secondary data used is known

The above information resembles the body of items one might consider in either a quality management plan or a project-specific technical specifications document. Scientists and lawyers have similar interests which are based on the overall objectives of the scientific effort. In some cases, quality control needs to focus on a single sample, when that sample might be used to prove the need for enforcement. In other cases, quality control needs to focus on a larger process such as the characterization of a site and potential cleanup. Still in other cases, quality control needs to focus on the proof of a research experiment which looks at a single technology application on a very small area or amount of material. In all cases, planning should consider the overall objective of the process considered during application of scientific techniques or theories.

Conclusion

The future holds many changes and challenges for geospatial data, image interpreters and the geospatial scientist. For example, the demand by the legal profession for GIS experts has increased since the GIS software has left the UNIX format and found its' way to more user-friendly software. This demand has been and will be intensified by the problems of environmental industrial contamination and the lawsuits brought against individuals and corporations by citizens, employees, and public agencies.

We predict that geospatial scientists, using advanced image analysis and GIS techniques, will become more adept at gathering data from complex problems. They will use this data in increasingly sophisticated ways to answer the numerous questions that surround legal cases.

The state of quality of geospatial science in the courtroom is still evolving as the courts continuously consider the quality of evidence. This is particularly true in cases where novel scientific techniques are used. Recent trends towards the use of remotely-sensed images, especially those using wavelengths outside the visible spectrum, beg the users to ensure that quality assurance and quality control policies and procedures are in place to ensure defensible evidence.

However, policies and procedures alone are not enough. Policies and procedures must be implemented and their use must be documented. The case of Brocklesby v. U.S. and Jeppesen & Co., highlights this fact. In this case, Jeppesen claimed that the defective data was obtained from the Federal Aviation Administration (FAA), and therefore no liability should be placed on Jeppesen. The court held that it was incumbent upon Jeppesen to verify the FAA's data by following its own Standard Operating Procedures which require Jeppesen to verify the integrity of the data (Ninth Circuit Court, 1985).

Additionally, the use of qualified experts that can translate complex and novel images or GIS products is becoming increasingly important. Indeed, litigators may increase the use of geospatial experts to help "translate" the technicalities of a case. While one may have highly defensible data, the communication of evidence to the lay persons (jurists) is critical in making a convincing presentation.

Image interpreters and GIS specialists are first and foremost analysts and their unique abilities will have an increasingly extensive applicability in the environmental arena. Therefore it is appropriate and necessary that geospatial scientists be involved from the beginning of the project. That is, "Plan the investigation, and investigate the plan."

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Knowledge Unification Processes

Strategic Planning for Sustainable Forests: The Plan Drives the Budgets Which Drive Results

Paul Brouha, USDA Forest Service, Washington, DC
Elisabeth Grinspoon, USDA Forest Service, RPM, Portland, OR

Abstract*—The USDA Forest Service is among the pioneers incorporating the Montreal Process criteria and indicators into its programs. Among its initial efforts is the adaptation of a criteria and indicators framework for its national strategic plan, which is the primary instrument for setting the course to achieve the Forest Service mission of sustaining the nation's forests and grasslands for present and future generations. This presentation describes the steps the Forest Service has taken to adopt and implement a criteria and indicators-based strategic plan. It also describes the challenges of formulating a budget based on performance measures in the plan and then creating field unit and executive and manager-level accountability for results that foster sustainability.*

"To sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations."—United States Department of Agriculture (USDA) Forest Service Mission Statement

Introduction

The mission of the USDA Forest Service is achieving sustainable resource management. The Forest Service is directly responsible for the sustainable management of 192 million acres of federal forests and grasslands in the National Forest System. The agency is also indirectly responsible for promoting the sustainable management of another one billion acres of publicly and privately owned forests and grasslands in the United States.

Essential to success of the Forest Service mission are long-term strategic plans, which communicate policy and guide the agency. Strategic planning provides guidance for future agency actions by elucidating the agency's mission, as well as strategic goals and objectives. These goals and objectives describe a specific course towards achieving the agency's mission.

The strategic plan, however, does not specify what work the Forest Service will undertake. It does provide an explanation of why certain types of work are necessary and proposes appropriate programmatic and integrated strategies for undertaking the work. Execution of the agency's strategic plan is the role of the Annual Performance Plan, which describes the annual program of work. Various unit plans, including the National Forest System's Land and Resource Management Plans and the Research Work Unit Plans, also communicate objectives for annual programs of work at the local level (fig. 1).

Strategic Planning History

When Congress established the Forest Service in 1905, it did not require that the agency write long-term plans. In the 1970s, controversy over forest service programs, such as clear-cutting on the national forests, increased. As a result, Congress instituted long-term planning requirements for the agency. Among these requirements, the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 facilitates the process of assessing the status of renewable resources and the process of designing ways to meet present and future needs (Public Law 93-378). The RPA assessment and planning activities were designed to provide more scientific bases for management of the nation's forests, to increase public participation in forest management, and thereby to reduce public contention over Forest Service programs.

Nearly twenty years after Congress first instituted long-term planning requirements, it passed the Government Performance and Results Act (Results Act) of 1993 mandating that each federal government agency prepare five-year strategic plans in consultation with Congress and with input from stakeholders. Eventually, Results Act strategic plans replaced RPA long-term plans as the means for establishing strategic direction for the Forest Service.

While the Results Act is similar to RPA, there are differences in language and purpose. An important change

Figure 1. The Forest Service mission is the foundation for planning and program delivery at every level of the agency.

is the shift from output to outcome-oriented planning. While the RPA Program was output-oriented, the Results Act mandates outcome-oriented strategic plans. In other words, RPA focused on outputs, which are the products or yields resulting from direct consequences of management activities. The Results Act emphasizes outcomes, which are cumulative results of many activities directed toward common purposes.

Although the Results Act mandated outcome-oriented strategic plans, the agency's initial long-term plan written under the Results Act, entitled the 1997 Strategic Plan, remained output-oriented and focused on management activities. In the 1997 Plan, each strategic goal was divided into several objectives with associated strategies, performance measures, and timeframes (GPRA Strategic Plan, 1997). For example, Goal 1 was: "Ensure sustainable ecosystems." It was divided into four objectives: aquatic ecosystems, forested ecosystems, rangeland ecosystems, and hazardous substance sites. Under forested ecosystems, an objective was to restore 5 to 10 percent of National Forest System lands identified as needing restoration. Some of the strategies for achieving this goal included conducting research, taking inventories, and developing collaborative approaches.

The above example is representative of the 1997 Plan in that it had poorly defined indicators. Lack of baseline data also contributed to difficulty in demonstrating progress toward specific objectives and overall goals. To improve the strategic plan, the Forest Service began linking goals and objectives to science-based indicators of sustainability derived from the Montreal Process. Before describing how science-based indicators enhanced the strategic planning process, this paper outlines the Montreal Process and its implementation in the United States.

Montreal Process

The Montreal Process is an initiative among governments of non-European temperate and boreal forest countries to develop and implement internationally agreed criteria and indicators for sustainable management of forests. The notion of sustainability became popular in 1987 with the publication of Our Common Future, which defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987).

Sustainable development was the focus of the 1992 United Nations Conference on Environment and Development, known as the Earth Summit, which led to an agreement among world leaders on principles of sustainable forest management called the Statement of Forest Principles and Agenda 21 (Floyd, 2002). Although the broad definition of sustainability produced by the Bruntland Commission has been widely accepted, the precise meaning of sustainability was, and still is, widely debated. The debate focuses on the attributes of a sustainable forest.

In order to further delineate sustainable forests, Canada convened in Montreal an International Seminar of Experts on Sustainable Development of Boreal and Temperate Forests. After the Seminar, the Montreal Process Working Group met for the first time and stated its goal: "… to advance the development of internationally agreed upon criteria and indicators for the conservation and sustainable management of temporal and boreal forests at the national level." In 1995, the Working Group issued the Santiago Declaration, named after the city in which group members endorsed the non-binding agreement on criteria and indicators for sustainable forest management. Twelve countries encompassing more than 90 percent of the world's temperate and boreal forests endorsed the declaration (MPWG, 1999).

The Montreal Process framework does not propose management standards, rules, or regulations for managing sustainable forests. Instead, the framework offers a data collection tool and communication device in the form of indicators. Sustainability indicators are analogous to national economic indicators. Indicators provide a common vocabulary for participation and collaboration among stakeholders. Just as indicators of inflation and unemployment are indispensable in assessing the nation's economic health, sustainability indicators are invaluable in tracking forest health and formulating analytically driven decisions regarding sustainability.

The Montreal Process framework is composed of seven criteria and 67 indicators, commonly known as the Montreal Process Criteria and Indicators (C&I). The Montreal Process Working Group defines criteria as categories of conditions or processes by which sustainable forest management may be assessed. Likewise, indicators are measures (measurements) of an aspect of a criterion. The seven criteria fall into three general categories: vital functions and attributes (biodiversity, productivity, forest health, the carbon cycle, and soil and water protection), socio-economic values and benefits (timber, recreation, and cultural values) and the laws and regulations that comprise the forest policy framework (MPWG, 1999).

On November 5, 1993, following the Earth Summit, the United States (U.S.) committed to a national goal of sustainable forest management through a presidential directive entitled Environmental Policy on International Desertification, Forest Conservation, and Fresh Water Security (Presidential Decision Directive/NSC-16).

The U.S. not only agreed to non-binding principles on forest conservation and sustainable use, the directive also stated "…we must take the lead internationally by observing these principles ourselves… The United States is committed to a national goal of achieving sustainable management of U.S. forests... Our national objectives are that: our nation's forest should be healthy and productive; the growth of our timber should exceed harvest; and our forests should be reservoirs of biological diversity and carbon" (Presidential Decision Directive/NSC-16).

As part of U.S. efforts to achieve sustainability, in 1994, the Forest Service and the U.S. State Department organized a group of stakeholders to provide a forum for discussion of the Montreal Process Criteria and Indicators (C&I). The forum, officially chartered in 1999, is known as the Roundtable on Sustainable Forests. Although the Roundtable is not a decision-making body, it enables better decision-making through the sharing of information and perspectives among individuals representing diverse interests. More than 40 government and non-governmental organizations participate in the Roundtable including federal government agencies; tribal, state, and local units of government; private landowners and citizens; industries and businesses; conservation and environmental groups; regional and community-based organizations; as well as researchers and academics.

Stakeholders have disparate ideas about how to achieve sustainability. To facilitate the resolution of these differences, Roundtable meetings are convened by a non-profit organization that specializes in solving problems related to the environment. The Roundtable meets regularly to discuss what C&I mean for forest management and conservation in the United States, how data for the indicators are collected, and who is responsible for acquiring the data. One of the biggest challenges for stakeholders has been reaching agreement on interpretation of specific indicators and means for evaluating them.

Building consensus is both a great challenge and benefit of the Roundtable. Finding ways for stakeholders with varying perspectives to communicate is especially important in a country as diverse as the United States with forestlands that are owned and managed by different private and public entities. Roundtable stakeholders use the C&I framework to resolve shared problems across multiple jurisdictions and tenure arrangements. In this way, the Roundtable and the C&I framework bring disparate parties together to build a consensus for achieving sustainable forestry. Because of the Roundtable's success, similar sustainability roundtables have been established concerning rangeland resources, minerals, and water.

Roundtable work is divided between two groups: a Communications and Outreach Work Group and a Technical Work Group. The former has sponsored workshops to inform state, county and other government officials, practitioners, as well as the general public about sustainable forest management and the criteria and indicators. The latter has held workshops for technical experts to identify regional and national data sets and information gaps. Workgroup members found that nine of the 28 Montreal Process biological indicators have been part of Forest Service sampling for 70 years (Robin Maille, 2000).

The Technical Workshops initiated production of a national report based on criteria and indicators addressing an array of environmental, social, and economic concerns. The report describes the current status and conditions of US forests, including trends in their health, productivity and use. Federal participants in the Roundtable formed the Sustainable Forest Data Working Group and collaborated with a variety of state, nongovernmental, and private institutions to compile the extensive report, known as the National Report on Sustainable Forests—2003 (USDA Forest Service, 2004) , which is a reference point for measuring national progress toward sustainable resource management.

Strategic Planning and the Montreal Process

Forest Service Strategic Planning has benefited tremendously from the efforts of the Roundtable on Sustainable Forests and the Montreal Process. In the year 2000, the Forest Service published a revision of the strategic plan with linkages to the Montreal Process framework.

Comparing the strategic goals in the 2000 Strategic Plan Revision with the core principles of the Montreal Process shows an overlap between them. The four goals of the strategic plan and the three core Montreal Process Principles cover the social, ecological and economic values of sustainability (John Day, 2000). The three Montreal Process Principles are: maintenance of ecosystem integrity, social values related to the forest, and production of goods and services. Similarly, the four Forest Service strategic goals are ecosystem health, effective public service, multiple benefits to people, and scientific and technical assistance.

The connections between the Montreal Process and the strategic plan are more substantial with respect to indicators and the objectives. The Montreal Process Indicators provide links between strategic objectives and results-focused outcome measures. An example is the best way to illustrate the linkages: Montreal Process Criterion 1 relates to the conservation of biological diversity. One of the indicators for this criterion is the status of forest-dependent species at risk of not maintaining viable breeding populations. Goal 1 in the 2000 Revision is linked to Criterion 1. Goal 1 is the promotion of ecosystem health and conservation to sustain the Nation's forests, grasslands, and watershed. One of the objectives associated with this goal is providing ecological conditions to sustain viable populations of native and desired non-native species. The measure for this objective is the status and/or trends in populations, habitats, and ecological conditions for selected species. Among the species tracked are the red-cockaded woodpecker and golden-winged warbler as representatives of the Long-leaf and short-leaf pine ecosystems in the Southeast.

Despite the linkages between the C&I and the 2000 Revision, measurement problems arose due to insufficient data. With respect to the example above, milestones set for meeting the objective were vague and data were not available for some indicator species. Another objective under Goal 1 concerning watershed health demonstrates similar problems with objectives in the 2000 Revision. The watershed health objective was designed to improve and protect watershed conditions. Progress toward the objective was not measurable because the Forest Service had not fully delineated watersheds and lacked a comprehensive monitoring protocol and program to assess watershed condition and function. Baseline data were also lacking for other long-term measures and milestones in the 2000 Strategic Plan Revision. This paucity of reliable baseline data left the agency incapable of credibly demonstrating accountability for the expected long-term results.

The 2000 Revision suffered from additional problems similar to its predecessor. Like the 1997 Strategic Plan, the 2000 Revision did not drive performance of agency programs because annual budget development and allocation remained independent of strategic planning. The disjuncture between budgets and strategic plans further hindered the Forest Service ability to demonstrate accountability and progress toward its mission of sustainable forest management.

Strategic Plan for Fiscal Years 2004-2008

In order to address these performance accountability problems, the Strategic Planning and Resource Assessment Staff has completed a new Strategic Plan (USDA Forest Service, 2004) that strengthens linkages between science-based criteria and indicators derived from the Montreal Process C&I and the agency's strategic goals and objectives. The objectives set forth in the new plan are largely based on contextual information from the National Report on Sustainable Forests—2003 and the 2000 RPA Assessment, both of which use C&I to assess status and trends in forest sustainability in terms of the ecological, social, and economic environment.

Although designers of the Montreal Process C&I framework warn that it should not be used as a performance yardstick to evaluate a nation's forest management program, using the systematic framework as a springboard for strategic planning assists the Forest Service in ensuring that it meets the varied aspects of sustainability and improves performance accountability. Adopting a C&I framework also provides an efficient means to communicate condition and trend information that forms a basis for forest policy dialogues. In other words, the C&I framework offers an effective vocabulary to engage stakeholders enabling them to work productively with different institutions and jurisdictions having mutual interests in sustainable forests. As figure 2 demonstrates, trend indicators and policy objectives function as crucial links in the Forest Service Performance Management System.

The new plan is organized around sustaining three conditions, which are parallel to the three main categories of the Montreal Process Criteria. The conditions are: sustain the health, productivity and diversity of the nation's forests and grasslands; sustain a flow of goods and services from the nation's forests and grasslands; and, sustain the organizational capacity to support conservation and management.

In order to prepare goals and objectives for the three conditions, the Strategic Planning Staff sought to

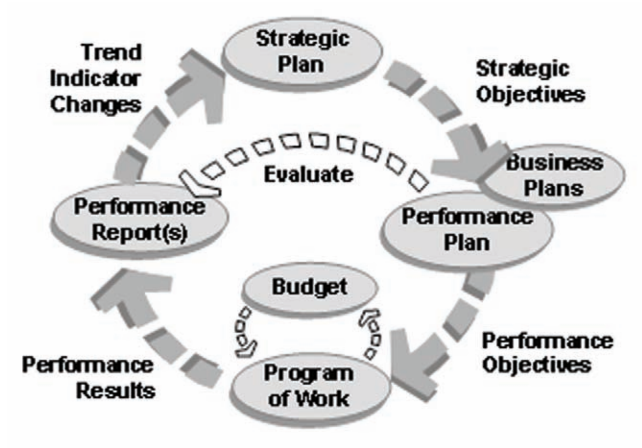

Figure 2. The Performance Management System integrates the Strategic Plan, Budget, and Performance and Accountability Report.

identify key indicators of sustainability from the full suite of 67 Montreal Process Indicators. Particularly useful were the twenty core indicators adopted from the C&I by the Northeast Area Association of State Foresters (NAASF), an organization that represents the directors of state forestry agencies in the northeastern U.S. The 20 indicators adopted by NAASF span the seven criteria of the Montreal Process framework. Each of the seven criteria is represented by one to three different indicators (Sourcebook on Criteria and Indicators, 2002). These indicators became the basis for drafting an initial set of goals and measurable policy objectives that address a limited set of high-priority issues, which emerged from analysis of the 2000 RPA Assessment and the National Report on Sustainable Forests—2003. As a result, policy objectives are linked to key social, economic, and ecological conditions. Taking a pragmatic approach, the staff made efforts to design measures to assess progress toward mission-critical objectives in order to have the capacity to demonstrate program effectiveness.

The mission-critical objectives reference the sustainability trend indicators upon which the objective is based. To determine if program management decisions and activities are advancing a particular policy objective, the Strategic Planning Staff refers to annual performance reports and to the RPA Assessment and the National Report on Sustainable Forests for baseline and trend data. Additionally, the new plan describes objectives in light of how it expects Forest Service programs to influence long-term trends. Potential interactions between various outcomes are also noted. These include adverse effects on carbon sequestration through controlled burns that aim to reduce hazardous fuels and improve forest health.

Plan Implementation—Driving the Budget

The integration of the Forest Service Strategic Plan and forest planning and how the result can inform development of the agency's performance budget is very much a work in progress. The agency is developing integrated goal strategies and program-specific strategies (fig. 3, item #1) to implement the strategic plan. These strategies will inform strategic business plans (fig. 3, item #2) developed at the Region/Station/Area (R/S/A) level which will address national goals and the basic programs that are essential to mission delivery as they also address objectives from forest and other unit plans. The R/S/A business plans will also propose funding needs to accomplish the proposed program. Each year, upon receipt of executive priorities, the R/S/As will request budgets to best meet the priorities while also addressing the needs detailed in their business plans. Their business plans will be updated to become a rolling three year framework for accomplishing their proposed program. During the first quarter of each calendar year the submitted requests will be compiled into a proposed performance budget and a tradeoff analysis undertaken (fig. 3, item #3) to enable agency leaders to choose the emphases to be included in the performance budget (fig. 3, item #4) that is submitted for funding through USDA and the Office of Management and Budget.

Assessing Results—Annually and Over Time

As proposed, a new Performance Accountability System (PAS) will come in to play as the agency annual

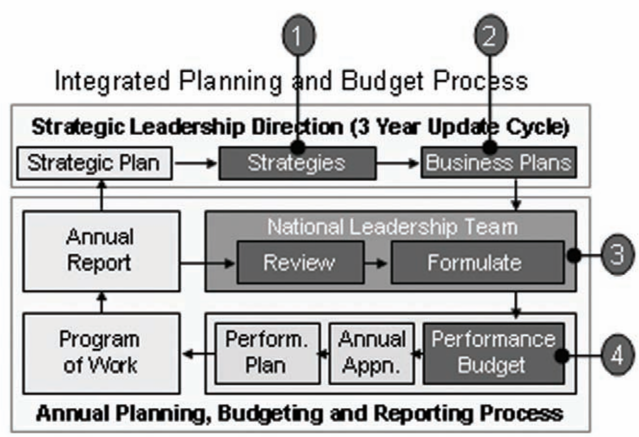

Figure 3. The Integrated Planning and Budget Process ensure Plan Goals drive the Budget.

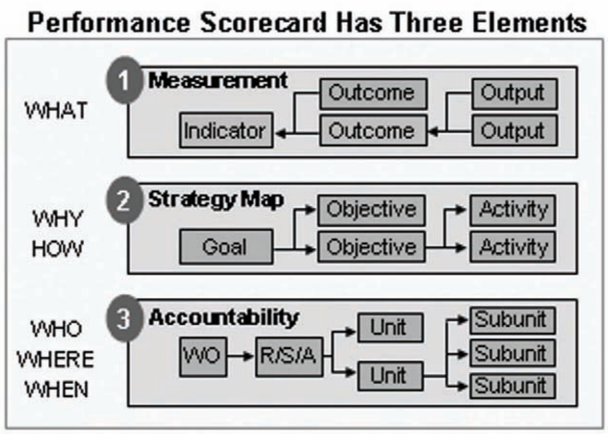

Figure 4. Performance Accountability System Scorecard provides 'line of sight' accountability.

performance plan allocates targets and funds. It will enable agency managers have a 'line of sight' understanding of how each project contributes to achieving strategic plan goals and contributes to sustainability (fig. 4). They also will be able to track accomplishment of work and expenditures during the course of the program execution year. To provide this capability, the PAS will draw information from the agency's databases of reference to provide each manager a frequently-updated 'dashboard' so the status of programs within their purview may be monitored. In addition, as the end of the execution year approaches, data from these databases will be electronically assembled to inform the agency Performance and Accountability Report and to assess the performance of the agency's Senior Executive Service cadre and GS 14-15 managers and supervisors.

In the longer term, the agency RPA Assessment and the included trend indicator changes will be designed to provide information regarding whether annual investments and their resulting activities on forest and grassland habitats are moving these lands toward or away from sustainability, as it is currently defined.

Conclusions

Strengthening the linkages between the Forest Service Strategic Plan and the Montreal Process C&I improves the agency's capacity to achieve its mission of sustainable resource management in several ways. First, the Montreal Process framework provides stakeholders with accepted sustainability indicators analogous to national economic indicators. These indicators, while recognized to be imperfect and in some cases infeasible to measure, offer a common vocabulary for effective collaboration among stakeholders. Second, the framework focuses scarce resources on work directly related to accomplishment of the Forest Service mission of sustainable resource management. Third, the framework offers trend indicators. In conjunction with annual performance reports, trend indicators enable the Forest Service to measure performance, which can then be evaluated during the periodic RPA Assessments and other national sustainability reports. Finally, these measured outcomes allow the Forest Service to demonstrate effectiveness in delivering its mission and to improve its capacity to achieve sustainable resource management in the future.

The United States is not alone in facing the challenge of sustainable resource management. Problems such as population growth, subdivision of open spaces, and wild land fires confront most of the 150 nations that are employing C&I to assess forest conditions. Employing C&I to simply assess conditions, however, is not enough to effectively influence policies and decisions to achieve sustainable resource management. Countries must further integrate C&I into their national forest programs. Like the United States, these countries are likely to benefit from the adaptation of C&I to strategic plans to meet the challenges of sustainable resource management.

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Implementation of the Montreal Process: An Oregon Case Study

J. E. Brown, Governor's Resources Advisor, Governor's Office, Salem, OR

Abstract—*The state of Oregon has about 28 million acres of forestland. The west side of the state is dominated by Douglas-fir forests, and most of the east side forests are occupied by Ponderosa pines or mixed conifers. The Oregon Board of Forestry is charged with making policy for Oregon's forests. It has relied on quantitative assessments of forest conditions for many years, but the Board's recent focus has shifted toward the concepts of sustainability and examining a wide range of outputs. The Board has adopted the Montreal Process criteria and indicators as a framework to use to measure and communicate about sustainability. Many indicators have been adopted for use in monitoring forest conditions and evaluating policy changes. Organizing around the seven criteria of sustainability provides a consistent framework that allows us create a continuous improvement process. Planning, implementing, monitoring, and evaluating with the same framework has the advantage of aligning programs to work together and will allow us to learn and adjust our strategies more rapidly. We have found the Montreal Process to be a useful framework for developing forest policies and the necessary actions that contribute to social, environmental, and economic sustainability at any scale.*

Introduction

The state of Oregon is located in the northwest corner of the United States. It is about 62 million acres in size, 28 million acres of which is forestland. The Cascade mountain range runs north to south bisecting the state into two major climatic zones. The west side of the state has a relatively moist Mediterranean climate while the east side is drier with forests only at the higher elevations. On the east side about 75 percent of all forestlands are capable of producing 20 to 84 cubic feet per acre per year. In western Oregon more than 85 percent of the forestlands are capable of producing 85 to 225 cubic feet per acre per year. About 64 percent of the forests in western Oregon are dominated by Douglas-fir. East of the Cascades, lower elevation forests are mostly ponderosa pine, while the forests at the higher elevations are a mix of conifer species. Oregon's forestland ownership is about 60 percent public, and 40 percent private.

Oregon's Forest Policy Makers

The Oregon Board of Forestry is a quasi-legislative body appointed by the Governor to make policy for Oregon's forests. The Oregon Board of Forestry has relied on assessments of forest conditions and outputs to make policy since 1911. Early assessments and policy documents were mostly concerned with economic outputs, especially timber production. However, starting with the conflicts over endangered species in the 1990s, the Board's focus has shifted toward examining a wider range of outputs provided by the forest.

Recent polling shows that most people in Oregon want a balance of environmental, social, and economic goods and services produced from the forest, and natural resource decision-makers, like the Board of Forestry, are left with the task of reconciling the conflicts and explaining their decisions to the public. The Board needed to articulate a common theme that makes sense to the public and explains decisions on forest resources, and explains the trade-offs among values and resources that must be considered in decision-making.

Sustainability

Sustainability is emerging worldwide as a unifying concept in forest management. Sustainability is meeting the needs of the present without compromising the ability of future generations to meet their needs. People understand the basic concept of sustainability: when we use wood and paper, we should not damage the forest's ability to grow trees in the future; we should not destroy the other, non-commodity values of the forest; and we should not consume wood and paper faster than trees can grow back. Due to the public's understanding and acceptance, there is power in the ideas and language of sustainability. The concept is broad and inclusive, and using the ideas of sustainability can significantly reduce the dynamics of confrontation.

The challenge became what framework to use to measure and communicate about sustainability. The Oregon Department of Forestry (ODF) has adopted the criteria and indicators developed through the Montreal Process. The criteria provides a framework that describes the goals of sustainability. The pieces we want to sustain are biological diversity, the productive capacity of the forest, the health of the ecosystem, soil and water resources, global carbon cycles, and socioeconomic benefits. And, we need a legal, economic, and institutional framework capable of providing those values. Several different indicators are used to describe and measure each criterion.

The Oregon Department of Forestry's forest assessment process generally includes data collection, analysis, evaluation, and policy development. In 2000 ODF completed a "First Approximation Report" (www.odf.state.or.us/DIVISIONS/resource_policy/resource_planning/far/far/default.asp) using the criteria and indicators of the Montreal Process. This was the first step in the Assessment Process, completed with the goal of gathering the data currently available to measure the criteria and indicators, and identifying what additional data is needed to understand conditions in Oregon's forests. ODF has selected a subset of indicators from among the 67 of the Montreal Process to use as the primary tool to monitor and evaluate conditions and trends of Oregon's forests.

In 2001 the Oregon Board of Forestry co-sponsored a symposium with Oregon State University to learn about the state of knowledge pertaining to each of the seven criteria of sustainability. The symposium provided information developed during the analysis and evaluation phases of the assessment process. Information from the symposium and the First Approximation Report was used to inform decision makers about current conditions and potential barriers to sustaining forest outputs. After the symposium, the Board convened a workgroup of legislators, landowners, NGOs and other interested parties to begin discussing policy options about how to manage Oregon's forests. The Board used a series of follow-up public work sessions to complete the policy phase. The following sections illustrate the practicality, application, and utility of the Montreal Process.

Using the Indicators of Sustainability

The Oregon Department of Forestry has adopted a "core" set of indicators from the Montreal Process to use as a tool to monitor and evaluate the conditions and trends on forestland in Oregon. The primary objective of the project is to collect data on a set of indicators that is large enough to provide the most important information described by the criteria from the Montreal Process, yet small enough to allow efficient assessment and tradeoff analysis to be completed in a timely fashion for policy analysis. We want to collect a mix of spatial and non-spatial data that can be used to display the condition of Oregon's forests at multiple scales (in other words, the ecoregion, county, or watershed scale) depending on the policy question. Examples of the data are included in the following sections.

Conservation of Biological Diversity

We are using a coarse filter approach to describe biological diversity. The available information includes a mixture of spatial data generated from satellite imagery and ground based sample data. The spatial data can provide locationally specific information to enhance watershed analysis capabilities, while the plot data provides an accurate way to monitor change over time.

Indicators used to describe biodiversity include:

- Forest types,
- Successional stages (forest size classes),
- Area by forest type in reserved area categories, and
- The status of rare, threatened, endangered species.

Other things being equal, maintaining a broad range of seral stages can enhance forest biodiversity. As shown in figure 1, even in the heavily harvested Douglas-fir forests of western Oregon, a broad range of size classes, and therefore seral stages, still exist. Over the past few decades Oregon has moved toward greater protection of water, wildlife, and other environmental resources in the management of its forests. The "reserve" strategy is employed on forestland when it is closed to commercial timber harvest by law, regulation, or forest plan requirement. The primary purpose of the reserve strategy is to set the land aside for other values than the economic value of wood production, namely, watershed protection, wildlife habitat, and scenic and aesthetic values. Trees are sometimes harvested in reserved forests, but only when this harvest is incidental to other activities and deemed to benefit the non-wood production values. About 31 percent of Oregon's forestland is managed under a reserve strategy. In addition to the reserves, a "multi-resource" strategy is employed on about 33 percent of Oregon's forestland. These management allocations are intended to yield a variety of resources including timber. However, it includes lands on which timber harvest is balanced with non-wood production values by means of state regulations, forest plan, agency policy, or owner objective. Multi-resource lands represent a wide range of

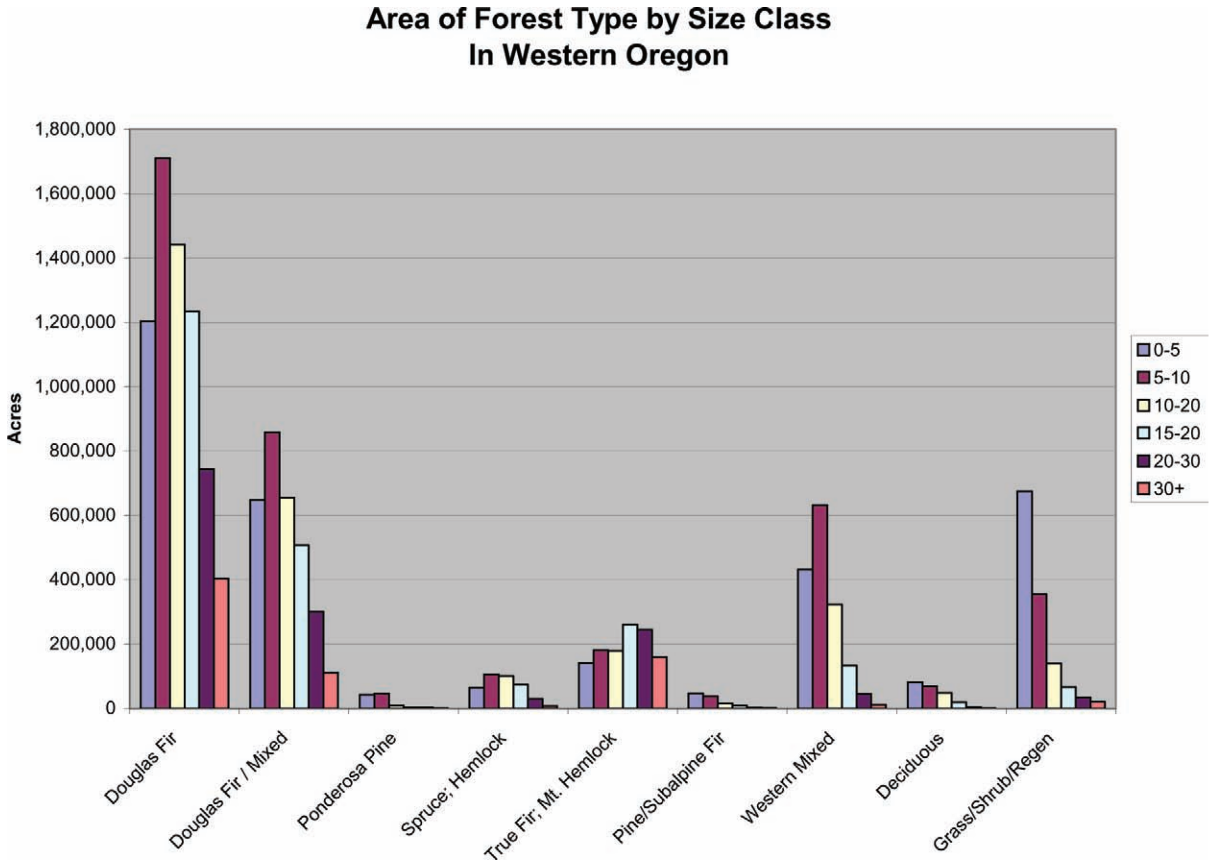

Figure 1. Area of Forest Type of Size Class.

management techniques and intensities, aimed at producing moderate to high levels of many social, economic, and environmental benefits. Modeling studies have shown that keeping these policy options in place will dramatically increase the amount of older forests over time.

Maintenance of Productive Capacity of Forest Ecosystems

Several sources of data are used to create estimates of whether the economic productive capacity is being maintained.

Indicators used to describe productive capacity include:

- Forest land available for timber production,
- Growing stock of merchantable and nonmerchantable species, and
- Annual timber harvest.

As the public land in reserves and multi-resource allocations has grown over time, the amount of timber that can be harvested sustainably from these forests has diminished. As shown in figure 2, the decline in both the sustainable harvest level and the actual timber harvest on public lands. Under the current land allocation rules, the sustainable harvest has dropped to about 16 percent of the forest's biological potential and actual timber harvest from public forestlands has declined to about 8 percent of the biological potential.

A stable forestland base is needed to sustain all forest values. Between 1953 and the mid-1980s Oregon lost about 20 percent of its private timberland to development. The rapid development on rural lands caused policy makers to create Oregon's Land Use Planning laws and to restrict rural development on forestland. Tracking the change in forestland available for timber production has allowed evaluation of the effectiveness of changes in the

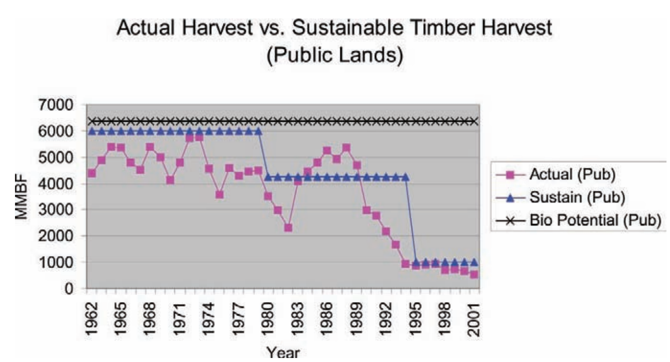

Figure 2. Timber Harvest on Public Forestland in Oregon.

policies designed to limit development. Each successive change has had a positive affect on maintaining forestland for commercial purposes, and the rate of forestland conversion has decreased. Unlike timber harvests on public lands, timber harvests from private lands have remained relatively stable, and harvest levels are close to both the sustainable level and the biological potential.

Maintenance and Enhancement of Long-Term Multiple Socio-Economic Benefits to Meet the Needs of Societies

Resources that have little or diminishing value to people will inevitably be converted to other uses. Therefore, in order to develop an overall measure of sustainable forest management, it is critical to understand the diversity of values that people find in forests, and also to understand how those values and priorities change over time. The indicators for socioeconomic benefits are designed to examine the total output of some of the most important items including wood products production, recreation, employment, and community well-being.

Indicators used to describe socio-economic benefits include:

- Value of wood products production, including value added through downstream processing,
- Area and percent of forestland managed for recreation and tourism,
- Employment in the forest sector, and
- Viability of forest dependent communities.

Oregon's economy has historically been built on natural resource industries, especially timber. The forest sector is very important to the state; it accounts for $12.8 billion in total industrial output, which is 6.9 percent of the state total. The forest sector is even more important in most rural areas. In three counties the forest industry accounts for more than 80 percent of the traded sector, and in 15 counties it is greater than 50 percent (2001 data).

Oregon's forest sector employment declined rapidly during the recession of the 1980s and because of the reductions in federal timber supply in the early 1990s. Total forest sector employment dropped by about 19 percent between 1980 and 1995, but has been relatively stable since then.

Average earnings per job are another indicator of the importance of the forest sector to local communities. While wages in the state have increased over time, many of the timber dependent counties in Oregon have not recovered from economic down-turns in the 1980s and early 1990s.

Many of the timber dependent counties also have very high unemployment rates and other indications of economic and social distress.

Maintenance of Forest Ecosystem Health

The major forest health problem in Oregon is related to changes in the historic fire cycles. Since the early part of the 20th century, human use and management of forests have altered the historical relationship between fire and forest. Past timber harvesting practices and a century of aggressive suppression of fires have fundamentally changed the makeup and structure of some of Oregon's forests, particularly in parts of the drier forest types in southern Oregon and east of the Cascades. A buildup of fuels in the form of needles, branches, logs, and living trees is at the heart of the problem.

Indicators used to describe forest ecosystem health include:

- Area and Percent of Forest Affected by Processes or Agents Beyond the Range of Historic Variation.

Information on fire condition classes is currently available from the US Forest Service. The data is in a spatial format and can be combined with forest type and size class data sets to provide an estimate of the spatial extent of the forest health problems and the forest types that are most affected. Many of the land allocations designed to produce older forest conditions are at risk of uncharacteristically severe wildfire. More than 60 percent of the wilderness areas and late-successional reserves in Oregon are in areas with moderate or severely altered fire regimes. In 2002 more that 8 percent of the total area in reserves burned in large wildfires.

Policy Development

The Oregon Board of Forestry has adopted forest sustainability as their primary goal. Their mission is to "lead Oregon in implementing policies and programs that promote environmentally, economically, and socially sustainable management of Oregon's 28 million acres of public and private forests." Their vision for Oregon's forests includes:

1. Healthy forests providing a sustainable flow of environmental, economic, and social, outputs and benefits.
2. Public and private landowners willingly making investments to create healthy forests.
3. Coordinated statewide forest resource policies among Oregon's natural resource agencies.

4. A Board of Forestry recognized as an impartial deliberative body operating openly and in the public interest.
5. Citizens that understand, accept, and support sustainable forestry; and make informed decisions that contribute to achievement of the vision of 2003 Forestry Program for Oregon (http://www.oregonforestry.org/fpfo/2003/).
6. Adequate funding for the Department of Forestry to efficiently and cost-effectively accomplish the mission and strategies of the Board of Forestry and department personnel policies that encourage and recognize employees, allowing them to meet their full potential in providing excellent public service.

To accomplish this mission and vision the Board has adopted seven strategies developed from the criteria of the Montreal Process. Under each of these strategies they have articulated priorities and actions that if accomplished they feel will lead to the achievement of the strategy and ultimately to sustaining forest outputs and values.

In consultation with the Board and other policy makers, Oregon's forest cluster has developed a Natural Resources Strategy for Oregon's Prosperity. It is a 9-point Plan that builds on the concepts of sustainability and Oregon's strengths. The nine points are:

1. Build economic strategies on Oregon's environmental performance, for example,
   - The Oregon Plan for Salmon and Watersheds – improved with federal agency "buy-in"
   - Oregon Watershed Enhancement Board and Ballot Measure 66 funds
   - Oregon Sustainability Act of 2001
   - Oregon Conservation Incentives Act of 2001
   - Forestry Program for Oregon – Sustainability
   - National Fire Plan & 10-year Comprehensive Strategy
   - Statewide conservation strategies – to be developed
2. Renew investments in education, research, tech transfer for innovators, new knowledge-based resource businesses, continual improvement in existing businesses
3. Differentiate products for market advantage "Brand Oregon"
4. Pioneer Innovation – high-tech, information systems, biosciences, marketing applied through natural resource clusters
5. Increase public investments for private contributions of public resource services, for example, salmon habitats, natural heritage protection
6. Expand natural resources trade, exports to create wealth
7. Solve problems through proactive, state, local-led, collaboration for natural resources sustainability (En Libra)
8. Strengthen partnerships with, roles for federal land managers – active adaptive management of federal lands for conservation and sustainable economic prosperity
9. Exert bold leadership in Western Governor's Association

Ultimately, the Oregon Department of Forestry hopes that using and implementing the concepts of sustainability will allow us to maintain the "social license" needed to practice forest management. We believe there is power in communicating though the language of sustainability. The framework from the Montreal Process is very broad and inclusive and has allowed ODF to have a more structured public dialogue about the issues and goals that are important to Oregonians. We have also found the indicators of sustainability to be a useful tool to tell the "stories" of sustainability in a language that the public understands and to answer questions about how Oregon's forests are doing at producing the range of values important to the public.

Organizing around the seven criteria of sustainability provides a consistent framework that allows us to create a continuous improvement process. Planning, implementing, monitoring, and evaluating with the same framework has the advantage of aligning programs to work together and will allow us to learn and adjust our strategies more rapidly. We have found the Montreal Process to be a useful framework for developing forest policies and the necessary actions that contribute to social, environmental, and economic sustainability at any scale.

Canada's Experience in Applying C&I to Measure Progress Towards SFM—Perspectives from the National, Regional and Local Levels.

John E. Hall, D. Phil (Oxon.) RPF, Science Advisor, Criteria and Indicators, Canadian Forest Service, Natural Resources Canada
S. R. J. Bridge, Criteria & Indicators Policy Advisor, Canadian Forest Service, Natural Resources Canada
Brian D. Haddon, B. Sc. F. Manager, Statistical Services, Canadian Forest Service, Natural Resources Canada

Introduction

This paper will provide perspectives of Canada's experiences in applying Criteria and Indicators (C&I) to measure progress towards Sustainable Forest Management (SFM) at the National, Regional (Provincial) and local levels. SFM is rooted in Bruntland's concept of Sustainable Development and is about providing for present forest-based needs without compromising future options.

Canada: A Forest Nation

Canada's forests are essential to the long-term well being of Canada's communities, economy, and environment. Almost half of Canada's land base is forested - representing 10 percent of the global forest. Recently released information from Canada's Forest Inventory 2001 indicates that there are 401.5 million hectares of forest and other wooded lands in Canada. About 143 million hectares of forestland are considered to be accessible and most likely to be subject to forest management activities. Harvesting takes place on about 1 million hectares each year. Most of the forest (93 percent) is publicly owned, the rest is on the private property of over 425,000 landowners. Over 300 communities are directly dependent on the economic use of the forest resource, and their work supports Canada's 20 percent share in global forest trade of forest products. In recent years Canada's annual positive balance of trade in forest products has been over $30 billion. In 1999 wages for the forest sector amounted to $12 billion. All this activity in turn brings domestic and international attention to our forest management choices and the implications of those choices on the condition of local and global environmental conditions and the social and economic circumstance over time.

Canada recognizes the multitude of forest benefits it enjoys as well as its role as steward of 10 percent of the worlds forests. Canada accepts its responsibility to maintain its forests in a vital state and to manage them in a sustainable manner. But, pressures on the forest are increasing; demands for increased access to the forest for timber extraction to meet the needs of international markets are often seen to be in conflict with the values of other forest users.

Canada's Commitment to SFM

Canada and the international community recognized the importance of SFM and the need for indicators in 1992 at the United Nations Conference on Environment and Development (UNCED) with the adoption of a Statement of Forest Principles. The concept was embodied in Chapter 11 of the conference's action plan, Agenda 21 and countries around the world began to demonstrate their commitment on the ground.

Canadians are demanding more information, more options, more involvement in decision-making, and more equitable sharing of benefits, and the marketplace seeks assurances that forest management in Canada is sustainable. To meet these challenges, managers and decision makers need tools to demonstrate progress toward sustainable forest management (SFM).

Criteria and Indicators (C&I) is one such tool. C&I provide a science-based framework to define and measure Canada's progress in the sustainable management of its forests. Criteria represent forest values that society wants to enhance or sustain, while the indicators identify scientific factors to assess the state of the forests and measure progress over time. The C&I enable a common understanding of what is meant by SFM. Collectively, they provide a framework for reporting on the state of forests, forest management, and achievements in SFM, by identifying those elements of the forest ecosystems, and related social and economic systems that should be sustained or enhanced.

Canada's Political Structure with Respect to Forest Management

To better understand Canada's experience with C&I at the national to local levels it is helpful (if not essential) to be aware of Canada's political structure and the various roles and responsibilities of each level of government with respect to forests. Canada is a federation of 10 Provinces and 3 Territories in which the Provinces and Territories have jurisdiction over forest on provincial and territorial crown land. Each Province and Territory has its own set of statutes, policies and regulations to govern the management of its forests. A broad spectrum of users – the public, forest industries, Aboriginal groups and environmental organizations – are often consulted to ensure that recreational, cultural, wildlife and economic values are incorporated into forest management planning and decision making. The federal government's role in forestry pertains to such areas as research, trade and commerce, international affairs, the environment, pesticide regulation, training and Aboriginal Affairs and the management of federally owned lands.

The Canadian Council of Forest Ministers (CCFM)

There has been a long tradition of cooperation between the federal and provincial governments in forestry matters. The creation of the Canadian Council of Forest Ministers (CCFM) in 1985 has provided an important forum for the federal, provincial and territorial governments responsible for forests to work cooperatively to address major areas of common interest. The CCFM provides leadership on national and international issues such as C&I for SFM and sets direction for the stewardship and sustainable management of Canada's forests.

Canada's National Forest Strategy (NFS)

The CCFM initiated Canada's National Forest Strategy (NFS) to establish the vision and goals for Canada's forests. In recognizing the complexity of SFM, each NFS is a product of an iterative process that involves many Canadians representing a broad diversity of backgrounds, interests, and expertise and forest values to describe Canada's commitment to SFM. These values and commitment to SFM are enshrined in the 1992, 1997 and 2003 National Forest Strategies. One of the commitments of the NFS is to develop and use C&I framework for SFM. Canada's approach to the development of C&I is based on collaboration internationally through its involvement with the Montréal Process and nationally through the CCFM.

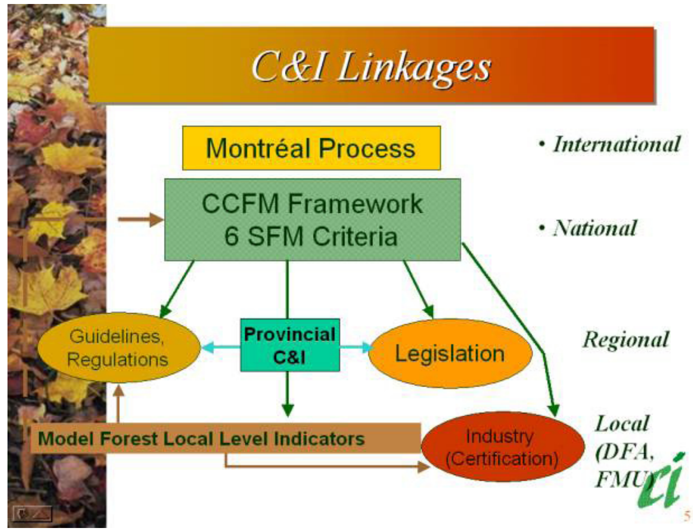

Figure 1. Canada's Criteria and Indicators Linkages.

Linkages: International to Local

Canada recognized at an early stage that the successful development and implementation of C&I would depend on the establishment and maintenance of strong linkages among those responsible for international, national, provincial and local perspectives. In figure 1, the linkages among the various levels of organizations involved in Canada's C&I for SFM are mapped. The international, national, regional (or Provincial) and local levels are linked and this paper will outline examples of how the national C&I are woven into the network of Canada's SFM activities.

National Use of C&I

For the purposes of this paper, the linkages at the national level (fig. 1) can best be organized under two general themes; either Canada's C&I linkages to National and International Reporting or Canada's C&I linkages to Policy fora.

Reporting National Progress toward SFM

CCFM & National C&I Reporting

The release of the Canadian Council of Forest Ministers (CCFM) Framework of C&I for SFM in 1995, and subsequent reports in 1997 and 2000, were important steps in implementing Canada's commitments in the national forest strategies, as well as the forestry commitments made at UNCED. In 2003, after broad public consultation, the CCFM released its revised C&I framework of 6 criteria and 46 indicators. The CCFM have agreed to produce their next C&I report in 2005. The sharing of information and resources between jurisdictions and stakeholders also helps to build capacity and reduce reporting costs. The CCFM C&I also provide a framework for standardizing national forest data collection and the framework has been used to guide national research planning.

The CFS is now engaged with its CCFM partners to prepare and produce the next C&I report for release in September 2005. This report will provide information on Canada's forests to domestic and international audiences to help demonstrate Canada's progress in SFM. The report will also contribute to Canada's commitments in the 2003 National Forest Strategy to establish better capacity for credible and authoritative reporting on C&I. Report preparation and production will engage staff from across the CFS, other federal departments and agencies, and provincial and territorial forest management agencies. The 2005 report will provide the public and decision makers with more information, increasing the range of options available for using the forest resource and hopefully leading to more involvement in decision-making by the public and a more equitable sharing of benefits.

Montréal Process and National C&I Reporting

With UNCED, the potential impact of global perspectives on local decision making for SFM was clearly understood by Canada. Canada joined the Working Group on C&I for the Conservation and Sustainable Management of the Temperate and Boreal Forests (est. June 1994). This working group, known widely as the Montréal Process (MP), is made up of 11 other countries that together represent 90 percent of the world's boreal and temperate forests. These countries agreed to work together to develop a common suite of measures (C&I) to use in reporting national progress to SFM. Canada is committed to the MP and collects a considerable amount of data and information to support the indicators through the CCFM. The C&I of the MP and the CCFM show considerable alignment in the values each has identified as important to measure progress toward SFM. This compatibility consequently allows Canada to report its national progress towards SFM using the CCFM C&I framework. Canada's C&I framework was released in 1995 and national reports were produced in 1997 and 2000.

In September 2003, the MP member countries reaffirmed their commitment to implement the MP C&I and agreed to review and revise the MP C&I. Membership in the MP is part of Canada's overall commitment to promote SFM. The Montréal Process provides an international forum for collaboration, including catalyzing similar national efforts and promoting a shared view about what constitutes SFM and how to measure it. The exchange of information and experience has enabled the member countries to identify common goals for action, consolidate technical know-how related to indicator measurement and data collection, foster bilateral and regional cooperation among members and enhance national capacity to report on SFM.

National Coordination of Data Collection and Management

The CCFM recently adopted an operating framework for better management of its activities. The core business of CCFM is to stimulate the development of policies and initiatives for the promotion of sustainable forest management in Canada. The activities of the CCFM are organized around five Strategic Directions: International Issues, Sustainable Forestry, Information and Knowledge, Science and Technology, and Forest Communities. The National Forest Information System (NFIS) and the National Forestry Database Program (NFDP) have aided the CCFM in its goal to accomplish a national and international forest information strategy. Specifically, the NFDP has established a comprehensive national forestry database to develop a public information program and to provide forestry information to the federal, provincial and territorial policy processes, while NFIS has built on existing databases and extensions to those databases to meet Canada's provincial, national and international reporting requirements on forest sustainability. Responsibility for reporting on the CCFM C&I now clearly rests with the NFDP. The new operating framework permits and promotes enhanced coordination of the various national information and knowledge initiatives. The challenge now is to ensure that these initiatives continue to work closely together to acquire the necessary forest information and establish the systems to better collect, manage, and provide Canadians with more ready and access to the data relevant to national C&I.

Consolidating Reporting to National and International Efforts Using C&I

Canada was the first MP member country to attempt to fully report using its national C&I, and was the first to complete a review of its national C&I framework. Exploring options to consolidate reporting on various initiatives and to various fora is a national action item outlined in the 2003 NFS. Canada already uses information gathered for the CCFM C&I to report on the MP C&I. Now options are being explored to consolidate reporting on other initiatives and fora. This includes looking at whether the national C&I can be used to report on the United Nations Forum on Forests (UNFF) Proposals for action (Pfa), the United Nations Convention on Biological Diversity (CBD) program of work, the Global Forest Resource Assessment (FRA) and the NFS commitments for action.

National Links to Other Federal Government Indicator Reporting Initiatives

As part of its efforts to consolidate reporting and be the authoritative source of national information on the forest sector, the CFS also participates and contributes to indicator initiatives led by other federal departments that are seeking to develop and report on indicators of sustainable development. Currently, CFS is engaged in the development of social and economic indicators of sustainable resource-based community development. The CFS is also engaged in initiatives lead by other federal departments seeking to develop and report on forestry indicators. Environment Canada has initiated a process to develop the Canadian Biodiversity Index (CBI) to assess the status of biodiversity in all of Canada's ecosystems. The proposed use of this index is to report on Canada's progress towards targets agreed to by the Convention on Biodiversity (CBD). The CFS has been involved in developing the draft framework to ensure links with existing forest biodiversity indicators. In addition, the National Roundtable on the Environment and the Economy's (NRTEE) Environmental Sustainable Development Indicators Initiative recently developed a set of indicators to report on Canada's natural capital that includes an indicator on forests. The CFS wants to ensure that the best available data on forests are used and reduce duplication of data collection.

Using C&I to Guide National Level Research

The C&I are being used to help guide national level research in Canada related to SFM. Recently, the CFS has begun research on public satisfaction in forest management practices and defining forest-dependent communities in direct response to knowledge gaps identified through the C&I process. Also, Canada's Sustainable Forest Management Network (SFMN), a part of Canada's Network of Centers of Excellence (NCE) established in 1995, supports university-based research and innovation that is relevant and necessary to sustain Canada's forests and forestry-dependent communities. The SFMN refers to the CCFM C&I framework as one tool in identifying SFM research needs.

C&I Reports Contribute to National Policy and Decision-making

International Trade

International competition in forest products is strong, forestland use pressures are increasing, and there are uncertain impacts on Canada's forests due to climate change. Within this context, C&I reports provide an effective tool for government to provide the international audience with a clearer insight into the positive impact the many changes made in Canada's forest sector have had on SFM and thereby contribute to strengthening Canada's SFM image in the market place.

Federal Social Agenda

While pressure on the forest resource is increasing, Canadians also want a vibrant 21st century economy and they see forestry as an important part of that economy. The government has committed to enhancing rural development by finding opportunities to add greater value to natural resources. The government also wants to reduce the economic gap between Aboriginal and non-Aboriginal communities. This means better economic opportunities for Aboriginals in communities, a higher quality of life, more economic self-reliance and better education and work-force skills. Since about 80 percent of Aboriginal communities are located in forests, the forest sector should be an integral part of achieving these goals. Canada's national C&I framework features a number of indicators directly related to these goals which may offer a tool to assist in determining progress toward these goals to better guide policy decisions.

Sub-National Use of C&I

Provincial and Territorial Use of C&I

In Canada, forest management responsibilities rest, for the large part, with the Provincial and Territorial governments. These jurisdictions clearly express their collective support to the national CCFM C&I process and to the National Forest Strategy. Guided by these national frameworks, each Province and Territory continues to create ways to improve their on-going support to their national level C&I commitments. Each jurisdiction is also responsible to determine how best to integrate and link C&I into their own management responsibilities to meet their particular circumstances and needs. In the following summary of the benefits being accrued by each provincial and territorial government to its forest management and accountability, responsibilities are evident as the linkages to C&I increase. These benefits include better evaluation of policies and regulations, increased capacity and reduced reporting costs, more meaningful public input into planning and improved forest practices towards SFM. Each province and territory is involved in the national C&I through the CCFM and with local level issues through their forest management planning processes and, where applicable, with their model forest(s). The provinces and territories dedicate expertise and resources to support national task forces for the development, reporting and data collection and management for C&I.

From the results of an ad hoc, informal survey conducted by the authors of provincial C&I contacts, most provinces and territories have, in their own way, begun to incorporate C&I into the sustainable management of their forests. Four provinces now have legislation or provincial strategies that require the use of indicators in assessing progress toward SFM. In some cases the legislation or strategies are explicitly linked to the CCFM C&I framework, using the criteria to help define SFM provincially or to help identify important strategic directions and values to which indicators should relate. In at least one case, a province has developed a resource evaluation policy to support its legislation, which outlines a provincial framework of C&I based on the CCFM C&I.

Reporting on progress is often done at both the provincial level and the Forest Management Unit (FMU) level. At the provincial level, at least five provinces have produced, or are committed to producing, a State of the Forest report. These reports can take various forms, ranging from complete C&I reports using a provincial C&I framework to more general indicator reports addressing issues of concern to the province or assessing the sustainability performance of all tenure holders. In addition, at least one province is producing an overall sustainability report that will include indicators on forestry in addition to indicators addressing other natural resources. Whatever the format the reports have taken, in many cases, the indicators used in the provincial level reports are developed using the CCFM C&I as a starting point. In addition, attempts have been made to more strongly link the provincial indicators to either management actions that the province, as owner of the forest, can undertake or to stated desired forest conditions.

At the Forest Management Unit (FMU) level, at least five provinces and territories have developed or are developing Forest Management Planning Manuals (FMPM) that will use indicators to assess progress toward goals and objectives. In most cases, the CCFM criteria are included in the FMPM and in many cases the FMPM requires indicators that explicitly address the six CCFM criteria. In other cases, the CCFM C&I are used as a starting point for developing indicators at the FMU level.

In addition to this, some FMUs have taken actions to better incorporate indicators into their planning processes above and beyond the provincial requirements. Some tenure holders have incorporated C&I based on the CCFM C&I into their planning process even though the provincial regulations do not require it. Others are pursuing certification of their forest products using the CSA certification, which uses the CCFM criteria. There are also examples of companies including their Local Level Indicator reports, which they have developed through their involvement with a Model Forest, as part of their report on operations to the provincial government. The work of the Model Forests will be discussed in more detail in the following section.

Local Level Indicators and Industry Certification

Achieving national goals of sustainability largely rests on actions carried out at the local or forest management unit (FMU) level. As the forestry paradigm changed from sustained yield to sustainable use, the desire to engage local stakeholders in forest management planning grew.

At the local level, the CFS is the founder and the primary supporter of Canada's Model Forest Program. The Model Forest Program is currently approaching the mid-point of its third five-year phase. The Model Forest Secretariat, led by the Canadian Forest Service, ensures that the model forests work as an effective network, sharing information, experience and best practices. The Secretariat has coordinators in Ottawa and regional representatives who are responsible for liaison with the various sites. Through the Secretariat, model forests benefit from joint strategic planning that supports local and regional leadership.

Local Level Indicators (LLI) were established as a strategic project of the Model Forest Network in Phase II (1998 to 2002) of the Model Forest Program to engage local stakeholders to identify their values and develop, test and validate indicators to show progress toward SFM. The Canadian Model Forest Network (CMFN) has since developed a number of users' guides, workshops and databases to increase the use of LLI. LLI have also influenced some forest certification schemes, which are market-driven initiatives to demonstrate that a local forestry operation is sustainable. Most LLI and the Canadian Standards Association certification system are based on the national CCFM C&I. Included in the objectives of the current phase of the Program (2002-2007) is to increase the development and adoption of SFM tools within and beyond model forest boundaries, disseminate knowledge gained, strengthen network activities, and increase local-level participation in SFM. (In addition the CMFN supports the efforts of the International Model Forest Network in developing indicators for international Model Forests).

Results of a recent ad hoc, informal survey conducted by the authors are reported below providing examples of the benefits that are being realized through the development of LLI by Canada's Model Forests. These examples highlight the value LLI has brought to the local level challenge of measuring progress towards SFM.

It was decided among the partners of the Manitoba Model Forest (MBMF) that the responsibility for continued monitoring and reporting of LLI would lie with partners having management authority or those having "more permanency". The major industrial forest partner with MBMF is Tembec Incorporated. This company has embraced the LLI process on a number of fronts. C&I are part of their annual operations plans and reports and are linked to their ISO system currently in place and are being incorporated into the development of their FSC certification expected within the coming year. A number of indicators impact directly on the company's forestry practices on their operations and are used to develop forest management plans. For example, in areas of core caribou habitat, 66 percent of the high value stands must be left intact at any given time, the density of forest access roads is restricted for each watershed and only 30 percent of any watershed can be depleted at any one time through harvesting or natural phenomena such as fire, insect and disease. A number of indicators required the development of new tools to determine such important values as natural age class variation over the licensed area, habitat suitability indexes, forest fragmentation and caribou location and habitat needs. To gain FSC certification, the company also needs to demonstrate effective consultation processes – especially with First Nations. The MBMF has set up Traditional Area Advisory Committees wherein the company meets regularly with FN and government to work together on issues within their traditional areas related but not restricted to the industrial forest operations. The MBMF is also involved in monitoring LLI but with an interesting twist aimed at increasing profile and awareness of SFM issues. Water quality on lakes and streams is monitored for the LLI by aboriginal and non- aboriginal school children as part of their curriculum.

The Western Newfoundland Model Forest (WNMF) LLI initiative formed the basis the ISO/CSA certification process and for its two industrial forestry partners. As well, one of the companies uses the LLI as a common check-off in developing district plans across the Province. The Newfoundland Provincial government, another partner with the WNMF, has integrated the LLI into its public planning team approach to its forest management plans across the province. This model forest's LLI work is also being transferred and adopted by the Innu Nation and the Provincial Department of Natural Resources in their collaboration to develop the certification process for the forest areas of Labrador.

The Fundy Model Forest in New Brunswick reports that its LLI have benefited its major industrial partner in planning and reporting on its SFM efforts and changed a number of forestry practices and inventory inputs to gain a finer scale and more robust data for its permanent sample plots.

A number of model forests with significant private landholdings within their boundaries facilitated the development and application of LLI to support the efforts of the private woodland owners in their area to develop certification schemes. In addition, at the Eastern Ontario Model Forest LLI are being used to enhance natural heritage planning and significant woodlands analysis work and have been instrumental in establishing data sharing agreements - all of which has been incorporated into several official plans and sub-regional, long-range planning initiatives.

In Alberta, the Foothills Model Forest used its 40 individual LLI that its partnership developed based on the CCFM C&I to publish a report on SFM in 2003. This work was adopted by their main forest industry partner, Weldwood of Canada Incorporated, for its Forest Certification program and for its 20 year

Forest Management Plan (that must be approved by the Province). Likewise, the provincial government is using the LLI work as a base to develop indicators of SFM for the province itself. Jasper National Park, a major land manager and partner with this model forest, is using the report as a key input into its deliberations to develop sustainable forest management plans specific to the mandate of the National Park. The FMF LLI team consisting of representatives from within its partnership has reviewed its LLI and will be presenting its recommendation to continue its LLI program to refine and to improve the indicators.

Understandably, each model forest and its partners have had unique experiences in through their involvement with the LLI process however, it is notable that there is concordance among the respondents regarding the utility of LLI in reporting on progress to SFM in the local area (although this has been deemed to demand excessive resources by some), in the evaluation of policies and regulations, in improving stakeholder capacity to provide more meaningful input and to provide guidance to forest practices for SFM.

The Model Forest Phase III (2002-2007) LLI Strategic Initiative has sought to bring together the indicators that were developed in Phase II into formats that are easily accessible by those engaged in SFM. Several individual Model Forests continue their efforts with the development, further research and adoption of local level indicators. Model Forests are also using LLI as the basis of reporting on their own SFM goals, and are providing LLI to industry, governments and First Nations for use in measuring and reporting SFM, to assist with public planning processes, and as the basis for achieving certification. These efforts engage people from individual Model Forests, CFS, Provincial and Territorial forest management agencies, forest industry, oil and gas industry, National Parks, and First Nations.

Evaluating Sustainability

Even once complete national data has been compiled, another challenge in evaluating progress toward sustainability is linking the indicators under the various criteria to make an overall assessment. During the CCFM C&I review, attempts were made to identify reference values for indicators, such as baselines, targets or thresholds, which could provide context for assessing the indicator. Because sustainability measures are still evolving, and because most of the forest management decision-making responsibility resides at the provincial and territorial level in Canada, few identifiable national targets or thresholds have been established. Most of the reference values identified are baselines of past performance.

Work is underway in Canada and around the world to develop more sophisticated tools and techniques to make an overall assessment of sustainability. One promising tool appears to be the Multi-criteria Analysis (MCA) technique adapted for use with C&I by CIFOR. So far, this technique seems to have been applied most extensively at the local level, however, the Province of Ontario has been exploring its use at the provincial level to provide an overall assessment of their progress toward sustainability based on their C&I report. One possible approach to providing an overall assessment is to invite individuals from various sectors of society to score and weight each indicator in the report. The subsequent weighted scores can then be worked up into a score for each criterion or even an overall score. Furthermore, the weighted scores from groups of individuals can be analyzed to see how different sectors of society are evaluating progress toward SFM. This analysis can form feedback into the policy making forum, allowing for the development of policies designed to raise indicator scores for some or all sectors of society.

Conclusion

Over the past decade and a half, Canada has enjoyed many benefits from its collaborative relationships in the development of its national C&I framework. The C&I, by providing a framework for standardizing the national forest data collection and for helping to develop and implement a national forest inventory, have lead to the establishment of many linkages between all levels of interest and responsibility. The sharing of information and resources between jurisdictions and stakeholders has helped to build capacity and reduce reporting cost, and the framework has led to the development of subnational and local level initiatives that help to evaluate policies and regulation, facilitate meaningful public input, and guide forest practices. A continued adaptive approach to the CCFM C&I framework and throughout the many linkages described in this paper will improve the framework as a tool to provide these benefits and ensure that C&I remain an important tool for helping Canadians achieve SFM.

Canada has seen the value of linkages among all levels of jurisdiction and seen improvements in the reporting of progress to SFM. Canada anticipates continued strong, collaborative relationships over the coming years in support of those taking on the challenge to refine and promote the use of better indicators to report progress towards SFM at all levels.

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Maryland's Strategic Forest Lands Assessment—Using Indicators and Models for Decision Support

J. L. Horan, Chief of Forest Resource Planning and Analysis, Maryland DNR Forest Service, Annapolis, MD

J. C. Wolf, GIS manager and landscape ecologist, National Park Service - Chesapeake Bay Program, Annapolis, MD

Abstract—*Sustaining healthy, ecologically functional, and economically viable forests is an increasing challenge in Maryland due to relentless urban development. Forests that once occupied more than 90 percent of Maryland's landscape today cover only 41 percent of the land. As forests become more fragmented and parcelized they begin to lose their ability to provide important ecological, social, and economic benefits. This paper excerpts the publication "Maryland's Strategic Forest Lands Assessment" which highlights the use of indicators to analyze forest sustainability and multi-variate GIS-based computer models to rank the ecological and economic importance of forestlands at the state level. It also addresses the methodology behind the models and showcases ways of enhancing them for making finer scale land management decisions.*

At the core of the assessment are four computer based thematic models that have used aggregated data sets to determine the Ecological Ranking of Forest Lands, the Economic Ranking of Forest Lands, the Vulnerability Ranking of Forest Lands, and the Riparian Restoration Potential of more than 1000 sub-watersheds. These GIS-based computer models were initially created as indicators and benchmarks at the state scale. More recently the tools have been further honed to help managers make decisions at a number of different scales.

The ecological ranking has been used to assess ecological importance at the state level, but it has also been adapted for use at the parcel scale to evaluate the ecological ranking of lands being considered for fee simple or easement purchase. Similar adaptations were made to watershed models to create a restoration model that could pick out individual stream segments that were of particular interest for forest buffer restoration. Much work still remains to be done, but the availability of finer scale data makes the use of these tools even more relevant for decision support.

Introduction

Maryland faces many challenges in sustaining healthy, ecologically functional and economically viable forests in the face of rapid urban development. Once, more than 90 percent of Maryland was forested. Today only 41 percent of Maryland's land is covered by forest. Maryland is the nation's fifth most densely populated state, with more than 5.3 million people. The rapidly growing population has more than doubled since 1950, threatening an already stressed forest.

Maryland's Strategic Forest Lands Assessment (SFLA) grows from the recognition that the state faces significant loss of the ecological, social, and economic benefits of forests without significant changes to the current pattern of land development. This pattern causes forests to be fragmented from large, contiguous blocks of forest into many smaller, isolated patches. Smaller patches are less effective in preserving ecological function and wildlife habitat. They are more difficult to manage to protect soil, air and water quality. They are also less likely to support the forestry and wood products industry, the fifth largest industry in the State. Maryland's wood products industry is already under significant stresses, but it is not clearly understood how any losses in this sector might impact the state's forests in the future.

Sustainable use of our forest resources, for the multiple benefits they provide, requires careful planning and management to meet the needs of today and tomorrow. This is particularly important in Maryland where pressures on the forest are acute. Maryland's Strategic Forest Lands Assessment provides a baseline of information about where we are now, and suggests criteria and indicators that can be used to measure change, as a first step in working toward sustainability for Maryland's forests.

Ecological Ranking of Forest Lands

To determine forest areas of high ecological value, the Maryland Department of Natural Resource's (DNR) developed a Geographic Information System (GIS)-based computer model that considers both the regional and local ecological significance of the forest. The regional evaluation looks at the ecological importance of large forest patches relative to other forest patches within the same physiographic region. Variables relevant at local scales help to identify conservation values at or in close proximity to a specific parcel.

The data that have been assembled for the ecological model were selected based on their utility in measuring ecological values important to land conservation programs. Specifically, principles of landscape ecology and conservation biology have been interpreted and represented by GIS data layers. Each data set was scored and weighted to represent the importance of that factor in assigning an overall ecological score.

The ecological model gives priority or greater weight to large forest blocks, particularly:

- forest patches with a greater proportion of "interior" conditions
- intact forest blocks (as opposed to patches containing substantial non-forest "gaps")
- patches with a diversity of habitat types
- patches that provide stream or erodible soils protection
- patches that are in close proximity to other forest blocks (as opposed to isolated patches with substantial inter-patch distance)

The ecological model also favors forested corridors that:

- are short as opposed to long
- are wide as opposed to narrow
- contain or have the potential to contain interior forest conditions are intact as opposed to fragmented
- link forest blocks ranking high as opposed to those that rank low
- link similar as opposed to dissimilar ecotypes
- have few or no road crossings
- protect and link riparian systems, and
- connect with large forest blocks

This ecological model was originally developed for use at the state scale, but has been widely used at the county and watershed scale for broad assessments and planning. More recently however the model has been enhanced to assist decision makers and resource managers in making land use decisions. Specifically, an algorhythm was written that allowed resource managers to evaluate and rank the conservation value of individual parcels that were being considered for protection or fee simple purchase through Maryland's Program Open Space. This process allowed staff to justify to the Governor, an acquisition of 58,000 acres, now called the Chesapeake Forest, located in five counties and spread over 200 separate parcels, by showing the protection of ecological function through a network of hubs and corridors connecting to other state and private conservation lands.

Today, every parcel considered for purchase through Maryland's Program Open Space, Maryland Agricultural Land Preservation Foundation, Maryland Environmental Trust or Maryland's Rural Legacy Program are evaluated using this ecological model (DNR 2001, Maryland's Green Infrastructure Methodology). Land conservation partners like The Nature Conservancy, The Conservation Fund, local governments, and local land trusts frequently ask for this analysis to be run on lands they are considering for protection in Maryland. This is an impressive and effective extrapolation of a tool that primarily uses 30-meter satellite data and was originally designed for use at the state or watershed scale.

Methods Used to Develop the Ecological Ranking of Forest Lands

The Ecological Ranking of Forest Lands used the Green Infrastructure methodology, where both hubs and corridors were evaluated and ranked within their physiographic regions. Physiographic regions have a characteristic geology and climate, which shape the ecosystems and biological communities within them. Methods were developed to ensure that ecosystems adapted to these different climates and substrates were represented in the top ranking hubs, so that the best examples in each region might be protected. Another reason for grouping hubs by region is that natural conditions and communities vary greatly between the Coastal Plain and the Appalachian mountains. For example, cypress swamp communities are not found outside the Coastal Plain, and high gradient streams are not found inside this region. A single ecological ranking of all hubs would compare "apples to oranges" and might not succeed in protecting the broad biological and geological diversity of the state.

Twenty-seven parameters were selected and given an importance weighting according to feedback from biologists and natural resource managers; literature reviews; minimization of redundancy, area dependence, and spatial overlap; balancing different ecotypes; data reliability; and examination of output from different combinations. None of the parameters were highly correlated (>80 percent). The highest correlation was between area of upland forest and interior forest streams (75 percent).

To derive a composite ecological ranking, the percentiles for the 27 ecological parameters were multiplied by an importance weighting and added together for each hub. The importance weightings were a function of the parameter's utility and data reliability. Although all hubs are ecologically significant, the ranking system can help prioritize initial conservation efforts. For additional detail on the hub ecological ranking parameters and methods, see the Summary of Methods to Identify and Evaluate Maryland's Green Infrastructure (DNR 2001).

Economic Ranking of Forest Lands

If managed properly, forests can continue to provide ecological services, water quality protection, and habitat, as well as a variety of forest products. The Economic Model for the Strategic Forest Lands Assessment uses GIS to help identify economically important forestlands, particularly those with the greatest potential to yield economic benefits associated with timber management activities. The model includes factors that relate not only to the short term potential economic return on a forest harvest operation, but also the long-term economic sustainability of forest land, considering local and regional influences. At a local or site level, the economic model considers biophysical factors that influence what tree species can be grown in a given area. Also included are data layers that aim to approximate constraints on management of the forest resource.

Site-specific factors incorporated into the model include:

- tree species composition
- soil productivity
- slope
- microclimate
- riparian and wetland features
- presence of sensitive species habitats

At regional or landscape scales, the economic model incorporates factors that affect the ability of the forest to support resource-based economies, including the importance of the timber management and wood products industry to local economies. Also included are data layers that attempt to capture the effects of State and local policy on forestland protection.

Regional or landscape scale socioeconomic and policy factors include:

- population density
- parcelization
- proximity of the forest resource to mills
- role of the forest products industry in the local economy
- existing or planned water and sewer service or other designations for urban growth existing working landscape protection initiatives (for example, Rural Legacy and Forest Legacy Areas)
- existing public and private forest land protection

Methods Used to Develop the Economic Ranking of Forest Lands

Like the ecological assessment the economic assessment uses a Geographic Information Systems (GIS) analysis to overlay multiple layers of spatially referenced data. These data layers, which reflect potential economic benefits or considerations, are used to identify the relative economic value of Maryland's forestlands. All GIS data were converted to grids with a uniform cell size of 30 meters x 30 meters. Elements in each data layer were scored according to potential economic impacts and relationships. Elements known to encourage timber management practices, or create higher potential economic value, were scored higher than elements which may impose management constraints or have lower potential economic value.

One of the parameters that has significant influence on the economic efficiencies of timber management is patch size. Economies of scale are more favorable when larger, although fewer, patches of forest are managed for timber rather than many smaller sized patches. There are also many socioeconomic issues that influence or create constraints for timber management, particularly in urban or urbanizing areas. Social tolerance, local economic importance, landowner objectives and industry infrastructure, will all have an influence on the likelihood of forestland remaining economically sustainable.

Population density is used to predict the social tolerance to and sustainability of commercial timber management activities. As population density increases, the likelihood of sustainable timber management decreases because of land use conversion to development and increasing intolerance to the noise, visual, and safety impacts associated with forest harvest operations. Land parcelization and contiguity of ownership were used as indicators for sustainable forest management. Large parcels of forestland have the benefits associated with economies of scale. Landowners owning larger blocks of forest are more likely to have management objectives that include timber management as compared to the objectives of small lot landowners.

Within the economic assessment we also tried to develop measures to evaluate the local importance of the forest products industry. The importance of the forest products industry to the local economy is evaluated at a county level by comparing the total industry output from the forestry and wood products sectors to the total industry output for all industry sectors (via IMPLAN). Two sector groupings were evaluated separately due to different proximity relationships to the forest resource base.

Maryland Department of Natural Resources (DNR) is currently working with local county officials to evaluate impacts of zoning regulations and incentives on forest ownership and forest industry viability. Baltimore County Maryland has begun an elaborate analysis of forests, ownership, and development patterns using the SFLA methods in an attempt to retain forests that are functioning for both their ecological and economic benefits. The enhanced models may be used to influence policy, direct county programs and to develop effective incentives to retain forestland.

Vulnerability Ranking of Forest Lands

Threats to forestlands arise from multiple potential stressors. The most obvious threat is the conversion of forestland into some form of urban use, such as residential, commercial, industrial, or institutional uses, with the consequent loss of most of its natural resource values. Maryland's forest resources are also threatened by other forces, including biological pests (for example, exotic species, overabundant deer, etc.) as well as abiotic factors (for example, fire, acid deposition).

For purposes of the Strategic Forest Lands Assessment, the vulnerability model that has been developed focuses on the threat of conversion of forestland to development. It only indirectly incorporates other biotic and abiotic stressors. The model looks at regional and site specific factors that contribute to the vulnerability of a given acre of forest to development, as well as factors that make its conversion less likely.

Examples of site-specific data layers used to determine an area's vulnerability include:

- the current level of protection arising from public ownership, conservation or agricultural easements
- constraints on development as a result of physical limitations or regulations associated with environmentally sensitive features, including wetlands and riparian areas, steep slopes, and sensitive habitats

The vulnerability of forestland to development is heavily influenced by the greater geographic setting. Market forces can drive the long-term sustainability of forests as a preferred land use. The vulnerability model approximates these effects by including data layers to assess:

- proximity to population centers
- road access and density
- proximity to existing protected open space
- real estate values

Finally, public policy and investment can also be used to direct growth and, correspondingly, the conservation of forest resources. The model addresses these factors by including data layers for:

- existing water and sewer service areas
- Priority Funding Areas for Smart Growth
- local zoning
- Maryland's Chesapeake Bay Critical Area (separate zoning categories within 1,000 feet mean high tide of the Chesapeake Bay and its tributaries)

Methods Used to Develop the Vulnerability Ranking of Forest Lands

Population growth or loss 1990 through 2000 was a major component of the vulnerability model. Rapidly growing areas were identified by looking at the last decade of population growth in Maryland. Year 2000 human population density within Maryland census blocks (from 2000 TIGER data) was compared to 1990 human population density within Maryland census blocks (from 1990 TIGER data).

Mean Parcel Size was also a major component of the model. The number of forest landowners in the U.S. has been steadily increasing since the early 1900's, and thus the average parcel size has been decreasing (Mehmood and Zhang 2001). In Maryland, the number of forest owners more than tripled between 1978 and 1994, increasing from 42,200 to 130,600 (Birch 1996). Total private forestland ownership increased only slightly, and the average parcel size decreased from 45 acres to only 17 acres. Parcelization often leads to forest fragmentation. As the number of landowners increases, their attitudes and objectives become more diverse, and many choose to convert their land to other uses, especially residential (Birch 1996, Mehmood and Zhang 2001). Parcel centroids were obtained from Maryland Property View. To make the dataset manageable, only parcels at least 1 acre or greater in size could be used in the analysis. Parcels smaller than 1 acre were generally considered to be already intensely developed.

Commute time to major town centers was also thought to be a significant factor in evaluating the vulnerability of forestland. Bockstael (1996), Geoghegan and others (1997), and Bockstael and Bell (1998) found that distance to urban centers such as Washington DC affects land value and the probability of housing construction on private parcels. Wickham and others (2000) found a strong correlation between forest fragmentation and a geographic gradient of urbanization pressure in central Virginia. Land demand pressure was interpolated as a ratio of urban center population, taken from the 1990 Census of Population for each Census Designated Place, over the distance along major roads from these urban centers (Wickham and others, 2000).

Wickham and others (2000) was used to evaluate land demand based on proximity to Washington DC and Baltimore. Land demand pressure was interpolated as a ratio of urban center population, taken from the 1990 Census of Population for each Census Designated Place, over the distance along major roads from these urban centers (Wickham and others, 2000). Extra weighting was given for proximity to DC and Baltimore, which have by far the largest concentration of commuters in the state. Other cities were addressed in the previous metric, commuting time to urban centers. Land demand was calculated from DC and Baltimore as the number of potential commuters divided by the commuting time to these areas.

Market land value was another parameter evaluated to determine vulnerability. Bockstael (1996) and Bockstael and Bell (1998) found that the higher the land value of a parcel, the higher the probability of its conversion to residential use or other development. Maryland's Property View database, which contains market land value, was interpolated to create a continuous cost surface. The distance from major roads make a particular area more prone to development, because of decreased construction costs and increased access to existing infrastructure. These primary and secondary roads improve general accessibility (Bockstael, 1996). Access to major roads is especially important to businesses; most major general access roads are lined with commercial and industrial enterprises. The distance of each grid cell from all interstate, primary state, and secondary state roads was calculated.

In Maryland the area of waterfront property also had to be considered to evaluate vulnerability. Waterfront property is generally more desirable to developers (Bockstael, 1996). Waterfront property was defined as cells adjacent to (i.e., within 166 feet of) river, lake, or bay shorelines, and generally excluding wetlands. Similarly, proximity to preserved open space increased parcel value, and thus its probability of conversion to residential use (Bockstael, 1996). To evaluate this, the distance of each forested cell to all protected lands such as public land, private conservation land, conservation easements, or agricultural easements were calculated.

Riparian Restoration Potential of Sensitive Lands

Still being modified and enhanced, is the GIS-based model to help rank the Riparian Restoration Potential of Sensitive Lands. This model is primarily aimed at prioritizing areas for riparian forest restoration and conservation as part of the Chesapeake Bay restoration efforts through Maryland's Stream ReLeaf Program. Restoration of stream buffers return the highest cost/benefit ratio of any best management practice used to reduce non-point source nutrient loadings to streams within the Chesapeake Bay watershed. Many ecological benefits are also associated with maintaining forest along streams (riparian forest). These include taking up nutrients in ground and surface water flow, as a buffer between streams and adjacent land uses; stabilizing stream banks; shading the water and maintaining its temperature; and providing food as substrate for aquatic and terrestrial animals alike.

The relative percentage of unforested riparian areas within a watershed can be an indicator of aquatic and terrestrial system stress. A Geographic Information System (GIS) was used to calculate the amount of forested and unforested riparian buffer in each watershed. First a 100-foot stream corridor (buffer) was identified around free-flowing streams mapped by the Maryland Office of Planning (OP). This information was combined with OP 1994 land use data showing forested land and with DNR's Forest Resource Inventory (DNR FRI, 1991). To calculate the indicator, the combined area of forested and unforested corridor was summed for each eight-digit watershed. The unforested portion was then divided by the total corridor area to create the percent of unforested riparian buffer.

In Maryland, which would naturally be 95 percent forested, almost all native organisms would have evolved under the influence of forested conditions. Therefore in a natural state, the percentage of unforested riparian buffer in free flowing stream systems should be close to zero. Head-water streams that are further up in a given watershed, create a higher benefit for restoration or protection than river shoreline or estuarine areas lower in a watershed.

In Maryland's Unified Watershed Assessment, completed as part of the Clean Water Action Plan (1998), watersheds with more than 49 percent of stream lengths unforested were considered to be in need of restoration. Watersheds having high percentages of unforested land in the riparian area bordering streams are potential targets for riparian reforestation. Where unforested riparian buffer areas represent smaller percentages of stream mileage, other restoration measures may be more appropriate to achieving water quality and habitat improvement.

This watershed targeting system has assisted DNR and partner agencies in restoring more than 70,000 acres of sensitive agricultural land through USDA's Conservation Reserve Enhancement Program (CREP), including the establishment of more than 1,200 miles of forest riparian buffers in Maryland. Watershed evaluations were done for each of the 127 separate eight-digit watersheds to determine rank. This information was shared with program partners and personnel resources were modified to assist program delivery. The Riparian Restoration Model will be further enhanced as part of the next phase of restoration efforts tied to the Chesapeake 2000 Agreement.

Conclusions

"Maryland's Strategic Forest Lands Assessment" highlights the use of indicators to analyze forest sustainability and the effectiveness of using GIS-based computer models to rank the ecological and economic importance of forestlands. These four GIS-based computer models; the Ecological Ranking of Forest Lands, the Economic Ranking of Forest Lands, the Vulnerability Ranking of Forest Lands, and the Riparian Restoration Potential Model, have been shown to be very effective at assessing forest sustainability at the state, county and watershed scale.

The methodology behind the models when enhanced has been shown to be a very effective decision support tool for making finer scale land management decisions. Much work still remains to be done, but the availability of finer scale data makes the use of these tools even more relevant for future decision support. The promise of these models is their ability to evaluate forest sustainability, land use patterns, and program delivery, simultaneously at the landscape and site level. The challenge will be to use this information to develop land use policy and incentives that will encourage forest sustainability in a rapidly changing environment.

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Soil Disturbance Monitoring in the USDA Forest Service, Pacific Northwest Region

Steven W. Howes, Regional Soil Scientist, USDA Forest Service, Pacific Northwest Region, Portland, OR

Abstract—*In order to make reasoned decisions, USDA Forest Service managers must understand how changes in specific indicators of soil quality resulting from project implementation affect long-term forest productivity and watershed health. They must also be able to efficiently and economically assess the degree and extent of such changes across specified areas and adjust management activities accordingly. In 1979, the Pacific Northwest Region was the first Forest Service region to develop and implement soil quality standards based on the best research available at the time. Initial monitoring of land management activities for adherence to these standards was uncoordinated and, in many cases, followed protocols that led to questionable results. In partnership with the Pacific Northwest Research Station, a standard soil disturbance assessment protocol was developed in 1983 to provide consistent, comparable, and defensible data across the region. This protocol eventually became a national model for conducting soil disturbance assessments on national forest system lands. Information generated by such monitoring efforts has led to significant changes in techniques used to accomplish land management objectives. Eventually, a need arose for less expensive and time-consuming soil disturbance assessment protocols that still provide reasonably accurate and comparable data. Also needed was a means to improve communication and increase the level of understanding among soil scientists, land managers, operators, and the public. A partnership effort involving research and management personnel from several governmental and large industrial forest land owners in the Northwest is attempting to develop soil quality standards based on visual classifications of disturbance. Land managers and research scientists are also working to develop models that can be used to determine the degree of risk of soil disturbance occurring as a result of equipment operation and burning. These can, in turn, be used to establish site-specific soil management objectives. Continued research and management cooperation is needed to quantify effects of soil disturbance on site productivity and hydrologic response.*

Introduction

The USDA Forest Service considers maintenance of soil and water quality a high priority as it plans and implements management activities. A number of laws regulating activities of the Forest Service (Organic Administration Act of 1897, Multiple Use and Sustained Yield Act of 1960, National Environmental Policy Act of 1969, National Forest Management Act of 1976) all mention providing high quality water, providing sustainable supplies of timber and forage, improving growth of forest and rangeland vegetation, not degrading the productive potential of the national forests, and disclosing to the public impacts of proposed activities on the soil.

Although the laws mentioned above speak to the importance of soils in ecosystems, there are no meaningful standards, procedures, or objectives provided to assess whether the intent of these laws is being met. There are no concise, common definitions of sustainable productivity or watershed condition.

The harvest and removal of forest products, and subsequent land treatment operations such as slash disposal and site preparation, generally result in some degree of soil disturbance. Soil disturbance is not necessarily harmful and, in fact, may often be a management objective, particularly where site preparation and restoration are concerned. However, land managers should be concerned when soils are disturbed to the point where their inherent productive potential is significantly reduced or hydrologic function is impaired. There have been many differences of opinion among soil scientists, foresters, managers, and operators about where this "significant" threshold occurs.

Detrimental soil disturbance commonly is in the form of compaction, displacement, and puddling resulting from the use of ground-based harvesting and slash disposal equipment. It can also be in the form of sheet and rill erosion or charred soil in intensely burned areas. Problems have arisen in operational settings in determining threshold levels for, or defining when, detrimental soil disturbance exists, and in determining how much can be tolerated on a given area of land before unacceptable declines in productive potential or hydrologic function occur.

Soil Quality Standards

The Pacific Northwest Region (R6) first issued a Forest Service Manual supplement dealing with soil productivity protection in 1979. It has been modified a number of times since then (USDA Forest Service, 1998). This direction specified threshold values for determining when detrimental soil disturbance occurs and also set area extent or tolerance limits for detrimental soil disturbance on an activity area basis. Most national forests within R6 incorporated these values as Forest-wide standards as they developed their initial forest land and resource management plans. Other Forest Service Regions subsequently developed similar policy and direction (Powers, Tiarks, and Boyle, 1998). Standards for determining detrimental soil compaction, displacement, puddling, and severely burned soils were developed based on the best research results available at the time. Meurisse (1988) has discussed the history and evolution of the R6 soil quality standards in detail. Howes (1988) has described their application in an operational setting.

Standards emphasize observable and measurable soil characteristics that field personnel can use to monitor effectiveness of activities in meeting soil management objectives. In summary, all forms of detrimental soil disturbance, including permanent features of the transportation system such as roads and landings, are limited in extent to no more than 20 percent of an activity area.

Initial Management/Research Soil Monitoring Partnership

After soil quality standards had been developed and adopted for use, a system of monitoring was needed to ensure that, in fact, they were being met. Initially, no standard monitoring protocol was available. A number of widely disparate sampling procedures were developed; some with questionable scientific basis. This led to inconsistencies in sampling between national forests and often to indefensible results and incomparable data. Results of sampling were frequently challenged by individuals from within the agency, as well as from the public.

The need for a sound soil disturbance monitoring protocol provided the impetus for an informal partnership between R6 and Pacific Northwest Forest and Range Experiment Station. In 1981, a cooperative effort was begun to develop a statistically sound and defensible soil monitoring protocol. Objectives were to:

1. Obtain a representative sample;
2. Control level of precision;
3. Obtain consistent results with repeated sampling; and
4. Sample all types of soil disturbance at one time.

Two years of coordination and field testing resulted in a monitoring protocol that was first described by Howes, Hazard, and Geist (1983) in a field guide prepared for use by R6 soil scientists. Sampling rules and supporting theory were subsequently described by Hazard and Geist (1984).

Briefly, the protocol calls for establishing a systematic sample of grid points, arrayed on a map or aerial photograph of the activity unit to be monitored (fig. 1). The entire grid is randomly located and oriented, and the distance between points is constructed to provide a sample size that meets precision requirements or cost limitations specified in the objectives. Each grid intersection locates a line transect that radiates in a random chosen direction from the grid point.

Soil condition classes (displaced, puddled, eroded, severely burned) are identified using visual surface characteristics and are measured by the proportion of the length of each transect contained in each class. Certain physical soil characteristics may require collection of soil cores or other measurements (porosity, strength) to assess properties along the line transect but within the soil. This is done at fixed intervals. For example, cores

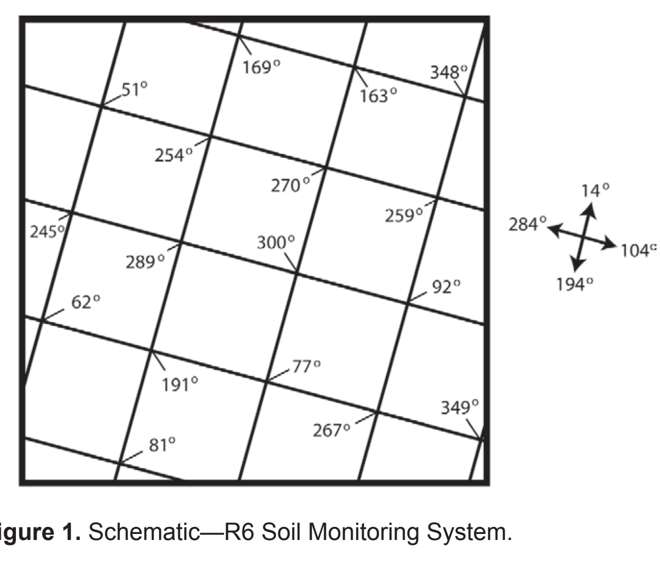

Figure 1. Schematic—R6 Soil Monitoring System.

can be used to assess soil bulk density and partition visual disturbance classes into either compacted or non-compacted categories. Measures of soil strength or porosity can also be used as indices of compaction.

Data collected on all transects provides a representative sample of the activity unit. The percent of the activity unit in each condition class is calculated by determining the proportion of each transect in that class, and averaging the proportions of all transects in the activity area. Reliability is estimated from the variance among estimated transect proportions of each condition class. A computer program was developed by the Pacific Northwest Research Station to assist field soil scientists in processing and summarizing data collected in the field (Hazard, Snellgrove, and Geist. 1985).

Collecting and processing soil core data was the most time consuming segment of the sampling protocol. A computer program to assist in this effort was also developed (Starr and Geist. 1983). Miller, Hazard, and Howes (2001) evaluated the precision, accuracy and efficiency of four tools for measuring soil bulk density and strength to help field soil scientists efficiently plan disturbance assessments.

Development of a simple yet statistically sound soil disturbance assessment protocol may not seem like a significant accomplishment. However, it served a number of purposes. It provided a standard protocol that produces information capable of withstanding legal or other challenges. Field soil scientists and managers began to think about experimental design as they planned soil disturbance monitoring projects. Managers began to understand the complexities involved in making soil disturbance assessments, that sound and defensible surveys took time, and they could involve considerable costs depending on survey objectives. Management needs to be involved in planning soil disturbance assessments. They must consider the kinds of decisions to be made, how information will be used, need for highly precise information (risk), and how much they are willing to spend to collect the data.

The sampling protocol has been used in a number of Forest Service research and operational studies in R6. Cochran and Brock (1985) used it in their study of the effects of soil compaction on initial height growth of ponderosa pine on the Deschutes National Forest in central Oregon. Laing and Howes (1988) used it in their survey of soil disturbance caused by a feller-buncher operation on the Colville National Forest in northeastern Washington. Much of the information generated from these studies has been used to guide soil management efforts within R6.

Sullivan (1987) compiled one of the most complete soil disturbance data sets on the impacts of ground-based harvesting systems on the Malheur National Forest in northeastern Oregon (fig. 2). The sampling protocol was used to monitor impacts of tractor yarding and machine piling on soils in 24 timber sale units. Forest managers were concerned that excessive soil resource damage was occurring where these management activities were being implemented. Detailed information was also collected on soil type, timing of harvest and slash disposal operations, and equipment used. The Forest used information from this monitoring effort to adjust its practices. Fuel management direction was clarified to lessen the extent of slash disposal thus reducing the amount of machine piling. Skidding impacts were reduced by calling for designation of trails prior to felling. Restoration of those units exceeding soil quality standards was called for as soon as practicable.

Such useful monitoring information is not obtained without cost. Sullivan (1987) also collected cost data for 8 of the harvest units he monitored. Cost per acre monitored ranged from $77 to $259. Total cost per unit ranged from $1151 to $2572. Personnel accounted for the majority of costs followed by processing of soil cores. Based on this information, it is easy to see that monitoring can be cost prohibitive when budgets are limited.

Later Partnership Efforts

Beginning in 1990, forest health and wildfire concerns became a major issue in the Blue Mountains of northeastern Oregon. Given the large acreage of overstocked stands requiring treatment, mechanical options, as well as prescribed fire, had to be considered as possible treatment alternatives. Between 1995 and 1997, a cooperative effort was initiated by the Pacific Northwest Research Station, Oregon State University, and the Wallowa-Whitman National Forest to study the economic and environmental impacts of fuel reduction practices used in mixed conifer stands in northeast Oregon (McIver, 1998). A primary objective was to measure effects of harvest activities on soils. The study was conducted on the La Grande Ranger District near Limber Jim Creek. This area of the District contained high fuel loadings, with many stands exhibiting fuel model 10 conditions (high potential for crowning, spotting, and torching during a wildfire). Six of the units consisted of pairs in which one unit of the pair was randomly chosen to be a forwarder unit and the other of the pair was chosen to be a skyline unit. At the request of the Forest, logs in the seventh unit were yarded with a skidder. Soil disturbance results from this unreplicated unit were used only for comparison purposes.

Of the seven experimental units, six had total detrimental disturbance levels under 10 percent (fig. 3).

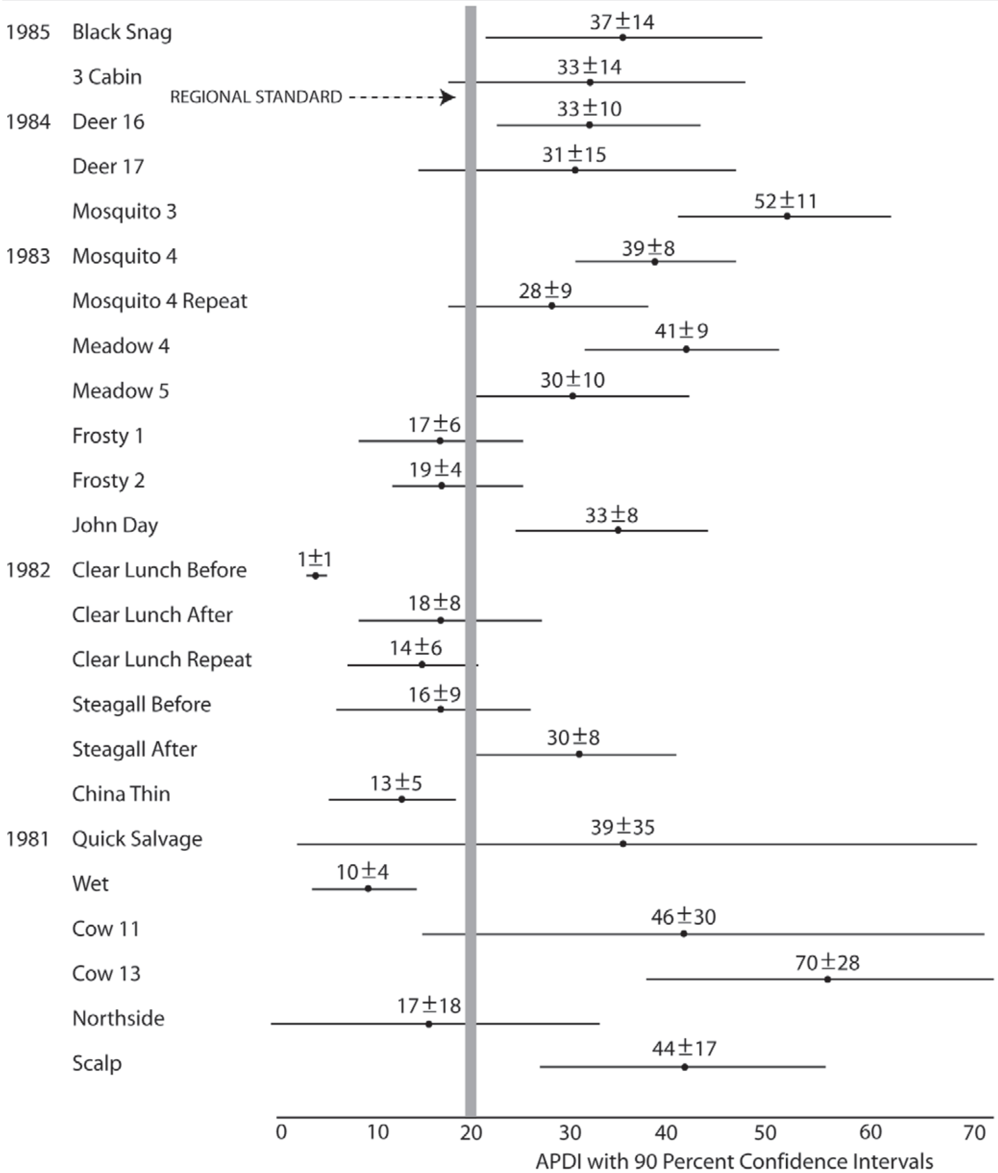

Figure 2. Average Percent Detrimental Impact (APDI) with 90 Percent Confidence Intervals.

Not unexpectedly, the unit harvested by conventional grapple-skidder contained the greatest detrimental soil disturbance. One interesting result was that, in all units, soil displacement (removal of topsoil) was the primary form of detrimental soil disturbance rather than compaction.

Again this may seem like a simple experiment, yet it yielded some very powerful information used locally in planning other fuel reduction projects. It demonstrated that operators at Limber Jim were able to meet Regional soil quality standards by keeping detrimental soil disturbance under 10 percent using cut-to-length timber harvest technology. Information generated as part of this study helped greatly in predicting effects of similar future projects occurring on volcanic ash soils in the Blue Mountains.

Given the costs associated with conducting sound soil disturbance assessments, alternative methods were explored. In 1998, the Wallowa-Whitman National Forest proposed using a modification of a system originally developed by Weyerhaeuser research scientists in 1979 and further described by Miller (1988). The system defines soil disturbance categories or classes based on observable characteristics. It then relates them to soil damage defining criteria and established standards for soil productivity protection. A seven-class system was originally proposed and implemented. Each of the classes could be assessed or measured using a variety of sampling systems.

In 2000, the USDA/USDI Joint Fire Sciences Program initiated a national "fire/fire surrogate" study to evaluate effects of four potential fuel management treatments on

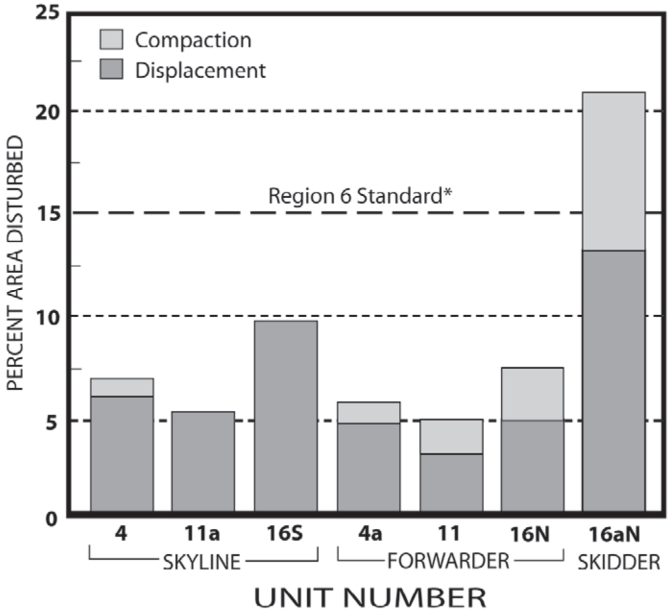

Figure 3. Percentage of soil area detrimentally disturbed among seven experimental units at Limber Jim. *Standard assumes 5 percent roads.

several core response variables including soils. Of particular interest was the amount of soil compaction generated by mechanical treatments. Given time and budget limitations, qualitative soil disturbance categories developed by the Wallowa-Whitman National Forest were used and measured on one of the installations in northeastern Oregon instead of using soil cores for bulk density determinations. During initial sampling, the number of disturbance categories was reduced from seven to four. Questions arose regarding the utility of this method as a research and monitoring tool. Currently, a cooperative study is being carried out by R6 and the Pacific Northwest Research Station to evaluate the precision, accuracy, and repeatability of such qualitative assessments.

Expanding the Soil Disturbance Monitoring Partnership

In the Pacific Northwest, there are a number of large private industrial forest land owners, public land management agencies, and research organizations interested in effects of soil disturbance on the sustainable production of forests and on watershed health. They have been loosely affiliated into a "Soil Disturbance Working Group" under the auspices of the Northwest Forest Soils Council. Scientists from these organizations are working together to develop a strategy for achieving uniformity in monitoring techniques and reporting soil disturbance for operational and research purposes as well as for reporting under international sustainability protocols such as the Montreal Process (Curran et al., 200X). A primary objective of this effort is to provide technical guidance that will facilitate effective communication and comparison of operational and research results.

This strategy contains five major components:

- Uniform terms for describing soil disturbance,
- Cost-effective techniques for monitoring or assessing soil disturbance,
- Reliable methods to rate soils for risk of compaction, rutting, topsoil displacement, and erosion,
- Effective approaches for using operational monitoring to meet a number of objectives including requirements of third-party certification and the Montreal Process,
- Objective comparison of current soil disturbance guidelines.

The importance of monitoring using a reliable process for achieving sustainable soil productivity and watershed health is also recognized.

Some significant progress has been made to date under several components of the strategy. R6 is currently bringing its soil disturbance monitoring methods more in line with the disturbance class approaches used by Weyerhaeuser Company and British Columbia Forest Service. A four-class system is now being tested on two national forests in northeastern Oregon (USDA Forest Service, 2001). R6 is currently cooperating with Weyerhaeuser Company and the Pacific Northwest Research Station to develop standardized models to rate soils for their relative degree of risk of incurring detrimental soil disturbance as a result of ground-based equipment operations. Separate models are being developed for soils east and west of the Cascade crest. Models are being calibrated using actual field monitoring data and professional experience. A model has also been developed to rate soils on the east slope of the Cascade Mountains in Washington State for degree of risk of damage by wildfire (Wenatchee-Okanogan National Forest, 2003). A cooperative effort is currently underway to publish this information and validate it for other geographic areas. These models will be used to adjust management objectives based on local soil conditions and on-site investigations rather than on blanket application of a single standard.

Soil risk ratings will also provide the basis for a standard Region-wide soil quality monitoring program consisting of five major components.

1. Risk assessment using common soil disturbance category definitions,
2. Soil management objectives (prescription),

3. Common monitoring protocols,
4. Maintain common monitoring database, and
5. Validate/adjust risk ratings and prescriptions based on results.

Future Partnership Needs

Although R6 has worked with the Pacific Northwest Research Station to test accuracy, precision, and repeatability of qualitative soil disturbance observations, final versions of category definitions and assessment protocols have yet to be developed. If common disturbance category definitions are the objective, then continued coordination among interested parties is essential.

Once soil disturbance category definitions have been finalized, a training and certification program for those making observations in the field must be developed and implemented. Consistency and accuracy of observations can be gained only through experience and continuous comparison of results collected using more quantitative methods. Development of common training programs among those groups making soil disturbance assessments will also enhance consistency and accuracy; and will encourage information sharing.

Relationships between qualitative definitions of soil disturbance and quantifiable indices of soil quality need to be determined. These indices must reflect physical, chemical, and biological processes important to productivity.

Finally, if sustainable forest productivity and watershed health are the ultimate objectives, then links between soil disturbance and vegetative growth or hydrologic function need to be established. In all probability, these relationships will change between soil type and geographic area. Quantification of these relationships will require continued strong partnerships between researchers and field practitioners in such fields as soil science, hydrology, geomorphology, silviculture, and range management.

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Northern Region Landbird Monitoring Program: A USFS-University of Montana Partnership Designed to Provide Both Short-term and Long-term Feedback for Land Managers

R. Hutto, Professor and Director, Avian Science Center, Division of Biological Sciences, University of Montana, Missoula, MT
Skip Kowalski, Wildlife Program Leader, USDA Forest Service Northern Region, Missoula, MT

Abstract—*The Northern Region Landbird Monitoring Program (NRLMP) began in 1990 as a cooperative effort between the United States Forest Service (USFS) and the University of Montana. The combination of a research-oriented perspective from the University and a management-needs perspective from the National Forests within the Northern Region led to the realization that landbirds as a group might serve as a powerful tool to address more widespread monitoring needs in the USFS Northern Region. The program quickly evolved from one that was put into place specifically to use federally earmarked dollars to address neotropical migratory bird conservation, into a more general region-wide monitoring program. Today, the program is uniquely designed to provide two kinds of monitoring activity—one is conducted during even-numbered years and is designed to shed light on the long-term population trends and habitat relationships of numerous landbird species within the region; the other is conducted during odd-numbered years and is designed to shed light on the ecological effects of various kinds of land use activity. The University of Montana had (and continues to provide) the expertise needed to handle the design, training, data management, analysis, and information dissemination components, while the USFS had (and continues to provide) the funding needed to hire seasonal technicians who conduct the actual bird monitoring and it has the management needs that serve as the primary driver of short-term management effects assessments. It is the short-term management effects monitoring and the habitat-relationships information that have generated the most support for the monitoring program within the USFS. Overall, the program is widely viewed as useful and successful, but obstacles that still need to be overcome include (1) the incorporation of monitoring results into a more formal adaptive management cycle within the USFS, and (2) the inclusion of additional state, federal, and private corporation partners so that the program emerges as one part of a more comprehensive statewide (or broader) landbird monitoring program, and (3) the recognition that monitoring buy-in involves support for more than the field effort involved with data collection.*

History of the Partnership

The origin of the Northern Region Landbird Monitoring Program (NRLMP), a cooperative effort between the United States Forest Service (USFS) and the University of Montana, can be traced to a landmark meeting held in Atlanta in the fall of 1990. That meeting, organized by the National Fish and Wildlife Foundation, brought together numerous federal agencies and non-governmental organizations, and other state agencies and industry representatives to encourage them to become partners in an effort to stem the tide of migratory songbird declines. This effort gave birth to what was to become "Partners in Flight," a non-binding cooperative effort among hundreds of partner organizations to work toward the conservation of most terrestrial bird species. By May of 1991, 7 federal agencies had signed an agreement to promote the conservation of neotropical migrants. The USFS alone pledged $6 million per year for five years to the effort, and each of the nine Regions identified approximately $300,000 per year for neotropical migratory bird conservation action. The Partners in Flight effort represents perhaps one of the greatest coups in the history of wildlife biology because it single-handedly moved the conservation of nongame wildlife into a position of prominence in management circles without ever once using the word "nongame."

Because Hutto had acquired considerable experience with migratory landbird research in both the western United States and western Mexico, he was approached by the USFS Northern Region Wildlife Program to help develop a neotropical migratory bird conservation action plan for that region. By the time the USFS Chief directed the USFS Regions to develop multi-year plans about how to use the earmarked funds; the Northern Region already had a proposal in hand. Although these action plans took somewhat different forms in each Forest Service Region, the Northern Region proposal focused on long term monitoring and habitat relationships. In retrospect, this partnership has demonstrated that academic partners can be of real use to government agencies; academics are generally very good at the synthesis of current information, and are also relatively good at developing proposals for meaningful work.

Early on, we organized a regional coordinating group that included personnel from Forest Service Research to refine aspects of our original proposal. This group gradually added interested partners and eventually evolved into the statewide Partners in Flight coordinating group. The first order of business for the coordinating group was to plan a meeting to discuss the development of a handbook of existing information on migrants (Dobkin 1992), and the development of a pilot project to test the efficacy of on-road vs. off-road counts (Hutto and others 1995). As the University partner, Hutto proceeded to plan, organize, and hire crews for the pilot field project and for a pilot effort to implement the program by 1994, by which time all permanent transects were to be in place and up and running.

It did not take long for us to realize that a program to monitor landbirds for their own sake would carry very little weight in management circles. Remember, this was still in the era where "nongame" issues were pretty much a joke in management-oriented societies and management circles, and the revolution in wildlife biology that occurred because of the emergence of the Society for Conservation Biology had only just begun. If it had not been for the foresight of a few high level managers, and if money had not been identified specifically for neotropical migratory bird conservation, we suspect that very little would have been spent on their behalf in 1990. Fortunately, the combination of a research-oriented perspective from the University partner and a management-needs perspective from the National Forests within the Northern Region led equally rapidly to the realization that landbirds might serve well as a powerful indicator group to address the broader, legally mandated monitoring needs in the USFS Northern Region. Specifically, we recognized that the bird monitoring program might help meet mandates that emerged from federal legislation such as the National Forest Management Act, which requires monitoring activity in order to assess whether vertebrate populations are being maintained throughout the individual National Forests.

There are a number of reasons why birds should be more widely recognized for their utility as effective monitoring tools. As outlined in greater detail elsewhere (Hutto 1998, Hutto and Young 2002, Hutto 2004), (1) landbirds are not only the most visible of vertebrate species, they also advertise their presence and identity through vocalizations. Thus, systematically collected field data are much easier and less expensive to gather for landbirds than they are for traditionally managed species that require trapping, radio tagging, locating, and so forth; (2) a single monitoring method can produce information on numerous species (a trained field crew can collect information on patterns of bird occurrence for well over 100 species using a single, inexpensive, point-based survey method). Sure, many of those species will be too infrequently detected to be monitored well, but having to manage for the maintenance of those that can be monitored will probably bring us much closer to maintaining populations of all vertebrates than would the still prevalent approach of managing entirely on the basis of a select few indicator (mostly game) species; (3) having to manage for the maintenance of many landbird species will force movement toward management at broader spatial scales. This is because, by using birds as monitoring tools, the list of monitored species will now be large enough and ecologically broad enough to reveal some species that will benefit from, and others that will be harmed by, any proposed land-use activity. On the surface, the use of so many species for monitoring purposes would appear to lead managers into a no-win situation because any proposed land-use alternative will hurt something, but the way out of this apparent dilemma comes from expanding one's focus beyond a specific project area. Clear recognition that local populations of some species will invariably be harmed by any proposed land-use action forces one to consider broader landscapes when thinking about the maintenance of populations. It is only at the landscape level that we can provide enough of each landscape element to maintain the populations of, and honestly claim "no effect" on, all vertebrate species. The local extinction of a species due to some land management activity is fine as long as the suitability for that same species is expected to increase at the same time in another part of the landscape (due to some other land-use activity or to ecological succession, for example).

Once the benefits associated with using birds as monitoring tools became better appreciated, the program quickly evolved from one that was put into place specifically to use federally earmarked dollars to address neotropical migratory bird conservation, into a more general region-wide monitoring program using both migratory and nonmigratory landbird species. We must add that an on-going in-house education effort is necessary because it is especially difficult for people to understand that ours is not a bird monitoring program; it is a program that uses birds as a monitoring tool (Hutto and Young 2002)!

There is, of course, the ever-present threat of not being able to commit to the program when money is especially tight. If there were ever a need for strong leadership at the regional level and a need for regional coordination, this is it. Broad-scale monitoring is one endeavor that would not work well if left up to individual Forests or Districts to implement. Most Districts and Forests would probably have little or no desire to do such monitoring on their own, and even if they did, without regional coordination, there would be little hope for the development of a system that would allow data to be merged in a way that might allow for collectively meaningful analyses.

So why is it that the USFS did not work with its own research arm to do develop a monitoring program within the USFS system? The answer is not entirely clear, but from the perspective of congressional appropriations, there is a distinction between research (conducted by the research arm of the USFS) and monitoring (conducted by the management arm of the USFS). This rigid distinction may have hampered the development of a first-class, well-funded, in-house monitoring program. In addition, personnel commitments and the difficulty of accepting "new" Research Station priorities during austere times probably contributed to the way this particular monitoring program unfolded within the Northern Region. Expertise was also an issue in this particular instance. Because the federal earmark involved the development of conservation plans for "neotropical migrants," and because very few research biologists within or outside the USFS had worked with birds as defined that particular way, it was natural to approach a University that harbored an individual who had amassed considerable experience with that group of birds. Thus, the region and the university came together as partners, and the partnership has evolved into a unique formal agreement under which the University works cooperatively with the USFS to "…improve the ability of the Forest Service to monitor population trends and to understand habitat relationships of landbirds across the Northern Region and adjacent lands" and to "(1) increase the understanding of landbird ecology, (2) understand the strengths and limitations of landbird monitoring efforts, (3) monitor the effects of Forest Service management activities on landbirds, and (4) use this information to help revise Forest Plans." In turn, it is intended that the University "…use this information to further education through the development or updating of curricula related to bird ecology and conservation."

That USFS-University of Montana agreement has served as the primary stimulus to create a regentially approved Avian Science Center on the University of Montana campus, which will facilitate growth toward a more comprehensive multi-agency monitoring program for the state as a whole, and will allow us to build a more rapid and effective web-based mode of information dissemination. By attaining full partnership of all organizations that are required by law (or simply desire) to conduct monitoring to assess the effects of their land use practices, we will have achieved a very powerful working model. Indeed, the involvement of numerous agency partners coupled with the central role of University research personnel as data collector, data analyst, and information disseminator helps the agency partners shed the difficulty of having their required monitoring activity appear to be self serving. University academies also house the highest possible level of research expertise and carry the highest level of credibility among peers. These benefits associated with the partnership cannot be overemphasized.

Overall Design of the Monitoring Program

During the design phase of this monitoring program, we suspected that many fledgling monitoring programs had probably come and gone because of a failure to attain the support needed for a long-term commitment to monitoring. In fact, our perception of the main weakness in monitoring programs was, and continues to be, that they tend to be heavy on the data collection and slow or weak on the usefulness of the data collected and on the transfer of information related to results from the monitoring effort. We, therefore, designed the NRLMP to circumvent that potential problem by de-emphasizing the long-term monitoring component and building a new emphasis on what could be called a "habitat relationships monitoring" component and a "short-term management effects monitoring" component. Today, the program is uniquely designed to provide both short- and long-term monitoring activity. The long-term, population trend monitoring component is conducted during even-numbered years and is designed to uncover long-term population trends and habitat relationships of numerous landbird species within the region (see example web output in fig. 1). The short-term components are drawn from bird-habitat relationships data that emerge from the long-term monitoring component and from separate more focused monitoring efforts (conducted during odd-numbered years), and both are designed to shed light on the ecological effects of various kinds of land use activity.

More detailed description of the design of this monitoring program, and a dialogue concerning aspects of the design are available elsewhere (Hutto and Young 2002, Ellingson and Lukacs 2003, Hutto and Young 2003), but to summarize the main points here, the NRLMP involves the breeding season monitoring of all diurnal (primarily forest) landbird species that can be detected through a single (point-count) methodology. The full-scale long-term monitoring effort involves single visits in every other year to about 350 permanently marked 10-point roadside or trailside transects that were originally positioned in a geographically stratified fashion throughout the region. Transects are positioned primarily within United States Forest Service lands (Northern Region), but some are positioned within the lands owned or managed by other partners that include Plum Creek Timber Company, Potlatch Corporation, Bureau of Land Management, United States Fish and Wildlife Service, National Park Service, Montana Department of Fish Wildlife and Parks, and the Confederated Salish and Kootenai Tribes. The points provide a representative sample of all vegetation cover types that occur within the region, including managed vegetation cover types. The inclusion of managed lands is the key to gaining inference about land-use effects from a retrospective,

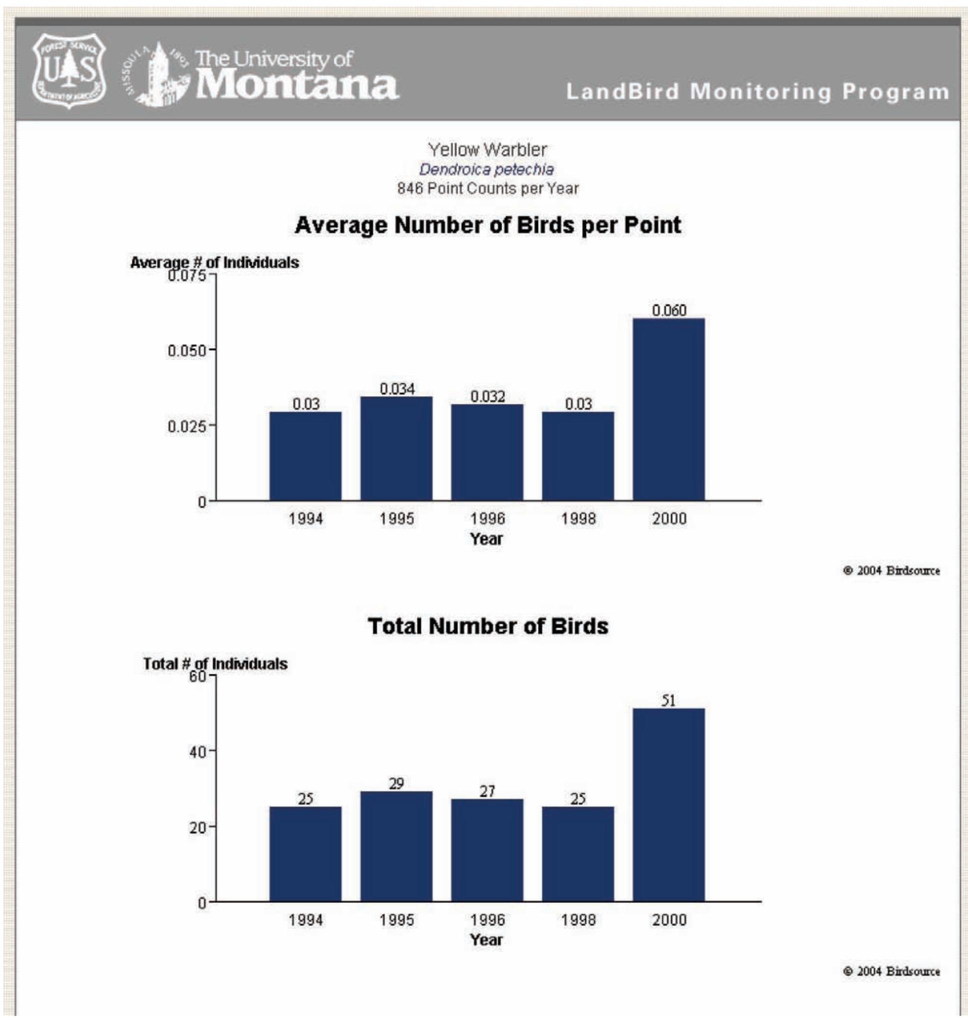

Figure 1. Example of web-based output of population trend data for a single landbird species, the Yellow Warbler. A simple histogram depicting the mean number of birds detected per point (across the 846 points from which this particular species was detected at least once in the six-year period) probably gives a reasonable picture of the status of this bird species until such time that we have enough years to conduct a more meaningful long-term trend analysis.

observational data set. Simply put, if we categorize what is admittedly a continuously variable world into discrete vegetation types, and if we include both heavily managed and less heavily managed lands in the groupings, we can gain insight into land management effects through comparative analyses among categories.

By including vegetation data from the area immediately surrounding each long-term monitoring sample point, we were able to build meaningful habitat-relationship models for more than 50 bird species in a matter of several years (Hutto and Young 1999; see example web-based output in fig. 2). And by including managed lands in the mix, we have been able to use comparative analyses to explore the effects of management activity on birds. While one can always argue that comparative analyses are of limited value, we are encouraged by the fact that the effects of partial-cut timber harvesting (as merely one example of a managed land type) as revealed through a retrospective analysis of data from our long-term monitoring points were the same as those revealed through a separate alternate-year experimental effort that involved a more formal comparison of a large number of replicate treatment and control sites drawn from throughout the forested parts of the region (Young and Hutto 2002).

The permanently marked, long-term monitoring points also avail themselves to before-after/control-impact (BACI) investigative approaches, which are generally assumed to be the most powerful and rapid way to gain knowledge of treatment effects (Stewart-Oaten and others 1986). For example, we were able to use a BACI approach to study the effects of the fires of 2000 in the

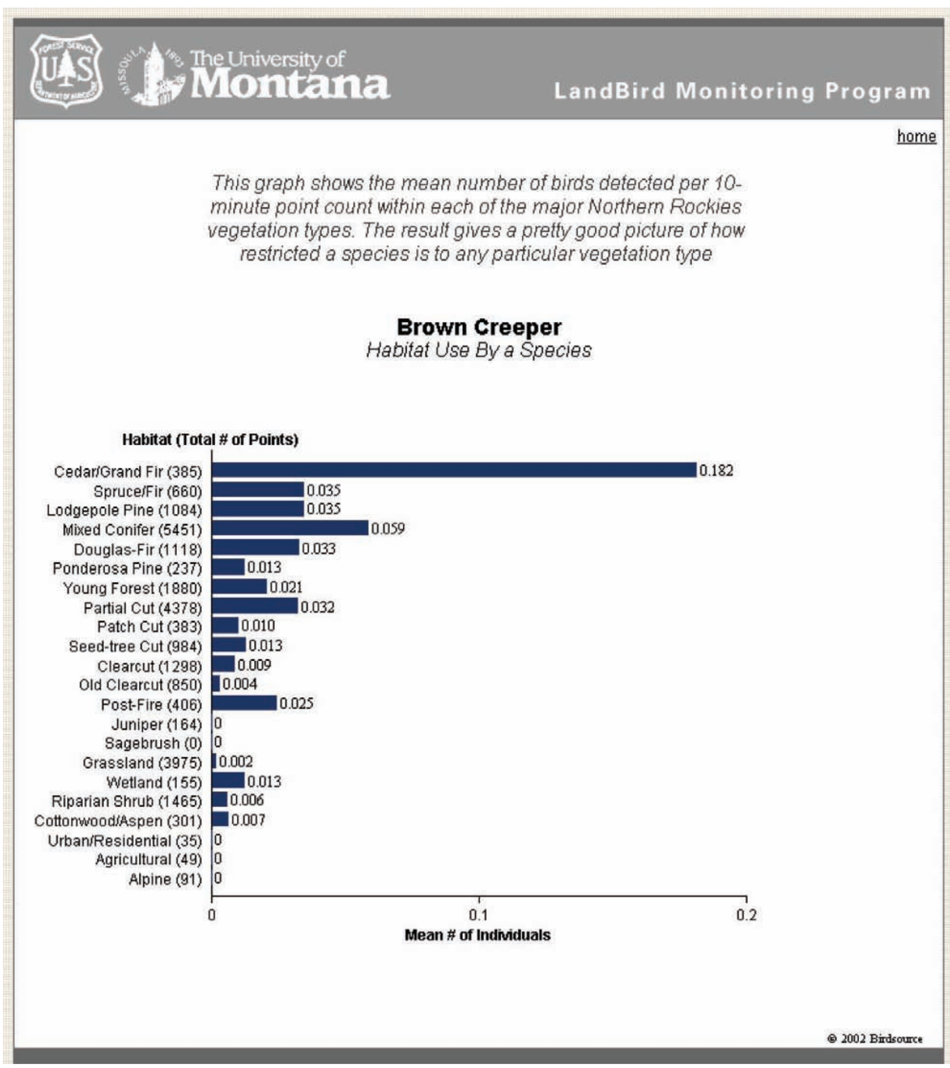

Figure 2. Example of web-based output of habitat relationships data for a single landbird species, the Brown Creeper. The mean number of detections within a 100-m radius around a survey point shows the bird to be relatively commonly detected in (and probably relatively more abundant in) cedar/hemlock forest types. Note the sample sizes associated with each vegetation type.

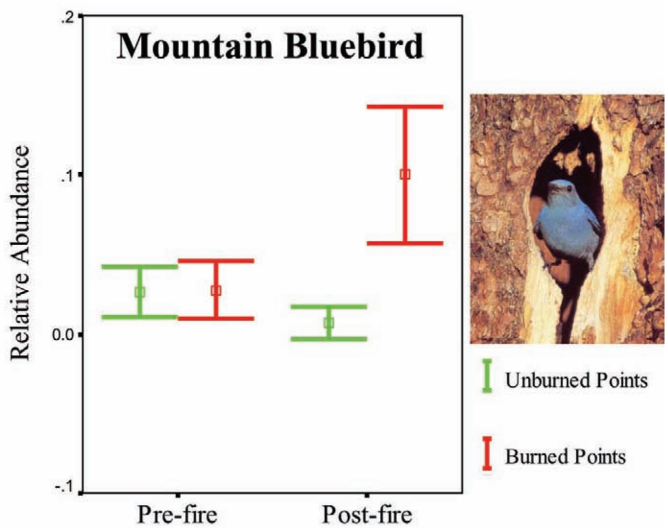

Figure 3. The use of a before-after/control-impact approach to study the effects of fire on landbirds produced results such as this one on Mountain Bluebird, a species that clearly responded positively to the sever fires of 2000 in the Bitterroot Valley, Montana (data from Smucker 2003).

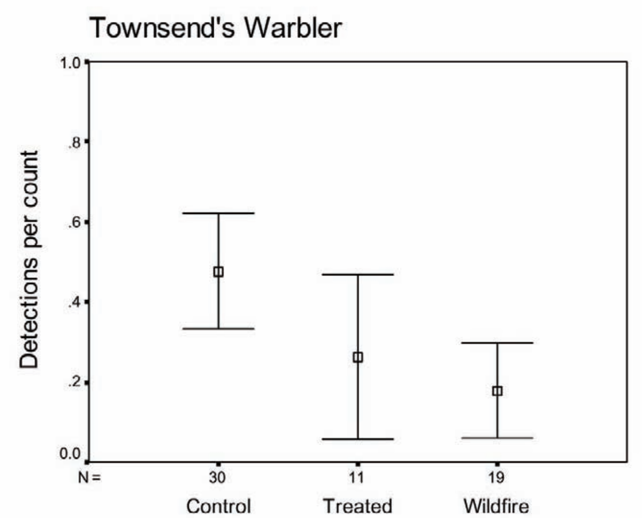

Figure 4. Example results from an alternate-year study designed to test the efficacy of restoration cutting and burning on landbird species. Note that the Townsend's Warbler is affected negatively and equally by experimental restoration treatment and natural wildfire disturbance, while the Hairy Woodpecker is affected positively and similarly by the treatment and natural disturbance. Note also the relatively large sample sizes (numbers of entirely different treatment and control plots scattered across numerous Forests in the Northern Region) associated with this alternate-year study. The utility of birds as meaningful tools for monitoring restoration effects should be apparent.

Bitterroot Valley, Montana, by virtue of the fact that we had about 100 points scattered through the burned area, some of which burned and some of which did not burn (fig. 3). It is nearly impossible to study the effects of severe disturbance events such as crown fires, hurricanes, and floods in a truly experimental arena, so the use of data from established monitoring points both before and after the disturbance will be as good as it can get to gain insight on the effects of such events.

Again, by design, we survey permanently marked long-term monitoring points every other year, which allows for a more focused monitoring effort related to issues of immediate management concern during the years when we do not collect data from the permanently marked points. As discussed elsewhere (Hutto and Young 2002, Hutto 2004), the monitoring crew is large enough (one seasonal technician per forest) to allow us to work with numbers of replicate sites that are greater than all but one of 95 studies published in various ecological, ornithological and conservation journals over the past 25 years (Sallabanks and others 2000). Thus, the power of this program to generate statistically meaningful data is directly linked with the commitment to maintain a large field crew during the alternate years, which we devote to gathering quasi-experimental data on the effects of various land-use practices (e.g., grazing, timber harvesting, prescribed fires) by positioning new sample point locations within treatment and "control" sites that are replicated throughout the region (fig. 4).

We view the short-term monitoring component to be a major strength of the overall monitoring program, but acknowledge that two major challenges will always accompany the inclusion of alternate-year, short-term effects monitoring as part of an overall monitoring program: (1) it can be difficult reaching a consensus among individual National Forests in the Northern Region regarding the focus of alternate-year work, and (2) the time, labor, and logistics associated with having to hit the ground running with a newly designed monitoring effort on an every-other-year basis can be daunting.

At this point, we should re-emphasize that the NRLMP emerged out of a real partnership—the University of Montana had (and continues to provide) the expertise needed to handle the design, training, data management, analysis, and information dissemination components, while the USFS had (and continues to provide) the funding needed to hire seasonal technicians who conduct the actual bird monitoring and it has the management needs that serve as the primary driver of short-term management effects monitoring.

Obstacles to Overcome

Overall, the program is widely viewed as useful and successful, but obstacles that still need to be overcome include (1) the incorporation of monitoring results into a more formal adaptive management cycle within the USFS, (2) the inclusion of additional state, federal, and private corporation partners so that the program emerges as one part of a more comprehensive statewide (or broader) landbird monitoring program, and (3) recognition that monitoring buy-in involves support for more than the field effort involved with data collection.

With respect to adaptive management, we have noted elsewhere (Hutto and Young 2002) that "if there is one weakness associated with adaptive management in practice, it is the lack of a formal involvement of monitoring participants in the adaptive management loop, where participants have a chance to present results that might bear on future land-use plans." Findings from the NRLMP that we believe have been successful at influencing policy have done so because the information filtered informally into management circles by way of discussions at our annual meetings with USFS Forest biologists. Monitoring results need to be better integrated into a formal management planning cycle that involves 1) gathering long-term and short-term monitoring data, 2) informing planners of results, and 3) discussing whether the results merit a consideration of changes in land-use plans.

With respect to expansion of the program to include all land-owners within the state or larger region, full financial participation in regional monitoring by prospective partners has been difficult to achieve. Ironically, significant financial participation by a broad cross-section of partners in the Northern Rocky Mountain Region was probably hampered from the start because (federally earmarked) USFS dollars were used to get the NRLMP up and running. These earmarked dollars were certainly critical to the development of a landbird monitoring program within the agency, but because the program received most of its funding from the USFS, we naturally labeled it as a "Northern Region" program. This label, in turn, fueled the perception that ours was exclusively a Forest Service program. We currently receive support for a broader monitoring effort from a variety of partners, and we now refer to most of our monitoring activities in the broader context of a multi-partner coordinated statewide monitoring effort. Nonetheless, had we labeled the monitoring effort as a pilot "statewide coordinated bird monitoring program" from the outset, we suspect it might have been easier to bring other partners on board sooner. We are now on the cusp of an expanded partnership between the University of Montana and numerous partners who see the benefit of participating in a coordinated monitoring effort, but only time will tell. Ideally, this and other state programs that are currently underway can evolve into even more ecologically based multi-state programs that use geographically broad ecological units, such as the North American Bird Conservation Initiative's "Bird Conservation Regions" as a basis for monitoring, evaluating, and reporting.

With respect to the issue that effective monitoring involves support for more than field work, potential funding partners generally fail to appreciate that support for monitoring means not just support for field technicians to collect data, but support for as comprehensive a level of data analysis as desirable and as sufficient a level of information transfer as needed to make a real difference. Information transfer in particular (getting the results out and in usable form) is precisely that aspect of the program that is needed to generate program support, and is the only aspect of the program that provides a voice for important monitoring results, but it does not get the attention or funding that it should. How many papers in this symposium, for example, deal with information transfer as it relates to monitoring programs? Because monitoring generally conjures up images of little more than an unending process of amassing data, is it any wonder monitoring is viewed as having little utility, or that such programs tend to have a limited impact on existing management? Information syntheses and information transfer (education) is never as high a priority as it needs to be with monitoring programs. We would even argue that because we already have more than enough definitive "monitoring" results to pass along to those who might find those results useful for their own decision making, we should devote more time and money to toward the synthesis of existing information. In addition, education about monitoring results includes education not just within the partner organizations themselves, but outside the agencies as well. What good does it do if the public does not fully understand, and is not fully supportive of, forest restoration plans, for example? The public-at-large elects politicians who, in turn, have the most powerful influence on policy, so all those elements of education need to be built into an effective monitoring program, and we would suggest that most monitoring programs (including our own) have considerable work to do on that front.

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The Process of Indicator Selection

Barry R. Noon, Department of Fishery and Wildlife Biology, and Graduate Degree program in Ecology Colorado State University, Fort Collins, CO
Kevin S. McKelvey, U.S.D.A. Forest Service, Missoula, MT

***Abstract**—Of all the steps in monitoring, choosing the correct indicators is arguably the most important. The challenge is obvious: among all the possible attributes of an ecosystem that can be measured, select a small number whose measurement will tell you something about all of the unmeasured attributes and processes. Even if a monitoring program is fully funded and implemented for many years, it will fail if the wrong indicators were selected. Yet establishing a strong logical basis for indicator selection is often overlooked. It is not unusual to discover that great thought and deliberation have gone into how, when, and where to measure a given indicator, but little discussion of why that particular attribute is being measured, what magnitude of change needs to be detected, and what the indicator tells you about unmeasured components of the ecosystem. Further adding to the challenge is the fact that there is no prior reason to expect agreement between scientists, managers, and the public on those attributes of ecological systems most logical and important to measure. How can one narrow down the field of all possible attributes and reach agreement on what to measure? Unfortunately, science provides limited guidance because no body of ecological theory or empiricism exists to precisely guide indicator selection. We therefore contend that partnerships are critically important to the development of prior agreements between multiple parties. Critical to this process is the collaborative development of common paradigms concerning how ecosystems are conceptualized. We believe this is best accomplished if scientists and managers collaborate in the following steps: 1) develop a conceptual model which reflects the hierarchial structure of the ecological system to be managed; 2) view the environmental hierarchy as a set of filters which constrain the plant and animal species observed on the ground; 3) identify the collection of traits of a set of focal species that reflect the desired states of the environmental filters; 4) focus on the factors that adversely affect the state of the environmental filters (in other words, take a stressor-based approach to monitoring). These steps should lead to a logical group of focal species and stressors to be monitored.*

Introduction

Compliance with environmental laws and the practice of adaptive management require ecological systems to be closely monitored to assess the effects of different management practices and various land uses. However, few examples exist of successful environmental monitoring programs and the essential components of such programs have only recently been articulated (NRC 1995, Noon 2002; table 1). All steps in the development of a successful monitoring program are important (table1), but perhaps none is as important as the selection of what to measure. Even if a monitoring program is fully funded and implemented for many years, it will fail if the wrong attributes were selected for measurement. Thus, the ultimate success or failure of the monitoring program may be determined by this one step.

We consider an indicator to be any measurable attribute that provides insights into environmental conditions that extend beyond its own measurement. Indicators are usually surrogates for properties or system responses that are too difficult or costly to measure directly (Leibowitz and Hyman 1999), and indicators differ from estimators in that functional relationships between the indicator and the various ecological attributes are generally unknown (McKelvey and Pearson 2001). Not all indicators are equally informative—one of the key challenges to a monitoring program is to select for measurement those attributes whose values (or trends) provide insights into ecological integrity at the scale of the ecosystem. Pragmatic considerations alone dictate

Table 1. Steps in the design of a prospective environmental monitoring program (from Noon 2002).

1. Characterize the anticipated stressors and disturbances according to the attributes of frequency, magnitude, and selectivity.
2. List the ecological processes, resources and species affected by the stressors or disturbances and the spatial scale at which they operate.
3. Ordinally rank the stressors according to their degree of impact and/or degree of irreversible consequences.
4. Develop conceptual models of the ecological system—outline the pathways from stressors to ecological effects at the appropriate spatial scale of the ecosystem.
5. Select an "optimal" set of condition indicators that reflect the action of the stressors prior to irreversible change.
6. Determine detection limits for the ecological indicators.
7. Establish critical decision values for the indicators (values that 'trigger' a management response).
8. Establish clear connection to the management decision making process.

that only a small number of indicators can possibly be measured. However, strategies and processes for selecting ecological indicators are complex and poorly developed (Barber 1994, NRC 1995).

On way to think of indicator selection is as a filtering process. The goal is to subject all the potential measurement variables to a logic filter that allows passage of only those attributes which provide comprehensive and reliable inference to the status of the managed ecosystem. Candidate attributes include measures of ecological processes (for example, primary productivity, rates of nutrient cycling), structural and compositional elements of ecosystems (for example, distribution and abundance of vegetation community types and seral stages), and species. What these sets of attributes have in common is that information on their status and trends provide insights into the status and trend of the larger ecological system to which they belong.

Developing the criteria that constitute the fabric of the filter is difficult—the scientific knowledge needed to guide this process has generally not been synthesized with monitoring questions in mind. It is clear, however, that the nature of the criteria will vary according the types of indicators considered. For example, the criteria for indicators of physical processes will differ from those for biological processes. Further, within the class of biological indicators, the criteria for indicator species selection will differ from those for indicators that reflect scale-dependent structural and compositional aspects of the environment.

Most of the relational information collected in the biological sciences is based on correlation. While often very practical and useful, dependence on correlational relationships is dangerous in the development of indicators. There are a number of pitfalls associated with such analyses. First, it is very difficult to infer causal relationships from empirical correlations. The fact that many ecological attributes co-vary, a property which forms the logical basis for an indicator-based approach, requires additional logical structures beyond simple correlation to determine those elements that are mechanistically linked to specific ecological attributes of interest. As an example, plethodontid salamanders have been shown to be strongly correlated to canopy closure (Welsh and Lind 1995) but, mechanistically, they are linked to cool moist understory conditions (Welsh and Droege 2001). Thus, in coastal redwood forests, where moisture stress is limited, correlations to canopy closure disappear (Diller and Wallace 1994). Because the relationship between salamander densities and canopy closure is correlational rather than mechanistic, it would only work sporatically as a salamander indicator. Secondly, even those elements that are mechanistically important must be evaluated within the context of the systems in which they exist. Whether a certain density of an organism is considered beneficial or problematic is entirely dependent on the context in which it exists.

Selecting indicators that reflect meaningful ecological change is further complicated by the dynamic, stochastic, and spatially heterogeneous nature of natural systems. Further, many changes that occur in space and time are not a consequence of human-induced impacts, and many are not amenable to management intervention. For example, at least three kinds of changes are intrinsic to natural systems: stochastic variation, successional trends following natural disturbance, and cyclic variation (Noon 2002). Potential indicators that vary by orders of magnitude, due either to cyclic or stochastic dynamics will likely make poor indicators even if they have strong mechanistic ties to the larger ecosystem. As an example, snowshoe hare are the only common winter prey species in the 1 kg weight range in many boreal forests, and therefore are essential to the larger predator community. However, 10-year population oscillations (Elton and Nicholson 1942, Keith and Brand 1979, Boutin and others 1995) mean that several decades are required to characterize these oscillations such that trend could be computed.

Of most interest to monitoring programs are extrinsically driven changes to ecological indicators that arise as a consequence of some human action. Concern arises when extrinsic factors, acting singly or in combination with intrinsic factors, drive ecosystems outside the bounds of sustainable variation. Thus, one goal of a monitoring program is to select indicators that discriminate between extrinsic and intrinsic drivers of change. That is, we seek indicators that allow us to filter out the effects of intrinsic variation or cycles (background noise) from the effects of additive, human-induced patterns of change (the signal we want to detect).

If the purpose of the monitoring program is to provide an early warning of ecosystem decline (or signs of improvement), then its success depends upon having selected an appropriate indicator or indicators, and knowledge of how much change in the value of the indicator signals a significant biological change. By itself, however, a monitoring program cannot (1) unambiguously ascertain the cause of a change (2) help decide on how much change is acceptable (in other words, is the observed change still within the range of acceptable variation?), (3) decide on threshold values of the indicator that trigger specific management actions or, (4) avoid false alarms. Specifically, because indicator activity cannot be expected to translate into precise understandings of most unmeasured elements, the simple idea of triggering specific management response based on the measured level of an indicator likely will likely prove ineffective.

Given the need to choose elements that are mechanistically linked to complex stochastic processes and structures, indicators cannot be selected without the logical rigor of carefully conceived ecological models of the system to be monitored. However, such models should reflect the fact that sustained ecosystems maintain the dynamic variations of key state variables with stable bounds (Chapin and others 1996). Unfortunately, the best state variables to monitor and their 'normal' bounds of variation are poorly known for most systems. As a result, monitoring should be an adaptive process designed to obtain accurate and precise estimates of the indicators and at the same time testing the validity of the conceptual model that lead to the current indicator choices.

Here we provide details concerning the four steps to effective indicator choice: 1) develop a conceptual model which reflects the hierarchical structure of the ecological system to be managed; 2) view the environmental hierarchy as a set of filters which constrain the plant and animal species observed on the ground; 3) identify the collection of traits of a set of focal species that reflect the desired states of the environmental filters; 4) focus on the factors that adversely affect the state of the environmental filters (in other words, take a stressor-based approach to monitoring). We focus on species to provide guidance to indicator selection for both pragmatic and scientific reasons. Pragmatically, we want to take advantage of all the species abundance/distribution data that are already available and continue to be collected. Scientifically, we want to build on the importance of the evolutionary connections between species traits and environmental attributes (Kolasa 1989 and Poff 1997).

Methods

Developing Conceptual Models

To select indicators that reflect the key elements of ecological systems—composition, structure and function—requires well-developed conceptual models of the managed ecosystem (Barber 1994, NRC 1995, 2000, Manley and others 2000, Noon 2002). The conceptual model(s) outlines the interconnections among ecosystem components, the strength, and direction of those linkages, and the attributes that characterize the state of the system. The model should demonstrate how the system "works," with particular emphasis on anticipated system responses to human-induced stresses. The model should also indicate the pathways by which the system accommodates natural disturbances and what system attributes provide resilience to disturbance. These processes could be portrayed by illustrating the acceptable bounds of variation of system components, and normal patterns of variation in input and output among the model elements.

To address all the factors mentioned above, the conceptual model must explicitly incorporate the nested, spatial structure of ecosystems (Allen and Hoekstra 1999, Pickett and Candenasso 2002). Each level of the hierarchy is defined by a set of state variables which yield scale-defined criteria based on the principle of constraint (Allen and Hoekstra 1992). By state variables we mean those habitat conditions expressed at multiple scales that influence the distribution and abundance of species. The upper levels of the hierarchy define the boundary conditions, and thus constrain, the levels below. Constraint arises because the hierarchial levels, or filters, determine the type of ecological community that will be observed. This occurs via a process of filtering out those species whose traits are incompatible with the state of the environmental filters.

Because of uncertainty over the structure and dynamics of ecosystems, reaching agreement on a single conceptual model to guide indicator selection is unlikely. Therefore, competing models are likely but not undesirable. Multiple competing models provide a formal expression of ecological uncertainty. As data accumulate from the monitoring program, they can be used to discriminate among competing models and the pool of potential models will decline over time. This will also lead to convergence on a 'best' indicator set.

Viewing the Environment as a Set of Hierarchial Filters

We build off of two well-established facts in ecology: 1) species are deterministically linked to environmental factors (in other words, suitable habitat), and 2) the mechanism for this deterministic linkage is the presence of specific behavior, life-history, and morphological adaptations. In addition, we assert that the environment is hierarchically structured in terms of physical, chemical, and biological elements and processes (Allen and Hoekstra 1992). Because these elements and processes provide the context for the adaptative relationships between organism and environment, the organism-environment linkage is also scale dependent (Poff 1997).

An ecological hierarchy is a system of interconnected elements and processes wherein the higher levels in the hierarchy constrain lower levels (Allen and Starr 1982, O'Neill and others 1986). Within a hierarchically structured ecosystem, levels are distinguished by differences in their characteristic process rates or spatial scales. Once position in the hierarchy is identified, it is necessary to look both to larger scales to understand the context and to smaller scales to understand the mechanism that give rise to the observed patterns (Allen and Hoekstra 1992). The most well-known ecological hierarchy describes the levels of biological organization—that is, the top-down progression from biomes to genes within individual

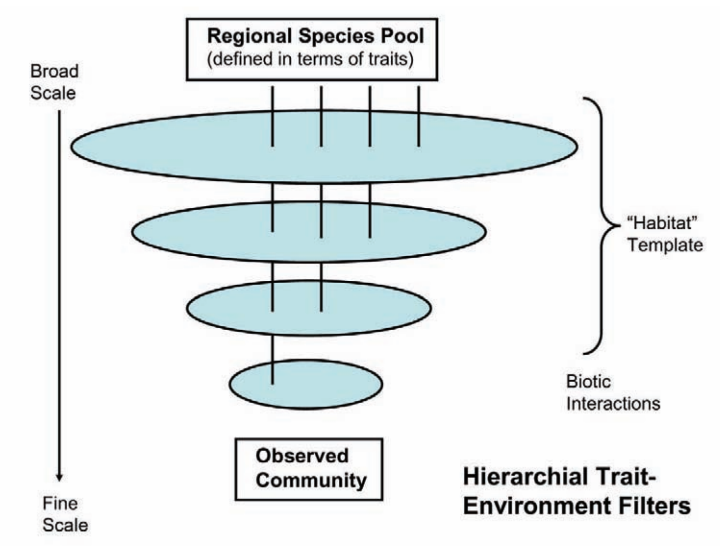

Figure 1. The trait-environment filter model developed by Poff (1997). The environment acts as a multi-scale habitat filter that ultimately determines the species composition of local communities. Species that lack traits suitable for passage through the are limited in abundance (or absence) at smaller spatial scales.

organisms. However, in this paper we refer to a hierarchy of landscape scales ranging from microhabitats to entire watersheds or basins. Following Keddy (1992) and Poff (1997), we refer to the different spatial scales as habitat filters that constrain the expression of species composition and relative abundance at lower scales. Each scale in the hierarchy is defined by a combination of physical and biotic variables that act as constraints on the regional species pool (fig. 1).

The relationship between a species adaptive traits and environmental factors provides the basis of the landscape filter theory of Poff (1997). Each level within the spatial hierarchy effectively eliminates any species whose functional attributes do not allow it to pass through the filter. Biotic interactions are also a potential filter that operates at the lower levels of the hierarchy (Poff 1997). Only species which pass through all the nested filters will be observed as a member of the local ecological community. This model is the basis on which to predict how changes in environmental conditions at different spatial scales will select against combinations of species traits (functional groups) and modify community composition (Poff 1997).

The linkage between species traits and the environment requires a characterization of the environment in terms of a specific set of state variables. These variables form the fabric of the filter—if the functional characteristics of the species fail to match the selective characteristics of the filter, the species will not occur in the community. To achieve the goal of indicator selection requires that both the functional traits of species and the environmental state variables to which they are linked be identified.

We believe the relations described above provide a framework for indicator selection based on hierarchy theory and the evolution of species trait-environment linkages. Both these topics have an extensive literature, much of it theoretical. What we find most relevant is the literature on species environment linkages that specifically incorporate the hierarchal structure of the environment and the role it has played in the evolution of species traits. What may be novel in our paper is the merging of these two areas of theoretical ecology to address the challenge of indicator selection for environmental monitoring programs. In adopting this approach we are emphasizing species composition at local and regional scales as the proximate measure of management success. If the expected complement and relative abundance of species is retained on the landscape then management is providing successful. If the expected values are not observed, then this suggests that one or more of the defining elements of the hierarchal environmental filter is missing. The focus is on functional groups as indicators of the state of the environment—that is, environmental state is the ultimate measure of management success.

Identifying Species Traits Consistent With Environmental Filters

To operationalize the process of defining species-environment linkages it is necessary to: 1) assign each species a trait strength that identifies its tolerance to different environmental filters at each hierarchal level; 2) assign each environmental filter a strength that determines the likelihood that a species with a given trait strength will pass through the filter. Based on these two sources of information, Parsons (19??) proposed a method of predicting local species composition and abundance patterns by multiplying indices of trait strength and filter selectivity to estimate a likelihood of occurrence. Occurrence likelihoods are subsequently associated with different abundance categories (for example, abundant, common, uncommon, rare). Coupling information from the regional species pool with desired environmental states yields an expected species abundance distribution. A comparison of the expected species composition and abundance patterns with that observed will identify "breaks" in the occurrence patterns (Kolasa 1989). Lack of agreement between an expected pattern and what is observed on the ground indicate that current environmental conditions are restricting the occurrence of (in other words, filtering out) specific species or functional groups. Information from trait-environment linkages of the missing species can then be used to identify those components of the environment that need to be changed.

The Use of Species Population Dynamics as Indicators

Species are common components of comprehensive indicator sets for several reasons. Pragmatically, species are often a good choice because they have value to the public. Even if they are not the best choice based on ecological criteria, public interest along suggests their inclusion in an indicator set. Fortunately, however, there are strong ecological arguments for the inclusion of species because their population status is often indicative of disturbance and stressors events that span a range of temporal and spatial scales. For example, changes in stream macro-invertebrate communities are good indicators of acute stressor events that may go unrecorded by infrequent water chemistry measurements. Indicators species may also provide insights to the status and trends of unmeasured species. For example, multi-species conservation issues in Africa and Australia have been addressed by concentrating on "focal species" (Davis 1996, Lambeck 1997). Often these species are simply those with large area requirements in habitats experiencing loss and fragmentation. By sustaining the populations of species with large area requirements, presumably those species with similar habitat requirements, but requiring less area, will also be conserved.

The Committee of Scientists (COS 1999) in their report to Secretary of Agriculture Daniel Glickman proposed the use of focal species as an integral part of the monitoring of Forest Service lands. The key characteristic of a focal species that make it particularly relevant to monitoring was that its status and trend were hypothesized to provide insights to the integrity of the larger ecological system to which it belongs. "Focal species serve an umbrella function in terms of encompassing habitats needed for many other species, play a key role in maintaining community structure or processes, are sensitive to changes likely to occur in the area, or otherwise serve as an indicator of ecological sustainability" (COS 1999). In this paper we have extended the focal species concept by emphasizing those species with strong trait-environment linkages.

The focal species concept differs subtly, but significantly, from the previous "management indicator species" concept. Rather than acting as an indicator of a specific management prescription or an indicator to the abundance of less easily survey species and their associated habitats, focal species allow induction to the state of the ecological system to which they belong. In this sense, the focal species concept is more closely aligned with the concept of a condition indicator (see discussion in Zacharias and Roff 2001). Even though species are key components of the indicator set, they are judiciously chosen so that inference is at the ecosystem level.

For pragmatic reasons it may be necessary to limit the set of trait-species to a manageable number of focal species. For example, in its recommendations for changes to the National Forest Management Act, a Committee of Scientists (COS 1999) proposed a focal species approach to monitoring on Forest Service lands where focal species where largely defined on the basis of their functional role in ecological systems. Others classifications of focal species can be derived by varying the selection criteria including one based on the possession of traits strongly linked to environmental filters. Other researchers have successfully defined functional species groups on the basis of evolved trait-environment linkages (Keddy 1992) and we propose a similar process with an objective of indicator identification.

A Stressor-based Approach to Indicator Selection

To be most meaningful, a monitoring program should provide insights into cause and effect relations between environmental stressors or specific management practices and anticipated ecosystem responses. Prior knowledge of the factors likely to stress an ecological system or the expected outcomes from management should be incorporated into the indicator selection process (NRC 1995, 2000). Narrowing down the list of candidate indicators is aided by an appropriate conceptual model that clearly links stressors (for example, pollutants, landscape change, management practices) to specific levels in the hierarchy of environmental filters (fig. 1). This process enables the monitoring program to investigate the relations between anticipated stressors and environmental consequences prior to irreversible change. Such predictive or stress-oriented monitoring seeks to detect the known or suspected cause of an undesirable effect before the effect has had a chance to occur or to become serious. The design chosen for effectiveness monitoring of the Northwest Forest Plan (USDA 1993 and others) was an attempt to incorporate effects-oriented and stressor-oriented thinking into the indicator selection process (Mulder and others 1999).

Indicator Selection

Figure 1 could be interpreted as either a top-down or bottom-up set of relationships. We have so far emphasized the top-down aspect of figure 1—that is, the environment acting as an hierarchal filter that constrains the species composition and abundance of a community at a given site. It is equally useful to view figure 1 from the bottom-up. In this case, it is the missing species or unexpected abundance patterns that indicate an undesired state for one or more of the environmental filters. Identifying the spatial scale of absence of a focal species or functional group identifies where an undesired environmental state resides in the spatial hierarchy. Thus, the linkage between species traits and environmental filters provides a model for the selection of both environmental and species indicators.

Given the significance of trait environment linkages, it is possible to outline a process of indicator selection. The procedure entails the identification of a set of species based on criteria such as their functional importance to the ecosystem (for example, keystone species, ecological engineers, competitive dominants), their role as an umbrella species, or their legal status (in other words, a listed species under the Endangered Species Act). Because they represent more general categories than species, several authors (Poff, 1997, Poff and Allan 1995, Weiher and Keddy 1995, and Statzner and others 2004) have argued for the identification of functional trait groups defined on the basis of trophic guild, habitat specialization, body size, and vagility, for example. Whatever criteria are used to select focal species, to be useful indicators they must possess traits that are strongly linked to the environment and collectively include the entire hierarchy. Each of the focal species has an expected distribution and abundance pattern based on the desired states of the environmental filters. The distribution and abundance patterns of the focal species then become the species-level indicators.

The process for selecting environment indicators is essentially the flip-side of selecting focal species. Those environmental state variables most frequently associated with the occurrence of the focal species (or functional trait groups) become candidate indicator variables. That is, the strongest trait-environment linkages help define the environmental indicators to be measured. For a given focal species these might include factors such as the abundance and spatial pattern of habitat at the landscape scale, the structure and composition of habitat at the home range scale, patches of food resources within the home range, and the presence of a suitable nest site within a resource patch. Alternatively, specific spatial scales for the environmental filters can be defined a priori. This was the approach used by Poff (1997) and Jensen and others (2001) in their hierarchial classification of drainage basins. Prior to identifying environmental state variables, Poff (1997) proposed the following nested scales: basin/watershed, valley/reach, channel unit, and microhabitat. Within each of these scales he identified measurable landscape attributes (state variables) that could be related to species presence/absence or abundance patterns.

Collectively, the trait-environment model helps identify two types of indicator variables: 1) focal species whose traits (for example, trophic position, behavior, body size, habitat specialization) are linked to environmental state variables, and 2) environmental variables that represent those habitat attributes that must be present to allow the focal species to occur. In addition, the environmental indicators are scale-specific—that is, coarse scale attributes are necessary, but not sufficient, to explain species occurrence patterns in local communities (fig. 1).

Discussion

A comprehensive monitoring program should include indicators that collectively measure compositional, structural, and functional attributes of ecological systems at a variety of spatial scales (Lindenmayer and others 2000, Noon and Dale 2002). Composition indicators usually are species-based measurements where the species measured provide insights to the status of trend of the unmeasured species. Concepts such as guild indicators species would apply here (Verner 1984). Function-based indicators include direct measures of processes and their rates. Examples include primary productivity, rates of nutrient cycling, and water flows. Structure-based indicators, measured at local and landscape scales, include elements such as vegetation structural complexity, among-patch vegetation heterogeneity, landscape connectivity and landscape pattern (in other words, the distribution and abundance of different patch types). These metrics are often assumed to constitute a "coarse filter" because of their ability to predict broad-scale patterns of biological diversity (Hunter and others 1989, Haufler and others 1996).

Both function- and structure-based indicators can be measured at multiple spatial scales ranging from local, to landscape, to regional. In addition, there are composition-based indicators that include the direct measurement of some aspects of a species' life history, demography, or behavior. These are often referred to as "fine filter" assessments because they evaluate the effects of management practices on individual species (Haufler and others 1996).

What we propose in this paper is consistent with these previous perspectives on indicator selection—it is multi-scale and based on composition, structure, and function indicators. What is novel is the emphasis on species traits and their linkage to environmental state variables to facilitate indicator identification. It is based on the understanding that the scaled habitat features of the environment influence the probability that individual species with specific traits will occur as members of local communities (Poff 1997). Viewing the observed biological community as a set of species traits enables two types of inference: 1) from species data to the state of the environment at multiple spatial scales, and 2) from the state of environment to the expected species composition. A missing species or an unexpected composition or abundance distribution is indicative of an undesired environmental state(s). Knowledge of the links between traits and environment state variables thus allows one to identify what in the environment needs to changed and helps guide an appropriate management response.

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Syntheses and Recommendations

Using Information and Knowledge Required In Assessment and Management Applications for Sustainability

Dr. Albert Abee, Planning Specialist, Ecosystem Management Coordination, National Forest System, USDA Forest Service, Washington, DC

A broader concept of sustainability was introduced. Ted Heintz introduced the concept of sustainability as a life sustaining property of earth's biosphere. Ted observed that Life in a wide variety of forms, interacting in networks of evolving relationships, has been sustained for nearly 4 billion years. Sustainability is a property of the system as a whole, a result of the structure of the relationships among its elements and processes, hence an emergent property that is different from the characteristics of the system's elements. Clearly this awesome and miraculous achievement must be our primary model of sustainability. While in recent times global discourse on sustainability as a societal goal is emerging, sustainability needs to arise as an emergent property of human cultures just as it arose as an emergent property of the biosphere.

Democratic processes of governance, market-based economic systems, and science-based information systems provide the institutional processes through which indicator based feedbacks can promote the social learning needed to achieve and sustain sustainability. Information that is most influential is information that is socially constructed in the community it influences. Information influences by becoming embedded in understandings, practices, and institutions rather than being used as evidence.

Societies will always have needed measures that require interpretation to generate information. At the symposium different approaches and strategies for formulating measurement systems were presented. A key ingredient for success is whether or not the information generated from associated measures has any systematic role to play in the realm of management decision-making (forest resources, other managerial context, including a political context). Effective collection and management of sustainability criteria and indicators focused on three issues: First is common agreement on what country level data are relevant to decisions that might assure the respective sector's contribution to sustainable development. Second is relevancy of country level data to regional and local level management. Third is country capacity to collect data and respond to assessment information.

Sustainability is about a diverse set of values. A presupposition of many presentations is that the aspiring social goals of sustainability—social equity, economic prosperity, and environmental health, embody values about the kind of world in which we want to live and maintain for future generations. Participants talked about employment, commodities to support life functions, and the desire for a healthy and secure environment that provides for non tangible human needs and which is inclusive of their national heritage of plant and animal species. Thus, sustainability is about choices regarding what to sustain, how, when, where, and for whom. Because human values are not fixed and depend on social, economic, and ecological context, multiple perspectives on what sustainability means and how it should be achieved and assessed were presented.

Sustainability, however defined, requires judgment about the state of our communities, country, and world. Inherent therein is valuation of those tangibles we believe should persist in space and over time, and the need to identify and agree upon key performance measures, 'vital signs' of sustainability that serve as a barometer of the state of our values. Many participants are burdened with information gathering - much which is redundant, underutilized, or are not value added to decision making. Several speakers reported on the use of the Montreal Process Criteria and Indicators. They demonstrated that organizing around the seven criteria of sustainability enables alignment of activities between scales; focuses scarce resources on highest priorities; and provides a consistent framework that allows continuous improvement processes. Speakers also demonstrated that organizing assessment, planning, implementation, monitoring, and evaluation processes in a unifying framework has the advantage of aligning programs of work together and allows managers to learn and adjust their strategies more rapidly.

Different approaches to generation information were presented. While the 'purest' of systems approaches are important in teasing out inter-relationships, they should not be considered the end all for dialog and decision making. Body temperature is a great global indicator – but it tells us little of why we have a fever. The link between specific environmental changes, the effect on human health, social & economic systems, and ecological condition is complex, often difficult to describe, and remains a significant challenge. Determining causal relationships between specific management actions and changes in environmental conditions will remain problematic because such relationships cannot be fully understood. This does not diminish the need to strive to understand such relationships through system approaches. However, as several speakers demonstrated, (Jim Brown, Paul Brouha, Jeff Horan, etc) C&I measurement frameworks such as the MP C&I are invaluable tools to inform dialog and decision making processes.

The challenge of writing to sustainability is to talk about it in a different way. The global community lives and works in an administratively fragmented landscape. There are multiple ownership patterns and political and/or administrative boundaries with each entity having unique roles, responsibilities, mission goals, and objectives. Yet, there are common, broad, social, economic, and environmental challenges that affect all and that defy remedy alone along administrative lines. No one entity has all the information or control. We need to work together. The importance of having capacity to share data was punctuated. Similarly, the importance of having unifying, agreed upon, 'dash boards' of 'vital sign' measures that cross administrative boundaries, to gauge aggregated outcomes, and inform dialog and collaborative decision making processes, was demonstrated. At this symposium we saw major progress in this area. For example, Dr Hall reported that at the provincial level, indicators have been developed criteria have been enshrined into their forest management legislation.

Condition and Trends of Ecological and Economic Systems

Dr. Harold Bergman, Director, William D. Ruckelshaus Institute and the School of Environment and Natural Resources, University of Wyoming
Sidney Draggan, Ph. D., Ecologist, Senior Science and Science Policy Advisor, Office of Research and Development, U.S. Environmental protection Agency

This Monitoring Science and Technology Symposium was designed to "*put it all together*" for the achievement of sustainability-related goals. It brought together senior policy makers, resource managers and scientists from many organizations and a wide range of disciplines to design a roadmap for addressing critical needs for unifying monitoring strategies, information and knowledge. Discussions during this first Closing Plenary Summary Session were arbitrarily limited itself to a primary focus on Ecological and Economic Systems; nonetheless, the Session did not neglect the import of Social Systems—dealt with in greater detail in subsequent summary sessions.

For this Summary Issue Area, panelists voiced agreement that the overriding focus of the Symposium, rather than being on defining and debating sustainability, was on highlighting monitoring-related tools necessary for—or capable of—meeting sustainability-based goals of differing stakeholders. Also, they voiced agreement that sustainability-based goals, of necessity, must integrate consideration and handling of environmental, social and economic influences or drivers.

The term 'disconnect' was employed by a number of the Symposium's speakers and Closing Plenary panelists. Discussions evidenced two levels of 'disconnect: *overarching* and *ancillary*. For one set of overarching 'disconnect', discussions focused on the split evidenced, overall, between stakeholders in developed versus developing contexts. In developed contexts sustainability-based goals were seen to have a primary emphasis on "environmental" drivers and outcomes, while in developing contexts much more interest has been concentrated on "social" drivers and outcomes. Not surprisingly, another disconnect between development contexts arises with a decided emphasis on newly-developed, technologically-based solutions versus solutions that derive from "simple", existing tools and natural processes. Finally, another example of an overarching 'disconnect' centered on whether "short-term" versus "long-term" perspectives play a predominant role in the process.

Examples of the ancillary type of 'disconnect' identified and discussed by participants included:

- **Disciplinary.** This type of 'disconnect' is exemplified by the well-recognized tension that exists between and among scientific, technical guilds. In fact, this type of 'disconnect' was a major impetus for convening the Symposium.
- **Participatory**. Efforts to address such issues as sustainability goals typically erect artificial barriers between what are known as "decision makers" and "stakeholders". Too often the fact that ultimately each of these interested parties will need answers about—and make decisions on—the sustainability goals is lost in the process and compromises the viability of outcomes. It is expected that this type of 'disconnect' can be overcome through highly-inclusive approaches to development of sustainability goals.
- **Information Integration, Synthesis, Interpretation and Analysis (Assessment)**. There is a plethora of data and information sources that may find use in the achievement of sustainability-based goals. Since they have been collected for differing purposes and at varied spatial and temporal scales, and with varying degrees of quality management, the utility of these resources is easily compromised. The issue of how to assure the greatest interoperability among such resources proves a continuing challenge to achievement of sustainability-based goals.
- **Education, Technical Capacity.** Unevenness in the educational and technical capacity of sustainability partners creates a major 'disconnect'—in particular, in an increasingly globalized context.
- **Performance and Result Evaluation**. Measuring the effectiveness and efficiency of efforts focused on sustainability-based goals is a prerequisite for acceptance and adoption of sustainability-related endeavors. These measures must be incorporated into clearly understandable communications to the varied interested parties.

Finally, during this Closing Plenary Summary Session on Condition and Trends of Ecological and Economic Systems participants noted a strong and continuing need for the varied disciplines represented to focus attention on how the data and information they generate can be applied to decision support tools and models. Need for this capability has been voiced by the wide range of stakeholders (that are formulating or acting upon sustainability-based goals) of whom all are decision makers. That is, decision makers who are from international, domestic or local governments and organizations; or who are consumers, farmers or sustainability-attentive individuals)—so as to make their decisions to protect the environment and public health in the long-term on sound scientific bases.

Problems and Issues Across Institutions and Programs

Douglas Powell, National Monitoring and Evaluation Coordinator, USDA Forest Service
Jim Wood, Director of Forest Resources Program, Natural Resources Canada, Pacific Forestry Centre

The symposium identified the major barriers to collaboration among institutions and programs. This synthesis, while admittedly drawing from only a sample of the papers presented, provides a synoptic view of the major recurring themes voiced by participants.

Several overarching statements were voiced. No one institution or one program in isolation can hope to provide and integrate all of the necessary monitoring data, supporting science and information, or technology capabilities for use of decision makers. Monitoring is the unifying and integrating aspect of natural resource management. Information is the common currency for all resource stewardship activities. Agreement on basic standards for data collection and storage among institutions and programs is required to ensure access to the information and appropriate interpretation of trends. Significantly, science and active monitoring are key components of public dialog and partnership.

Many speakers discussed the need for multi-national and cross-institutional collaboration as a pre-requisite for sound decision making in the 21st century. Participants identified several characteristics of the new century, including a growing global population, increasingly scarce natural and financial resources, expanded global trade and commerce, and greater frequency of natural disasters. This century will demand innovative thinking and a renewed commitment to collaboration. Examples of where environmental disasters have forged new partnerships were presented. Global trade and commerce has created nodes and pathways of moving resources around the world, and this has forced countries to work together. An institution's mission may demand reaching across institutions and programs. For example, space agencies in different countries are collaborating on space sensors and platforms. Modest funding has forced cost-leveraging partnerships and integration.

In Canada, United States, and Mexico, for example, the environment has been identified as the issue most in need of institutional integration. Similar responses exist in other countries and continents. Who has the data and expertise often determines what institutions and programs will work together. Geography of concern defines partners. Complex issues require more program involvement from a wider range of partners than more narrowly defined issues.

Many challenges, problems, needs, and disconnects were identified. Monitoring science is still not considered "real science." Does monitoring science really address the challenges of sustainability? How will we address cultural barriers among disciplines and partners? Data sharing across institutions can be a problem if standards are not in place and systems are incompatible. Intellectual property rights: that is, who owns the data and who must pay for access present formidable challenges. For example, how can we overcome mistrust when sharing data across nations, especially between developed and developing countries? Given uncertainty in how the data were collected, we need to be realistic about the actual usefulness of monitoring data. Sound interpersonal relationships and trust are key to reaching out to others and breaking down barriers. It is important to move knowledge into action and to get the results of science into the hands of decision makers in a form that they can readily interpret, absorb, and interpret. Organizational structures can create significant barriers.

The three North American countries have specific challenges related to national environmental monitoring. For example, in Canada, the distribution of powers among federal, provincial, and territorial governments can create institutional challenges. For example, differing land ownership patterns across the country, diversity of landscapes, and a highly urbanized population with increasing interest in the rural environment. The relatively small population compared to the immense size of the country presents unique challenges for ecological monitoring. The country struggles over the definition of ecosystem health and debates continue over meaningful indicators with which to measure it.

In the United States, there are many definitions of monitoring, which often hinder communication. There is a tendency to collect much data and use only a fraction of it. We lack consensus on what are the few vital indicators to assess environmental health. There is some level of distrust of government and industry, which makes information they provide suspect; hence the need for transparency. Organizational incentives and rewards are often lacking. There is no national monitoring program for rangelands or grasslands. Multiparty monitoring is being demanded by many interested parties.

In Mexico, challenges to the development of an effective national monitoring program include: lack of existing national monitoring programs; differing institutional mandates at the national, state and local levels; long term institutional stability; data access at the appropriate scale; and lack of consensus on which environmental indicators to monitor (both ecological and social). The lack of a multi-scale policy on what to measure, how, where, when, and why has led to problems with data integration, comprehensiveness, completeness, scientific credibility, technical defensibility, utility of results, and limited inter-operability.

Many recommendations and potential solutions were offered by speakers to overcome barriers:

- Science evangelists must build support among all key sectors.
- Improve the efficiency of data sharing and management through adoption of standards and definitions. Data accessibility can break down barriers; citizens can compare data from a variety of sources. Geospatial interoperability--involves data standards and easy access and use.
- GIS is a great integrator and revealer.
- The path forward for monitoring for sustainability is partnerships among scientists, public, and resource managers in which technology transfer plays an important role in bridging the gap among all three sectors.
- Use infrastructure and governance of local communities to involve people.
- Keep monitoring simple: easier to conduct, understand, and communicate.
- Clearly define to decision makers/organizations how breaking down institutional barriers will be of benefit.
- Have all the ground work completed with pilots and demonstrations to illustrate vision and desirable outcome.
- Communicate/communicate/communicate.
- Reduce risk for decision makers; show how costs outweigh benefits. If you have a good idea/vision keep at it and look for the window of opportunity.
- Think big; have a vision that will excite and lead to positive outcomes.
- The concept of "boundary organizations" was put forth as an important means of overcoming institutional barriers to collaboration. Boundary organizations were defined as organizations that were created to address a specific issue in a particular time frame. They often have their own governance structure and consist of resources, both human and capital, from many organizations.

Many valuable lessons were shared. Government has an important role to play in bringing diverse groups together and in reaching out to the private sector to improve science and technology. Technology developed by one agency can find application by other agencies.

Identify shared vision and specific objectives. Senior-level managers must support monitoring and not see it as a threat. The process is of equal if not greater value than the outcome. Different institutions bring different expertise and perspectives to the problem. Indicator selection should be a partnership endeavor. Collaboration can be synergistic and achieve cost efficiencies.

Different countries adopt different views of sustainability. Environmental focus in the developed world and socially focused in the developing world. Be opportunistic and inclusive, work with all interested parties. Maintain continual dialogue between scientist and managers or program will disappear.

Standard protocols are necessary to withstand scientific and legal challenge. They are useful also in helping managers understand the complexity of monitoring and the need for appropriate designs.

Toward a Unified Knowledge-based Society for Sustainability—Developing a Synthesis on the Methodological Level

Alec A. Schaerer

Abstract—*The debates on development manifest an increasing concern for sustainability, but as yet little awareness of the hierarchy in the ideas through which humans contribute to the problem. This gap is widened by a widespread but nevertheless unnecessary acceptance of unreasonable elements such as paradoxes, or the general fragmentation in knowledge, or allegedly general limits to it. First the character of such impediments is assessed, partly in theoretical considerations and partly through examples. This analysis reveals the root of a widespread self-limitation in thinking. Understanding its structure allows to synthesize an approach in which the problems do on principle not arise. It is conceptually precise but nevertheless universally applicable within the chosen query perspective, and hence useful for unifying knowledge toward a general sustainability of development.*

Outlining the Problem

The contemporanean social sciences describe an astonishing feature: in the known period of history, there has never been as much activity in international relations as now; and yet since a few decades the common of mortals feels increasingly insecure (see for example Beck [1992], [1999], Frank [2002], Landes [1999], Monbiot [2000], Stiglitz [2002]). A new uncertainty on the global level produced fear and mistrust, making arise two calls: one for more rules, laws, prescriptions, and power, as well as one for indicator systems and methods for measuring the sustainability of the development. But can they dissolve the core of anxiety, fear and distrust? Upon approaching a tunnel, one would understandably like to know more about it. Wanting to know the conditions and obstacles on the path, and making sure one can defend oneself, can be useful ingredients, but do not include the clarification of one's own perspective to the point of excluding securely one's own stance and contribution to the problems. After all, the latter are mainly man-made. The crux seems to be in the pursued objectives, whose legitimacy seems to have no better foundation than interests and values. But approaching them on this basis must remain vague, since—as Max Weber famously has argued—even the validity of values cannot be ascertained scientifically. Nevertheless, for a sustainable solution it is necessary to develop a securely complete view, including all of the viewer, his ideas, and ways of thinking. Here we encounter an obstacle that looks formidable at first glance: contemporanean philosophy and science declare in unison that certainty and completeness of view are unattainable ideals. Are we thus left only with the 'choice' of more measurements and more rules? Since these always stem from mere perspectives and can never cover all cases, they can never warrant ultimate objectivity. Somebody will always attack them, feeling sufficiently justified by being limited. Is strife and conflict therefore inescapably our lot? Acting out this belief produces more fear and distrust, more armor and bristles, more conflict ... a vicious circle (which is, as mentioned, precisely what can be observed empirically already now). Hence the question is when does one start to think about the origin of the vicious circle? The uncertainty and incompleteness of contemporanean philosophy and science make also the assessment unreliable whereby there is no other path than theirs. For thinking beyond this 'mental sound barrier', must one be coerced by pain and sufferings, or is there some prospect of success for starting to think before?

As is being emphasized in cultural anthropology, a culture survives through producing and offering encouragements for thinking before hardship arises, for being able to avoid pointless suffering. Such encouragements can only be effective when they address the understanding of problems at stake and hence the conceptual level of the public debate, even if the means for conveying a message must of course be material (the carrier of meaning should not be confused with the meaning itself, e.g., a messenger with his message).

One of the endeavors in this direction was the symposium "Toward a Unified Knowledge-based Society for Sustainability." The emphasis on unifying knowledge is a wise choice, given the fact that only a securely complete perspective can warrant any real sustainability. Yet this emphasis proved to be a daunting task for the vast majority of the symposium participants, even though many manifested a sincere desire to move in this direction. The problem seems to be in not knowing how to unify knowledge. One layer more deeply, the crux of this 'how' is rooted in the difficulty of realizing that bridges towards more unified views can only be built by means of conceptual work, which can itself only be discussed in concepts, which then may sound very far away from anything 'real' or even 'normal' according to the practician. He or she is not trained to operate in conceptual considerations per se. Yet this level of intelligibility as such is and remains the decisive locus. Everything else revolves around it, in a preparing sense or in the sense of consequences. For secure sustainability, science itself must become fully sustainable. In this light the unifying potential e.g., of physics is insufficient, as it approaches reality in terms of 'things' without addressing fundamentally the conceptual instrumentation for grasping them in a strictly complete and secure way. This systematic incompleteness is not debated sufficiently. What may look at first like a sustainable path in one perspective can look very limited in a more encompassing view. An example: medieval Europe wanted to sustain its expansion, as colonialism was under way, so it cut down forests wildly for construction work, especially in the Mediterranean area—producing problems of erosion and draught for our era. Yet at that time all experts agreed that trees grow anyway and that therefore the chosen path was reasonable. Today many will laugh at such a crass example. But the type of problem still remains: believing to know about totality is not the same as securely knowing about totality.

In such situations, the crucial question is what kind of path one wants to pursue. Under the impression that one has to decide and act under the presently given conditions (uncertainty of knowledge), there is no other choice but to proceed pragmatically, adopting the state of the art and hoping for the best—even though this may not be the optimal solution, or may even lead ever deeper into problems. The vast majority of the currently debated theoretical streams has nothing better to suggest. Nevertheless, this path is not totally satisfying—which is not very astonishing since it has its roots in mere beliefs. While some practical decisions may have be taken pragmatically, it is thus very reasonable to limit these to the strict minimum, pursuing simultaneously also all investigations for reassessing uncompromisingly the very foundation of methodology towards the prerequisite of real sustainability: a real unification of knowledge.

From a thoroughly encompassing point of view it makes thus sense to address especially the fundamental interconnections in a new way; that is the purpose of this essay. First I will outline a problem that has escaped broad attention: the character of the limits to knowledge that are inherent in today's mainstream methods, whose root is in the habit of setting out from basic assertions (axiom, definition, hypothesis, etc.). This is relevant for our topic, since many difficulties also in the sustainability debate are only a result of not having come to grips with this point. While practically everybody admits a limit, many believe today's basic beliefs will always offer possibilities of overcoming it (as in pragmatism, scientism, etc.); others know the limit but believe it is absolute since all currently used approaches manifest it (as in skepticism, postmodernism, etc.). But the limit is not absolute: it is determined by the categories in which knowledge and thinking is being thought. For disentangling this web we will have to get into some thinking of the philosophical sort, moreover one that goes beyond the habits of today's mainstream. But I will try to show that it can be done without needing previous philosophical knowledge. It is sufficient to face squarely the relevant points. This analysis paves the way for the approach I propose: 'systematic attentiveness,' covering the subject matter as well as the categorial instrumentation. It solves the crux by clarifying fully the nature of perspectivity and then developing systematically a special kind of concepts, which are strictly universally applicable within the chosen query perspective. They allow the new approach to be not only inter-disciplinary (useful for academic disciplines interacting), but trans-disciplinary (useful for general interaction—also with firms, NGOs, administrations, the civil society, etc.). For not remaining in abstraction I slip in some practical examples of where conceptual problems lead, taken from economics and medicine, as they are relevant to our topic: real sustainability. I close this presentation by outlining how systematic attentiveness can be implemented in practice. Since it is universally applicable, I will apply it first to the crucial point, the process of thinking, including the mind thinking itself—which usual approaches can cope with only in compromises. Then I show how it allows significant advances in traditional scientific fields, exemplified for the problem of sustainability by its own domain of debate: the geosciences.

In the Vein of an Introduction: Concepts and Their Relevance

Some might wonder why conceptual work should be decisive, especially since the currently prevailing opinion is that any knowledge should be based on empirical facts for being reliable. The basic idea is that something must exist for being able to talk about it; clarifying first fully the instrumentation for thinking and talking about everything is still a relatively rare endeavor. In trying to find an orientation in the maze of the many perceived external things and internal emotions, in thinking and talking about them, people have since long been using expressions for characterizing them. But using them is not the same thing as being aware of their relevance in the cognitive process, which is necessary for constituting reliable knowledge as opposed to expressing mere belief. The problem is that any observable fact can be interpreted in different ways—more or less completely and more or less correctly, depending on the conceptual frame of reference. In fact, any description inevitably contains an interpretation, due to the specific perspective out of which it arose (any expression is said to be 'theory-laden'). The ultimately decisive element is always in the deciding mind—which must make sure, by considering fully the context, that its interpretation is adequate. For achieving this, the difference between the perceptual and conceptual side of the cognitive process is essential, and it can adequately be conscious only when thinking in terms that are finally beyond all observability, i.e., which are of conceptual nature themselves. For making completely sure, the structure of the conceptual side must thus be accepted as part of the necessary considerations. This endeavor constitutes philosophy proper—as opposed to (natural) science, which is dedicated to observation and description, not to purely conceptual considerations.

In the course of history, many philosophical theories have been set up about the conditions for warranting knowledge, differentiating aspects in the cognitive and discursive process. They manifest different grasps and understandings of the mental correlates of observed facts, which are understandable as a result of different foundational assumptions, and ultimately of varying degrees of self-awareness of their authors. Such differences appear collectively in the historical development of ways of thinking, in types of philosophy, but also individually, in differences between persons. Whichever way these differences may be structured, they can be assessed fruitfully only in purely conceptual terms. Wanting something existent as a foundation for assessing conceptual structures—as for instance in 'naturalizing' epistemology (taking results of natural science as a theoretical foundation), or in rooting mathematics in (mental) objects—inevitably engenders limits. They may not easily catch the eye, but will invariably limit the validity of the respective philosophical theory. In a pragmatic use of such theories their limit looks negligible, but it is crucial for complete reliability—as in needing a foundation for overall sustainability. In a strict view it is not sufficient to remain in beliefs that worked till now, as this would only mean prolonging into the future a knowledge that was useful in the past.

Since orientation in the maze is a problem of types of order, it is not astonishing that the developed conceptual means finally address forms of order. This is not a presently prominent view, because the explanatory traditions have developed on the basis not of the explanandum ('that which is to be explained,' seeking to understand ways of handling types of order, which occurs also in types of order), but of the explanans ('the means through which an explanation is to be achieved,' i.e., the linguistic instrumentation for handling types of order). Philosophy developed historically in considering first the nature of being as what things are in themselves; this view does not cover securely the thinking agent itself, so then consciousness as the locus of thinking was contemplated; this view too does not allow all of the desired understanding, so lately the emphasis is on language as a general mediator. Although this is today's state of the art, it does not mean that the development can go no further. Presently the difference between language as a structural principle, the uses of language, and the ('preverbal') mental processes behind these uses, is coming into focus. The question is how the old border can be crossed.

When setting out from the linguistic instrumentation, the complex on the thinking side (autonomy, 'I,' personal identity, the psyche, thinking as an activity, etc.) looks mysterious, because the decisive part is an activity in choosing ideas (types of order) for putting them into material reality. Viewed 'from outside,' the act must seem mysterious or at best spontaneous, because its origin is directly evident only when one does it oneself in self-awareness (which may be rooted in perfectly clear reasons). Thinking in linguistic terms can 'see' only results, not the activity itself. This gap can't be closed by formal methods of any sort or amount, as formal logic can preserve truth in the logical steps, but not find or constitute any new truth. On its path the danger is to invent so many formal subdifferentiations that one 'ceases to seek the forest, being busy with all the trees.' Further down we will again come across the problems produced by thinking in instrumental terms, for probing this issue some more. The underlying thrust behind today's philosophical development, on its path of finding the ultimately relevant forms of order, is and remains therefore the need to make fully transparent the structure of the conceptual side. Whether one is aware of this need is quite another question.

Handling types of order has essentially two aspects: one of order in the world and one of order in the mind. This does not imply introducing a dualism, for instance of a Cartesian sort, but that any lack of clarity implies a difference between two aspects, of which one is querying the other. Whether these two aspects can be unified is not prejudiced by this distinction. In broad brush strokes, the first side is marked by words like law, sort, structure, type, etc., the second by words like concept, idea, notion, term, etc. There are bridging elements, marked by words like content, meaning, order, etc.. The used words are less important than what is being meant by them—while the crucial point is that thinkers are responsible for their mental order, their interpretative structure, because they themselves build it up, albeit under social influence.

Talking about forms of order (laws) evolved in two traditions: universal realism encouraged thinking of actual order in nature (lately called 'truth-makers' of corresponding propositions); in parallel, and opposing universal realism, nominalism fostered thinking about statements concerning regularities, maintaining that forms of order (laws) don't exist as such. This second position, looking more tangible, has been dominating—producing a widespread imprecision in conceptualizing man-made laws and laws of nature (forms of order) by conflating order and involved agency. Then the overall order cannot be grasped whereby a combination is as it is, and not otherwise. Yet laws as such can't act in any way, they have nothing coercive in them. The question is whether one thinks about them on the level of everyday talk, or of complete intelligibility. Where a form of order is conceptually mixed up with the agency, the process is not thoroughly understood.

The nominalist view—whereby there is no objective order in the world, holding that all we have is statements concerning regularities—can of course be maintained, like any other belief, but at the cost of losing touch with part of reality, namely the mental and worldly agency. It is not only an incomplete view, but also an incoherent one: if there were no laws, no order in the world, as maintained, it would be impossible to distinguish anything from anything else. The fact that things are distinguishable, but just as they are, is a form of order. The question is whether one wants to admit an overall order, for then analyzing its substructure.

The tricky thing about pure forms of order is that they are a structure of content, balanced in itself, which looks different depending on the content implied in approaching it. Following, this aspect will become more explicit, using the law of the circle as an example: depending on the used conceptual elements in seeking to formulate a definition of the circle, the definition will look different; it is true within that perspective, but covers only the corresponding part of the implications of being a circle, while no definition can ever encompass all of them. And yet a thinking mind can refer to the pure law of the circle—otherwise it could not reach any true conclusions in new considerations. Whether one is aware of a mental act (such as referring), or whether it occurs by dint of influences beyond one's full control (as in automatic reactions, or in obeying blindly a formal rule), is another question. The function of elements and structures of order in the mind—in short: concepts and theories—is to allow referring consciously to pure forms of order (for instance laws), for handling them adequately in processes of thinking and verbal interaction. The question is whether they can really warrant this performance. For example believing that concepts can only be of linguistic character, i.e., that no other elements can be relevant, confuses the material existence of elements with their structural necessity. As we will see later in this document, precisely those elements which are decisive for intelligibility—for example laws and forces—cannot easily be said to exist in the usual sense, even though they define the gist of existence of 'things'. Wanting to base one's considerations only on what is somehow tangible is not ultimately reasonable.

Few people realize that absolutely any content implied in approaching pure forms of order tint the impressions of what is being approached. Also the habitual gesture in philosophy and science of setting out from basic assertions (axiom, definition, hypothesis, postulate, premise, etc.) is such a content. Formally speaking it is a step of pre-determining something 'plausible' of the subject matter before it has been given the chance to present itself in its strict totality to the querying awareness. Namely formal systems, rule-based systems etc. inescapably embody this prejudicial character. But believing in 'plausibilities' limits the validity of the respective theoretical system. Due to its initial successes this gesture has been extremely attractive, in spite of its long-term drawbacks; it engendered the predominant abstract way of dealing with everything, irrespective of its nature—the gesture of administration, dominance, management, technique, etc.—and made computers ('that which obeys all orders') ubiquitous. The ultimate incompleteness of understanding, which this gesture embodies nolens volens, is the reason why we then are compelled to reflect back on our doings, wondering for instance about sustainability.

The difficulties in approaching pure forms of order appear also in today's concept of 'law of nature.' Quite generally, and in spite of its importance, the concept of law of nature is far from being clarified. Not being able to approach phenomena and the process of thinking them in one homogenous (i.e., universally applicable) conceptual framework led to a widespread belief that a multitude of types of laws (in the linguistic view: law statements) must exist—causal laws, laws of synchronic coexistence, structural laws, laws of functional analysis, etc. (see for example Armstrong [1983], [1989], Earman [1978], [1984], Hooker [1992], [1998]). Hooker has put the crux as follows in the Routledge Encyclopedia of Philosophy in the entry "Laws, natural":

Some laws are inclusionary: all electrons have charge e; some are exclusionary: nothing travels faster than the speed of light in vacuo. Some laws are deterministic: f = m·a, Newton's second laws of motion, while others are statistical: given an incident UV photon, a skin cell has the probability P of dying. Some laws interrelate localized individuals (for example, the gas coexistence law PV = T), others concern field states (for example, the superposition principle, which has no equivalent among individuals). Symmetries, that is, invariance constraints, ground derived structural laws and may lie behind causal laws (quantum field theories). There is no single or simple relationship of laws to causes (of law statements to causal statements). ... Nor is there any single or simple relationship between laws and regularities (between law statements and descriptions of regularities). .... Conversely, empirical regularities have diverse relations to laws.

The distinction between order and agency opens a path to unlimited processual clarity: in nature, forces associated to an order produce material structures, and in the mind, the will of thinking must associate correctly the respective law with its condition of applicability. In this light it is amusing to hear for instance some physicists talking about 'changing laws of nature' and mentioning e.g., time, or the speed of light, as examples—which are not laws at all, but phenomena rooting in more basic forms of order. Based on the nominalist line, they developed a habit of calling a 'law' the mathematical notation of that law. But this entails its cost: one is then seduced into talking for instance about 'reversible processes' because in the respective mathematical notation time happens to be reversible; yet in reality no process can ever be reversible; a pattern may look the same again, but the constitutive bits of matter are changed.

Instead of thinking regularities in the countless events as accounts of how things appear, exist, vanish, and new ones of the same type reappear, the idea of regularity was thus reduced to those partial (mechanical) aspects that became known as the laws of nature—the laws of classical mechanics, of gravity, of thermodynamics, of entropy, etc. Applying such rigidified ideas, notions, and concepts, inevitably fragmentizes the view and counteracts the flow of life as a whole, constituting an obstacle for the completeness of understanding. To remain within physics for a moment, is for example gravity only something that happens between singled-out material objects? If yes, at the end of this line of reasoning, one cannot avoid postulating a carrier of this specific effect (gluons, gravitons, the Higgs field, or maybe entanglement itself mediating mass). Then mass and gravity must look mysterious. Of course this line of thinking allows to develop theories that correspond quite well to empirical measurements; nevertheless it remains in the basically paradoxical nature of 'looking from outside at the object,' which can't warrant complete self-transparency because it can't encompass also its own act (not only in the quantum approach a 'blind spot' remains; this crux is discussed later.

Quite generally, the way concepts are usually being conceived, they have become traps for a process of alive thinking. Based on the presently dominant idea of life, scientists are busily searching for life all over the universe—but that type of definition excludes the possibility of recognizing other forms of life, even if they appear under one's nose. With narrow definitions, one can't realize for example that the most alive process is completely conscious thinking.

The point of concepts is to allow referring to types of order (e.g., laws) for handling them in processes of thinking and verbal interaction. As an example for handling facts through laws we can take the law of triangularity in geometry. One can define general triangles, rectangular and equilateral ones, etc., and all interactions, and believe to have captured neatly the problem of anything appearing in a triangular way (an analogy: appearing in a material way). But the point is that the law of triangularity actually means simultaneously the precise order of being triangular in structure and the freedom of allowing all possible triangles. These look different depending on the medium of appearing; the law of triangularity can become manifest only to the degree allowed by the intrinsic order of the medium.

Thinking geometry in a strict way means handling its conceptual elements in an absolutely clear way. Then the law of triangles reveals having itself two polar aspects: triangles can be approached either as three straight lines crossing each other, thus defining three points, or as three points that are joined, defining three lines (in analogy: wave or particle view). And what do you see in three lines crossing each other (not in one point)? A triangle? No, there are four of them, of which three go through infinity. Note that in infinity the triangular area delimited by a line changes sides; further down we will encounter again content that is polarized under the condition of strict totality. Paradoxes—also e.g., in the quantum approach—arise when the facts are not grasped conceptually in their infinity, i.e., when the completeness of interrelations is pictured somehow, but not in its strict totality. Today's science sees the phenomenal aspect of reality. But this is only one side; as mentioned, the conceptual side is at least as relevant: it determines the interpretations of the phenomena. In any complete view it is the decisive part and should thus duly be considered. The complete law of the geometrical triangle, covering infinity—which is not only quantitative – does not invalidate any casuistry of triangles, but complements it decisively. In analogy, the complete law of materiality covers also the part which still remains hidden in 'complementarity,' 'non-locality,' the 'velocity' of light, the 'black holes,' 'dark energy,' and other limits in today's physics. For a truly complete understanding, it is not sufficient to encompass all objects; is it necessary to grasp also fully the categorial (and hence conceptual) elements that determine the chosen perspectivity. Not having achieved this is why for instance the quantum approach shows that observation must somehow be implied ('decoherence,' 'entanglement'), or in the relativity approach that moving objects must imply a mutual relation, while the respective physical theory cannot explain completely why and how this is the case. Categorial (and therefore conceptual) strategies that allow things to become manipulable—in the mind or in the reality 'out there'—embody the danger of self-deception by believing to be in control. Then errors are compelled to add up in effects until becoming empirically conspicuous—producing crises, and manifesting an inefficient research process.

For some these considerations might sound relatively unworldly, interesting only for a few wizards. But in fact they concern us all directly. So let us go through a practical example that shows the relevance of conceptual structures and is fairly clear to the open mind: the way resources are being handled, due to ideas—embedded in the currently dominating economic system and its theoretical foundation, economics—which determine the activity.

A Practical Example: Conceptualizing the Economic Process

Especially in the debate on sustainability, the notion of 'resource' is essential, but it remains vague. Since the Brundtland Report the distinction between biotic (alive) resources and abiotic (mineral) resources is being neglected—in spite of crucial differences in their characteristics (e.g., renewability and its cycles). The idea of sustainability is now being used for both types of resources, even though the mineral ones are clearly nonrenewable and subject to irreversible degradation (e.g., Georgescu-Roegen [1971]). The Western hemisphere owes its rapid rise to an extensive use of mineral resources. By allowing exponential growth, which abiotic resources can't permit due to their renewability cycles, they nourished the thermo-industrial revolution. The new habit—widespread especially among economists—of not distinguishing adequately between the two resource types, talking only about 'natural resources,' allows to maintain the illusion that exponential growth can generally be sustained even though the technically induced entropic degradation, and the transfer of lithosphere material into the biosphere, are of course limited. The unclear conceptualization was pushed into wide acceptance by influential agents, pleased by a rosy picture of eternal economic growth.

The self-deception is no accident, but the result of a technological path-dependency based on a belief that institutionalized property rights (ownership as power of disposal, 'Eigentum')—which allow for instance to sell and purchase goods—can constitute a generally sustainable order. Many forget that this aspect of property depends on a more fundamental one, namely possession rights (ownership as entitlement to use, 'Besitz') due to competences in dealing with things. As an institutional pillar, property has two economic potentials which entail a hierarchically ordered logic of decisions: as an entitlement to possession, property defines rights of use by competence; as an entitlement to dominion, it offers security (under mortgage) in credit contracts, allowing property societies to create endogenously the institution of money in a specific way. This contract structure has a strategic value through the pressure of contractual indebtedness, which stipulates a repayment within temporal limits, burdened by interest on capital and defined according to the monetary standard of the creditor. This structure explains why vested monetary interests call for 'ownership society,' but not for acknowledging implicitly engendered burdens, making others carry them. This conflict arises by splitting off competence (understanding as regards content) from property (formal dominion).

In dealing socially with objects, the way of handling the difference between possession and ownership determines on principle any economic system. Agrarian societies usually operated on the basis of possession in the cycle of biotic resources (which are renewable) for agriculture and energy; this made the process sustainable. The situation changed with the emergence of industrial society and the invention of property rights. Industrial society made extensively use of mineral resources (which are not renewable)—and then became addicted to their characteristics. The corresponding institutional framework will thus naturally favor two types of technology and social engineering: those enabling a direct translation of its structural pressure into material production (essentially the thermo-industrial methods, which allow exponential growth but impose entropic degradation and pollution); and in the domain of non-exponential growth those methods which permit possession structures, accumulated in the past, to be converted into structures of future dominion (biotechnology, privatizing water sources, transferring collective knowledge into 'intellectual property,' etc.); for instance an interest in species diversity can then exist only insofar as nature becomes instrumentally exploitable. For an analysis see Steppacher in Bieri et al. [1999], contextualized in a discussion of modern agriculture.

Any institutional framework based on property rights (not possession rights) can't avoid making everything into a commodity, forcing new markets into existence and imposing the standard of monetary decision-making. The latter engenders itself an exponential type of growth by the way money is being institutionalized: not as a means of free exchange, but itself as a commodity, with a price for being used. In this way, money can be made out of money—a seductive idea for many. Money is being put in circulation through a primal debt, by central banks crediting commercial banks which then credit individual borrowers. Following the logic of property (not possession), the central banks were gradually all privatized. At each step the debt inevitably increases (since everybody on the way wants his part of the cake); it shows in the interest rate which forces borrowers to pay back more than they had received. This debt burdens all facilitated infrastructure for production; as a side-effect, prices of goods contain an increasing portion of cost for paying back the invisible series of debts that allowed to produce them. The reality of today's global monetary system is not full freedom, as many believe, but coercion organized in an imperceptible way. Everybody is subject to it; whoever manages to operate close to the monetary origin is not free either, since being there requires endorsing beliefs that don't allow to overcome on principle the system.

This system and its money is burdened by another theoretical problem: goods are valued (and hence measured) in monetary terms, while the value of money is measured via the total amount of goods (the 'domestic product'). One accepts thus 'A is a function of B, while B is a function of A,' which would not get mathematics very far. Applying this questionable basis (the domestic product), combined with subjective value theory, leads to a valuation of money that coerces agents, through the competition on the monetary market, into following the rule of return on investment. As a result, money can never become a free medium of exchange that serves everybody in equity: the 'big' capitalist always has an advantage over the 'small' one.

What is currently being called 'globalization' is essentially a process of globally imposing property conditions, which entail corresponding techniques and technologies. This process is obviously not sustainable in a strict sense, but the conceptual basis of mainstream economics does not allow the insight that the process stands on an ice floe that is melting away under our feet, while most of the critique of globalization is based on vague hunches. Solving the problem requires a solid knowledge of the conceptual structure that produces it. All its aspects are a result of mere assumptions and thus purely conceptual distinctions; therefore no amount of empirical work on this basis can ever amount to any uncompromised solution. In the face of its challenge, economics sought to secure its methods by means of mathematical rigor. But no amount of handling empirical data with sophisticated mathematics can ever bridge the induced gap in fundamental content. As Geoffrey Hodgson [2004] has put it succinctly, discussing a critique of mainstream economics by Mark Blaug and Tony Lawson: "the victory of technique over substance is a chronic problem within modern economics." Basing the abstractions on empirical data allows to grasp some of what has been done until now, but not the overall law of ecosocial process as a whole and—based on that—an insight into the way things should be. Accepting what has been done until now as the order to be followed in future is one version of the 'naturalistic fallacy': in spite of widespread beliefs, no 'is' can ever constitute a sufficient basis for determining the 'ought'. In following this path, one finally produces an inflation of words, which may sound like justifications to the credulous but must fail in complete reality. An economics allowing 'laissez-faire' finally fosters the law of the jungle. By prolonging habits of the past instead of achieving fundamental clarifications, mainstream economic thinking has allowed moral weaknesses to thrive—to the point that agents in the resulting system became psychologically dependent on them. This shows in needs of publicity to keep consumption going, or in the irrational pursuit of economic growth due to an addiction to high returns of investment. By its type of approach, such a theoretical system can't contribute directly to moral strength. Tougher ethics can't lead to a real cure, because the morally conditioning influences reach more deeply than such correctives can ever handle. Under such conditions it is no coincidence that only few cultivate an understanding of life, and the respect for it as a whole.

The biotic resources and their particular qualities—impossibility of exponential growth, restrictions in time use due to renewability cycles, hence an impossibility of utilizing fully the production capacities, and a relative unattractiveness for monetary capital seeking returns on investment, etc.,—led historically to incompatibilities with the logic of property. The sheer dependency of society on biotic resources has made necessary some restrictions of this logic, for example as rural rights of inheritance, environmental and developmental planning, subsidies and protective tariffs. The actual dependency leads to double-faced official reactions: on the one hand proclaiming rules as stipulated by the WTO, on the other hand trying to maintain a protective agenda. Property is a reasonable relation for handling inert entities, but it produces tensions—thus reducing the overall efficiency of the process—when dealing with alive ones. Wanting to manage scarce resources instead of fitting the man-made process into the natural process, any exploitable potential is being called a resource, encouraging boundless pillage. But resources being scarce is not as primordial as their being available in nature's organization. Imagine living on a barren rock! In agriculture, introducing industrial technology up to genetic manipulation can't offer sustainable solutions, as it shifts the problem to other realms by not addressing the overall law of the process. A problem can become invisible in a theory, but conflictual results finally always call us back. Some aspects of the real solution have always existed, but were pushed aside by powerful interests vested into the logic of property. They can be found from works in the Marxian tradition to Veblen [1919] and modern ones such as Steppacher et al. [1977], or Heinsohn and Steiger [1996].

Problems stem also from neglecting the distinction between the use value and the exchange value of goods. Adam Smith eliminated the use value as a result of thinking in terms of trade, believing the exchange value reflects adequately all of economic reality. One consequence is the 'diamond-water paradox': why are actually useless diamonds expensive while water, essential to all forms of life, is cheap? Believing the value of goods is determined by what the agent is ready to trade in (the imaginary values of 'subjective value theory'), overlooks the real value (or use value), which determines existential reality and hence also politics. This view forgets the law of nature that governs all forms of economy: the act of setting resources into value is the necessary and sufficient condition for carrying the whole economic process and constitutes thus the fundamental form of capital, prior to any subjective assessment (in monetary or other terms) and to activities like saving or investing. Usual forms of economic value—property, monetary capital, interest, means of production, labor, human capital, natural capital, etc.,—are secondary, a juxtaposed layer of imaginary values (Schaerer [2003b]). This intrinsic overall law of the ecosocial process contains as aspects the usual laws of economics (e.g., production function, law of diminishing return etc.), and governs all economies—irrespective of being subsistence toil or high-tech, involve money or not, are capitalist or socialist, growing or recessive, etc. Due to its 'enveloping' quality, this law is a solid basis for determining the real value of money—in contrast to the intrinsically limited considerations via the social product.

Since theory did not discover the law of nature that governs all forms of economy, it could not optimize and harmonize the economic process out of a secure overview, but had to take archaic pseudo-optimizing features such as personal interests ('homo oeconomicus'), the need to know ('complete information'), or the need to survive ('competition') as allegedly relevant theoretical elements. Once the idea of exchanging goods is chosen as the theoretical basis—not the ecosocial process—the whole can be grasped only in its trade and commerce aspect. As a result, all income must be squeezed out of this type of activity while the theory excludes sources and sinks of the process, locking them up in 'ceteris paribus' clauses. Theory sacrificed the overall advantage of division of labor to its one-eyed view, and allowed survival to depend on squandering resources, producing ever more scarcity: now all agents are coerced into the role of the (entrepreneurial) middleman for ensuring their subsistence by fighting for income. Consumer prices may be lowered a bit in this way—but at a high social cost which no traditional balance sheet reveals. Now the sectors of the ecosocial process that can't offer quick returns on investment because their efforts become appreciable only in the future—e.g., agriculture, education, health care, the social process called 'the state,' etc.,—suffer from a shortage of investment (money). Probably nobody wanted money to become scarce in these sectors, but this is the systemic result. It would not occur on the basis of the said law of real value, which is generally valid, even in a universe of purely mental matter, in mental economy: the necessity for future cognition to produce first a set of mental representations (a language), is of the same order, since the use of signs is necessary for organizing the ever-new process of cognizing (fig. 3).

The point is that all the decisive elements of this structure follow from purely conceptual distinctions. Any empirical element enters the scene only in ulterior steps. The real solution therefore is in a fully clarified conceptual basis. There is an increasing debate on weak points of the ruling type of economics—for example in Daly [1996], [2001], McCloskey [1996], [1998], Ormerod [1997], Galbraith [2000], Keen [2001], Bernstein [2001], Nelson and Stackhouse [2001], Rees [2002], Stiglitz [2002], Lee [2003], Fullbrook [2003], [2004], etc..

So much for economics as symptomatic example of a doubtful conceptual foundation. The problematic point, namely belief, can obviously not be eradicated from social interaction—especially in everyday life. For instance in a foreign town, inquiring about a location requires believing the informant. This is fine in pragmatic situations where following an erroneous path implies no danger. But, in scientific theories, belief as a basis should have no chance at all. Not only can it lead to erroneous knowledge, which is a general social good that endangers others when it is unreliable. Beyond this aspect, not noticing the problematic conceptual foundation of a theoretical structure is methodologically inefficient, because the phenomena then impose—through their intrinsic interconnectedness—ever more subdifferentiations and classifications, ever more detailing (many believe this to be progress because of clever-looking casuistries and mathematics). Nevertheless, the substance of the distinctions can fall into place only when it can enter the considerations in a non-adulterated way at the primal level of conceptualizing the problem as a whole. In principle, philosophy and science are our institutions for doing so.

The Symptoms of the Problem, in Philosophy and Science as a Type of Endeavor

The objective of this symposium, seeking to ascertain everything relevant for sustaining resources, is only a partial problem of philosophy and science, but reflects all basic issues. It is a challenging endeavor already as such: whatever field one studies—ecosystem parameters, climatic dynamics, policy making, techniques of management, measuring, monitoring, etc.,—at the end of a line, the more one is involved, the more something at the edge must be given up for not getting lost in a maze, while the real problem is nevertheless connected to just about everything else on this planet. Those who do not approve of the sacrifice might wonder how such a bag of fleas can ever be contained in a rational conceptualization that is peacefully beyond the paradox effects of observing and describing, or the fuzzyness of mere probabilism which characterizes today's widespread emphasis on quantity and statistics. Thompson Klein [2003] offers a good overview over the current debates in the wider earth sciences. But can science, as a way of proceeding intellectually, ever be secure and thus sustainable on principle? How can we clarify this point, which finally implies complete self-referentiality?

There is obviously a problem of true science versus mediocre science, but the criteria for distinguishing them are far from being obvious. Some believe 'sound science' is distinct from 'junk science' by knowing how to measure correctly—where the problem remains of how to ascertain (in this view: measure) the instrument, namely science itself. Others emphasize the value of 'thinking big' (i.e., beyond usual limits)—but can propose only pragmatic hopes, no systematic guidelines, so one never knows whether one is slipping into 'thinking grandiosely, but slightly wrong,' or even 'thinking bloated.' In the contemporary mainstream, the ultimately objective criterion for strictly complete and secure science remains an unsolved issue.

Such gaps are no coincidence, but only the result of how philosophy and science in general are now structured. At first glance they seem to constitute a very pluralistic network, but this is only because a common feature is not duly recognized, whose effect glues them all together: they all set out from fundamental assumptions of whatever sort. As this inevitably is a way of 'talking' into the overall interconnection of content before it has been given a chance to unravel as a whole to awareness, they wind up in problems on principle—for example undecidability (remember Kurt Gödel, or the continuum problem), or uncertainty (as e.g., Edmund Gettier has revealed), or indeterminacy (as e.g., in quantum theory), or paradoxes (e.g., the 'blind spot' of systems theory), etc.. Philosophy ended up in ideas such as the 'Münchhausen trilemma' (formulated by many from Agrippa to Hans Albert: any justification or account winds up in a circularity, an infinite regress, or a dogma), 'écart' (Merlau-Ponty), 'différance' (Derrida), etc. Such notions formulate an aspect of the general limit, depending on the basis of the respective approach. The basic gesture of positing an idea, however 'plausible,' has more consequences than we are commonly being told. Whether an assumption is conscious and rational ('atomic fact,' axiom, definition, hypothesis, postulate, premise, etc.), or emotional or unconscious (anxiety, belief, desire, hope, illusion, paradigm, etc.), does not modify its effectiveness. The difference between rational and irrational prejudices is only that rational ones allow logically consistent systems to be set up. But even the strictest logical consistency can never warrant any actual completeness of grasp and certainty. The completeness in formal systems is far from covering reality. In language-based considerations, completeness and certainty inevitably must look like a quantitative problem of getting hold of all relevant propositions. But the core issues can't be solved there.

The limit is not unknown, but discussing it within the mainstream leads to results that are not ultimately dependable: a knowledge within limits is also of limited validity when it judges the limit itself. This restricts the real sustainabilty of mainstream science, because within it one cannot know where the problem finally is. This is not to say that the limited theories are simply wrong. They do offer successes, at least at first, when manipulating 'things,' including one's own mind. Achieving effects through manipulation still is attractive worldwide; hence many accept the belief that this is a beneficial path, and the powerful nourish the sources of manipulability.

Attitudes such as technocracy, materialism, or consumism are no coincidence, but effects of a locally rational behaviour that is globally irrational. The corresponding results include a reduced overall sustainability. The question is: how can we find a viable solution?

One can choose not to care about theory, for proceeding pragmatically; this is widespread. But whatever the basis of a pragmatism may be, it can never offer a systematic basis because it takes for granted the overall order instead of being able to explain completely its structure. Pragmatic stances lack precisely the kind of knowledge that allows for secure sustainability. But one can wonder and take seriously the nature of basic assumptions and beliefs. Where this is not done, science can become a tool for eluding one's responsibility for totality—in this case: thinking about thinking—by allowing to escape into ever new fields of 'progress,' 'truth,' and 'knowledge,' instead of fully facing the crucial issues: that (a) everything appears to us according to our primal distinctions (problem of categoriality), and (b) we can't stop thinking, but we always direct it by accepting the focus of our attention (problem of intentionality); even when we believe we do nothing we always direct our flow by the focus we accept. Any bias has its effect. For example believing that nature basically consists of mechanisms will yield the corresponding theories and scientific models, which have their grain of truth, but also their limit of validity. By the way, nature can be thought in a totally organic way without needing the concept of a Supreme Creator, as for example in the process philosophy of Alfred North Whitehead ('systematic attentiveness' constitutes a viable alternative).

Seeking unification by addressing totality is typically the aim of religion. Since classical antiquity there have always been two strands of this endeavor: one seeking a rational grasp of the conceptual means for handling strict totality, and one of seeking the kind of insights that allows to dispense revelatory knowledge. Acquiring these insights requires discipline in mental openness, which may seem superhuman; especially adepts of some mystical traditions believe thus it is possible only by 'stopping to think.' The point really is in what is being meant by 'thinking.' Certain psycho-organic techniques allow to block the mental process, which nature re-equilibrates in 'breakthrough' experiences of mental light (hence the name 'enlightenment'). These do not prove having stopped the mind as such, however; they are the result of immense mental efforts while the subjacent organizing activity remains, unnoticed. Yet such impressive experiences reveal—even if only for the short moment they last—the overall structure of the mind in a special state, in which the (blocking) doer and the (blocked) result seem to be one and the same, because they mirror each other. The question is how such acts and experiences, and the memories they engender, should be interpreted. One of the profound realities to be understood is the mirroring quality of the mental realm. The use of mental blocking techniques may finally lead to certain quite deep insights, but how can we be sure that they really cover absolutely everything? To be convinced by an experience is still a form of belief, not yet the guarantee of a complete understanding. It is helpful to distinguish the basic gesture of belief or what I call confessio (belief in foundational ideas or statements, which lead to mere professing and declaring) and the principle of religio (the rational gesture of 'connecting to the whole,' the basis of secure insight). The point is that staunch belief can only end in dogma, producing new forms of wars of ideology—the 'tower of Babel' problem. In the last instance we can't escape the need for conceptual (or rather: categorial) clarification—which does not mean, however, that habitual ways of conceptualizing the act of conceptualizing have been adequate.

You might notice that I do not only offer abstractions. I address also the practical view of self-referentiality by speaking about experiencing your own doings in your own mind, not just rashly using it and taking for granted its functions, in this way reducing it to a mechanism, a mere slave. Instead I encourage the integrity of being completely aware, also of what happens in your mind. At first glance this method of your experiencing your mental activity might look like mere subjectivity. But let us be precise. The point is that the conditions for achieving any objectivity must be produced by the subject—in this case you. Personally producing adequate conditions for objectivity to be able to express itself is not a contradiction. The question is how can this reliably be done? what is the locus of ultimate objectivity? Instead of expressing a hypothesis, at this point I propose to work through the ways in which objectivity usually was sought, and the ways in which they have failed. On this path we can learn something also about the nature of objectivity.

The Produced Limits in Actual Knowledge

While the fundamental cause of the exposed limit in the hitherto usual methods for gaining knowledge is in the habit of setting out from assumptions, this habit led to a series of several structures that are causal for fragmentizing and limiting end effects. A splitup—as the final consequence of presupposing ('talking' into the issue as a whole, instead of 'listening' into all of the interconnectively relevant content)—can take many shapes, the study of which can reveal some of the mechanism of self-limitation.

An important feature of assumptions concerning ourselves as cognizing organisms is their absolute and precise effectiveness. Believing for example that 'X is unknowable,' or 'the mind is an Y,' or 'complete integrity is unattainable,' actually makes X unknowable for the believer, allows only Y-type characteristics of the mind to be known, and will foil complete integrity indeed. Believing for instance in the results of the cognitive sciences and neurosciences is of this type that fosters self-estrangement; not computers are dangerous to society, but people who robotize themselves. Knowing about this type of limit is exact as soon as one knows the self-oriented presuppositions, since they operate 'from within' thinking. Presuppositions that determine the mental process, through which the mental process itself is then being judged, can evidently have no other effect than precisely what their content dictates. The less one is aware of the presupposition, the more easily one will slip into the circularity of an addiction, but becoming aware of it removes the spell (for example psychoanalysis works in this way). In contrast to this precision of content, any knowledge that is based on observing processes 'from outside' can never reach the respective core—as Kant had to state concerning his 'thing as such'—and therefore can yield only probabilistic results, in which the single case and the covering law (the overall order of phenomenon) elude the method. The widespread turn of late towards statistical methods is no improvement, but a concession to the drawbacks of external observation because it has become ubiquitous. The insight is crucial that these limits or split-ups are all man-made. A belief does not become objective by projecting the respective fantasy into its medium of appearance, as for example Churchland [1994] does, concerning causality:

> "Electrical current in a wire is not caused by moving electrons; it is moving electrons. Genes are not caused by chunks of base pairs in DNA; they are chunks of base pairs. Heat is not caused by the movement of atoms, it is the movement of atoms ... [and in the same sense] awareness just is some pattern of activity in neurons."

because this seeming objectivity merely shifts a basic lack of explanation into ever smaller 'pieces,' onto ever new levels of mystery, producing new splitups. Many call this progress, because new elements seem to become accessible. In such attitudes, what reality ultimately is—in Churchland's case: effects in matter, beyond its finite bits and pieces—is not being clarified. Especially philosophers give up their credibility when they give up the objective of ultimate clarification, in this case succumbing to 'naturalization' (believing blindly in natural science).

A splitup can result from confusing the modes of language and fully coherent thinking. This difference was blurred by the 'linguistic turn' (a widespread turn in philosophy, based on the assumption that thinking must be structured discursively, if it is to be rational). In its heyday, reviving the distinction must sound like blasphemy to many. But their god is, as we saw, not firmly in his saddle—held only by belief, not secure knowledge. Saussure proposed a useful distinction between language as a system ('langue') and the use of language as an alive process ('parole'). Spoken 'parole' is always beyond structural 'langue.' But for clarifiying fully the issue, language as a principle must be considered in a wider way than what is proposed by the linguistic approach, because it is centered too much on the signs and neglects thus the core: the signified content as such. Once one is stuck with results of thinking content (propositions, signs, etc.), the adequacy of an expression (often this is called 'truth') can only be measured within language against reality, in a procedure that requires thus another linguistic element (or a network of such), because reality does not respond directly. But then any investigation has no anchor in overall reality, it can only float on the sea of purely man-made, intersubjectively agreed opinions (beliefs). This method can offer no warranty against collective error, while it neglects a structurally fundamental difference between language and thinking. Consider the following basic regularity. Within language any contradiction can be formulated, from 'straight is curved' and '3+5=9' to antinomies like 'I am lying,' up to voluntary deception—while it is impossible to think such linguistic structures in one single coherent thought. Whoever adopts fundamental beliefs that lead to some paradox is compelled—for accommodating it coherently—to remain within the corresponding set of elements (signs) that are intrinsically interrelated according to the causal prejudice. But 'interrelation between a set of signs' is the intrinsic law of being a language system (Saussure: 'langue'), not mere noise. Sticking to beliefs produces thus a dependency on 'langue' for keeping together the assumption's effect. Without 'langue' everything would fall to pieces for this psyche—but it cannot remain only within it, because 'langue' can contain only the past. Life is pointless when restricted to unalterability; this is why spoken 'parole' is always beyond structural 'langue.' For example, using the personal pronoun 'I' can be authentic (in psychic integrity), or false (when remaining in 'langue'); fully understanding the self-referential unity of personal identity requires transcending 'langue' and is thus possible only in pure thought, considering content as such. Language offers a surrogate for perception, allowing to deal with what is not physically present. It is not the basis of all of thinking, even though many people are indeed conditioned to ways of thinking that remain in a mental use of language in forms of 'talking to oneself.' The question remains of how thinking can be sure of its dealing with reality, beyond anthropocentrism. The call for justifying beliefs, as must be postulated upon following the 'linguistic turn,' is no ideal solution but produces a fateful dependency on intersubjectivity and makes theories into cobwebs of hypotheses. As stated in the Duhem-Quine thesis, a single hypothesis can't be tested in isolation, because all others are implied too; inversely, by sufficiently modifying those, practically anything can be made to sound like being justified (e.g., Davidson [1984]). A connection between problematic suppositions and a subsequent addiction to language is not limited to individuals, but can arise in styles of writing or of politics, schools of thought, philosophical or scientific positions, institutions, etc. In this light, 'publish or perish' is perilous, as it engenders a semiotic infarct.

A splitup can also result from an emphasis on measuring appearances, thus losing contact with the overall order according to which they arise, exist for their time, vanish, and reappear renewed in what can be called 'the four seasons of being.' The centerpieces of intelligibility, i.e., the conceptual elements that determine a real understanding of appearances—for example laws and forces—are not observable and hence not measurable as such, but only their effects. The decisive elements can be grasped as such only in thinking, and even then only under the appropriate conditions. Nevertheless, the idea of measuring has practically been made into the guideline of today's science. What can't be measured is left up to thinking in terms of 'values,' which can never reach beyond a certain vagueness, or to religious considerations. Yet thinking in terms of measuring injects a specific content into the research process: a comparison with an alien element. Measuring is indeed possible only after having posited conceptually an element of reference, which cannot avoid embodying some arbitrarity; this element explains why for instance the measurement problem of quantum theory—often hailed as the only fully secure theory—can't be solved materially in a strictly complete way. In the course of its development, this theory has led to a hunch that matter finally does not consist of fundamental pieces (even if entities do exist, but only for their duration of time). The separability of physical systems—an idea that even Einstein never gave up—had thus to be abandoned. But the separability of observables (such as location, velocity, spin, impulse, etc.) was kept; these are what is being measured. The result is the paradox features of this theory: At the 'small' end it features an indeterminacy that can only be shifted into 'new' areas (e.g., of time or space), and at the 'large' end it is conceptually compelled to postulate 'emergent' features of objects; complementarity arises at the 'observable' end, and nonlocality at the 'relational' end, because matter does indeed not consist of basic pieces. The idea of 'entanglement' illustrates the conceptual problems, but has no explanatory value. The theory is always correct, even in counter-intuitive setups—but because of its paradoxes, or more precisely because of the conceptual basics that generate its paradoxes, the results of this theory always require an interpretation. Currently there is about a dozen of them, but none is strictly conclusive. In spite of its correctness in any given material setup, even the quantum approach is therefore not an adequate basis for unifying knowledge. Prolonging it into the theory of self-organization ('autopoiesis') or complexity theory (as in the Santa Fé Institute) does not solve the issue, but only shifts its 'blind spot' somewhere else.

Another version of the splitup results from hoping to achieve objectivity by approaching things 'from the outside', following René Descartes' idea of separating mind from matter for understanding reality. In this vein, even the functions of the mind have been subjected to the seeming objectivity of a functional view, expecting for instance reason or perception to work like mechanisms. Whether the seemingly objective gesture is one of distinguishing, observing, describing, measuring, or intervening, is finally irrelevant: it is always one of comparing the subject matter with something else, alien to it. This gesture inevitably creates a corresponding 'blind spot'—for example an observer can observe everything except his own act of observing. Logicians discovered that the blind spot cannot be discovered from within the system: The system can't see what it can't see, and it can't see that it can't see what it can't see—namely the paradox that the system, splitting up the universe between system and environment, must on the one hand be distinct from this distinction, while it must on the other hand exist within this distinction as part of the whole and hence as an object of investigation. In this paradoxical situation, observing other observers in their activity of observing can look helpful, but the blind spot can never be overcome, it can merely be shifted around (Luhmann discusses this aspect eloquently in his systems theory, but can offer no solution on principle). Whether one considers material things or mental elements, is irrelevant, because both are not the respective order as such, but only its manifestations and hence appearances—in the external world or in the mind. In this context it is useful to remember that mathematics can never offer more than a description, as it is only a language, albeit a precise and completely formalized one. Especially in its algebraic branch, mathematics can never get rid of its language status because it is formal: the symbols stand for something else. The syntactic information 'hidden' in a language should not be expected to yield new truth just because it leads easily from one logical step to another (a fallacy arising often e.g., in physicist's or economist's thoughts). Terms in an equation take their meaning from conceptual attributions in that application, not only from the interrelation between terms. Remaining within a system (i.e., way of thinking) that is not totally clarified, can finally only suggest an arbitrary move—an auxiliary hypothesis, etc.—for 'outgrowing' its drawback at the edge. Such epicycles make the problem reappear in a 'new' area; in this way, e.g., agency has forever been sought in ever smaller 'basic elements', even though inert matter can't really act. The nature of today's mainstream is indeed fundamentally conflictual, making it into part of the problem rather than its complete solution. Its fundamental problems are usually not being solved, but only avoided. Sometimes evasions look extremely successful at first—in logics for instance Tarski's approach to the concept of truth, seeking to avoid formal paradox by introducing meta-languages, separated from the object-languages—while in new perspectives any meta-language is again an object-language and the meta-language of all meta-languages is everyday language –; or in type theory (Russell and Whitehead), segregating propositional properties, relations and sets, into 'types'—which does not clarify the ultimate basis for, and effects of, performing this type of segregation –; or in Spencer-Brown's protologic based on the primal act of distinguishing—with its problem of 're-entry' because distinguishing presupposes distinctions, otherwise there would be nothing to choose 'primally.' As outlined above, the gesture of trying to escape engenders the structure of language and 'justification'—as opposed to the unifying effect of integrative thinking. Thinking is the process of relating to forms of order, producing linguistic elements. Hence the question is how to think order as such, not only how to get along with appearances and talk about them.

Here we are not denying that knowledge can be unified to quite an extent and under many banners, for instance under measurement, statistics, or language—in the same way as many definitions and theories of a given phenomenon are possible, which moreover need not exclude each other. For example the pure order (law) of the circle in plane geometry can be approached and defined in many ways, manifesting different types of interest: in terms of distance from a given point, or of curvature, or of the rectangular point of all triangles over a line, etc. (fig. 1).

Or in today's physics, matter can be approached via the quantum, relativity, nonlinear dynamics, quantum field, string, or any other perspective. Again one is coerced by the type of interest, determined by what one wants to measure—the infinitely small, or movement, or changes in appearance, etc. All these approaches rely on the 'mental gesture' of measuring—but none can offer a complete understanding of its object's intrinsic nature, because they all operate in categories that are inadequate to the respective overall order as such, in this case of materiality. Whether they finally are verifying their theory, or caught up in some self-fulfilling prophecy, is empirically undecidable, since any setup considered in the language of measuring always reconfirms this language, but its blind spot remains. Setting out from preconceptions is a sure-fire path towards finding only aspects. This is why contemporary physics cannot get together all its theories in a strict way. Achieving this requires complete clarity beyond any specific object-orientation: purely categorial work. Operating within distinctions which stem from measuring can on principle never yield a complete understanding of the intrinsic nature of matter, because they inevitably introduce an alien element. Remaining on paths that can only ignore the ultimate nature of matter, while professing a 'materialism,' is thus something rather oxymoronic, in spite of being very widespread. It is in fact an idealism (or rather a fantasism), because one sets out only on metaphysical beliefs. Being able to

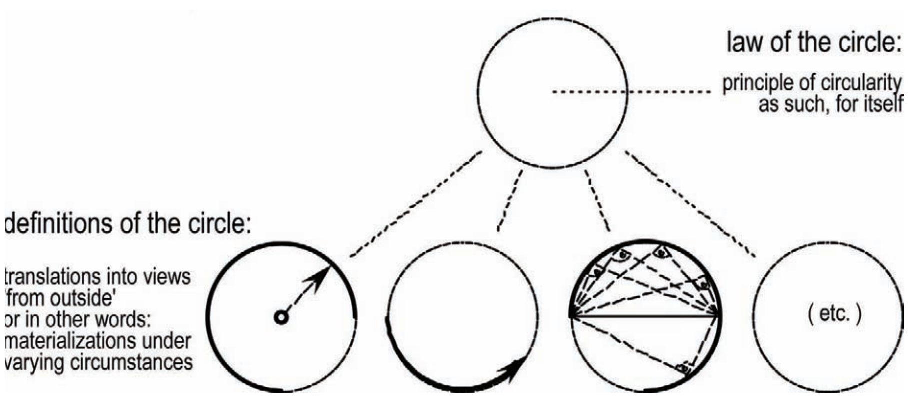


Figure 1. Lawfulness and its material appearances N in mind as definitions, in material matter as specimens.

manipulate matter according to found laws is no proof of complete understanding: any animal can produce change without needing to know all of why the desired change occurs. This loud call for ethics of late is due to this gap. In the end the problems are always on the cognitive level: also the moral philosopher must understand why some idea or action is good or not. The question is on which channel the universal laws are being referred to, for commitments to be generalizable.

A noteworthy point is that the centerpieces of intelligibility, i.e., the conceptual elements that determine the full understanding of appearances—for example in a processual approach: laws and forces—are never observable and thus not measurable as such, but only their effects. As the example of the circle shows, the means for intelligibility become propositional only upon being approached from a perspective, i.e., upon being interested in them in a specific way. As such, forms of order are nothing but themselves. This is not in contradiction with the fact that they can be characterized by their content, which interrelates with the content of all other forms of pure order, up to the overall order of the universe. For the intelligibility of order, conceptually polar aspects are relevant. Polarities are total opposites; appearances (materiality) can't be manifestly polar—simultaneously also immaterial and still material –; therefore materiality displays dual aspects (e.g., symmetries in physics and in living beings). Judging a form of order is not being that order, unless the act of judging conceptually is purely that order. A comparison with an infinitesimal alien element may seem negligible, but always has its price on the level of strict totality: a paradox, a gap, a (self)-limitation in the theoretical understanding. Struggling for complete transparency (which can be called truth) always makes sense, while material strife is finally always pointless.

Methodologies based on assumptions allow a certain degree of sustainability, reflected in phrases like "sustainability of what sort, for whom" etc.. The multitude of partial truths then becomes a problem: how should they be unified? Beyond that, aiming at real sustainability merits a better grasp than adding up piecemeal results. Seeking the 'optimal assumption' won't solve the crux, because any presupposition inevitably compromises the respective approach. The question is with how much (un)certainty one is ready to acquiesce. This in turn depends on the choices one has. We saw that wanting to grab the overall order in appearances, even in what appears in the mind, leads imperceptibly to a loss of what one is ultimately aiming at. There are better choices, but they are barely ever thought of. This is the tragedy of our times.

For determining types of knowledge which allow a secure overview, ideas for 'logical', 'metaphysical', and 'moral' certainty were proposed, but there is little assent on the whole. Mittelstrass [1982] distinguishes 'knowledge for the sake of orientation' vs. 'knowledge for the sake of action' ('Orientierungswissen'/'Verfügungswissen'). But he too does not base the more complete type of knowledge (seeking/offering orientation) systematically in a universal way; in spite of his intention he remains in the linguistic turn and its intrinsic self-limitation.

For closing the gap I propose a completely uncompromised distinction, namely between the language of intelligibility and the language of manipulability. The first consists of laws (forms of order, pure structure), which we grasp by means of concepts, ideas, or representations that can be communicated by using names and predicates; all forms of understanding are ways of grasping the ultimately relevant order. The language of manipulability consists of names and predicates ('handles' for catching 'things' in representations). At first glance it seems to allow complete intelligibility; only upon thinking through the network of all names and predicates, one can notice that it can't cover strictly the whole, that something is missing somehow, can't fully be understood, or produces surprises. Remaining in the language of manipulability impedes knowing just what goes wrong. An example is causation—think e.g., of the 'covering-law' type of explanation that can't allow to know on its own whether the explanandum is causally effective, or a necessary condition, or an inevitable concomitant element. The distinction of two 'languages of thinking' is similar to Mittelstrass' of two types of knowledge, but more promising, as he offers no proposal for overcoming the language of manipulability. Remaining within it while believing it can serve as language of intelligibility logically must lead to believing the encountered limit is absolute—while only the belief in the language of manipulability is absolute. Such knots are unnecessary. The failures they produce often are noticeable only much later. Many need to experience failure for wanting to learn, but it's more efficient to think clearly beforehand, addressing the fundamental issues. This is the substance of culture.

The Ideas of Mechanism and Organism as Mirrors of Sustainable States

In a figurative sense, problems of sustainability can also be viewed as problems of overall health and disease of systems and even of theories—healthy in the sense of being sustainable, where noxious influences call for corrective action in the same sense as implementing a cure for inducing a healing process. One can question the rationality of this analogy, since the patient in nature is not as evident as the patient in medicine, and theories are rarely viewed as something whose correction is in fact a healing process. But are these the truly fundamental points? Already in the traditional medical situation the question is whether the interconnections can be grasped in an ultimately valid way. After all, medicine is held to be part of natural science, while no process is healthy or unhealthy per se, but only in an organic context. What does this context encompass? All physiological data, or also the process of body regulation? Only once the very principles are clarified, which become manifest in health and disease, their domain of applicability can securely be assessed. The structure of physiological data, in which the health of an organism can be described, does not contain the way it maintains its health, but only the tangible result of its doings, and health allows and even implies ongoing development. On the other hand, disease cannot securely be grasped by determining the elements that many believe to be causal (influences such as viruses, bacteria, ameba, poisons, etc.), because individuals do not all react in exactly the same way. Additional aspects must be taken into consideration.

In these questions too the view is determined by the categorial foundation, i.e., the basic ideas in which health and disease are being mirrored. Contemporary natural science has chosen the basic idea of mechanism and is trying to formulate the principle of organism in terms of structured mechanisms. This is the course of action in modern biology, based on the 'New Synthesis' of Darwinian and Mendelian lines of thought. Here too the investigations were led into ever smaller details—microbiology, in its widest sense—without noticing that the path is imposed by the categorial choice (this mental mechanism has been explained ealier). For discussing the implied crux, here we will consider especially an example in medicine, namely Paul Thagard's widely acclaimed book How Scientists Explain Disease [1999].

An analogy of the human organism and the organism of reality as a whole is of course very problematic to the contemporanean mind, because there is a priori no evidence for this link, but at best some vague or even mystical old sayings such as "as above, so below," which can indeed seduce into fantastic misconceptions when formulated out of inadequate basic ideas. Yet on the other hand there is no proof for the irrelevance or even absence of this link. While a person can be held accountable for sensing its limbs and hence being able to equilibrate herself towards health, in nature or natural systems there is no tangible person. But here too we are confronted with the question of how, or more precisely through what ideational mirrors, the subject matter of regulation is being approached and thought. It is evident that the choice of 'mechanism' as the guiding idea can only yield perspectives and problem solutions in terms of mechanisms. The question is how adequate is this approach? On the meta-level there is the question of how adequacy can be ascertained. Can for example a technique for suppressing the symptoms of disease be called a successful means for healing? There is a question of frames of reference, on which not everybody agrees. For some, getting rid of symptoms is health, while others consider side-effects, relapses, the gained personal strength in overcoming on their own the disease's nature, etc. Hence part of the problem is that also the practical results are being judged—as much by doctors as by patients—through an ideational mirror. If it is the same as the one that led into the situation, the 'blind spot' remains and erroneous aspects can't become perceptible—in spite of all empirical evidence—until a situation becomes grotesque, maybe revealing the crux even to an untrained eye. One can think for instance of a disease that is held to be normal in one society, while in some other one it appears as a result of bad habits or mad ideas. For a secure assessment one can't escape the need for grasping the problem as a whole.

In humans, health regulation occurs partly in ways that are given by nature—for instance in digestion or respiration—and partly through sensing one's own organism, which implies the mind. The mind must find its bearings in its own organic body, but this is not one-way traffic: in doing so it develops conceptually its capacity of dealing with its body. It is thus reasonable to view the organism as the wholeness of body and mind in a dialectical process.

Hence organic regulation does not necessarily imply a mind, while any mind must produce its adequate conceptual means, for which its body is the teacher. The question finally is in what terms one approaches the issue. Even on the theoretical level there are indications for a complete interrelation ('organic interconnectedness') already in the realm of inert matter itself; we might remember the immediacy of action-reaction, and the fact of quantum nonlocality. In the alive Body ('Leib,' body and mind), the gist of being organic is in its structure of conscious "double sensations" (Husserl [1952]), which no kind of mechanism can replace or reproduce: sensing for example the left hand by touching it with the right hand is impossible without the left hand sensing simultaneously also the right hand. The point here is that organic bodies are not built along intensive quantities (such as charge, pressure, temperature, or volume)—which today's science chose for depicting nature—but along hierarchies of equilibria. Since the organic body operates in self-referentiality, it can create its instrumentation in a free way—conceptually not in rigid object-oriented fixations ('names and predicates,' language of manipulability), but in 'pincer'-type structures; manifestations of this "double sensation" type range from the symmetry of the prehensile hands to the necessary conceptual polarization in complete forms of conceptualizing. The brief digression here is to indicate that appropriate conceptual conditions—namely a reference to universal forms of order, which lead to universally applicable concepts—allow to recognize in a unified way the intrinsic interrelatedness of all material structures, from the inert ones—which are determined by external conditions (whether by 'chance' or by 'necessity')—to the organic ones, which can impose change to their own structure as well as to outside conditions. Grasping the nature of polarity and duality allows to understand how structural symmetries in organisms relate to conceptual polarities, and are not mere coincidence.

In contrast, Thagard [1999] follows contemporary science in holding repeatedly that—as opposed to mathematics and physics—there are no universal laws that account for the causes of disease; he deduces that the corresponding reasoning can thus on principle not be deductive. Even though this opinion is relatively common, it is true only within the self-limited view of today's mainstream, which does not permit to know whether a methodology might be found that reveals the desired universal laws. Believing today's habitual way of theorizing is the only possible one, not doubting the foundation of today's mainstream, makes absolute today's self-limitation in a self-contradictory way: the belief suggests knowing everything relevant (which is thus generally valid, some sort of universal law), simultaneously negating it in what is being expressed. This is a case of self-deception (believing one's belief to be more justified than it is). It would thus be more correct to say: 'within the horizon of todays generally accepted beliefs there are no universal laws,' for doubting the beliefs and remaining open for a better approach.

The problem has two essential elements: (a) what one believes to be a law, particularly a universal law, and (b) what one believes causation to be. In both questions, the context of health and disease is particularly interesting, because the consideration must finally cover totality in a strict way for offering certainty. One can of course acquiesce with less, but at a corresponding cost in understanding. Whether a view becomes majoritarian or minoritarian is another question, while the ultimately fruitful ideas never come from the majority.

In his careful analysis of today's scientific approaches to disease, Thagard considers science (descriptively) as what scientists are actually doing—not (normatively) as what ought to be done for making sure the problems are adequately being dealt with. In his considerations, the latter aspect enters the stage only in a secondary way, not on the level of the first principles. Of course descriptive accounts of science can inform normative conclusions (said explicitly in [1999:94]), but when the certainty of potential knowledge is at stake, the relativity implied by this procedure should not be tolerated. Thagard's stance is a bit astonishing, since after all he professes philosophy of science. But it corresponds to contemporanean habits, exemplifying a naturalization in thinking which shaped today's majoritarian view—as much in philosophy as in science—in spite of incurred drawbacks, outlined above. Thagard, seeking to explain as much scientific work as one of its fields: disease, trusts his choice in saying "This book is about the causes of disease and the causes of science" [1999:preface]. In understanding science he seeks to bridge a gap between the 'traditional' view, perceiving science primarily as a matter of logic, and the 'postmodern' view, perceiving science primarily as a matter of politics. As a solution he proposes his "integrated cognitive-social explanation schema" ([1999:8]). In understanding disease Thagard follows the path of causal structure in historically relevant disease concepts. A point to note here is that today's usual interpretation of the Hippocratic humoral theory, accepted also by Thagard, does not correspond fully to the way things were seen in classical antiquity. The four fundamental elements (earth, water, air, fire) were not meant as materially palpable forms, but as the type of order which organizes matter in a certain way; in the same vein, the four humors (blood, phlegm, yellow bile, and black bile) did not just mean material fluids, but types of order that permeate in a 'fluid' way the organism in maintaining its functionality—so of course any disequilibration of this order of four sub-orders was causal (corresponding to the modern aspect of psychosomatic causation). This does not contradict the severe lack of empirical detail that lasted for centuries, limiting the language for conceptual considerations (we will come to this point later). Neglecting the conceptual detail, Thagard espouses the object-oriented materialist path, which started with the germ theory of infection, as initiated by Louis Pasteur, and had to be complemented—because of the actual complexity in disease causation—with aspects of nutrition, autoimmunity, genetics, and environmental influence, leading to 'multifactorial' views of disease [1999:20-36, 148-163].

As much for explaining scientific work as disease causation, Thagard sets out on the idea that the whole complex of 'exterior' and 'interior' factors must be addressed [1999:5f and many indications later]. This is certainly the only reasonable way of approaching the problem. But on the systematic level he does not address on principle the difference between conceptual problems (debating empirical phenomena in a structure of terms) and categorial problems (fundamental distinctions that determine what structure of terms can evolve), even though he had worked extensively on conceptual revolutions—to the point of making these two words into the title of one of his important books (Thagard [1992]). Although he certainly is aware of the systematic relevance of the categorial aspect, it seems he does not yet see how it can be made fully transparent (which is an aim of 'systematic attentiveness'). As a result, also with Thagard the crucial problems can't be approached uncompromisingly. For example causation remains under the spell of mechanism as an explanatory principle [1999:106ff], even though—as has been exposed—for disease as much as for scientific activity, the ultimate root of causes reaches deep into the part of the personality that can't be reached by mechanisms. It is true that contemporanean science is still operating on the conceptual foundation of mechanism, but Thagard's topic would merit more critique of this approach. In scientific work, the relative success of vigorous interrelation among scientists [1999:70ff] cannot make up for the absolute gap produced by thinking only in terms of mechanism. For finding a thoroughly secure answer to the question "what causes scientific change?" [1999:94ff], Thagard's "integrated cognitive-social explanation schema" cannot suffice, because it considers science only as a social process that is determined by sets of beliefs. The 'conceptual unification' he offers does not cover the crucial categorial level. Thagard considers only very marginally the possibility of abandoning altogether the principle of belief, in the skeptic attitudes that some scientists manifest, but he does not develop a consistent method for doing science without any belief—while relying on belief is the reason for wild meanders in forms of understanding, as history reveals. Yet most scientists are very vexed when confronted with the fact that their activity is ultimately based on mere belief (for instance in the certainty offered by the principle of measuring, of which they forget the 'blind spot'). They usually defer such questions, for example by attacking the questioner as a member of the 'other side' in the 'science wars' (opposing natural science and the humanities, the 'two cultures' according to C.P. Snow). But this opposition does not solve the problem—if only because both sides still prop up their systems on fundamental beliefs, albeit of a very different sort. This is why none of the two sides can win (e.g., Brown [2001]). In this struggle, a sustainable clarification and durable peace will be found only once a robust methodology is adopted that can deal uncompromisingly with the acquisition of knowledge, without any basic belief whatsoever. It is true that today's mainstream can't offer this type of methodology (above we have seen why)—but this situation is not "the end of history".

Under the presently usual cognitive and theoretical conditions, there is thus a certain risk in trusting the offered type of explanations, as much of science as a type of endeavor as of the causes of disease as a type of organic disorder. It is interesting for example that in Thagard's account the difference between curing and healing does not appear in a clear way. Given the presently habitual path of reasoning, this is no coincidence, but practically inevitable. Within its framework it is extremely difficult to know whether the explanandum is causally effective or only a necessary condition. In old times doctors knew that medicus curat, natura sanat (the doctor administers a cure, but it is nature that heals), acknowledging that human intervention can only influence conditions, but not impose a healing process as such. This distinction is not part of medical knowledge any more. We have entered an era of a purely technocratic type of science: it is oriented towards manipulating symptoms, affording no mentions that healing is a process in which the stricken organism can learn something about itself, especially about its needs and mental techniques of equilibration. Insofar as the distinction between curing and healing is abandoned, while medication is being administered as some sort of magic bullet, the difference between medicine and magic, or implicit coercion, is eroded. Behind the impressive display of ever more refined technological instrumentation, there is a relapse into old patterns of mind. As much the understanding of human ways of being as the self-understanding of the patient is at stake, including widespread misunderstandings of death and dying.

This aspect leads us to the 'inner front' of human beings, their self-understanding, and as a result their psychic status. By being implemented in practice, the doubtful theoretical basis of today's mainstream produces myriads of microconflicts, of practically imperceptible clashes between the nature of things in their own right and the scientifically (and therefore 'officially') justified human interventions. These conflicts are accumulated and amount to something like an invisible wall that nevertheless determines the course of the individual. This is not to say that ancient times were always better, but that the massiveness of belief in today's habitual approach is an obstacle on the path towards sustainability. The provoked crises are necessary not in an absolute way, but for waking up to reality in a more complete sense. We mentioned earlier a specific form of coercion that is organized in an imperceptible way, arising from a specific way of handling property. But there are many other such forms of coercion; in sociology, especially Pierre Bourdieu coined the term of 'structural violence.' These implicit coercions have an insidiously intimidating effect.

Sensitive and helpless individuals often have no other choice but to develop a mental disorder; a widespread form of it is depression. The spreading of substances such as Prozac is no coincidence. The phenomenon is relevant not only psychologically, but shows increasingly also a sociological dimension. Subjecting reactive children to a coercive regime (for instance by means of Ritalin) is not a sign of coming to grips with the real problem, as it does not stem from a deep understanding of life in its own right. Imagining life can arbitrarily be manipulated is an endangering belief. It neglects the distinction between causes (activity in its widest sense) and conditions (materiality in its widest sense), obscures the difference between curing and healing, and makes autonomy into a huge problem.

As a result, the approach to psychic disorder evolved in strange ways. While the founding fathers of psychology—for instance Sigmund Freud—sought to heal people by helping them to solve their problem, addressing it on the psychic level in intelligibility, mainstream thinking increasingly acqiesced with possibilities of manipulating the symptoms, up to making them vanish as by magic. Thanks to neuroscience and biochemistry, pharmacological substances are now extremely effective in doing so. Administering these drugs allows the patient to meet the usual social duties to a certain point. The trouble is that the actual problem is not being solved in this way, but only deferred—in fact it very often becomes chronic and the patient becomes psychologically dependent on the medication. In the end it is not clear any more whether such substances are a medicine or a drug, since this type of medicine is breeding an addiction. One cannot truthfully talk about healing such psychic disorders: the symptoms are only faded out of consciousness by the cure. The public is rarely being informed about this side of the facts, because many articles in the media are sponsored by the pharmaceutical industry (for example Alain Ehrenberg [1998] gives a detailed account of the historical process, including a wealth of pharmacological details). Given the overall structure of the problem, and the scant understanding of personal identity that the mainstream in modern philosophy and science allows, it is easy to predict that the 'inner front' will become a major spanner in social interaction probably relatively soon. A population kept biochemically in self-alienation—since the root cause of psychic disequilibration remains unsolved, only symptoms are being eliminated –, will not be able to solve adequately the fundamental questions of existence. The probability of irrational reactions, from exaggerated religiosity up to running amok, is actively being increased rather than decreased. Escaping the created loop requires understanding human nature in a complete way—which becomes possible only by overcoming the categorial self-limitation of today's mainstream: assumption-based (and hence finally formal-mechanical) ways of thinking.

The bottom line of our analysis is: at the very end of any of its threads today's mainstream can not distinguish knowledge from mere belief—indeed, it defines knowledge as 'justified true belief.' This situation is not improved decisively by introducing additional formal criteria of corroboration. The available explanations too often are mere descriptions—allowing a partial understanding through detailed imagery, but not reaching full conceptual clarity on the level of intelligibility.—This critique is not meant as an accusation, it only aims at revealing the point where mental mechanisms are still allowed to operate where a truly organic endeavor would be appropriate. Such critiques often express a moralizing appeal—which is not helpful. The only reasonable means for improvement is insight into the phenomena and their interconnections, seeking the level of pure intelligibility. The considerations up to here show that the presently majoritarian belief structure is (a) not compelling, and (b) not fully up to the task; they should thus allow its origin and nature to become more clear than usual. As a result, the reader might have developed a hunch that, in spite of widespread fears, a viable methodological alternative should exist that allows a unified knowledge-based society for sustainability to arise.

So much for the diagnosis. But what can a sound therapy actually look like?

Solving the Problem on Principle

The principle of the new proposal is simple, but implementing it is rather demanding. The point is that an uncompromised scientific procedure, capable of coping with unity and hence strict totality, can be warranted only by leaving away all fundamental assumptions—or, in the mentioned jargon, 'listening' to the overall interconnection of content instead of 'talking' into it prematurely. All worthwhile philosophy proposes this gesture for its beginning: Socrates and Descartes in systematic doubt, Kant in suspending judgment, Husserl in epoché, Arendt in 'new life,' etc. In fact, at the root of all real progress one always finds this basic attitude. But it seems awfully difficult to perform and to sustain, even though in principle it is easy to stop talking into the problem before it can unfold. The act of stopping one's 'mental radio station,' for being attentive to an object or idea, is always a possible choice, even if not all conditions allow to materialize it. While no belief is necessary, beliefs can be accepted under pressure, adapting to given conditions—for instance canonical prejudices in a scientific paradigm, or the way of life in an ideologically tinted social environment. For example our Western civilization succeeded in installing a type of everyday life that continuously distracts from a chosen topic. A systematic understanding of how sustained attention can be achieved is then helpful.

A sound systematic basis can thus be found by following closely the process of querying. We can approach things only in a perspective, out of a specific interest. Actively sustaining a query has a purifying effect. The deeper we reach, the better we can grasp the complementing/polar background of what we saw at first. Studying the genesis of concepts shows that any conceptual aspect A can in the very end be thought only on the 'mental background' of non-A, the content that is strictly polar to A. This fact gave rise to many streams of thought under the title of dialectics, because knowing A makes aware of its intrinsic conceptual dependency on non-A; hence becoming aware of non-A leads to realizing what A really means. Then A and non-A together cover totally the universe, under one aspect: the queried one (in this example: A). Hegel unceasingly draws from this well, and it allows to draw a conclusion for systematic attentiveness: upon completely exhausting a query perspective conceptually, its perspectivity and universality become fully compatible.

The other side of the coin is that any query leads in the very end to a polarized conceptual space, as required for really understanding the query's content. The more intellectual efforts are fathomed, the more examples abound, showing why sustained attentiveness to the subject matter is crucial. For instance Aristotle, querying the nature of change, eventually found 'form' vs. 'matter'; Kant querying cognition finally found 'perception' vs. 'thinking'; or Saussure, scrutinizing the primal nature of the sign, reached 'the signifying' vs. 'the signified'; etc..

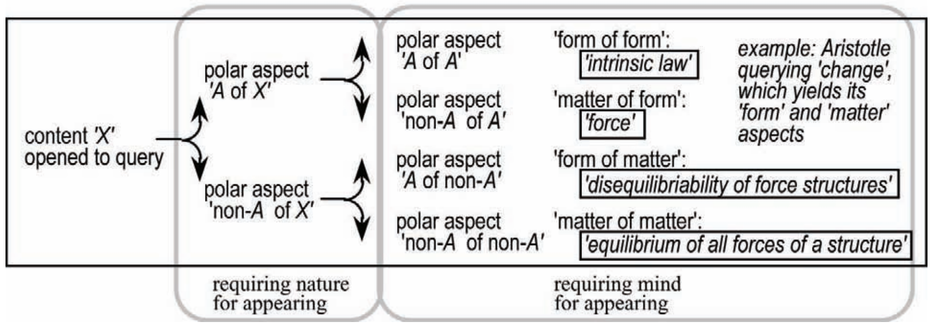
It is of course not evident that such polar structures do not merely stem from logocentric mental habits, but reflect a real law of nature. The most compelling evidence for the second case is available in a branch of mathematics called 'synthetic projective geometry', of which a glimpse was given earlier through the example of the triangle. It is interesting especially since Hilbert's program of axiomatization proved not to be realizable that synthetic projective geometry is finally the 'mother' of all geometries, including the now famous non-Euclidian ones, and that it has been most fruitful where it was approached non-axiomatically, as by thinkers from Christian von Staudt and Felix Klein to Henderson [1998], thus avoiding the self-limitations of traditional formalization. The path was to develop the elements (point, line, plane) intuitively instead, with linearity as the only invariant and infinity not as a special case, as in Euclidian geometry, but being strictly thought through at every step of developing further the geometric structures. Formal approaches to projective geometry are of course possible and in fact are the most prominent ones in actual application, for instance in physics, but the front of heuristic insight has remained in the synthetic branch.

Nevertheless, a conceptual polarity, discovered upon fully having queried a content, does as such not yet disclose all the implications of that content. For example in Aristotle's query, 'form' and 'matter' do not disclose totally what is actually operative in the 'form' aspect and what the precise qualities are of the 'matter' aspect. But we already know the instrumentation for an extended interest: to follow up the queried content to its very end. Indeed, asking about the nature of the two 'ends' of a polarized content is of just the same type as asking about the nature of that content itself. Hence we can apply the acquired polar concepts upon themselves. (for details about the systematic development of the concepts, see Schaerer [2002], [2003a]). The result is always a set of four conjugated categorial concepts, a consequence of the query's content. Every query content defines its corresponding four categories. As an example we take Aristotle's query of change, querying first 'form' (the agency), then 'matter' (the respective 'mirror' or 'conceptual background', indispensable for understanding).—A graphic illustration of the systematic structure might be helpful (fig. 2).

In this example we consider the perspective of querying processuality, particularly useful for natural science and its approach to 'things', which should be understood in their intrinsic dynamics, because no material thing is eternal. Today's mainstream attempts this too, but is limited by its own assumptions; even 'energy' and 'information' are not suitable notions for a strictly universal solution, because neither is a really fundamental concept. Energy cannot be primal, because it is force organized in spatio-temporal dimensions (the agency is conflated with the medium in which it operates, space and time); the primal term is force, not energy. Information can't be a primal term either, since its definition—whether with Shannon (signal theory) or Boltzmann (structure theory)—excludes the information required for distinguishing between meaning and mere noise; the relevant term here is pure order. Relying on 'energy' and 'information' as a conceptual basis sets the stage for a long period of deferring crucial points into 'new' ideas and research areas—but we should be cautious, because not all the resulting fragmentation is progress: as we saw, basic errors 'evolve' into ever more words, languages....

Systematic attentiveness encompasses, in the result of its processual query, all types of structural change in

Figure 2. The structure of self-equilibrated conceptual tetrads.



anything that appears as a processual unit, from particles in physics to beings, populations, ecosystems, economies, propositions, and mathematical equations. The specific qualities of the developed categoriality stem from being developed coherently—in full self-referentiality—out of one content; it embodies thus itself the essential characteristic of that content. In the example of processuality, its sheer dynamism permeates the four categories themselves. The two equilibrium conditions (disequilibriability and foundational equilibrium) are therefore to be understood in a dynamic sense: every 'thing' is constituted by equilibrating its intrinsic flux: energy (particle, substance), water (waterfall), material/mental metabolism (alive being, group, population, ecosystem, city, nation), value (economy), conceptual content (metaphor, proposition, mathematical equation), etc.

The difference between being inert and alive requires additional criteria for the structure: heteronomy vs. autonomy, which can be partial (having organs regulating sub-equilibria, which one does not control oneself). The existential laws of the inert are a subset of the laws of life: also matter arises and disappears, and should finally be understood in its complete cycle.

The perspective of processuality is useful for approaching directly the problem of life and death. No living being ever fears the law of death, because this law is an integral part of its life cycle. But all living beings fear the materialized process of dying as soon as it is inflicted by others. Our two equilibration formulations are exactly the categories needed for distinguishing dying out of self-fulfillment from dying out of external influence (in cell biology: apoptosis vs. necrosis; today's biology can't explain why two types of death exist). The idea of equilibrium is useful also for explaining the role of sleep (the 'little brother of death'), which can be noticed in empirical approaches, but not fully explained as the need for regeneration through higher forms of dynamic equilibrium than what is produced by everyday activity. The basis of sleep is in the foundational equilibrium of material matter, as it corresponds to what is called 'death' in biology (Schaerer [2002]). Alertness of mind in this basic point transmutes 'death' into 'life'—yet this awareness must be willed. Material matter is the ultimate master, but in its own way.

Problems of hierarchy 'within' live units, for instance in humans with body-independent thoughts, stop arising when acknowledging these as part of the constitutive flux: humans are not only their body—and can be understood in all aspects. Nothing is beyond this grasp, and immateriality needs no mysterious connotations, since the categories disclose the structural identity of material and immaterial processes, in inert just as in alive entities: while structures in the material realm are the result of actual equilibrations, correct propositions and equations express conceptually the conditions of the equilibria. In the debate, three forms of truth should be distinguished: (a) truth on the level of overall order (intrinsic law), as the mirroring 'zero-force' equilibrium between the two involved sides (depending on the chosen query perspective: percept and concept, subject and object, signifier and signified, mind and material fact, etc.); this form of truth is often referred to as a 'regulative idea'; and (b) truth on the level of appearances as (b1) truth theories, whose form is determined by the aspects they emphasize, and finally (b2) the adequate mental impression and then linguistic expression of a specific fact, which appears in the truth-values of propositions. Error, self-deception, and lying, result from holding specific types of belief.

Questions remain concerning an 'inner sense' that must exist, as thinkers have an awareness of what they think. Logic could not make sense without this sense organ. The materiality of a sense organ is another point; understanding existential structures as law-cum-force complexes offers a new key, also example to the 'mind-body-problem' and its prolongations into the (un)-freedom of will. Since both the categorial setup of a mind and material matter are conceivable as law-cum-force structures, albeit not produced in the same way, self-movement is possible to the degree of mastering one's intrinsic material structure (organism, body and mind). This is achieved in infant life, internalizing interactions in a long process of automatizing gestures by relating mentally to material conditions, until developing deliberation. In interactions between laws-cum-forces, force on the mental level (will, choosing motives) and on the physical level (moving one's own and other matter, following chosen motives) does not operate under the same condition. The material condition of the mind, deliberating its actions, is the categoriality it adopted (by having invested will in basic decisions, specific forms of order); this structure determines its limit. In physical action, the material condition is imposed first by the body, whose structure the mind can't determine, and then by all other material conditions of the universe. In the free will debate, freedom of thought and of action are thus being differentiated (Kane [1998] offers an overview). A Laplacian demon is an inadequate frame for determinism, because it hinders the clarification of the conceptually bridging element between matter and mind. Mastering one's bodily condition—the root of correctly understanding materiality—can't be achieved by means of abstract 'information' and exterior manipulation, it is a concrete conceptualization that must personally be worked through; the person is totally involved at the crossroads of her subjective motivational choices and objective material conditions—as any infant shows in its exploratory process, or later any psychotherapy.

Traditional approaches make it particularly difficult to fathom whether immaterial beings can exist or not. The solution is in realizing that any being can become independent of material matter by achieving full self-regulation in the dynamic equilibrium of its mental law-cum-force elements. Shaping one's categoriality in this direction—liberating oneself from compulsions—is best possible while incarnated, because only this condition allows to act autonomously and test the effect. Spirits don't inhabit the necessary materiality: an individual material body. The ultimate activity is 'listening' to the activity itself of 'listening'—actively, directly enacting self-referentiality. It is no coincidence that this threshold is essential in all religions. In systematic attentiveness, Science, Art, and Religion cease to look antagonistic, revealing parallels instead.

While 'hard' sciences learned to manipulate objects of the material world, 'soft' sciences manipulated the possible presuppositions, producing all sorts of paradigms, also for the 'hard' sciences. They produce techniques of manipulation, but when manipulation is left to its own devices, sooner or later it manifests a one-eyedness: it is blind to its own foundational doings. A one-eyed vision can only be cured by developing self-awareness. Whether a civilization has learned to manipulate 10, or 10,000, or 101000 objects, is irrelevant compared with whether it has seen through the idea of manipulating its own mind by believing in favored assumptions. Being able to handle ideas like things has been a very seductive idea—up to becoming a myth whereby control and domination is universally possible. But corresponding losses in the long run remind of unsolved problems. Assumptions may seem plausible at first, but in the course of interacting with reality they require to correct the theoretical structure, working off the assumption's effects, which shape thus the respective philosophy or method.

In systematic attentiveness there is no need to assume anything. Instead one first clarifies one's will—i.e., what one really wants to know, finding the appropriate perspective—unifying thus on principle the point of departure. Two paths are possible: one can choose a query perspective that has already been developed, providing the corresponding fundamental polar concepts (such as 'form vs. matter', 'perception vs. thinking,' 'the signified vs. the signifier,' etc.), or one can develop oneself the content of a query perspective (which takes a long time, however, for getting to the categorial bottom—in the mentioned examples, this process took Aristotle, Kant, or Saussere some decades). Our proposal is to prolong the polarizing process, applying the relevant one to itself, for discovering the rest of the implied content. This path does not face the limit of assumption-based systems, because the query content can unravel completely according to its own nature. The given topic is taken as it is, applying no arbitrary primal distinction, not even 'subject' vs. 'object.' The produced categorial structure then is on the level of origins (arché), yielding the ratio cognoscendi in the epistemic perspective and the ratio essendi in the ontic perspective. In the result, conceptual unity and differentiation can be equilibrated in a precise way. This is the condition for systems to be adequate to wholenesses.

Whoever is accustomed to thinking in a traditional frame of reference will have an aversion against the ideas of universality and certainty. This is justified in such a framework, because it does indeed not allow much of the sort. But that's not exactly the ideal solution. For breaking loose, it is helpful to realize that the mentioned examples—'form vs. matter,' 'perception vs. thinking,' 'the signified vs. the signifier'—are well-known concepts that are strictly universally applicable (i.e., not only to objects in the traditional sense, but also to the act of thinking about them) within the respective query perspectivity. This is clearly a form of universality, and it is not at all impeded by using these concepts in a self-referential way. Systematic attentiveness merely generalizes the polarization pattern, introducing no anthropocentrism of any sort.

The question of certainty is situated on another level. It is pretty obvious that no amount of observation of something can ever exhaust the possible predication. Insofar there seems to be an absolute limit to the certainty of any grasp. But the developed categorial tetrads don't offer any direct predicates (e.g., 'this thing is red'); instead, they are heuristicically relevant (e.g., 'check on the color': useful for guiding the observation, phenomenology, etc.). This is clearly a form of certainty, albeit of an unexpected sort. The respective phenomenological assessment or hermeneutic investigation still needs to be achieved of course, but its categorial guidance is secure. Phenomenology and hermeneutics also propose to open up to the subject matter, i.e., to 'listen' to it instead of 'talking' into it—which can be understood by anybody in any culture and is thus a trans-disciplinary basis—but they cannot achieve immanently a clarification of their own categoriality. The widespread complaint, whereby knowledge can never be totally secure, addresses only gaps in what is observable or can be handled as data. But in systematic attentiveness, instead of talking about such tangible aspects only (attributes and predicates, the language of manipulability), one talks about the qualities which are relevant in an overall structural way (addressing order as such, operating in the language of intelligibility). Attempts to grasp the 'essence' of things are doomed to failure when hoping to reach the goal by predicating attributes—because these are always contingent (i.e., not ultimately compelling, but determined by chance), since doing so depends on the chosen but not clarified perspective. In contrast, the approach we propose fosters an uncompromised quality by proposing to clarify the nature of perspectivity itself, revealing the law of nature that governs it (polar conceptualization upon fulfillment of content), and proceeding from there. By setting out integrally, the cognizing subject can operate integrally.—But how does this look in actual practice?

Considering the Mind Itself

For approaching whatever, it is useful to make sure first about how to use the instrument: our own mind. Some of this could already be read above between the lines, but now we can make use of the limitlessness of the proposed approach for considering the activity itself of querying and understanding, also in how habitual science goes about this topic. The resulting new clarity liberates the mind on the one hand for an uncompromised self-understanding, and on the other hand for applying the new approach also in the other scientific domains.

The mind is produced by nature without providing a user manual. The social context has its effects in conditioning new life gushing forth that learns how to use its mind by encountering malleability and resistance in the social structure. Much can be shaped by this context, but not strictly everything. We all build up our system of categories and representations by experiencing our alive bodily organization that is constituted by the same 'language' as the whole rest of the universe. The judging instance is always the same: the 'I,' whether conceiving emotions or what body senses present. Insofar the now widespread question 'how does the world get into our head?,' based on the idea of some 'reality independent of our consciousness,' displays essentially an estrangement from our own potential of integral conceptualization. It splits up artificially the continuum of openness and interjects abstractly a sensory system, which is in full reality precisely a bridge to otherness, not the imagined abyss. The fantasy in alienation is that our skin is the limit for understanding physical reality—as if all our own body and its sensory system, including the brain for mental sensitivity, were not understandable in exactly the same way as all other appearances. Of course in 'summer' of the 'four seasons of being' our body is more closely linked to us than other material objects, because we have to learn how to move it non-conflictually. The real question therefore is whether we aim at totality and get our foundational concepts right, or in other words our categoriality. Only this path can teach us for instance why human beings have no body senses for electricity and radioactivity: wherever the corresponding phenomena happen to arise, they are equilibrated by nature towards zero (overall electron-proton-ratio, radioactive decay, etc.). If humans decide to accumulate matter in a way that produces such phenomena, they are responsible themselves. There is no point in feeling superior to nature because it has allegedly forgotten something.

A problem might arise for some by talking about the 'I,' since it is not a palpable object of the material world. We mentioned that the finally relevant elements for intelligibility (e.g., laws and forces) are never directly observable. It is therefore naive to expect the 'I'—the locus of intelligibility becoming relevant—to be a palpable entity. In this question too the distinction between (a) an order as such and (b) its manifestation in other forms of order is useful. Taking complete self-referentiality as the type of order that can be called the 'self,' and manifestations of this order as what can be called the 'ego,' solves the problems that object-oriented methods produce for themselves. This conceptualization of the self corresponds to what was sought in the 'essence' of being human. Critics of an essentialist perspective should not forget that their limit in understanding this perspective does not mean that the perspective is obsolete. And critics of the self as principle of complete self-referentiality might remember the scrupulous investigation of Søren Kierkegaard [1983]. Prolonging his philosophical considerations—of which his theological interpretation is not compulsory, as he writes himself—reveals that the type of relation called the 'self' is not its manifestations, in fact it can't manifest itself on its own. It is essentially the type of organization that distinguishes human structures from other ones. The necessary 'force' aspect resides in the 'individual desire,' manifest in an individuality (appearance in time: what evolves self-fulfillment of a person) and its personality (appearance in space: what can be perceived of a person). Without desire there is no manifestation of the self; the 'ego' is the totality of personal manifestations. In our new approach, the important difference between values and ideals as sources of motives also becomes more transparently intelligible than in traditional systems, where they are usually mixed up. Values (e.g., virtues, but also power, ownership) draw from the well of collective attractivity, while ideals (e.g., beauty, freedom, friendship, harmony, love, peace, truth, understanding) stand out by relating to conceptual totality in a non-coercive way, and need not represent a collectively attractive idea. The difference in animals and plants is that their fundamental desire and hence agency is located on a collective level, i.e., the specimen cannot autonomously reflect ideals and manifest independent individuality. The validity of values and ideals can become rationally debatable in a universal conceptual framework—as opposed to the usual ones, which are indeed limited.

In any approach looking 'from outside,' the mental act must remain mysterious because it occurs in the crossover point of 'cause' and 'condition.' Categorially speaking, agency is polar to its result, the product of agency. A direct way of becoming aware of this is in considering our own mental act. To feel something or think of something does not occur 'out there,' since we are doing it (in the 'I'-mode), engrossed in the specific content we deal with ('consciousness of something'). We can't notice this fact during the mental act because we are occupied with just this content. From a propositional point of view, this fact must logically lead to a belief that this duality is inevitable: either think content or think the idea of thinking content. This is correct insofar as the average person is indeed not aware of something and simultaneously of thinking it. Looking only 'from outside', an abyss—moreover one polarized into the categories of subject and object—seems to separate pure object and pure act. But sensed 'from inside' we are all perfectly coherent (even if seldom aware of our own coherence, since we don't focus our attention on it), and we can develop our awareness beyond the usual one into new areas, precisely because we are ourselves all of the mental field. We can focus anew and don't only have results, offering what a propositional point of view works with, and what any formal logic requires. One may fantasize that qualia (profoundly individual experiences) are mere illusions, but if the individual thinker saying so had no clear idea of what he is thinking about, he or she would not be able to theorize correctly. The key to understanding the 'innermost' is in noticing that any clear thought always shows all of its content, there is never a hidden part of an idea—in contrast to materialized life, where everything is limited to some perspectivity. On the other hand, clarity is not given for free: without our directed attention it can't securely become manifest. Without using our will we remain in associations, fantasies, suppositions, whims, a wandering mind, etc.; some people never go beyond. The universe features freedom, which includes in other words: no material compulsion to develop one's mind.

In systematic attentiveness, there is thus no mystery between order and agency in the 'I': they converge in the 'I,' or rather in 'I-ness' (the self, not the ego on its own). We all know this through the fact that one can understand totally only oneself what one is doing in one's own mind (in philosophy this is the 'other mind problem'), while doing so is always an activity, in which one can be interested by participating in one's own intentionality instead of letting one's mind drift off on its own. The self constitutes an overall order that allows simultaneously full differentiation and full unification. For the individual person herself this is not too mysterious, but when thinking of the universe in its overall order, where there is also immediacy, most natural scientists will feel uneasy at the thought that there might be an 'I-ness' within it. Note that we do not need any hypothesis of God in systematic attentiveness, but that this approach is compatible with it: there is no contradiction. Note also that 'I-ness', or God (or whatever other name it may be given), does not mean that this instance has manufactured the beings like people manufacturing gadgets in a factory. This is a relevant point for the debate between proponents of Darwinian evolution, 'intelligent design,' and creationism, in which all sides are caught up in ultimate inconsistencies; as things are, none can win. Once one gets used to 'listening' to one's own activity itself of 'listening,' the whole setup can reveal itself as being conceived in a much more intelligent way that any of our factories can ever be. It embodies the art of perfecting continuously the overall order, which can be grasped only in pure intelligibility. Not the material product (the evolving beings) is the result, but the overall framework within which the beings unravel their evolution; they are simultaneously totally free (in choosing their perspectivity) and yet perfectly embraced (in the ultimate consequences of their choices). A noteworthy point (especially for undogmatic feminists) is that in alive 'I-ness' the traditionally 'feminine' aspect of being, sensitivity ('listening') and its 'masculine' aspect ('acting out') are united, structured according to the content that is being dealt with. In terms of pure intelligibility, the overall order is of the character of 'I-ness' (or selfness), simultaneously all-encompassing and perfectly equilibrated in content. It allows all beings to manifest their own paths—they are free to choose even their own degeneration. Where hindrance arises, it does so only between beings—while the solution in conflicts can be found in considering the overall order, 'I-ness,' selfness, etc. (the name is less important that what is being meant by it).

Today's mainstream operates in a look 'from outside,' hoping it will warrant objectivity. The stance stems from a myth whereby the problem is true predication. The obsession is to find truth in propositions. It leaves no other choice but to shift crucial questions into forever smaller details, while no propositional system can ever be absolutely true. The real task is to care patiently about strict totality, 'listening' to all facts before predicating. Otherwise one is only the priest of a confessio, causing wars between paradigms, as Thomas Kuhn has shown. The principle of religio can't be fulfilled by seeking a 'co-evolving' relation with neighboring disciplines, or by making absolute one's favorite partial holism (e.g., epistemic holism, ontic holism, quantum holism, semantic holism, etc), of which none is completely holistic.

The danger of science on such paths is that it produces objectively unnecessary problems. The Necker cube and similar graphic arrays are a good example (fig. 3). We can either see a cube facing down to the right or one facing up to the left, but not both cubes at the same time. Is this an illusion, as we are 'scientifically' being told? And if it is one, will it be dissolved by seeking the ultimate neuronal correlate of consciousness, and detecting it—e.g., in the inferior temporal cortex? (For a fairly detailed presentation of the current debate, see MITECS: The MIT Encyclopedia of the Cognitive Sciences, online on http://cognet.mit.edu/MITECS).

We can notice that once we saw both cubes, we can decide which one to see, and switch at will. In this way we can experience what makes the real difference (since the percept as such is the same): the mental representation that we produce by our interpretation at will. Offhand we can coherently have only one representation at a time. Wanting to have both requires quite some effort: mere gazing at the lines won't yield the result, but people who are sufficiently trained mentally can remain even in the undecided state of mind. What they did is understand the facts, thereby creating mentally a representation which encompasses both in the mirroring equilibrium. The choice at will is crucial—and precisely what the cognitive sciences will never be able to find, because it is unthinkingly excluded from their categorial structure and can thus not appear in their query. Whoever seeks mechanisms can of course find only mechanisms.

Other 'illusions,' such as the Müller-Lyer lines of seemingly different length, or the vase vs. two profiles facing each other, can be disentangled in the same way, by conceiving the facts between perceiving and thinking as they ultimately really are. A seeming difference in length, or the choice between vase and facing profiles, is a result of interpretation: a conceptual act, but not of perception. The crux is our unawareness of automatized interpretations which we perform all the time. Usual science can't be helpful in this point, because it only measures the automatisms, it can't detect their erroneous conceptual basis. Higher precision in measuring will not lead further. The habit even in the most advanced forms of psycho-physiology is to not distinguish conceptually between the polar aspects of pure perception on the one hand, which appears in consciousness without the subject's contribution, and representational interpretation on the other hand, which appears in consciousness as something being modifiable at will within the scope of what is recognized and reasonable. The actual facts have to do with illusions only to the degree of remaining in some categorial confusion. The real problem is too narrow ideas of what categories and concepts are, and a widespread unawareness of one's own mental activity. There is an illusion in the belief (and as a result 'scientific' interpretation) that some perceptions are 'really' mere illusions. Science would do well to become completely scientific; it could do so by reflecting completely its categoriality.

Inadequately understood mental automatisms are the source of more problems. Take the example of the neurosciences, where measuring brain processes led to the notion of 'readiness potentials': the brain structures content which appears later in consciousness. Technically,

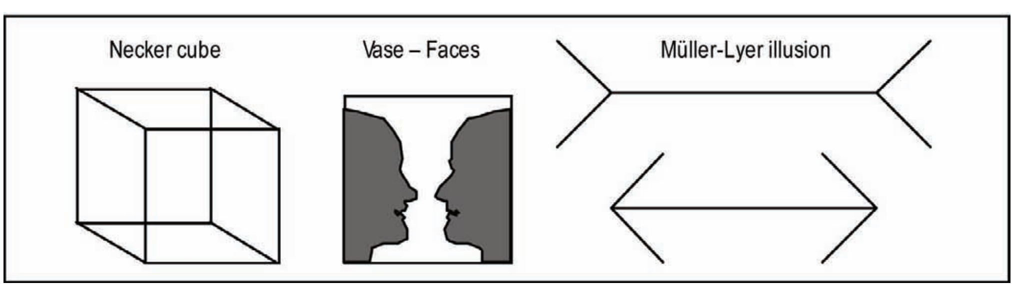


Figure 3. Optical illusions.

the measurements certainly are correct; there is no need to doubt that. But what structures are being measured? Where do they originate? Neuroscientists don't seem to observe attentively the infant's active exploration of material reality, in which it produces countless automatisms because it would be impossible for instance to move a limb or walk straight if one always were compelled to think of the many partial movements. The partial automatisms and their overall organization must be 'deposited' in some way in the organism (Michael Polanyi has called this 'tacit knowledge')—which does not mean the material traces are the causal ones. But it is no surprise that an intentional call to some order (content) then evokes the respective processes, which can be measured in the organ of sensitivity for pure order, the brain. For knowing this, no natural science is necessary. It is sufficient to realize that order (content) can be operative ('law-cum-force') without needing to take a propositional form. The possibility of translating pure order into conceptual and propositional form doesn't mean that nature itself is operating in that way. Precisely the infant proves this. Of course the whole setup can also be depicted through the categories of neuroscience, leading to a picture that is useful in some respects and will look convincing to those who believe in the scientific attitude. At the very end of that line there is nevertheless no full certainty, but a mere set of beliefs (basic 'scientific' assumptions).

I have chosen the example of neuroscience monitoring brain activity, and in parallel the geosciences monitoring nature's activity, for several reasons. One is that thinking is the domain we all can experience hands-on, discovering how different things look depending on the used conceptual spectacles. Another reason is that the two fields have more in common than what meets the eye. Whether seeking to secure sustainable forms of understanding and theorizing, or seeking to secure sustainability for life (or at least survival), one-eyedness is not a good option—while the mentioned intrinsic limit in content that ought to be mastered is not just an attribute of the neurosciences, but a general feature of the instruments for gaining knowledge which have been developed in the Western hemisphere. It may seem strange, but the cause of the limitation that is inherent in these instruments led also to their success in influencing the rest of the planet. Remember our two equilibrium conditions: disequilibriability and fundamental equilibrium. Brute power and domination always produces a first 'success' (because all structures are vulnerable, modifiable), but in the long run brute power and domination always is compelled to disintegrate, because it does not produce sustainable conditions. Once one really knows, there is thus no need to attack brute domination; it is sufficient to wait until the process ends itself. This is why there is no Celestial Intervention when horrors are being perpetrated: no supreme being has any need to interfere when humans are stupid enough to aggravate their existence. On the contrary, the precise non-intervention of such beings is the only real guarantee for the cognitive process in unaware beings to unravel in a non-adulterated way (in a superior equilibrium). The framework of the universe is their playground until they learn what things are about. One point is in understanding the inverting quality of birth and death, and the important difference between living in self-fulfillment versus living in coercion. In scientific activity, the habits of dominance do not have the spectacular results of obvious horror, so they can go unnoticed until their effects accumulate. Wanting to base everything on empirical evidence compels the produced errors to appear on the empirical level too—which explains why man-made catastrophes do occur and constitute a systematic danger.

A good way out is to apply the proposed new approach onto one's own psycho-organic being. Try yourself, experience the effect of sustained mental 'pulling' instead of 'pushing'; 'aspiring to something' and 'being inspired' are quite appropriate expressions. Self-clarification is first physical (relax the body completely: attentively accompany all muscles to the 'zero-force' overall equilibrium), then psychic (let idiosyncrasies pass away, finding 'peace of mind': attentively accompany all thoughts to the silence of overall equilibrium), for then taking care of chosen content (allowing it—a question, a mathematical equation, etc.—to equilibrate itself according to itself: attentively accompany the complex of content until it is poised relaxed in itself). You can experience how sustaining your openness—akin to the active curiosity of a small child, but now made adult by willful choice—has the effect of concentrating your being towards its own 'inner roundness,' transforming even quite heterogeneous elements of the past into part of what you always wanted to be, but could not manage to integrate. At its best, this process unravels in a wordless but fully aware way. It allows the relativity of assumptions, beliefs etc. to be perceived; they are not instantly overcome (integrity requires complete 'inner digestion,' more than the first move), but at least they can surface in awareness. Depending on the person, her interests and degree of psychic (non)integrity, the mental discipline of sticking to a subject matter for its own sake may require particular care. Infants can sustain openness naturally when they are well-equilibrated, but cannot choose to do so at will, while adults often must learn the whole process anew. Nevertheless, the practice of mental 'pulling' instead of 'pushing' is the only fully honest way of living—and also of doing philosophy or science; real progress always draws from this well. I merely propose a new systematization.

Earlier, we touched upon the earliest approach to totality by seeking enlightenment for actualizing revelation as a source of knowledge. Now theoretically nearly everybody rejects revelation as a method or systematic foundation, but in actual practice even nowadays a high priest's attitude has not entirely disappeared among scientists, especially where they have led fragmentation into 'causative elements' to the point of these disappearing from the material level, making believe then the spiritual level is being addressed; understandably they sincerely believe in the foundational assumptions of their methodology. The opposite side is in seeking revelation by means of allegedly stopping to think—not realizing that this path builds up a conceptual barrier through extremely intense thinking, of which 'not thinking' is only an effect of the barrier collapsing. Adepts of the respective (often Oriental) techniques tend to cut out this fact. The abstractly willful, even arbitrary mental activity that led there is being faded out in clinging to a myth. The unity of the doer and his result requires no such procedure, and can sustainably be experienced by becoming aware of categoriality and intentionality. An activity of 'thinking not-thinking' is indeed not the same as 'willing non-will' in a sense of 'listening' in simple openness to reality; the closest version to this is in the Zen tradition, in which the categorial conditions are not fully clarified, however. A danger of experiencing purely mental light is to believe oneself to be an infallible authority, imagining this to be God's way of being. Having had such experiences makes it difficult to grasp their relativity. Apart from the basic difficulty of knowing what 'God' really means, it is useful to realize that structurally all beings are the same as the cosmos insofar as they all embody, by dint of their material organization as entities, the principle of self-equilibration, without which also the universe as a whole can find no dynamic stability; the debate around the 'Anthropic Principle' reflects this issue. Activities such as self-reference, self-regulation, or self-realization, are all ways of actualizing that principle on various levels. The principle itself is not its actualizations. Practices leading to enlightenment can produce a singularity where the agent and his result are one and the same for a while; but this procedure is neither a necessary nor a sufficient condition for this unity, which becomes quietly sustainable (i.e., non-singular, instead of pointedly impressive) through the gesture of asking, querying, seeking to understand. It culminates in 'listening to the activity of listening,' which opens the door to the structure of the mind. Addressing unity in a fruitful way is possible only on a non-conflictual path, leaving away all personal interventions and desires—also those of achieving 'enlightenment.' Instead of experiencing that light, finding total transparency is the relevant issue; awareness need not be sacrificed. Nothing can replace the actual practice of 'listening to listening,' letting pass away all words and imagery for the sake of remaining on track towards unity. Temporality remains only through introducing changes, and spatiality when entertaining differences. Sustained 'listening to listening' has a clarifying, purifying, unifying, healing effect. Even CEOs are now discovering this dimension. Evidently, monastic discipline and deep silence are helpful conditions. One can talk about the experience only afterwards, expressing aspects (here too fig. 1 is relevant). Gradually understanding the overall interconnections is the type of knowledge that is adequate to complete reality.

The advantage of the proposed tetradic categorization shows especially in borderline cases of the mainstream view—for example at the edge of life, in the way infants proceed into what usually is called life, and elderly people into what usually is called death. They do not do so in an object-oriented way, obeying the current scientific paradigm, but in a way that is rooted in the whole. Intrauterine and neonate life sets out in holistic sensations, increasingly attributing meaning to gestures (forms of ordered movement, mental as well as material), later associating the regularity of sounds with the regularity of gestures (this is called 'language acquisition'). Observe infants in how they move: they set out from their inner equilibrium, moving their feet and hands out of this sensation—at first not at all in the aim of going somewhere, but simply in experiencing and experimenting their potential of self-dis-equilibration and re-equilibration. The more an empirical scientific approach of these phenomena interconnects the details, the more it must acknowledge that infants develop meaning from the whole to the parts (see e.g., Stern [1992], Dornes [2001]), not as widely expected the other way around. At the other end, when old age gradually merges into the process of dying—we mentioned the crucial diffence between dying out of self-fulfillment and dying as an effect of alien intervention—, the inverse process can be observed: the less the process is disturbed, the more the affected psyche refers to the whole in gently shifting overall equilibria, letting go of particularistic object orientations (e.g., Kübler-Ross [1997], Albery et al. [1993]). Such a death can be totally peaceful—which is more probable when having led a tranquil life. At both ends of earthly life, the said holistic features can be observed empirically. This is not yet an explanation for their way of arising. But the proposed conceptualization offers that for the whole cycle of 'four seasons of being,' through precise ways of grasping perspectives of the overall order. It can be helpful for those in the humanities who feel they are in need of new prospects (Schaerer [2004]).

Applying the Proposed New Approach in General

The new unified approach, being fed by the intrinsic overall order, complements is a precise way the traditional ones, which are fed by their object-orientation (fig. 4). It operates out of fulfilled integrity: by going through all of oneself one can interact adequately with ever more forms of otherness—an aspect that is often debated under the title of 'alterity.' One can indeed grasp in otherness only what one has clarified—or at least become aware of—in oneself.

An ever more profound self-awareness is helpful for grasping the scientific process as a whole of aspects that interrelate in a specific way: the empirical side yields data for knowing concretely what we talk about, while the rational side yields universal concepts for knowing how to talk reasonably about data. Only both together allow science to function organically—as much in the single mind as on the institutional level.

In the habitual paradigm, one hopes to be able to reconstruct the whole through a synthesis of analyzed 'elements.' But regardless of how detailed a breakdown into 'elements' is, the thing as such can never be understood (as for example Kant demonstrates); then the considerations can never leave completely the mechanistic realm.

The practical applicability of the new approach implies first a translation process of the usual view for the phenomena into a view through the new categories. This translation effort is rewarded by discovering a new transparency in the structural parallels across the fields and disciplines, and by achieving finally also a higher overall efficiency of the research process.

Obviously not everybody is immediately interested in venturing into such a new field and form of action, even though there are many advantages in doing so. For those who choose this path, it is therefore useful to pursue simultaneously two tracks: a pragmatic interaction with present debates on the tactical level, while regularly feeding it by the activity of 'listening' into the overall order as the foundation on the strategic level. The approach proposed here is not adequate for manipulatory intentions, as the now usual forms of science are. It is no 'mental instant coffee', but requires patient care: it needs to be sustained. In fact, the sustained activity of 'listening' is what in classical antiquity was called hypokeimenon: the subjacent basis which allows (material or mental) 'things' to become what they finally are; the polarizing arrows in figure 2 can indeed easily imply, in mental practice, the effort of a few decades (as documented by many examples in the history of philosophy).

The sciences implied in the considerations of this symposium on monitoring are rooted at their one end in natural science, and at the other end in policy making and hence in the social sciences and humanities. The symposium emphasized the triad of 'ecological, economic, and social' points of relevance. This intention can be rounded off by considering that all beings are a living span between their material organization and their way of handling their own overall order. So three basic conceptual aspects are relevant for their wholeness: their material body, their intrinsic order (law-plus-force) that organizes it, and the oscillating mediating 'something' that produces the individual movements, which actualizes the principle of self-equilibration. The difference between inert structures and alive ones is only that first are fully determined by exterior influences; what the self-modifications are attributed to—a genome, an entelecheia etc.—is another question (for details see Schaerer [2002]). For coordinating conceptualizations, three fields of contemporanean science are conceptually critical and can be particularly fruitful when newly being based on an uncompromised way of 'theoretical theorizing':

- theoretical physics (understanding matter),
- theoretical biology (individual mediation),
- theoretical economics/social science/humanities (making explicit togetherness).

For the time being, a clash of ideas is still going on—beyond the clash of scientific cultures (C.P. Snow) and the clash of civilizations (Sam Huntington). It is an ideological war between minds seeking domination and minds seeking understanding. Maybe we can offer

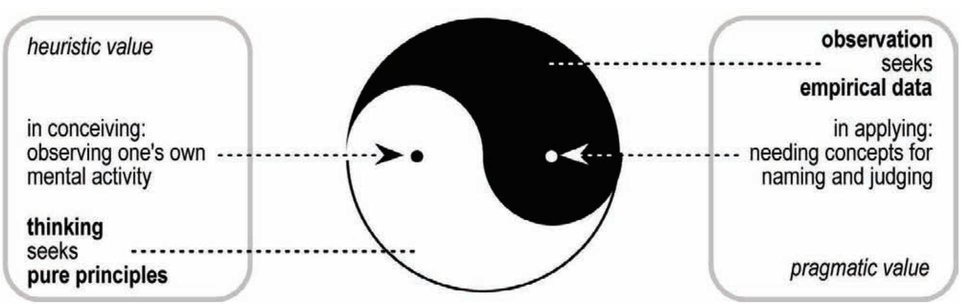


Figure 4. The scientific endeavor as a coherent organic wholeness capable of housing conceptually all life.

a bridge. For the moment it is still easy to seduce many people with what they can 'do,' not with what they can understand. Problems like sustainability are like catalysts in the process of reconsidering.

Of all natural sciences, the geosciences are especially interesting (and relevant in questions of sustainability), because they need to integrate methodologically the full scope between the mineral, vegetative, animated, mental and social levels of existence—the more seamlessly, the better. In all of its realms, 'systematic attentiveness' offers significant conceptual advances. On the level of pure natural science (physics and chemistry), an approach to the nature of matter is possible that can encompass life as a principle. Matter reveals itself as never being causal, but the indispensable condition for all processes. Grasping this difference—which can't become clear in habitual approaches (think e.g., of the deductive-nomological schema of causal explanation)—can liberate science from many burdens. In physical geography, the pragmatic categories of 'accumulator,' 'regulator' and 'process' can be reduced to the principle of 'process', thus simplifying the terminology. In climate studies, the constitutive notions of 'energy' and 'information' can be purified towards their real meaning. Both are not suitable for a strictly integrative view, since neither is a really fundamental concept. In the lithosphere the edaphon with its interlacing inert and alive structures can be approached terminologically in a unified way, avoiding reductionist paths; then for example ion exchanges, chemical weathering, and a mykorrhiza can be contained in a homogenous conceptual grasp. In geoecology, the existence of homogenous landscape units can be approached through the idea that such units arise where specific parameters warrant a dynamic equilibrium; this avoids anthropocentrically 'intuitive' definitions (e.g., via watersheds), since the parameters can objectively be studied until finding a homeostatic overall order. In biogeography, the hitherto mysterious link between the mineral and biotic realms can be approached through the principle of organs regulating sub-equilibria of the overall equilibrium—without the fallacies of the physicalistic or geneticist sort, where order and agency can never become ultimately clear, with the result that it was superseded by a belief whereby nature works in the same dominative way as humans try to justify for their own doings. How come a blade of grass can grow gently through concrete, where we must use a pneumatic drill? In human geography, the question of autonomy and heteronomy, freedom and constraint, can be solved in a non-conflictual way upon having unmasked the conflictual ways of hitherto usual science and intervention. Traditional riddles such as the 'mind-body-problem,' personal identity, or the freedom and unfreedom of will, become transparent in the proposed categoriality. In the structure of sociality, the efficiency of decentralized intelligence can become clear—as opposed to the hitherto favored model of centralized processing and command, whose apparatus entails unnecessary burdens. The best oil in the social gearbox is the autonomous capacity to think things fully through; no wonder it bothers those who wish to free-ride the social engine for their own ends. Finally, on the level of the purely theoretical geosciences, an overall categorial order can be found in which many old inconsistencies and incompatibilities can be leveled out. The proposed approach allows to address all types of entities, processes, and issues, on all scales, in a conceptually homogenous way.

Closing Remarks

The essential element of the presented proposal is the gesture of 'listening' to the problem at stake, instead of 'talking' into it, mentally 'pulling' instead of 'pushing,' 'sucking' instead of 'pressing,' i.e., seeking to understand fully instead of wanting to dominate. As has been shown, neglecting this ideal inevitably produces a fundamentally conflictual tendency already on the level of theorizing. In our era, blinded by short-term success of techniques, this neglect became habitual. The result is a lack of long-term certainty, or in other words of sustainability. This systematic drawback has its root in unawareness of one's own mental life and can be overcome only by becoming aware of this fact. In spite of its deep reach, the proposal of fundamental 'listening' instead of 'talking' can be understood by anybody, in whatever culture.

When pursued philosophically on the categorial level, this basic gesture allows a type of conceptualization that does not entail the cognitive self-limitations which characterize today's mainstream methods. The proposed approach requires, however, a particular dedication to the questions at stake. Pressures of whatever kind—conceptual (for instance paradigmatically, as in the 'science wars'), political, economic, etc.—as they often are being applied to the research process, are not conducive to circumspection; overall efficiency can't be achieved by pressure. Such pressures do not arise accidentally, however, they rather are a result of society struggling with malice while many judgments are muddled up by psychological projections (that darned phenomenon of not seeing the beam in one's own eye, but only the straw in other's). There is much need for more (self)-transparency—and 'listening' instead of 'talking' is the best method for that because it covers as much 'inner' as 'outer' reality, in a complete way. It is helpful also for discovering the primal source of malice: conditioning influences in infancy and childhood, which reach much more deeply than many would acknowledge, and yet are fully man-made.

A presence or absence of 'listening' instead of 'talking' as the socially effective basic gesture is thus not only of vague academic interest, because its material consequences reach extremely far. Think for instance of the 'youth bulge'—the high birth rates in certain areas of our planet, where simultaneously the young generation faces poor prospects and develops corresponding revolutionary desires, reproducing the basically conflictual gesture that Western influence had imposed, leading them to where they are now. This is now being discussed among strategists (see for example www.cia.gov/nic/speeches_demochange.html, www.populationaction.org, or www.wilsoncenter.org, www2.ucsc.edu/cgirs). Also in this explosive problem area, the usual intellectual response is only blown-up tactics, it doesn't stem from a truly strategic overview. Discussing the problems in terms of subjectivity and fighting for one's 'values' and 'interests' will not solve them. In actual policies, contraception, professional training and job creation is not enough, because such measures miss the origin of the vicious circle, they merely shift the problems into new areas. And wanting to control violence by the type of counter-violence that is organized by the state, as has become habitual since Max Webers view of the state, will never lead to the intended social order, but to always new forms of conflict flaring up. Hiding the crux in structural violence—for instance by instrumentalizing jurisprudence—is of no help. Under the practical conditions produced by superficial analyses, for example the gesture of wanting to grab resources under the impression of being in need is understandable—which gives rise to the problems of sustainability.

A sustainable solution requires the effort of thinking through the overall interconnection of facts in a strictly complete and totally secure way—including therefore the categorial system through which the facts are being interpreted. To mention only the problems on the economic level: the questions raised by thinkers such as Marx, Veblen, Myrdal, or Georgescu-Roegen, can't be solved by putting them aside for long enough, as is believed in the lore of mainstream (neoclassical) economics. For being able to evolve in constructive ways, the young generations need fundamentally true prospects, a materially and intellectually open horizon. The now still habitual approaches, methods, and theories can't warrant this. But this is not the end of the story: limits of understanding are not our fate, they are always only provisional and merely reflect the fundamental beliefs of the day. Doubting dogmas and 'listening' to the problem at stake, instead of 'talking' into it, is always a possible option.

Even Zbigniev Brzezinsky, who has an excellent grasp of the international situation and certainly is not a friend of demure attitudes, is gradually realizing the problem to some extent—not generally in the role of methodological work, but pragmatically in the problem's practical impact, for instance in losses of credibility. In his latest book [2004], Brzezinsky explicitly cautions the United States to seek global leadership instead of global domination. The outlined methodological considerations allow to know in a secure way that any limit in achieving this ideal will always be determined by limits in the sincere desire of understanding all the implied facts and interconnections in a complete way—beyond still widespread basic beliefs—and by taking materially a position that enslaves others in whatever way. The ideal of not limiting each other's liberties has always been a powerful part of the American self-understanding, but—as a few massive aberrations have been revealing lately—materializing it requires some better thinking than the average optimism can warrant.

But it is necessary to realize that good thinking outside the box requires at least as much precision and discipline as the rigor of which especially so-called 'hard' sciences are proud—the strictness is merely on another level. Their feeling is nevertheless not completely off track since the 'soft' sciences neglected the foundation of their own way of thinking. In contrast, the categorial instrumentation proposed here allows to cover seamlessly both sides. Making use of it, investigating and monitoring can cover also the hithero neglected aspects of its objects in the traditional sense, as they can then be approached uncompromisingly in their processual nature and specific degree of autonomy. The method for doing so is to think in a secure way from totality towards its aspects, encompassing also the principle of categoriality, i.e., the conceptual instrumentation through which any subject matter (for instance 'objects') is being dealt with, including thus the activity of thinking about them. This must seem impossible in today's mainstream of philosophy, philosophy of science, and science; the present essay is an attempt to outline an unexpected feasibility—thus hopefully encouraging those who always wanted to go beyond the alleged impossibilities, but could not get beyond wondering how to do so.

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