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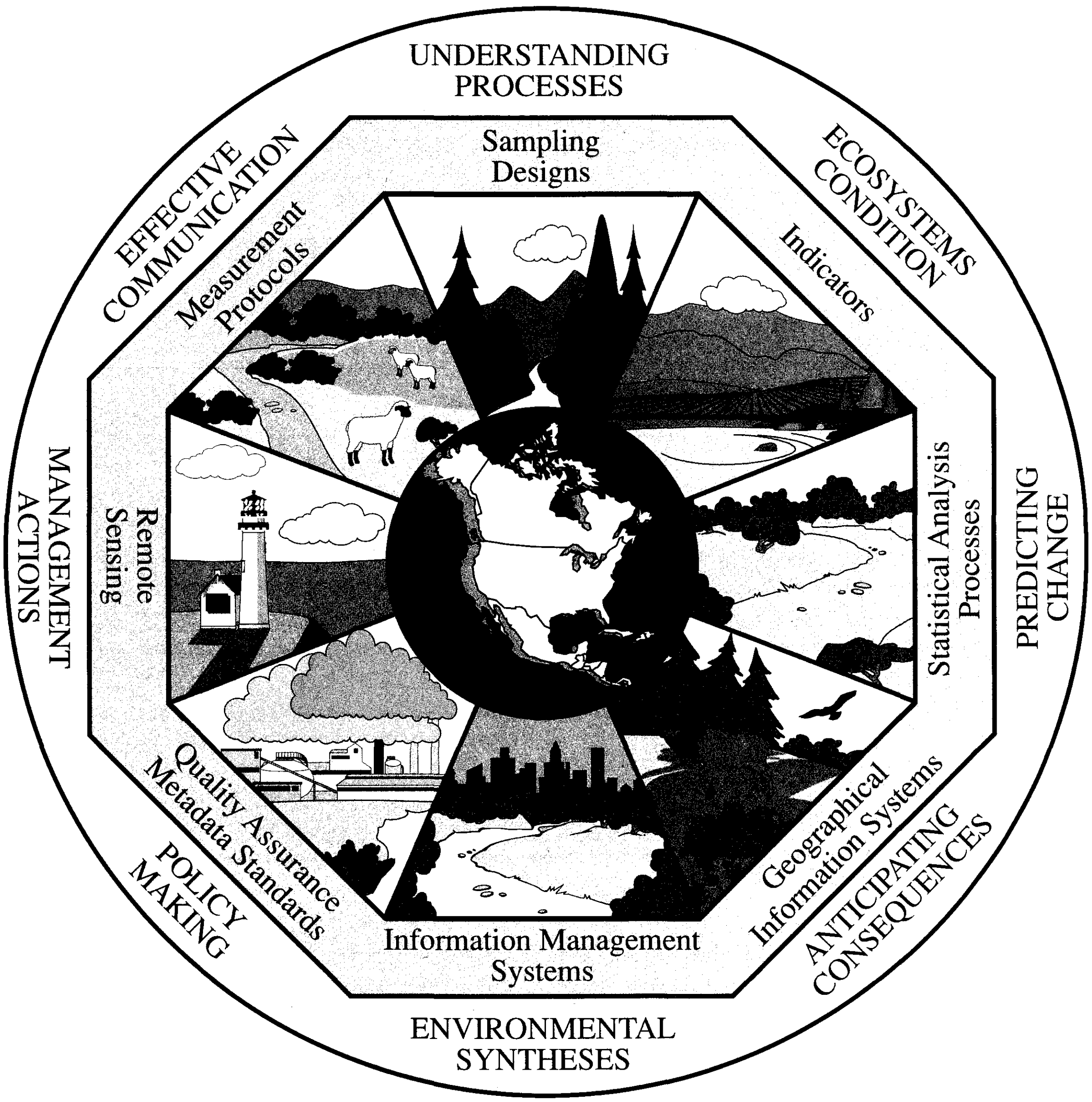
NORTH AMERICAN SCIENCE SYMPOSIUM

Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources



Guadalajara, Jalisco, Mexico
November 1-6, 1998

Abstract

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The general objective of this Symposium was to build on the best science and technology available to assure that the data and information produced in future inventory and monitoring programs are comparable, quality assured, available, and adequate for their intended purposes, thereby providing a reliable framework for characterization, assessment, and management of forest ecosystems in North America. Central to the syntheses delivered in this Symposium was the conclusion that a fundamental improvement in the approaches used for inventorying and monitoring ecosystem resources is required to meet current and future environmental uncertainties. Specific actions were proposed to address these challenges. These strategic actions are described in the last chapter of these proceedings.

***Editors's Note**: In order to deliver symposium proceedings to users as quickly as possible, many manuscripts did not receive conventional editorial processing. Views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA Forest Service. Trade names are used for the information and convenience of the reader and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA Forest Service.*

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North American Science Symposium

Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources

Simposio Cientifico Norteamericano

Hacia un Planteamiento Unificado para Inventariar y Monitorear los Recursos de los Ecosistemas Forestales

Guadalajara, Jalisco, Mexico
November 2-6, 1998

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Foreword

As we enter into a new century, it is very satisfying to notice that a growing number of institutions of Canada, United States, and Mexico are successfully integrating their capabilities to advance and share the knowledge needed for managing the North American ecosystem in a sustainable manner. Since our first 1995 North American Workshop on Monitoring for Assessment of Terrestrial and Aquatic Ecosystems in Mexico City, the increased interaction has galvanized many institutions and individuals to expand collaboration to assure transfer of technology and access to scientific information. The results achieved from the most recent North American Science Symposium again demonstrate to the world the power of working in partnership across institutional and national jurisdictions to confront the complex challenges of the 21st century. Thanks to this synergism the need to understand better a variety of ecological-economic processes at multiple levels of scale has become increasingly more important to the countries of the North American Free Trade Agreement (NAFTA).

Our institutions' studying and monitoring of the complex continental environment constitute one of the most important long-term scientific investments for the sustainability of the North American Ecosystem. Many of those syntheses and assessments covering a wide spectrum of issues were presented in this symposium. These contributions testify to the work scientists and other professionals are doing to meet a growing demand for scientifically credible information about the status and trends of the condition and sustainability of our ecosystems. This information helps us to better understand and manage our ecological systems for their sustained use, within and across national jurisdictions, at multiple levels of temporal and spatial resolution, to ensure their functional unity and integrity, their sustained productivity, vitality, diversity, and societal value.

Central to the syntheses delivered in this symposium was the conclusion that a fundamental improvement in the approaches used for research and monitoring ecosystem resources and the environment is required if societies are to meet environmental uncertainties. These syntheses also emphasize the urgent need to expand and diversify existing partnership efforts across institutional and national boundaries. A number of specific proposals for action were presented at the end of the symposium. Additionally, sponsor representatives signed a nonlegally binding statement expressing their intent to continue the partnership in research and technology transfer efforts emphasized in the symposium's conclusions and recommendations.

For North America, with a multinational free trade economy, it is essential to develop a unified strategy for advancing research and monitoring approaches for the assessment of ecosystem sustainability. Though at present the NAFTA countries do not have such a strategy in place, its development and implementation is particularly important given their geographic adjacency, and ecological, economic, and socio-cultural linkages and interdependencies. Building this institutional capacity would make possible the development of comprehensive environmental syntheses to inform society about the status of ecosystem resources and the environment—and if they are changing, why and how that change is taking place. Symposium participants noted that if scientifically credible information is not available to provide policy alternatives, the documented impacts of global change on the environment and human health will continue, with the potential to increase the level of uncertainty of policy decisionmaking processes. These conclusions and recommendations, therefore, constitute an important outcome of this symposium, and a number of ongoing activities are directed to implement them. Success is critical to the formation of new partnerships so that our institutions can more effectively wrestle with the complex problems of providing a sustainable world for future generations.

This publication and the symposium constitute a real achievement in partnership by many institutions and individuals of Canada, United States of America, and Mexico. In Canada, we thank the following sponsoring federal agencies and individuals: Environment Canada (Minister, Christine Stewart); Natural Resources Canada, Canadian Forest Service (Minister, Mr. Ralph Goodale, AD Minister, Dr. Yvan Hardy); In the United States of America: U.S. Department of Agriculture (Secretary, Mr. Dan Glickman); USDA Undersecretary of Natural Resources (Dr. James Lyons); USDA Forest Service (Chief, Dr. Michael Dombeck); U.S. Environmental Protection Agency (Administrator, Ms. Carol M. Browner, Ms. Norine Noonan, and Dr. Henry L. Longest II); U.S. Department of the Interior (Secretary, Mr. Bruce Babbitt); US-DOI Geological Survey (Director, Dr. Charles Groat), USGS-Biological Resources Division (Dr. Dennis B. Fenn); U.S. National Park Service (Mr. Robert Stanton, Dr. Michael Soukup); In Mexico: Secretaria de Medio Ambiente, Recursos Naturales y Pesca (Secretary, Ms. Julia Carabias Lillo); Secretaria de Agricultura y Desarrollo Rural (Secretary, Mr. Romárico Arroyo Marroquin); Gobierno del Estado de Jalisco (Governor, Ing. Alberto Cárdenas Jiménez); Coodinación Nacional de la Fundación Produce; Fundación Produce Jalisco, A.C; National Autonomous University of Mexico, Institutes of Geography and Ecology); Universidad de Guadalajara, and Universidad Autonoma de Guadalajara.

We also acknowledge the efforts of individuals who played a significant role in planning of this symposium. In Canada, we thank the following individuals: Environment Canada (Dr. Hague Vaughan, Director, Ecological Monitoring and Assessment Network; and Dr. John Lawrence, Director, National Water Research Institute); Natural Resources Canada (Dr. Carl Winget, Director, Science Branch, Canadian Forest Service; and Mr. Harry Hirvonen, Science Advisor, Canadian Forest Service). In the United States of America: USDA Forest Service (Dr. Robert Lewis Jr., Deputy Chief for Research and Development; Dr. Richard W. Guldin, Director, Science, Policy, Planning and Information; Dr. Douglas Powell, National Monitoring Coordinator; Dr. Andrew Gillespie, Program Manager, Forest Monitoring; and Dr. Cele Aguirre-Bravo, Mexico Research Coordinator); U.S. Environmental Protection Agency (Dr. Sidney Draggan, Senior Science Advisor, Office of the Assistant Administrator for Research and Development); USGS-Biological Resources Division (Dr. Thomas J. Stohlgren, Project Manager, Midcontinent Ecological Science Center); U.S. National Science Foundation-LTER Program (Dr. James R. Gosz, University of New Mexico); Colorado State University (Dr. David R. Betters); and University of Las Vegas (Dr. Craig Palmer). In Mexico: SEMARNAP-Subsecretaria de Recursos Naturales (Dr. Victor Villalobos Arambula); SAGAR-Instituto National de Investigaciones Forestales y Agropecuarias (Chief Director, Ing. Jorge Kondo López; Dr. Carlos Rodriguez Franco, Director, Forest Science; and Dr. Ramon Martinez Parra, Regional Director, CIR-Pacifico Centro); National Autonomous University of Mexico (Dr. José L. Palacio Prieto, Director, Institute of Geography; and Dr. Gerardo Ceballos, Professor, Institute of Ecology).

Similarly, the participation of many other professionals (authors, contributors, reviewers, chairs, interpreters, translators, publishers, and volunteers) has been invaluable. To all of them, we are grateful to have benefitted from their experience and support.

Dr. Denver P. Burns
Director, Rocky Mountain Research Station
USDA Forest service
Fort Collins, Colorado, USA.

Contents

Subject III
The Evolving Complexity of Inventorying and Monitoring Forest Ecosystems

Subject IV
New Approaches to Integrated Inventory and Monitoring of Forest Ecosystem Resources

Subject V
Challenges to Achieving Integration

Subject VI
Conclusions and Recommendations

Keynote Speech[1]

Robert Lewis Jr.[2]

Governor Cardenas, and esteemed colleagues of Mexico, Canada, United States, and other parts of the world. It is my great honor to represent the USDA Forest Service during this North American Science Symposium on **"Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources."** I bring you warm greetings from Mike Dombeck, the Chief of the U.S. Forest Service. Mr. Dombeck extends his apologies that he cannot be present with us on the occasion of this important scientific event.

This Science Symposium is of special significance for the USDA Forest Service as well as for other U.S. Land Management Agencies which have active research and operational programs for inventorying and monitoring terrestrial ecosystems. The exchange of scientific information and experiences that will take place in this meeting is also of major significance for the NAFTA countries since our nations need to know the status of their ecological systems, soil, water, plants and animals, water and air; and if they are changing, why and how that change is taking place. In this important meeting, scientist from our respective institutions will address the issues of drivers of change as well as scientifically based approaches to:

- Understanding and reporting on the status and trends in ecosystem condition;
- Describing emerging ecological problems;
- Aiding in the design of ecosystem management activities;
- Evaluating ecosystem management programs in terms of their performance; and
- Responding to ecological emergencies.

Central to the goal for this Symposium is to build on the best science and technology available to assure that the data and information produced in future inventory and monitoring programs are comparable, quality assured, available, and adequate for their intended purposes, thereby providing a reliable framework to support informed and responsible decision making.

Please let me emphasize that the USDA Forest Service views this **"North American Science Symposium"** as an important integrating mechanism for carrying out and advancing many of our responsibilities. While our forests are generally healthy, we know that past and/or current management practices, and change in our global ecological systems, have increased the risk of catastrophic wildfires, and increased the severity of drought, insect infestation and disease. Our nations face serious forest ecosystem health problems, and therefore, ecosystem management practices need to be improved based on the best available scientific data and information produced by our research monitoring and inventory programs. Also, the relationship between the well-being of people and the healthy condition of ecological systems is critical to the future of human society. Simply put, people's needs cannot be met if the health of our ecological systems is not secured.

Understanding this complexity constitutes one of the most fundamental challenges society and governments face today and into the twenty-first century. In this Symposium, scientists, resource managers, and a variety of experts from North America and other parts of the world will address the complexity of these issues and the scientific approaches needed to confront them.

As our economic systems become more interdependent and global, understanding the vulnerability of ecological systems to the different drivers of change is fundamental to insuring their sustained productivity and societal value. Sustaining the health of ecological systems, and particularly, managing and mitigating change in those that have already been damaged, are also among the most critical issues and challenges governments and societies face today and in the foreseeable future. Because the complexity of these issues transcends national boundaries, the collective environmental and economic performance of our countries becomes an essential condition for achieving and securing the sustainability of ecosystems.

Various international mechanisms and protocols have been developed to address the complexity of these issues. In particular, the USDA Forest Service has been working internationally to address these concerns. As in many other related cooperative undertakings, sponsoring this Symposium in partnership with federal agencies of Canada and Mexico is a clear example of our international commitment to ecosystem sustainability for generations to come.

In closing, there is much to be encouraged about in the progress made so far by our respective agencies since our 1995 Science Meeting on **"Monitoring for Ecological Assessment of Terrestrial and Aquatic Ecosystems"** held in Mexico City. There is an openness in diplomacy among our governments for cooperation in many sectors. Thank you for hosting this Symposium in the beautiful City of Guadalajara — ***The Western Pearl of Mexico***. I look forward to the fruits of our work in partnership.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

[2]Robert Lewis Jr. is Deputy Chief, Research and Development,USDA Forest Service, Washington, DC.

A Welcome Reunion[1]

Sidney Draggan[2]

Bienvenidos, Bienvenue, Welcome to our Symposium participants. For you who are joining us for the first time; we have come together for a working reunion among the participants in the First North American Symposium held in 1995 in Mexico City. Since that time, we have become more aware of the number and the complexity of North American environmental concerns. The complexity of these concerns indicates clearly that rather then being amenable to absolute remedy, many environmental concerns can be handled best by more comprehensive and more practical management. North American environmental managers need defensible, comparable and credible data and information to achieve this more comprehensive and more practical administration of our valuable ecological systems.

I want to call your attention to three recent reports that encourage this view. *New Strategies for America's Watersheds*[3], was prepared by the U.S. National Research Council's Committee on Watershed Management. The committee found that watershed-scale management can be difficult since it requires cooperation—and information sharing—across different jurisdictions and agencies. Nonetheless, the Committee sees management at the watershed scale to be the best way to address diverse resource management problems in an integrated way. This is because watershed scale management draws together concepts from the physical, biological, social, and economic sciences.

The second report, *Overview—Global Environmental Change: Research Pathways for the Next Decade*[4] by the U.S. National Research Council's Committee on Global Change Research, notes that maintaining old—and establishing needed—observational and monitoring systems will be especially challenging. This is due to their cost, and to the fact that their components must serve the needs of the different communities that use their outputs.

The third report—*Using Stakeholder Processes in Environmental Decisionmaking:: An Evaluation of Lessons Learned, Key Issues, and Future Challenges*[5] by Terry F. Yosie and Timothy D. Herbst—notes that, "Stakeholder involvement in environmental decisionmaking by government and industry is inevitable and will continue to expand".

The report shows clearly that calls for greater use of stakeholder-sensitive processes over the past decade represents a clear societal need for more interactive forms of decisionmaking. This third report is of most interest to us as it appears at a time when some scientific and risk experts[6] are voicing frustration about the emphasis governments are placing on the use of stakeholder decisionmaking processes. These experts feel that this emphasis is leading to an underreliance on technical and scientific information in decisionmaking. This tension between the science community and non-scientific stakeholders must—somehow—be addressed and reconciled. I hope that you—participants in this Second North American Symposium—will help to achieve measurable progress in this reconciliation during your work this week. Again, thank you for joining us.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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[3]1998 Prepublication Copy. Published book will be available from: National Academy Press; 2101 Constitution Avenue; Washington, DC. Available on Line at: http://www.nap.edu/readingroom/enter2.cgi?0309064171.html

[4]Available on Line at: http://www.nap.edu/readingroom/enter2.cgi?ES.html

[5]American Industrial Health Council. 1998. Washington, DC. Available on Line at: http://www.riskworld.com/Nreports/1998/STAKEHOLD/HTML/nr98aa01.htm

[6]EPA Emphasis on Stakeholder Process Exasperates Risk Experts. Risk Policy Report Volume 6, Number 10:6-7 [October 16, 1998].

Subject I

Global Environmental Change

Global Change Impacts in Nature Reserves in the United States[1]

Thomas J. Stohlgren[2]

Abstract—Large natural areas such as national parks, forests, and wildlife reserves have provided the U.S. Global Change Research Program with an important outdoor laboratory that provides an index of change in our most treasured ecosystems. Rapidly changing climates are superimposed on other ecosystem stresses such as urbanization, air pollution, habitat fragmentation, loss of native biodiversity, and the invasion of exotic species. Climate influences the frequency and intensity of disturbance (e.g. fire and insect outbreaks), species distribution patterns, hydrological patterns, and forest condition. I present examples of research and monitoring activities on Department of the Interior lands, primarily in the western United States. Evidence of regional warming comes from rapidly disappearing glaciers in Montana, lake level decline in Crater Lake, Oregon, and expansion of high-elevation forests in Colorado and Washington. I also present evidence of regional cooling in the summer months due to land-use changes in the plains of Colorado, where crop irrigation and landscaping have influenced the climate, hydrology, and forest vegetation patterns in the adjacent Rocky Mountains. In some areas, the effects of land-use practices on regional climate may overshadow larger-scale temperature changes commonly associated with observed increases in CO_2 and other greenhouse gases. Our understanding of rapid climate change, and other equally important multiple stresses to forest condition, is aided by strong ecosystem research and long-term monitoring programs. Our challenges in North America (and the world) are to: (1) determine which species, habitats, and ecosystem processes are most sensitive to rapid environmental change and multiple stresses; (2) monitor ecosystem change in consistent and comparable ways; and (3) coordinate mitigation strategies and efforts.

Natural areas set aside to conserve natural resources and protect biological diversity also serve as outdoor laboratories. They are ideal for monitoring ecological processes that act on long temporal scales such as climate change, long fire return intervals, and periodic droughts. They provide an index of change in our most treasured ecosystems and a comparison to the more heavily altered landscapes in which most of us live. They provide us with unparalleled opportunities for research and public outreach.

The U.S. Global Change Research Program (USGCRP) is a multi-faceted program involving several Federal agencies including the Departments of Agriculture, Commerce, Defense, Energy, and the Interior, the Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, Smithsonian Institution, and Tennessee Valley Authority (National Science and Technology Council 1997). Key research areas include ozone depletion, seasonal to inter-annual variations in climate, climate forcing, climate change over decades to centuries, detection and attribution of climate change, terrestrial and aquatic ecosystem feedbacks and effects, land cover and land use, and climate effects on marine ecosystems.

The U.S. Geological Survey portions of the USGCRP involve many research projects ranging from studies of sea-level rise to changing bird populations and wetland habitat loss (Figure 1). Summarizing the research of all these sites is beyond the scope of this paper. Within the Biological Resources Division of the USGS, the global change research program focuses primarily on terrestrial ecosystem research and multiple stresses to USDI lands including climate change, human population growth and land-use change, air and water pollution, habitat fragmentation, altered disturbance regimes, and invasive species (Figure 2).

Examples of Global Change Research on Department of Interior Lands

In this section, I provide selected examples of global change research primarily conducted on national parks and monuments, wildlife reserves, and national resource areas managed by the Department of the Interior. In Sequoia,

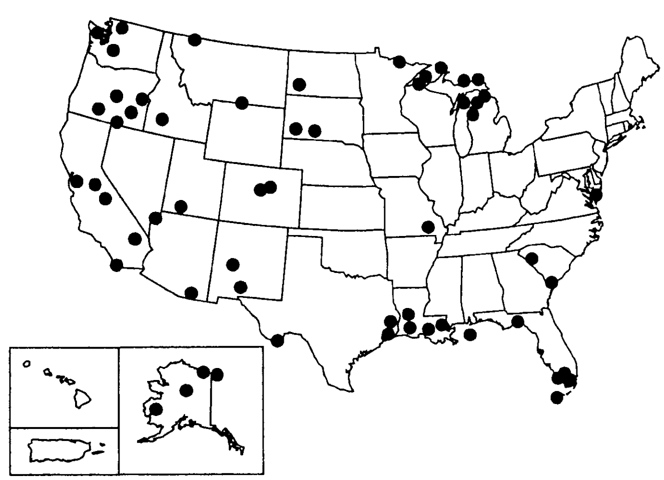

Figure 1.—Map of U.S. Geological Survey global change research sites.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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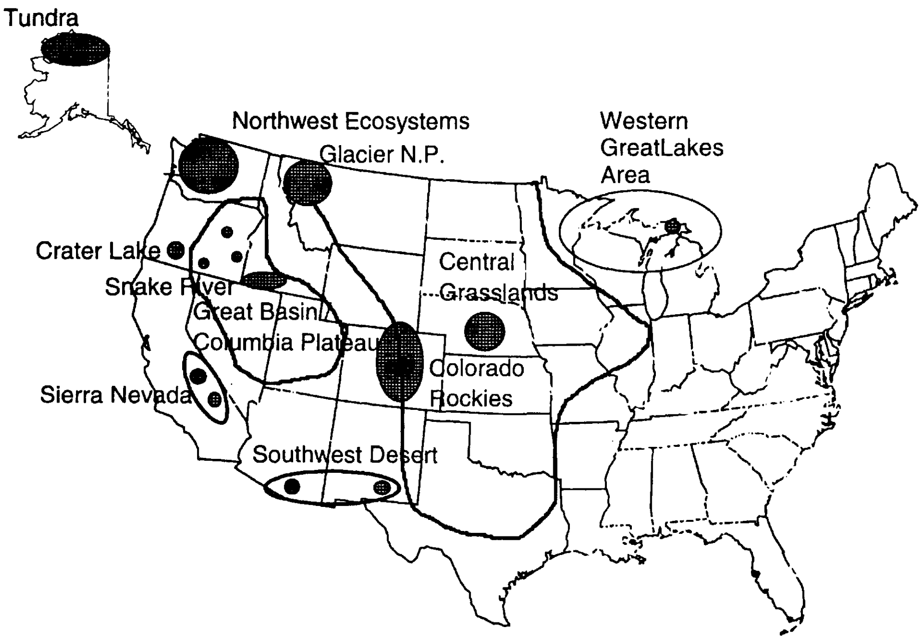

Figure 2.—Map of selected terrestrial ecosystem sites in the U.S. Geological Survey's global change research program.

Kings Canyon, and Yosemite National Parks in California, for example, ongoing studies on paleoecology, forest dynamics, and forest modeling are determining how changes in climate affect the frequency and size of wildfires (Swetnam 1993, In Preparation). The research developed tree-ring climatology techniques on long-lived giant sequoia (*Sequoiadendron giganteum*), and improved insights into fire frequencies over the past 5,000+ years. More importantly, resource managers now have detailed maps of areas most influenced by recent decades of fire suppression as a basis to set priorities for prescribed burning.

In Glacier National Park, Montana, observations that some glaciers have receded at alarming rates over the past few decades have sparked ecosystem-wide interdisciplinary studies of climate, hydrology, and vegetation. Spatial models of snowmelt, forest growth, and soil moisture provide a basis to understand forest species distributions and change (Fagre In Press). In Crater Lake, Oregon, scientists are monitoring lake level decline in recent years, reminiscent of the severe droughts of the 1930's (G. Larson, personal communication).

In Olympic National Park and adjacent lands, detailed monitoring of forest dynamics has shown increased migration of subalpine trees into meadows and forest openings in response to recent climate warming (Peterson 1994). Dendrochronology techniques comparable to those used throughout the western U.S. are adding to a regional and sub-continental understanding of climate change.

In the Great Basin, studies are linking climate change and land-use change with well-replicated experiments using rain shelters and various grazing regimes to assess potential changes to plant species composition and diversity (Pike and Borman 1993). In the southwestern U.S., research is focusing on tree-ring climate reconstruction on the shrub and grassland ecotones (Woodhouse 1997), and on monitoring the effects of climate change on invasive plant species (Huenneke 1997). In the Central Grasslands, scientists are modeling vegetation change under various climate change scenarios (Neilson 1995).

The Colorado Rockies Global Change Research Program

I now provide a case study of the ecosystem-scale global change research program that I have coordinated for seven years. The research team was selected to include climate modelers, plant ecologists, geographers, and hydrologists to assess the effects of climate and land-use change in the Rocky Mountains of Colorado. Our scientific goal is to develop a better understanding of regional climate/hydrologic patterns and species-environment relationships to determine which species, habitats, and ecosystem processes are most sensitive to rapid environmental change and multiple stresses. Our resource management emphasis continues to provide timely, scientific data to meet the high priority needs of resource managers. In the first seven years of the research program (1991-1998), we developed a basic understanding of vegetation change, climate change, and hydrologic change as described below.

Evidence of Vegetation Change

We developed an understanding of forest distributions, productivity, and disturbance patterns. Our research team produced solid evidence that the growth rates of krummholz (wind-trimmed low-growing trees) have increased in the forest-tundra ecotone of Rocky Mountain National Park (Baker et al. 1995). Substantial tree invasions into openings between patches of subalpine forest have been documented (Baker and Weisberb 1995; Weisberg and Baker 1995). Our field studies also showed that forested ecotones (i.e., boundaries between forest types) are sensitive to changes in regional climate (Stohlgren and Bachand 1997). We established 14 long-term vegetation transects (20m x 200m+) as "ecological time capsules" to monitor vegetation distribution changes and the invasion of exotic plant species (Stohlgren et al. 1998a, In Press).

The analysis of climatic variation on fire regimes in the montane zone of the Front Range over the past 400 years showed that fire occurrence is extremely sensitive to climate (Mast 1993; Veblen et al. 1994; Mast et al. 1997, In Press). During severe droughts that occur approximately once per century, nearly half of the entire montane zone burns during a single year. Fire in the montane zone would likely increase due to greater climatic variability. Tree-ring studies show that when years of above-average precipitation are followed by springs and summers of below-average precipitation there is an increase in the area burned. Such periods of extreme climatic variability at time scales of two to four years are closely linked to El Niño Southern Oscillation events which yield strong signals in the tree-ring record of fires in the Front Range (Veblen In Press). Since approximately 1915, fire suppression has created major changes in Front Range ecosystems, including forest structures that are more susceptible to catastrophic wildfires, or more likely to occur under future scenarios of warmer and/or more variable climates (Mast 1993; Veblen et al. 1994; Mast et al. 1997, In Press).

Evidence of Climate Change

Colorado State University's Regional Atmospheric Modeling System (RAMS; (Pielke et al. 1994, In Press) results suggest that the Rocky Mountains, with extreme elevation and vegetation gradients, are very sensitive to regional and global climate change (Copeland et al. 1996a,b; Chase et al. 1996). Land-use practices in the plains influence regional climate and vegetation in adjacent natural areas in the mountains in predictable ways (Chase et al. In Press). Modifications to natural vegetation on the plains, primarily due to agriculture and urbanization, produce a regional cooling effect expressed as lower summer temperatures in the mountains. Combined, the mesoscale atmospheric/land-surface model results, short-term trends in regional temperatures, forest distribution changes, and streamflow data indicate that the effects of land-use practices on regional climate may overshadow larger-scale temperature changes commonly associated with observed increases in CO_2 and other greenhouse gases (Stohlgren et al. 1998b). Regional model simulations on seasonal time scales demonstrate a significant sensitivity of regional weather, and therefore climate, to land-use change (Chase et al. In Press; Pielke et al. In Press).

Evidence of Hydrological Changes

Paleo-climate records contained in lake sediments provide evidence that biological and geomorphological processes in high elevations of the Rocky Mountains have been very responsive to climatic variability in the past 12,000 years. Evidence of changes caused by temperature variability and shifts in the amount and seasonality of precipitation are found in debris flow frequency and movement of vegetation up and down an elevation gradient (Menounos 1994, Reasoner 1996).

Ecosystem/hydrology models suggest that land cover and climate change influence different parts of the Rocky Mountains and plains in complex ways, depending on location, climate, and topography (Lammers et al. 1997). Land cover change exerted stronger controls on plant productivity and water fluxes to the atmosphere than temperature changes in low-elevation foothills and grasslands. In contrast, temperature was a more important influence on water fluxes and plant productivity in high-elevation coniferous forests and tundra. In high-elevation watersheds, cooling or warming had a great influence on the timing of snowmelt (Baron et al. 1997a, 1998, In Press). More importantly, the long-term data set from Loch Vale watershed (Baron et al. In Press), shows a steady increase in nitrogen deposition (3 to 4 kg/ha/yr N) from air pollution, which along with climate change, has enormous potential to affect stream biota, native plant species, and water quality (Baron et al. 1997b).

Proposed Future Research

Now that baseline climate, hydrology, and vegetation data are available, future research is designed to evaluate multiple stresses, including rapid environmental change, that affect the management of key natural resources and processes in Rocky Mountain National Park and the region (Figure 3). Our interdisciplinary approach to ecosystem science will address high priority issues such as: (1) providing better climate change scenarios to land managers to assess the "vulnerabilities" of ecosystems to rapid environmental change; (2) assessing how climate change influences air quality values (visibility and pollution) in Class I airsheds (e.g., Rocky Mountain National Park); (3) quantifying climate change and nitrogen deposition effects on water quantity and delivery, water quality, and aquatic diversity; (4) developing GIS-based disturbance history maps (fire and insect outbreaks) to aid the Park's Fire Management Program; and (5) determining how climate change, vegetation management practices, and disturbance affect key wildlife habitat (e.g., aspen) and the spread of exotic plant species (Figure 3).

Our proposed synthesis involves partnerships with several USGS Global Change Research Programs (Glacier, Olympic, Sequoia, Central Grasslands), other U.S. Geological Survey research and monitoring programs, Long-Term Ecological Research Sites, and many Bureau of Land Management, National Park System, and U.S. Fish and Wildlife Service management units to assess regional patterns of climate change, exotic plant invasions, air pollution, and disturbance effects. The ongoing synthesis of these studies is assessing the interaction between land-use change, regional vegetation distribution, mesoscale climate, and hydrology (Stohlgren et al. 1998b).

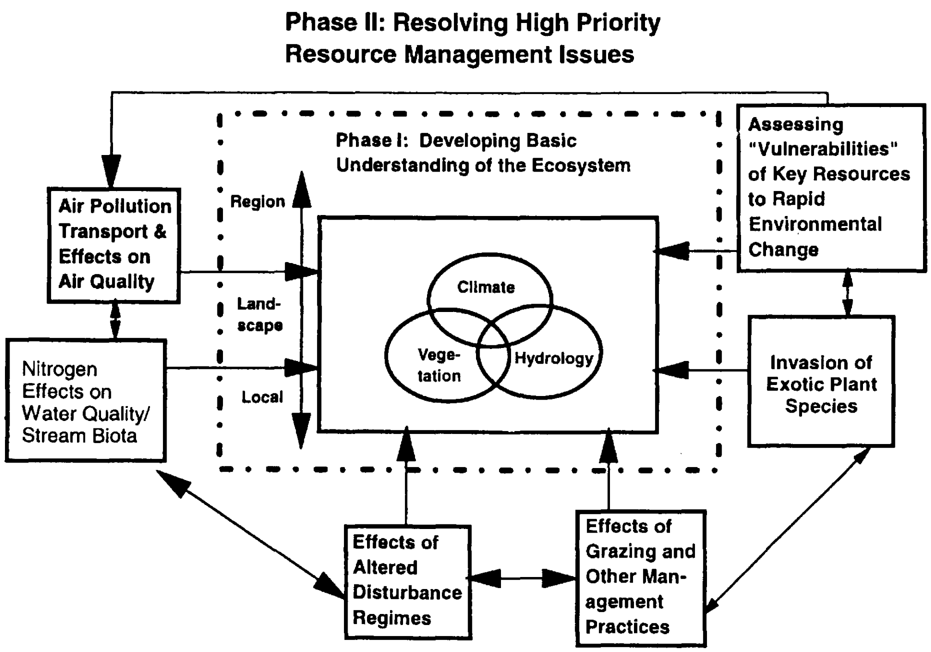

Figure 3.—Schematic diagram of Phase I (1991-1998) and Phase II (1999-2003) of the global change research program in the Colorado Rockies Biogeographical Area.

Challenges of Future Global Change Research in Nature Reserves in the U.S.

There are several positive aspects of the global change research programs in nature reserves in the U.S. The various agencies involved have expressed a long-term commitment to the programs, many of which have maintained funding since 1991. The research is based on scientific peer-review of proposals, and periodic program reviews. Continued funding is contingent on the quality and relevancy of the science, meeting the needs of land managers, scientific productivity, and public outreach. In fact, all projects in the USGS Biological Resources Division's Global Change Research Program are currently re-competing for funding, so Figure 2 may look different in the near future.

There are, however, many ways in which the global change programs can be improved. Greater efforts must be made to standardize many of the methods used to increase the comparability of data, not only among the Department of the Interior programs, but with other agencies and research programs (e.g., LTER sites, U.S. Department of Agriculture Forest Health Monitoring). Also, a greatly expanded network of global change research and long-term monitoring sites is needed to assess multiple stresses at local, regional, and national scales. Despite strong individual research projects, many ecosystems in the U.S. are not now being closely monitored in consistent ways. Thus, it is difficult to assess cumulative effects or regional impacts of forest distribution changes, altered disturbance regimes, altered hydrological regimes, habitat loss, or the invasion of exotic species.

Certainly, much work lies ahead. An additional positive step in global change research in the U.S. is the current Congressionally mandated "National Assessment of Global Change," under which agency and academic scientists are working closely with regional stakeholders (e.g., from agriculture, energy industry, ranching, recreation) to strengthen existing efforts. The report to Congress is due January 1, 2000, but the process has already led to better understanding and communication among scientists, stakeholders, and the public.

Conclusion

Just as better coordination is needed among U.S. global change research programs, better coordination of international research and monitoring could be mutually beneficial. Our challenges in North America (and the world) are to: (1) determine which species, habitats, and ecosystem processes are most sensitive to rapid environmental change and multiple stresses; (2) monitor ecosystem change in consistent and comparable ways; and (3) coordinate mitigation strategies and efforts. Sharing expertise, data, models, and model program designs is the first step. Creating an expanded network of monitoring sites with comparable data collection remains our most significant challenge.

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Literature Cited

Baker, W.L., J.J. Honaker, and P.J. Weisberg. 1995. Using aerial photography and GIS to map the forest-tundra ecotone in Rocky Mountain National Park, Colorado, for global change research. Photogrammetric Engineering & Remote Sensing 61: 313-320.

Baker, W.L. and P.J. Weisberg. 1995. Landscape analysis of the forest-tundra ecotone in Rocky Mountain National Park, Colorado. Professional Geographer 47:361-375.

Baron, J.S., D.S. Ojima, M.D. Hartman, T.G.F. Kittel, R.B. Lammer, L.E. Band, and R.A. Pielke, Sr. 1997a. The influence of land cover and temperature change on hydrological and ecosystem dynamics in the South Platte River Basin. Pages 279-287 in J.W. Warwick, ed. Water Resources for Education, Training, and Practice: Opportunities for the next Century. AWRA , Herdon, VA.

Baron, J.S., D.S. Ojima, E.A. Holland, and W.J. Parton. 1997b. Nitrogen consumption in high elevation Rocky Mountain tundra and forest and implications for aquatic systems. Biogeochemistry 27:61-82.

Baron, J.S., M.D. Hartman, T.G.F. Kittel, L.E. Band, D.S Ojima, and R.B. Lammer. Land cover, water redistribution, and temperature: factors influencing ecosystem processes and land-atmosphere fluxes in the South Platte River Basin. Ecological Applications 8: 1037-1051.

Baron, J.S., M.D. Hartman, L.E. Band, and R.L. Lammers. In Press-b. Sensitivity of high elevation Rocky Mountain watersheds to climate change. Proceedings of the 5th National Watershed Coalition.

Chase, T.N., R.A. Pielke, Sr., T.G.F. Kittel, R. Nemani, and S.W. Running. 1996. The sensitivity of a general circulation model to global changes in leaf area index. Journal of Geophysical Research 101:7393-7408.

Chase, T.N., R.A. Pielke, Sr., T.G.F. Kittel, J.S. Baron, and T.J. Stohlgren. In Press. Impacts on Colorado Rocky Mountain weather and climate due to land use changes on the adjacent Great Plains. Journal of Geophysical Research.

Copeland, J., R.A. Pielke, Sr., T.G.F. Kittel. 1996a. Potential climatic impacts of vegetation change: A regional modeling study. Journal of Geophysical Research 101:7409-7418.

Copeland, J.H., T.N. Chase, J.S. Baron, T.G.F. Kittel, R.A. Pielke, Sr. 1996b. Pages 199-212 in Regional Impacts of Global Climate Change: Assessing Change and Response at the Scales that Matter. Battel Press, Richland, Washington.

Fagre, D.B. In press. Understanding climate change impacts on Glacier National Park's natural resources. In M. Mac, P.A. Opler, C.E. Haecker-Puckett, P.D. Doran, and L.S. Huckaby, eds. Status and Trends of the Nation's Biological Resources. US Department of the Interior, Washington D.C.

Huenneke, L.F. 1997. Outlook for plant invasions: interactions with other agents of global change. Pages 95-103 in J.O. Luken and J.W. Thieret, eds. Assessment and Management of Plant Invasions. Springer, New York.

Lammers, R.B., L.E. Band, and C.L. Tague. 1997. Scaling behaviour of watershed processes. Pages 296-317 in P. van Gardingen, G. Foody, and P. Curran, eds. Scaling Up, from Cell to Landscape. Cambridge University Press.

Mast, J.N. 1993. Climatic and disturbance factors influencing *Pinus ponderosa* stand structure near the forest/grassland ecotone in the Colorado Front Range. Ph.D. dissertation, University of Colorado, Boulder.

Mast, J.N., T.T. Veblen, and M.E. Hodgson. 1997. Tree invasion within a pine/grassland ecotone: An approach with historic aerial photography and GIS modeling. Forest Ecology and Management 93: 187-194.

Mast, J.N., T.T. Veblen, and Y.B. Linhart. In Press. Disturbance and climatic influences on age structure of Ponderosa pine stand structure at the pine/grassland ecotone, Colorado Front Range. Journal of Biogeography.

Menounos, B.P. 1994. A Holocene, debris-flow chronology for an alpine catchment, Colorado Front Range. M.S. thesis, University of Colorado, Boulder. 160 pp.

National Science and Technology Council. 1997. Our Changing Planet. The FY 1999 U.S. Global Change Research Program. Washington, DC.

Neilson, R.P. 1995. A model for predicting continental scale vegetation distribution and water balance. Ecological Applications 5:362-385.

Peterson, D. 1994. Recent changes in the growth and establishment of subalpine conifers in western North America. Pages 234-243 in M. Beniston, ed. Mountain Environments in Changing Climates. Routledge Press, London, UK.

Pielke, R.A., Sr., T.J. Lee, T.G.F. Kittel, T.N. Chase, J.M. Cram, and J.S. Baron. 1994. Effects of mesoscale vegetation distributions in mountainous terrain on local climate. Pages 121-135 in M. Beniston, ed. Mountain Environments in Changing Climates. Routledge Publishing Company, London and New York.

Pielke, R.A., Sr., G.E. Liston, L. Lu, P.L. Vidale, R.L. Walko, T.G.F. Kittel, W.J. Parton. In Press. Coupling of Land and Atmospheric Models over the GCIP Area - Century, RAMS, and SiB_2C. In Proceedings of the 13th Annual Conference on Hydrology, 77th AMS Annual Meeting, Long Beach, California.

Pike, D.A. and M.M. Borman. 1993. Problem analysis for the vegetation diversity project. U.S. Department of the Interior, Bureau of Land Management, Oregon State Office, Technical Note T/N: OR-936-01, Portland, OR.

Pielke, R.A. Sr., G.E. Liston, L. Lu, P.L. Vidale, R.L. Walko, T.G.F. Kittel, W.J. Parton. In Press. Coupling of Land and Atmospheric Models over the GCIP Area - Century, RAMS, and SiB_2C. In: Proc. 13th Ann. Conf. on Hydrology, 77th AMS Annual Meeting, Long Beach, California.

Reasoner, M.A. 1996. Late Quaternary alpine and subalpine lacustrine records: Canadian and Colorado Rocky Mountains. Ph.D. dissertation, University of Alberta, Edmonton, Alberta, Canada. 132 pp.

Stohlgren, T.J., and R.R. Bachand. 1997. Lodgepole pine (*Pinus contorta*) ecotones in Rocky Mountain National Park, Colorado, USA. Ecology 78:632-641.

Stohlgren, T.J., R.R. Bachand, Y. Onami, D. Binkley. 1998a. Species-environment relationships and vegetation patterns: effects of scale and tree life-stage. Plant Ecology 135: 215-228.

Stohlgren, T.J., T.N. Chase, R.A. Pielke, T.G. F. Kittel, and J.S. Baron. 1998b. Evidence that local land use practices influence regional climate and vegetation patterns in adjacent natural areas. Global Change Biology 4(5): 495-504.

Stohlgren, T.J., D. Binkley, G.W. Chong, M.A. Kalkhan, L.D. Schell, K.A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and Y. Son. In Press. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs.

Swetnam, T.W. 1993. Fire history and climate change in giant sequoia groves. Science 262:885-889.

Swetnam, T.W., G. Montenegro, and T.T. Veblen, eds. In Preparation. Fire regimes and climatic change in temperate and boreal ecosystems of the western Americas. Academic Press.

Veblen, T.T., K.S. Hadley, E.M. Nel, T. Kitzberger, M. Reid, and R. Villalba. 1994. Disturbance regime and disturbance interactions in a Rocky Mountain subalpine forest. Journal of Ecology 82:125-135.

Veblen, T.T., T. Kitzberger, R. Villalba, and J. Donnegan. In Press. Fire history in northern Patagonia: The roles of humans and climatic variation. Ecological Monographs.

Weisberg, P.J. and W. L. Baker. 1995. Spatial variation in tree seedling and krummholz growth in the forest-tundra ecotone of Rocky Mountain National Park, Colorado. Arctic and Alpine Research 27: 116-29.

Woodhouse, C.A. 1997. Tree-ring reconstructions of circulation indices. Climate Research 8:117-127.

Ecological Change and the Challenges for Monitoring[1]

Thomas Brydges[2]

Abstract—Anthropogenic activities are changing the chemical composition of the global atmosphere, as shown by the increasing concentrations of carbon dioxide, methane, nitrous oxide and HFC's. In addition, sulphur and nitrogen compounds have changed the chemical character of precipitation on a regional scale in North America, Europe, and Asia. These changes in turn, alter the physical properties of the atmosphere with responses such as stratospheric ozone depletion, ground level ozone formation and modifications to the radiation balance. Changes in radiation balance are expected to increase the average global temperature. However, local and regional changes in temperatures will be larger and more varied with areas, such as Eastern Canada, having experienced a cooling trend. (Environment Canada 1995)

The biosphere is affected by the chemistry and physics of the atmosphere, so we would expect it to respond to these new conditions, and it already has.

Emissions of sulphur dioxide and nitrogen oxides have altered the chemical characteristics of precipitation in areas near and downwind of large sources. Damage to lakes, forests, human health, building materials and atmospheric visibility has been documented in eastern North America. (Environment Canada 1997) That report also drew attention to the fact that present control programs are not strict enough to fully protect the environment. Further reductions in emissions, particularly of sulphur dioxide, are needed.

Keeling et al 1996, have reported on changes in the global carbon cycle. The amplitude of the yearly cycle has increased by 20% at the Mauna Loa, Hawaii observatory over the past 30 years and by about 40% over Arctic sites at Alert in Canada and Pt. Barrow in the United States. In addition, the yearly minimum atmospheric concentration in July is now observed to occur about a week earlier than 30 years ago. These changes appear to be a response to increasing average temperatures. Keeling et al, ibid, noted "These striking increases over 30 years could represent unprecedented changes in the terrestrial biosphere, particularly in response to some of the highest global annual average temperature since the beginning of modern records, and particularly in response to plant growth being stimulated by the highest concentrations of atmospheric CO_2 in the past 150,000 years.

Briffa et al 1998 reported on tree growth from 300 locations at high latitudes in the Northern Hemisphere. Over the past 50 years, the expected patterns of growth related to temperature have not been observed. Instead, growth rates are less than expected. While the reasons for these observed changes are not known, they are an indication of wide scale disruptions of normal processes in the boisphere. Such changes should be viewed at least as an early warning of further responses to the changing atmosphere.

Alterations in atmospheric characteristics are taking on a more complex pattern. The IPCC 1994, reported on interactions between the global warming effects of greenhouse gases such as carbon dioxide, methane, nitrous oxide and halocarbons and the cooling effects of sulphur dioxide and stratospheric ozone depletion. The net change in radiative forcing and corresponding global temperature increase are difficult to define precisely and the net global effect may mask larger regional changes in temperature. There may also be important changes in precipitation at the regional level.

More recently, Wardle 1997, has reported on stratospheric ozone depletion over Canada's Arctic. Low values of ozone in the spring have been increasing in both frequency and severity, due to low temperatures in the stratosphere. The lower temperatures in the stratosphere may in turn be caused by higher concentrations of carbon dioxide. He postulates that increasing atmospheric concentrations of carbon dioxide will cause even lower temperatures to occur in the winter stratosphere, thus increasing the ozone depletion. This may happen even though the concentrations of CFC's in the atmosphere have increased very little in past few years.

Overall, we can anticipate a wide range of complex ecological responses to the changing atmospheric properties. The natural resources that are being affected are the basis of large parts of the economies of North America. It is essential that we record and understand changes in these ecosystems in order to manage the associated industries in a sustainable way.This represents a major challenge for our monitoring programs, and particularly for the integrated monitoring sites.

References

A State of the Environment Report, 1995. The State of Canada's Climate: Monitoring Variability and Change. SOE Report No 95-1, Environment Canada.

Briffa, K.R., F.H.Schweingruber, P.D.Jones, T.J.Osborn, S.G.Shiyatov & E.A.Vaganov 1998. Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. Nature Vol 391, 12 February.

Environment Canada, 1997. 1997 Canadian Acid Rain Assessment, Volume One, Summary of Results.

IPPC, 1994. Radiation Forcing of Climate Change. The 1994 Report of the Scientific Assessment Working Group of IPCC, Summary for Policy Makers. WMO/UNEP.

Keeling, C.D., J.F.S.Chin & T.P.Whorf 1996. Increased activity of northern vegetation inferred from atmospheric CO2 measurements. Nature, Vol 382, 11 July.

Wardle D.I. 1997. Trends in Ozone over Canada, Ozone Depleting Substances and the UV-B. Air Waste Management Association, Calgary, 19 September.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Algunos Aspectos del Cambio Global Desde la Perspectiva Mexicana[1]

María de Lourdes de Bauer[2]

Resumen—México el vecino del sur de dos países desarrollados comparte con Canadá y Estados Unidos, no sólo el área sino también problemas ambientales como el intercambio de contaminantes aéreos. Este intercambio es debido a la presencia de una área biogeográfica contínua en la porción central del subcontinente que va a través de los tres países.

De acuerdo con la información disponible, México es uno de los 15-17 países productores más importantes de CO_2 en el mundo. Esta contribución, representa el 96.42% del total nacional de gases de invernadero, el metano el 0.79% y otros gases el 2.49%. El país contribuye con menos del 2% a las emisiones globales.

El país con un área total de 1,964,387.1 kilómetros cuadrados muestra gran diversidad en todos sus componentes: población, condiciones topográficas y climáticas así como flora y fauna. Se considera como una de las reservas biológicas más importantes del mundo y es uno de los doce países clasificados como megadiversos.

La República Mexicana ha tenido un incremento demográfico muy considerable durante las últimas décadas. Su población es al presente de cerca de 100 millones de habitantes concentrados en las regiones del centro, norte y noreste del país. Sesenta a 70 millones de personas viven en la pobreza o extrema pobreza; como consecuencia directa, sus recursos naturales sufren de un deterioro crónico. Por ejemplo, se calcula que en Chiapas en solo 5 años (1988-1993) tuvo lugar un cambio de uso del suelo del 16.5% de áreas boscosas hacia otros usos.

En general la población mexicana no está consciente del Cambio Global Ambiental. Se requiere más educación en los aspectos ambientales. Asimismo, es necesario un mayor énfasis en la estimación de su impacto, en las políticas nacionales de investigación en aspectos económicos y sociales.

Abstract—Mexico, the southern neighbour of two highly developed countries shares with Canada and the United States not only land but also such environmental problems as transboundary interchange of air pollutants. The interchange is due to the presence of a continuos biogeographical area in the central part of the subcontinent that goes through the three countries.

According to available information Mexico is one of the 15-17 most important CO_2 producers in the world. This contribution accounts for 96.42% of the total national greenhouse emissions, methane for 0.79% and other gases for 2.49%. The country contributes less than 2% to global emissions.

The country with a total area of 1,964,387.1 square kilometers shows a great diversity in all of its components: population, topographic and climatic conditions; and flora and fauna. It is considered one of the world most important biological reserves and is one of twelve countries classified as megadiverse.

The Mexican Republic has had, during the last decades, a very significant demographic increase. At present, its population is around 100 million peopleæconcentrated in the central, northern and northeastern regions of the country. Sixty to 70 million people live in poverty and extreme poverty. As a direct consequence, its natural resources suffer from chronic degradation. For example, it has been calculated that in Chiapas within only 5 years (1988-1993) there was a landuse change of 16.5% from forested areas to other uses.

In general, the mexican population is not aware of Global Environmental Change. More education in environmental issues is needed. Also emphasis is needed on factoring the impact of this important issue into national research economic and social policies.

México es vecino de dos países altamente desarrollados con los que comparte su destino biogeográfico (Bryson y Haze, 1974; Burkart et. al., 1995; Husar, 1985; Middleton y Haagen Smit, 1961). Es parte importante de América del Norte y durante décadas ha permanecido en un período de transición sin tomar un rumbo definitivo. Sin embargo tres fenómenos sociales son evidentes: centralización, industrialización incipiente y urbanización.(INE, 1995).

El país es un mosaico de diversas zonas climáticas y de diversas culturas que tal vez en el caso de algunos grupos aislados, no han encontrado, por diversos motivos, el rumbo conveniente aún después de 500 años de haber sufrido un gran cambio que les fue impuesto por la cultura europea, en todas estructuras. Los recursos naturales del país son muy valiosos, así como sus energéticos (INE, 1997; Cuadros 1 y 2). En tanto que Canadá y Estados Unidos avanzan por un camino científico-tecnológico México, se encuentra en vías de desarrollar sus grandes posibilidades, entre ellas sus

Cuadro 1.—Superficie forestal por ecosistema. Forest surface according to ecosystem.

Ecosistema Ecosystem	Superficie Surface	Porcentaje Percent
	ha	
Bosques Forests	30,433,893	21.47
Selvas Tropical forests	26,440,061	18.65
Vegetación de Zonas áridas Vegetation in arid zones	58,472,398	41.25
Vegetación hidrófila y halófila Vegetation hydrophilic and halophylic	4,163,343	2.94
Áreas forestales perturbadas Disturbed forests areas	22,235,474	15.69
Total	141,745,169	100

Fuente: SARH. 1994. Inventario Nacional Forestal Periódico

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Cuadro 2.—Recursos energéticos Energy Resources

- Hidrocarburos = 50,812 Millones de barriles (80% petróleo crudo y condensados y el 20% gas natural)
  Hydrocarbons = 50,812 millions of barrils (80% crude oil and condensates and 20% natural gas)
- Carbón (en cuatro cuencas) = 662.9 millones de toneladas
  Coal (in four watersheds) = 662.9 millions of tons
- Uranio = 14.5 miles de toneladas
  Uranium = 14.5 thousands of tons
- Fuentes potenciales = solar, geotérmica, nuclear y eólica.
  Potential sources = solar, geothermic, nuclear and eolic.

Fuente: Secretaria de Medio Ambiente Recursos Naturales y Pesca, 1997.

recursos naturales e.g. los forestales. Surgen toda una serie de preguntas, entre ellas y tal vez las más importantes, y ahora con mayor énfasis al tener a la vista el Cambio Global: ¿Es que el país habrá de encontrar el camino correcto aún a tiempo?, ¿Cuál será el sitio de México en el siglo XXI?
Los problemas agobiantes al presente son:

- Incremento poblacional
- Producción insuficiente de alimentos
- Agotamiento de recursos naturales

De la Problemática Ambiental

El desarrollo demográfico acelerado que ha experimentado México en las últimas décadas, se encuentra íntimamente relacionado con la destrucción de sus bosques y selvas. El desmonte en México ha adquirido niveles alarmantes aún cuando diversos factores contribuyen al mismo (Cuadro 3).

Este fenómeno es palpable hoy en día, en toda su magnitud en Chiapas en donde según señala Parra (1998), durante un período de sólo 5 años, esto es de 1988 a 1993 el 16.5% del área cambió de bosques y selvas hacia otro uso. Así por ejemplo, por razones económicas el bosque se convierte después de incendios o tala en plantación cafetalera. Esto indica que, a través de la simplificación del nuevo ecosistema tiene lugar un cambio trascendental en cuanto a composición de especies. Lo anterior es sólo un ejemplo de como ocurre una pérdida de biodiversidad que se repite con frecuencia en el territorio mexicano.

Al considerar la problemática relacionada con el deterioro de los recursos naturales pueden enlistarse los factores siguientes:

- Desmonte y Cambio de Uso del Suelo
- Pérdida de Biodiversidad
- Erosión y Desertificación
- Contaminación del Acuífero
- Contaminación Atmosférica Urbana

Otro factor sumamente importante que ha afectado la calidad atmosférica en México ha sido el desarrollo industrial que registró el país a partir de 1950, en particular por el establecimiento de manufacturas intermedias o maquiladoras (Ezcurra y Masari-Hiriart,1996).

A pesar de los graves cambios ambientales, el país ofrece algunas valiosas características que lo hacen muy deseable en trabajos cooperativos norteamericanos, entre ellos los de monitoreo. El área geográfica que ocupa el país (Fig. 1) y las

Cuadro 3.—Desmonte en Mexico Deforestation in Mexico

Causa **Cause**	**Contribución** **Contribution**
	percent
Bosques **Forests**	
Incendios Fires	50
Ganadería Animal husbandry	28
Agricultura Agriculture	17
Otros others	5
Selvas **Tropical forests**	
Ganadería Animal husbandry	60
Incendios Fires	Entre el 7 y el 22 Between 7 and 22
Agricultura Agriculture	Entre el 10 y el 14 Between 10 and 14
Otros Others	Entre el 4 y el 23 Between 4 and 23

Fuente: Programa Forestal y de Suelos 1995-2000, Secretaría de Medio Ambiente, Recursos Naturales y Pesca.

zonas cubiertas por bosques y selvas (Rzedowsky, 1978; SARH 1994a y 1994b, Fig. 2), así como la altura de algunas montañas de más de 5 km y grandes litorales a diversas latitudes, son elementos para llevar a cabo un monitoreo in situ que ayude en las tareas de definición del CG. La región que ocupa el país debe considerase también como una fuente importante de emisiones de gases traza (Cuadro 4) y partículas tanto de origen natural, incluso volcánico, y antropogénico, con un fuerte impacto tanto regional como global.

DEL APORTE dE ESPECIES VEGETALES NATIVAS COMO MONITORES eN ECOSISTEMAS FORESTALES

Las investigaciones llevadas a cabo a partir de 1976 año en que se detectó el daño por gases oxidantes en los bosques del sur y suroeste del Valle de México (Fig.1; Krupa y Bauer, 1976) acorde con las descripciones del movimiento del viento dominante en el área de Jáuregui (1958, 1993), abrieron diversas posibilidades, entre ellas:

- Estudios sobre el impacto urbano en ecosistemas forestales vecinos.
- Caracterización de especies a nivel inter e intraespecífico presentes en el área en cuanto a su sensibilidad a gases oxidantes, especialmente a ozono.

El estudio del impacto urbano en áreas boscosas, como son El Ajusco y el Parque Recreativo y Cultural Desierto de los

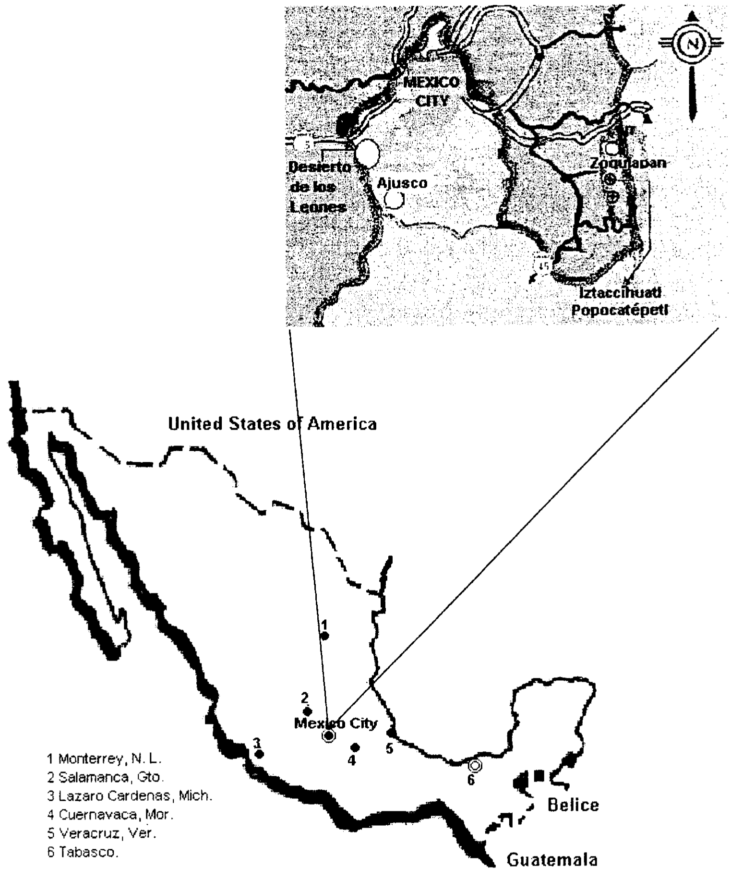

Figure 1.—Vista general y de algunas áreas urbnas importantes. General view of Mexico and some important urban areas. Source: Bauer, Hernandez and Skelly (in press).

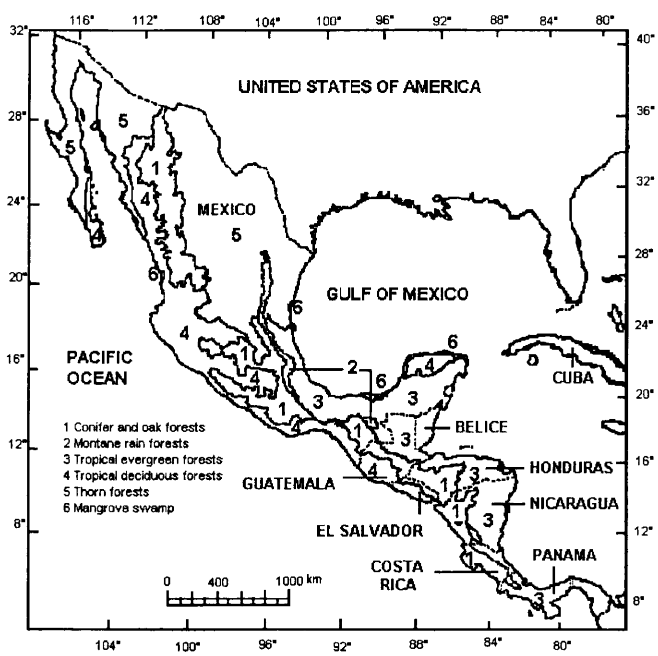

Figure 2.—Distribucion de diferentes comunidades forestales mexicanas y centroamericanas. Distribution of the Mexican and Central American different forest communitites. Source: Bauer, Hernandez and Skelly (in press).

Leones ha abarcado diversos aspectos, en cuanto a los ecosistemas forestales ahí establecidos.

De algunas de estas investigaciones, en los últimos años realizadas en colaboración con científicos de Canadá y EE. UU., han derivado aportaciones significativas (Bauer, 1991; Bauer, Hernández y Manning, 1985; Hall et al 1996; Miller, et al, 1994). Ente los trabajos más destacados, figuran los siguientes:

- Identificación de especies forestales e.g. *Pinus hartiwegii*, *P. ayacahuite*, *Prunus serotina* spp. *capuli* y *Salix* spp. y

Cuadro 4.—Inventario Nacional de Gases de Invernadero (1990)* National Greenhouse Inventory (1990)*

Bióxido de carbono Carbon Dioxide	444,489.97 Gg = 96.42 %
Metano Methane	3,641.66 Gg = 0.79%
Otros Gases (N_2O, NO_x,CO, NMVOC) Other Gases	= 2.79 %

Fuente: Secretaría de Medio Ambiente, Recursos Naturales y Pesca 1997.

especies del sotobosque como: *Solanum* spp. sensibles a oxidantes (Hernández y Bauer, 1986; Skelly et al, 1997).

- Interacción de gases oxidantes con patógenos bióticos e.g. ozono sobre la interacción *Lophodermium* spp.-*Pinus hartwegii* (Alvarado y Bauer, 1991).
- Estudios sobre la declinación del oyamel *A. religiosa.* (Alvarado et al. 1993, Bauer y Hernández, 1986; Quevedo et al 1998).
- Estudios dendrocronológicos en *Pinus hartwegii.* (Alarcón et al, 1995).
- Estudios de sedimentación de nitrógeno y azufre a través de la lluvia penetrante.(Fenn et al, 1998).
- Estudios del impacto del ozono sobre la regeneración en rodales de *Pinus hartwegii* (Hernández y Cox, com. personal).

Las áreas, ubicadas en las Sierras del Ajusco y Chichinautzin, son sitios experimentales de renombre, en particular el Parque recreativo y Cultural Desierto de los Leones, que se ha convertido en un laboratorio internacional en el que diversos investigadores del país y del extranjero, se dan cita para estudiar el impacto de la megalópolis en los ecosistemas forestales. Se estudian diversos aspectos como: emisiones de poluantes biogénicos, presencia y distribución de líquenes, efecto sobre la fauna silvestre y otros.

Ciertamente, ha habido una evolución en cuanto a la vegetación de las áreas afectadas del sur y suroeste de la Ciudad de México. Esta se ha simplificado, incluso de acuerdo con investigaciones recientes (Alvarado y Hernández, 1998), es probable que las poblaciones más sensibles a oxidantes hayan desaparecido. Es así como el índice de mortalidad del oyamel (*Abies religiosa*), ha descendido. Esta, especie se consideró homogéneamente sensible al ozono, sin embargo la mortalidad de los árboles, al parecer, se encuentra en una etapa de desaceleración lo cual puede indicar, que sí hay diferentes genotipos en la masa forestal de esta especie ubicada en el Parque Recreativo y Cultural Desierto de los Leones.

La atmósfera de la megalópolis es también un medio adecuado para la evaluación y selección de especies sensibles. En las diversas avenidas y calles arboladas y, en general, en áreas verdes, se aprecian muy diversos síntomas en la vegetación ahí establecida que por tanto son confusos; destacan dos hechos:

- Alteración del ciclo en cuanto a pérdida del follaje en especies forestales caducifolias.
- Altas infestaciones insectiles e.g. en fresnos (*Fraxinus* spp.).

De Las Perspectivas

Estos fenómenos, de defoliación prematura y de mayor severidad de infestaciones insectiles, han sido descritos por diversos investigadores bajo condiciones experimentales, en diferentes especies vegetales. En este caso, bien pueden servir de modelo, en términos de monitoreo de CG en zonas urbanas altamente perturbadas como es la Ciudad de México (Bauer y Krupa, 1990).

Numerosos investigadores e instituciones a nivel nacional e internacional han hecho contribuciones importantes encaminadas a esclarecer diversos aspectos de la problemática ambiental en el país y en particular, en el Valle de México. En el ámbito nacional es preciso mencionar los esfuerzos de algunos grupos que trabajan con gran dedicación en cuestiones relativas al CG, aún en regiones aisladas. Entre estos estudios se encuentra en marcha el proyecto sobre evaluación de captura de carbono, en la Sierra Mixteca de Oaxaca, en especies forestales y cultivos en las laderas de las zonas montañosas. (Jiménez, 1998, com. personal).

Estos estudios, señalan que hay información disponible que servirá de base para investigaciones que apoyen el monitoreo de los ecosistemas forestales norteamericanos.

Es evidente que los aspectos sociales, desventajosos al presente en México, juegan un papel muy importante en la conservación de los recursos forestales, por lo que una contribución eficiente a las acciones pertinentes es sumamente deseable.

Metas Propuestas

Por tanto, las metas que se proponen son:

- Conservar los recursos naturales en conjunto en particular los forestales, relacionados con la gran riqueza en cuanto a diversidad biológica en América del Norte.
- Establecer un sistema cooperativo norteamericano que combine: conocimiento científico de vanguardia, alta tecnología y la más valiosa biodiversidad.

Bibliografia

Alarcón, M. A.; Bauer, L. I. de; Jasso, J.; Segura, G., and Zepeda, E. M. (1995). Patrón de crecimiento radial en árboles de *Pinus hartwegii* afectados por contaminación atmosférica en el Suroeste del Valle de México. Agrociencia, Serie: Recursos Naturales Renovables 3(3):67-80. México.

Alvarado, D.; y Bauer, L. I. de. (1991). Ataque de *Lophodermium* sp. En poblaciones naturales de pinus Hartwegii de "El Ajusco", México, bajo el efecto de gases oxidantes. Micol. Neotrop. Apl. 4: 99-109

Alvarado, D.; Bauer, L. I.de, and Galindo, J. (1993). Decline of sacred fir (*Abies religiosa*) in a forest park south of Mexico City. Environ Pollut 80:115-121.

Alvarado-Rosales, D. And Hernández Tejeda, T. 1998. Twelve years evaluation of sacred fir decline (Abies religiosa) evolution at the Desierto de los Leones Park, Southern Mexico City. Phytopathology 88 (9 Suppl.):S3

Bauer, L. I. de, (1991) La influencia urbana en el área del Ajusco. Mem. I Simp. Nal Sobre Agricultura Sostenible. Comisión de Estudios Ambientales, C.P.-MOA/INT. pp. 173-181.

Bauer, L. I. de, y Hernández Tejeda, T. (1986). Contaminación: Una amenaza para la vegetación en México. Talleres Gráficos del Colegio de Postgraduados. Chapingo, Méx. México. 84 pp.

Bauer, L.I. de Hernández, T.T. and Skelly, J.M. Air Pollution Problems in the Forested areas of Mexico and Central America (in press).

Bauer, L. I. and Krupa, S. V. (1990). The Valley of Mexico: Summary of observational studies on its air quality and effects on vegetation. Environ. Pollution 65:109-118.

Bryson, R. A., and Haze, F. K. (eds.). (1974). Climates of North America. Elsevier Sci. Publ. Co. New York, USA.

Burkart, R.; Marchetti, B., y Morello, J. (1995). Grandes ecosistemas de México y de Centroamérica. En: El futuro ecológico de un continente. G. C. Gallopín (ed.). UNC-FCE. México, D. F. pp 101-163.

Ezcurra, E., and Mazari-Hiriart, M. (1996). Are megacities viable? A cautionary tale from Mexico Fenn, 1992. City. Environment 38(1):6-35.

Fenn,M.E. (1992)Deposicion atmosferica en bosques dentro de la cuenca atmosferica de Los Angeles, California y del Valle de

Mexico Mem. II Simp. y I Reunion Nacional Sobre Agricultura Sostenible. Comisión de Estudios Ambientales, C.P.-IICA. pp. 33-39.

Fenn, M. E.; Bauer, L.I.; Quevedo, A., and Rodriguez, C. (1998). Nitrogen and sulfur deposition and forest nutrient status in the Mexico City air basin. (In press).

Hall, J. P.; Magasi, L.; Carlson, L.; Stolte, K. W.; Niebla, E.; Bauer, L. I.; González-Vicente, C. E., and Hernández-Tejeda, T.(1996). Health of North American Forests/L'état de santé des forêts nord-américaines/Sanidad de los Bosques de América del Norte. Natural Resources Canada. Ottawa, Ontario, Canada. 66 pp.

Hernández Tejeda, T., and Bauer, L. I. (1986). Photochemical oxidant damage on *Pinus hartwegii* at the "Desierto de los Leones, D. F." Phytopathology 76(3):377.

Husar, R. B. (1985). Chemical Climate of North America: Sources and deposition with special emphasis of high elevation locations. Proc. Air pollutants Effects on Forest Ecosystems. St. Paul, Minnesota, USA. pp 5-38.

Instituto Nacional de Ecología (INE). (1995). Elementos de política ambiental para una ciudad sustentable: Manejo de la cuenca atmosférica de México. SEMARNAP México, D. F. 13 pp.

Instituto Nacional de Ecología (INE). (1997). Mexico Climate Action Report.

Jauregui, E. 1958. El aumento de la turbiedad del aire en la Ciudad de México. Rev. Ing. Hidr. en México. 12(3).

Jauregui, E. (1983). Visibility Trends in México City. Erdkunde 37: 296, 299

Krupa, S. V., y Bauer, L. I. 1976. La ciudad daña los pinos del Ajusco. Panagfa 4(31):5-7. México.

Middleton, J.T. and Haagen-Smit, A.J. (1961).The Occurrence Distribution and Significance of Photochemical Air pollution in the Unites, Canada and Mexico, J.APCA 11(3): 129-134.

Miller, P. R.; Bauer, L. I.; Quevedo, A., and Hernandez Tejeda, T. (1994). Comparison of ozone exposure characteristic in forested regions near Mexico City and Los Angeles. Atmos. Environ. 28(1):141-148.

Parra Vásquez, M.R. 1998. Biodiversidad y Conservación de Recursos Naturales. Taller Sobre Metodologías de Medición de la Captación de Carbono y Conservación de la Biodiversidad. Colegio de Postgraduados. Montecillo, Mex.

Quadri, G., y Sánchez, L. R. (1994). La Ciudad de México y la contaminación atmosférica. Ed. Limusa-Noriega. México, D. F. 316 pp.

Quevedo, A.; Bauer, L. I. de; Miller, P. R.; Perea, V. 1998. La probable relación entre algunos factores meteorológicos y la declinación forestal en el Parque Nacional Desierto de los Leones (In press).

Rzedowsky, J. (1978). Vegetación de México. Ed. Limusa. México, D. F. 432 pp.

Secretaria de Agricultura y Recursos Hidraúlicos (SARH). (1994a). The forests of Mexico. Ed. AMAC impresos. México, D. F. 189 pp.

Secretaria de Agricultura y Recursos Hidraúlicos (SARH). (1994b). Inventario nacional periódico 1992-1994. Ed. ATT Diseño. México, D. F. 81 pp.

Skelly, J. M.; Savage, J. E.; Bauer, L. I de., Alvarado, D. (1997). Observations of ozone-induced foliar injury on black cherry (*Prunus serotina*, var. capuli) within the Desierto de los Leones National Park, Mexico City. Environ. Pollut. 95(2):155-158.

Global Change and the Prospects for Humanity in the Knowledge Age[1]

Thomas F. Malone[2]

Abstract—Development of a holistic, integrated, and reliable framework for characterizing, assessing, and managing North American forest ecosystems is a task inextricably embedded in the overarching challenge confronting society in the twenty-first century. We are challenged to transform the Environmentally unsustainable, economically inequitable and politically unstable trajectory on which global society is presently embarked into a path that is sustainable, equitable, and stable. An appropriate response to this challenge is to articulate a vision* of the future that exploding knowledge in the natural sciences is bringing within reach and, then, to design a knowledge-based and stakeholder-driven strategy to pursue this vision. The strategy will involve harnessing that knowledge explosion to human progress, by (1) integrating it with expanding knowledge in the social sciences and the humanities, (2) augmenting this body of knowledge with new findings in all disciplines, (3) disseminating a growing knowledge base widely with the aid of a revolution under way in information technologies, and (4) applying this expanding storehouse of all knowledge wisely and imaginatively to the human choices that will determine the future course of society. Nothing less daunting is involved here than changing the way people think and act, and making human knowledge an organizing principle for society—just as energy and finance have been during the 20th century. Entirely new patterns of interdisciplinary collaboration must be fostered. Novel modes of cooperation need to be forged among nations, and among academia, business and industry, the several levels of government and nongovernmental organizations. The proposal is made that the nations of the Americas act in concert to address this challenge in their own interests and with the intent of creating the prototype of a model that might be emulated globally. A suggested agenda for an American Vision and Knowledge Strategy for the 21st century (AV/KS-21) includes as priority items: (1) alternative energy sources to power environmentally benign economic growth, (2) nutritious food, (3) human health, and (4) potable water—with an overarching educational theme of lifelong learning for all individuals. Worldwide, a Global Vision and Strategy for the 21st century (GV/KS-21) is in order to ensure an attractive prospect for humanity as we enter the Knowledge Age. It is within such an American and Global context that efforts to develop an effective framework for the care of North American forest ecosystems are most likely to succeed.

*A society in which all of the basic human needs and an equitable share of human wants can be met by individuals in successive generations, while maintaining indefinitely a healthy, physically attractive, and biologically productive environment.

Between 1820 and 1992, the world population grew fivefold. An expanding storehouse of human knowledge powered an eightfold increase (albeit highly uneven among and within nations) in the average capacity of individuals worldwide to convert natural resources into goods and services. The result was a forty-fold expansion in the world economy, accompanied by a 540-fold increase in world trade. The added stress on the world's natural resource base of air, land, water, plant, and animal raised questions concerning the sustainability of environmental support for economic development in the 21st century. These questions were sufficiently worrisome that nations of the world gathered at the Earth Summit in Rio de Janeiro to frame a strategy for addressing them (AGENDA 21).

The issue of sustainability before the Rio conference was aggravated by a vexing inequity in economic development. One-fifth of the world's people in the 46 industrial countries produced and consumed nearly two-thirds of the global economic output, while the one-third of the world's population in the 62 least-developed nations shared less than one-tenth of that output. The average individual in the industrial countries had access to fourteen times the economic production of the average individual in the least-developed nations. This gap was growing, as were similar gaps within individual countries, indicating an inequitable trajectory of economic development that contributed to political instability.

A scenario postulating population growth at the rates anticipated during the 1990s, combined with gains in the capacity of the average individual to produce goods and services that prevailed during the 1980s (with adjustment for the spectacular growth in China), indicates a threefold increase in world population and an eightfold increase in the global economy by the year 2050. In that scenario, the 10 percent of the world population in the 46 industrial countries would have 40 percent of the global production of goods and services, while one-half of the world population in the 62 less advanced countries would have to share only about 10 percent of the global economic output (fig. 1, 2050 A). The gap between the average per capita economic consumption in the industrial countries and that in the poor countries for this scenario would increase by 33 percent over the gap in 1990-1991, with troublesome implications for increased political instability.

An alternative scenario assumes a 50 percent reduction in population growth rates everywhere with annual gains in individual economic productivity of 1.5 percent in the 46 industrial countries, 3.5 percent in the 65 evolving countries, and 4.5 percent in the 62 least advanced countries. A substantial step toward equity would result (fig. 1, 2050 B). However, the global economy would still be eight times larger than it was in 1990-1991.

Comparable scenarios have been prepared for the sixteen countries originally involved in the Inter-American Institute

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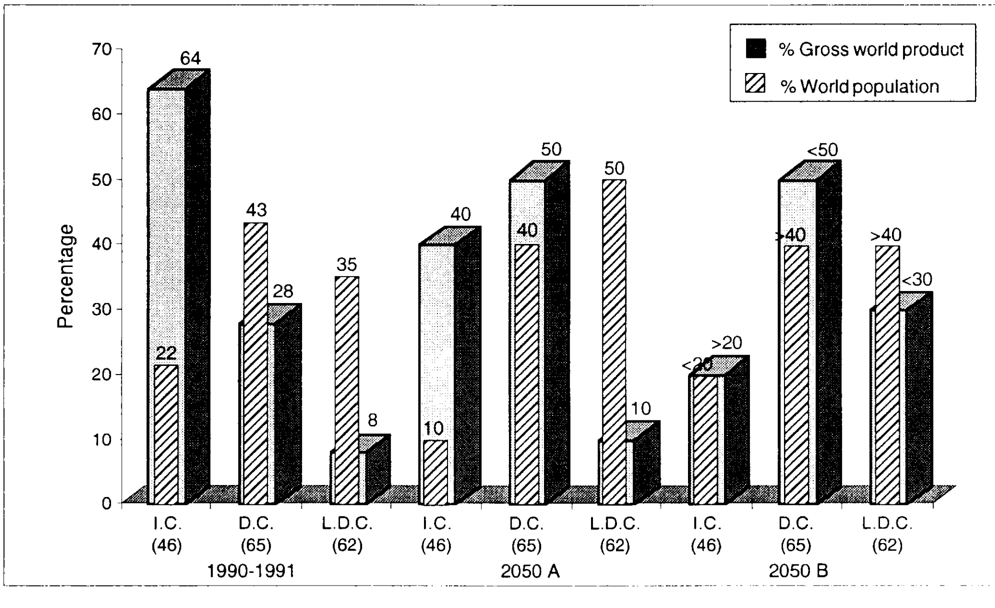


Figure 1.—Distribution of gross domestic product (GDP) in relation to population for the two global scenarios described in the text. GDP is given in purchasing power parity dollars that reflect local costs of goods and services rather than exchange rates. (Data from UNDP Human Development Report 1993.)

for Global Change Research (IAI). For these scenarios, the United States and Canada were designated as Tier I countries, Uruguay, Argentin Chile, Costa Rica, Panama, Colombia, and Mexico were designated as Tier II countries, and Brazil, Ecuador, Paraguay, Cuba, Peru, Dominican Republic, and Bolivia as Tier III countries.

A scenario for 2050 based on demographic growth rates anticipated in the 1990s, with gains in the economic productivity of individuals the same as those that prevailed during the 1980s, yields a doubled population, and an increase in the aggregate economies of about four-and-a-half times. Individual economic productivity would double, but with a widening gap between the average standard of living in Tier I countries and the one in Tiers II and III (figs. 2 and 3). One-third of the region's population would share more than four-fifths of the production of goods and services in the regional economy while two-thirds of the people in the region would share in less than one-fifth of that production (fig. 4, 2050 A). As David Landes wrote in his classic, *The Wealth and Poverty of Nations*, "Now the big challenge and threat is the gap in wealth and health that separates rich and poor...Here is the greatest single problem and danger facing the world millennium." It is worthy of note from Figure 3 that the increase of $30 trillion in this regional economy in 1991 would be larger than the total global economy in 1991 (about $27 trillion).

An alternative scenario takes as given a 50 percent reduction in demographic growth rates everywhere, with gains in individual economic productivity of 1.2 percent in Tier I countries and 3.0 percent in Tier II and III countries. The aggregate population in IAI countries would increase by only 50 percent, however the increment in population would be greater than the total population in Canada and The United States in 1991 (fig. 2). The total economy would still expand about four-and-one-half times, with an incremental growth greater than the total world economy in 1991, as in the scenario above. The average individual economic productivity would increase threefold and there would be a marked improvement in equity (fig. 4, 2050 B compared with 1991).

These scenarios suggest that both the World and the Americas are at a defining moment as the threshold to the 21st century approaches. The issues of environmental sustainability, economic equity, and political stability define that moment. Even if population were to be stabilized in the interests of sustainability, further economic growth in the interests of equity must be achieved with technologies that are environmentally benign. Interest is moving toward sustainable solutions (fig. 5), supported by the forward-looking document, *Changing Course*, contributed to the 1992 Earth Summit by the Business Council for Sustainable Development.

It is clearly time to add the arrow of exploding human knowledge to the quiver of financial measures that have been deployed in recent decades to address these issues. Knowledge has been one of the driving forces propelling society along its present trajectory. One key to the increase in economic productivity and gains in living standards between 1820 and 1992 was the continuing accumulation of knowledge in the physical sciences—knowledge that made it possible to harness energy and machines to power economic growth. The explosion of knowledge underway has the potential of being a forcing function to change that trajectory.

In recent decades, breakthroughs in the biological sciences have given great leaps in understanding of living organisms, fueling the explosion of knowledge in the natural sciences. There appears to be no limit to the discovery, integration, dissemination, and utilization of knowledge. These attributes of knowledge have been identified as the proper functions of scholarship by the late Ernest Boyer in his classical essay, *Scholarship Reconsidered*.

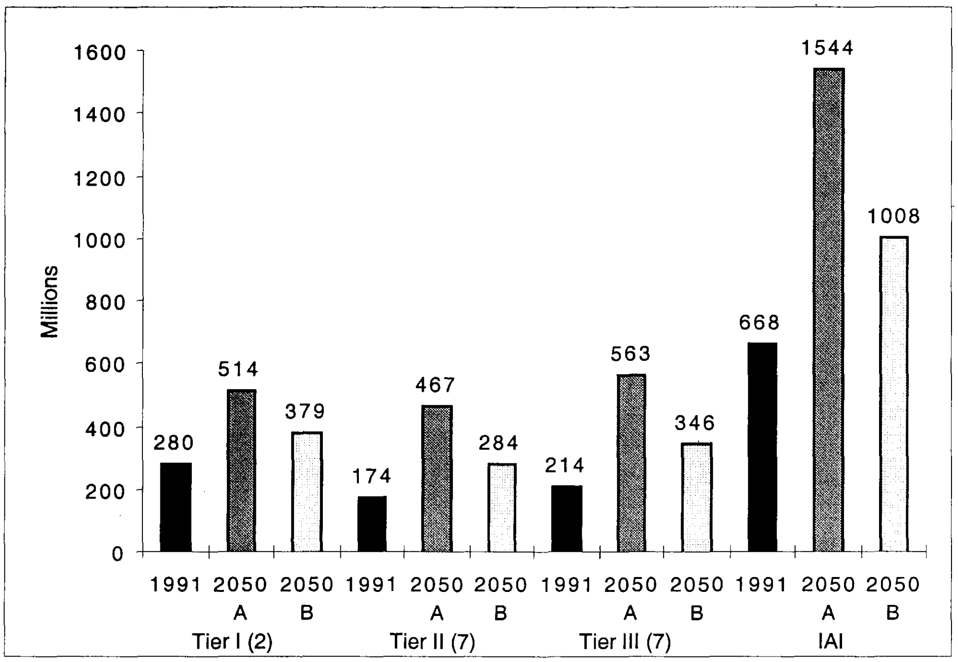


Figure 2.—Population for two Inter-American Institute for Global Change Research (IAI) scenarios. (Data from the UNDP Human Development Report 1993).

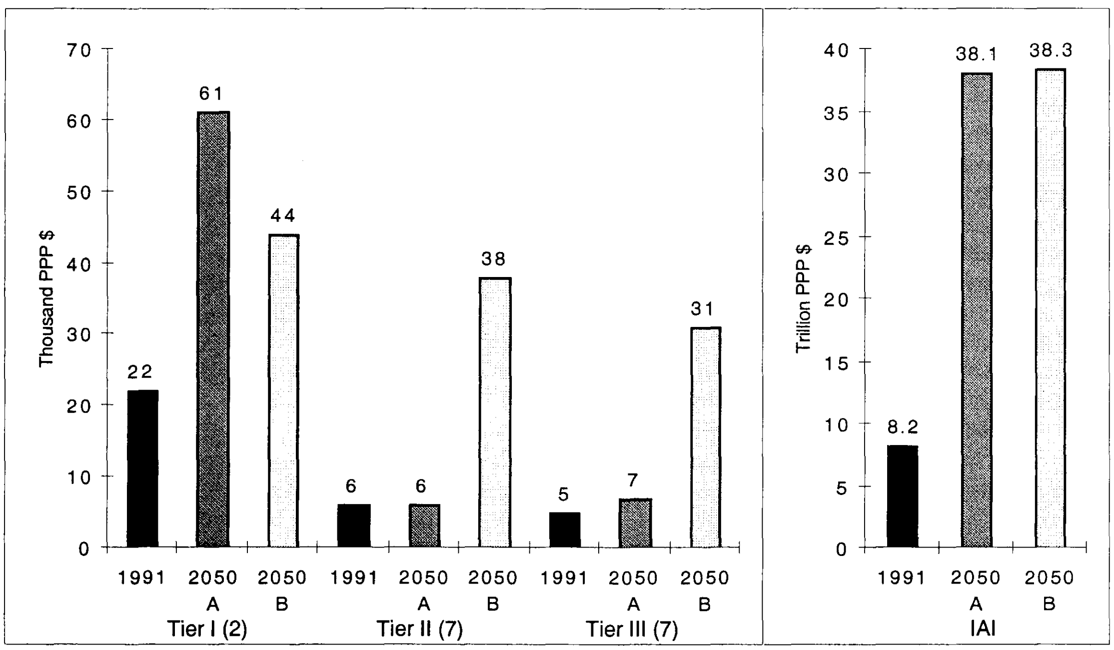


Figure 3.—Gross domestic product per capita (for two Inter-American Institute for Global Change Research (IAI) scenarios.

The potential implications of this explosive growth in knowledge have been magnified by revolutionary developments in the technologies for distributing and using information. These developments open the door to more effective integration of enhanced understanding in the natural sciences with expanding knowledge in the social and human health sciences—and in the humanities. As Landes points out, "If we learn anything from the history of economic development, it is that culture makes all the difference."

At this defining moment in the story of human destiny, we need to recognize that cascading human knowledge is bringing within reach a new vision for society in both the World and the Americas.

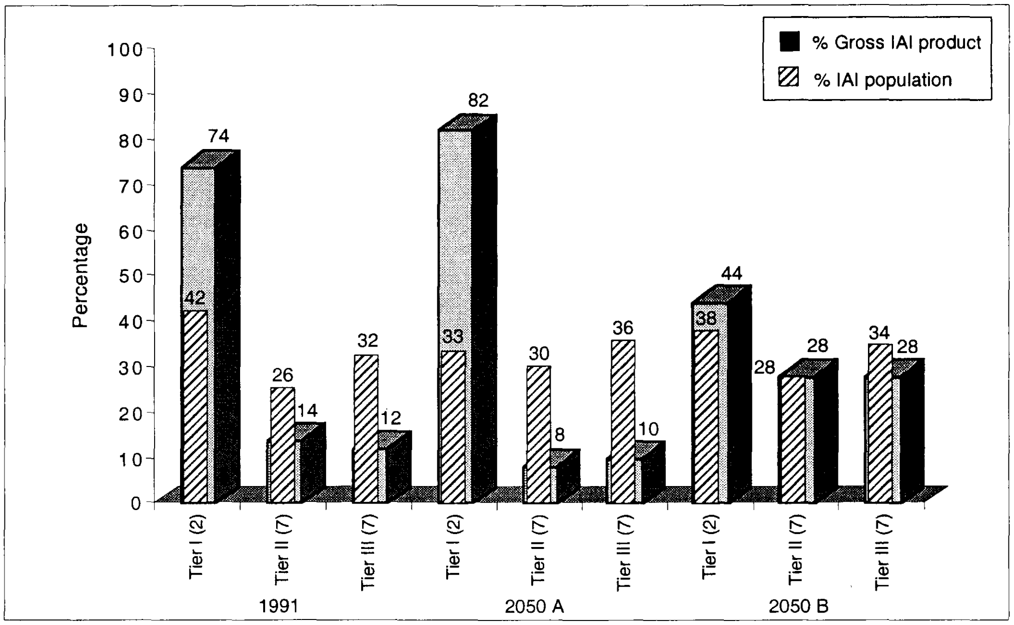


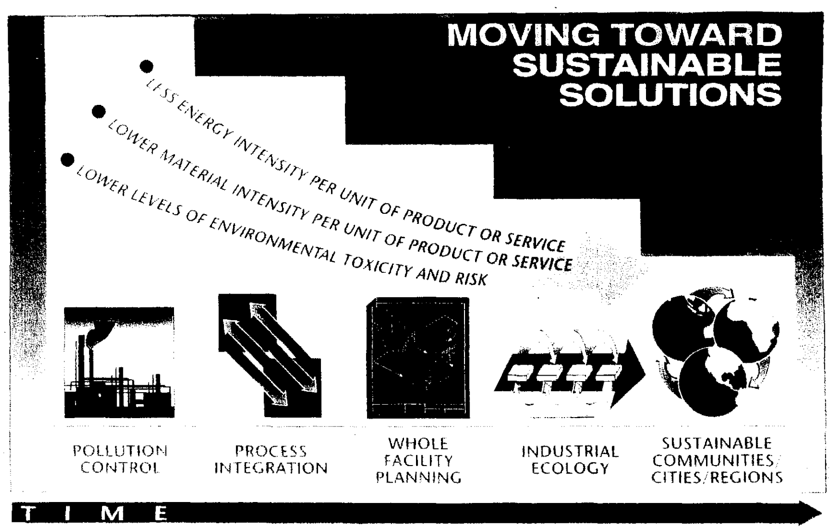
Figure 4.—Distribution of gross domestic product in relation to population for two IAI scenarios

> *This vision is a society in which all of the basic human needs (food, clothing, shelter, etc.) and an equitable share of human wants (education, culture, luxuries, etc.) can be met by individuals in successive generations while maintaining indefinitely a healthy, physically attractive, and biologically productive environment.*

Pursuit of this vision will require focused atttention on the *Cascade of Knowledge.*

> *This cascade is the nonlinear process connecting the discovery, integration, dissemination, and wise use of knowledge concerning the nature of matter, living organisms, energy, information, and human behavior and the manner in which they can interact with one another as a force for human progress (fig. 6).*

Discovery involves research that has emerged during this century as a highly organized activity in society. Integration requires interdisciplinary collaboration among the physical, biological, health, and social sciences, engineering and the humanities. Dissemination implies education extended to embrace lifelong learning. Wise use of knowledge means forging within and among nations new and imaginative



The shift to more sustainable technologies will mean significantly reducing the amount of energy and materials we use in producing our goods and sevices while decreasing risks to humans and the environment.

Figure 5.—Moving toward sustainabe solutions.

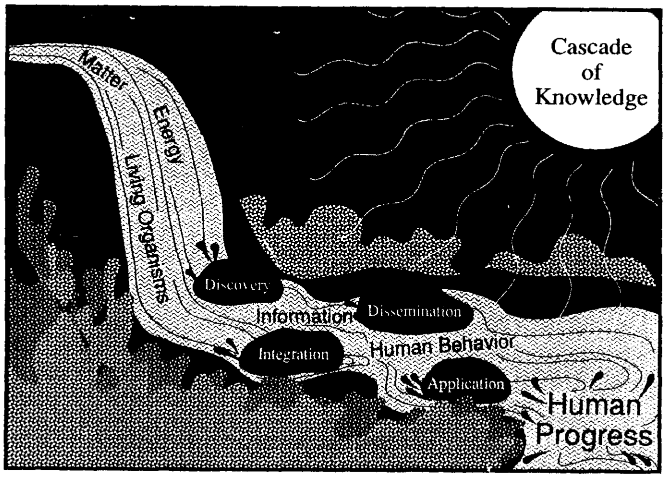


Figure 6.—Schematic representation of the cascade of knowledge.

modes of cooperation among academia, the several levels of government, business and industry, and the growing array of nongovernmental organizations.

In stimulating the knowledge cascade, focus is desirable on developing the capacity of individuals. Knowledge gained by lifelong learning empowers individuals to expand their options for meaningful and rewarding participation in the process of socioeconomic development that regenerates rather than degrades the physical and biological environment and

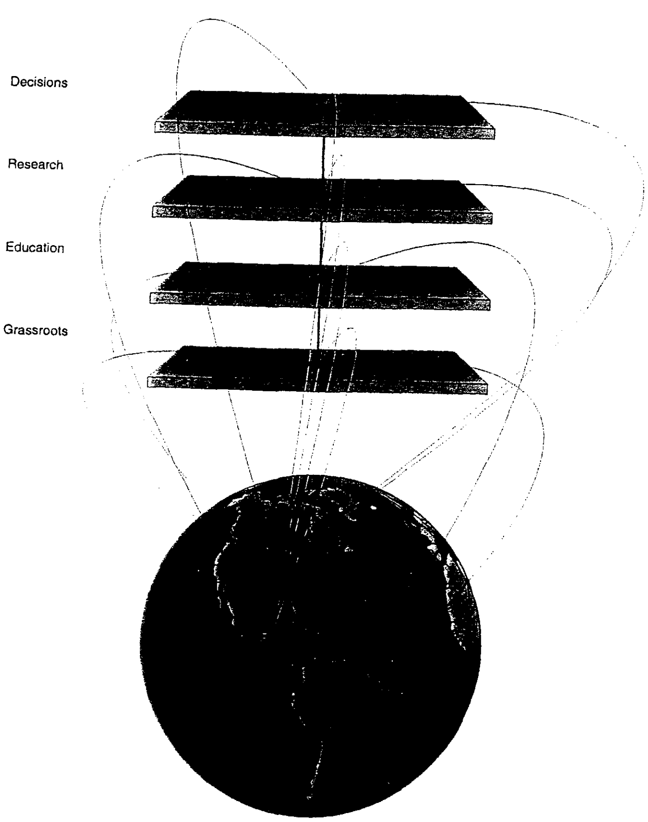


Figure 7.—Schematic representation of a knowledge network for the Americas.

enriches rather than impoverishes the social environment. In this process, greater attention is given to the quality of economic growth than to the quantity of that growth. Political and religious freedom, and personal security, are hallmarks of this process.

Communications technologies are near at hand (e.g., internet, distance learning, hyperforums, collaboratories, etc.) to design community-initiated programs, to articulate visions, to analyze options, to make choices, to fashion knowledge-based and stakeholder-driven strategies, to pursue those visions, and to aggregate local and regional efforts to national and international levels.

A special opportunity is emerging to link individuals and institutions in an American Knowledge Network (fig. 7) dedicated to the pursuit of a sustainable, equitable, and stable society in the western hemisphere. An agenda for this pursuit would require careful thought. The importance of energy to power an expansion in the economy of the region that would exceed the magnitude of the entire global economy in 1991 suggests high priority be accorded to developing alternatives to traditional dependence on fossil fuels for energy. The importance of providing food for an increment of population greater than the combined population of Canada and the United States in 1991, suggests emphasis on nutritious food, potable water, and human health. Since knowledge would be a dominant functional activity, an overarching educational theme on lifelong learning would be in order.

Parts of the infrastructure for such an initiative are already in place. The intergovernmental IAI could provide a foundation upon which institutional arrangements could be built, involving the nongovernmental START program. The WhichWorld HyperForum is available (http://www.hf.caltech.edu/WhichWorld), bringing within reach on-line analysis of the significance of long-term trends and the interaction of an array of demographic, economic, social, and environmental factors. Which World scenarios for 2050 in several regions, including Latin America and the highly industrialized countries, permit on-line exploration of critical issues of public policy.

The nations of the Americas could create a consortium to focus on an American Vision and Knowledge Strategy for the Americas in the 21st century (AV/KS-21) to serve the interests of their citizens and be a model for a worldwide effort that might be called a Global Vision and Knowledge Strategy for the 21st century (GV/KS-21). From grass roots programs such as these, there could emerge the leaders called *Trustees 21* under consideration by the World Economic Conference to serve as catalysts for progress.

Not the least important task for these activities would be the development of a holistic, integrated, and reliable framework for characterizing, assessing and managing America's forest ecosystems. The approach proposed above may be the most effective way to proceed with that development.

Readings

Boyer, E. L. 1990. Scholarship reconsidered. Lawrenceville, NJ: Princeton University Press. 146 p.

Bugliarello, G. 1995. The global generation, transmission and diffusion of knowledge: how can the developing countries benefit?

In: Marshaling technology for development; proceedings of a national research council symposium; 1994 November 28-30. Washington, DC: National Academy Press: 61-81.

Eddy, J. A.; Malone, T. F.; McCarthy, J. J.; Rosswall, T., eds. 1991. Global change SysTem for Analysis, Research and Training (START). Global Change Report No. 14. Stockholm: IGBP Secretariat, Roy. Swedish Academy of Science. 40 p.

Galbraith, J. K.; 1998. Created unequal: the crises in American pay. New York: The Free Press. 350 p.

Hammond, A. 1998. Which world? Scenarios for the 21st century. Washington, DC: Island Press. 306 p.

Landes, D. L. 1998. The wealth and poverty of nations. New York: Norton. 650 p.

Maddison, A. 1995. Monitoring the world economy: 1820 to 1992. Paris: Organization for Economic Cooperation and Development. 255 p.

Malone, T. F. 1994. Sustainable human development: a paradigm for the 21st century. A White Paper presented at the annual meeting of the National Association of State University and Land Grant Colleges; Chicago, IL. Washington, DC. 37 p.

Malone, T. F. 1995. Reflections on the human prospect. In: Socolow, E. H., ed. Annual review of energy and the environment. Palo Alto: Annual Reviews. (20): 1-29.

Malone, T. F. (convener). 1995. A knowledge network for the science agenda of the Inter-American Institute for Global Change Research. Summary report of a workshop; July 25-28. 22 p.

Malone, T. F. 1997. A new agenda for science and technology in the 21st century; In: Proceedngs of the KOSEF 20th anniversary symposium; June 2-6. Seoul: The Korean Science and Technology Foundation: 67-90.

National Research Council. 1993. National collaboratories. Washington, DC: National Academy Press. 105 p.

National Science and Technology Council. 1994. Technology for a sustainable future. Washington, DC: The White House, Office of Science and Technology Policy. 154 p.

Organization for Economic Cooperation and Development. 1996. The knowledge-based economy. Paris: 57 p.

Schmidheiny, S. 1992. Changing course: a global business perspective on development and the environment. Cambridge: MIT Press. 374 p.

Wilson, E. O. 1998. Consilience: the unity of knowledge. New York: Knopf. 332 p.

World Bank. 1998. Knowledge for development. World Development Report 1998/1999. Washington, DC.

Comunicación Ambiental y Recursos Naturales[1]

Luis Manuel Guerra[2]

Resumen—Quienes abogan por un desarrollo sostenible y los ambientalistas que los precedieron han aprendido mucho sobre la manera de realizar una comunicación eficaz. Inicialmente hacían hincapié en la correcta aplicación de su saber, prestando poca atención a la manera de comunicar las conclusiones y hacerias pertinentes para un publico amplio, no técnico. Se suponía que los hechos hablarían por si mismos. Lamentablemente, las cosas no resultaron tan sencillas.

Es importante examinar las dificultades que se plantearon, para poder evitarlas en el futuro. Hay varios conjuntos de problemas: La influencia de los intereses creados; la omisión de aplicar estrategias de comunicación, o las fallas de éstas; la complejidad de los mensajes y la lamentable tendencia de algunos de íos mensajeros de dedicar más tiempo a charlotear entre si, que a comunicarse con el público.

Una de las lecciones que ofrece la experiencia reciente es la necesidad de establecer estrategias de comunicación eficaces en todas las investigaciones o programas cientificos de gran envergadura. Para poner de releve esa necesidad se puede formular una comparación entre el Proyecto Nacional de Evaluación de Precipitaciones Acidas (NAPAP), en los Estados Unidos, y el Panel Intergubernamental sobre el Cambio Climático (IPCC), establecido en 1988 por el Programa de las Naciones Unidas para el Medio Ambiente (PNUMA) y la Organización Meteorológica Mundial (OMM).

El NAPAP, si bien muy prestigioso entre los cientificos, prácticamente carecía de estrategia de comunicaciones. En consecuencia si bien sus investigaciones y recomendaciones eran tenidas en cuenta, no disponía de muchas actividades de seguimiento. En el IPCC se ha tratado de evitar esa falla manteniendo a la comunidad científica y al público en general informados desde el comienzo mismo, en forma sistemática, sobre su labor y sus conclusiones. También se ha preocurado, con considerable éxito, tender puentes hacia los responsables de la elaboración de políticas, para que conozcan las consecuencias de las conclusiones que van emanando del panel, y obrar en consecuencia.

Informando al público, el IPCC ha hecho que sea mucho más dificil limitarse a archivar sus conclusiones. La enseñanza que de esto se desprende es que la comunicación debe concebirse como un proceso interactivo a largo plazo estratégicamente encaminado a grupos y audiencias particulares, no como el mensaje final que se elabora cuando un proyecto o panel está por presentar su informe final y dar término a sus actividades. No es necesario - ni siquiera es conveniente - Que los científicos se conviertan en propagandistas, pero es esencial que los estudios realizados en interés publico dispongan de medios adecuados para comunicar sus conclusiones al público en beneficio del cual se han realizado.

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Subject II

Science and Technology Applications

Spatial Data Infrastructure and Geostatistical Analysis of Forest Canopy–Hydrologic Interactions, at the Fraser Experimental Forest, Colorado, USA[1]

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Abstract—Development of a geospatial infrastructure, including 2-meter topography, digital orthophotos, satellite imagery, and global positioning system (GPS) locations of research plots has allowed the application of geostatistical methodology in research at the Fraser Experimental Forest. GPS has allowed field navigation to truly randomly located plots, georeferencing of long-term sample locations, and navigation to new sampling locations selected through spatial analyses in the office. This precise location of sample plots, in turn, allows the application of geostatistical techniques to interpolate point data on forest canopy conditions, integrating ancillary GIS and remote sensing information that is measured throughout the watershed to improve overall precision. The goal of this research is to use this spatially interpolated canopy information to improve predictions of water yield from forested ecosystems.

The Fraser Experimental Forest, located approximately 200 km northwest of Denver, Colorado, USA, is an 11,000 ha research area maintained by the USDA Forest Service, Rocky Mountain Research Station. Established in 1937 to study the integration of water, vegetation, fish, and wildlife in high elevation subalpine coniferous forests, much of the work has centered on determining how forest canopy conditions affect water yield. In recent years, research has indicated that the main component in moisture loss prior to snowmelt in the spring is canopy interception and subsequent sublimation (Troendle et al. 1993). Thus, the crown area profile of a forested stand is an important predictor variable in estimating snow interception in the canopy, and deposition processes under the forest canopy, and subsequent stream flow in the spring. In the current study, efforts are focused on spatially correlating forest canopy conditions, physiography, and other continuously measured GIS and remote sensing information, with snowpack accumulation in the spring, and potentially with stream flow. This capability will provide an important research cornerstone to measuring, monitoring and predicting the influence of overstory vegetation components on hydrologic behavior of the landscape represented by the Experimental Forest.

Background

Prior to 1995, georeferencing of research projects in the Experimental Forest was on an *ad hoc* basis, and was generally dependent on United States Geological Survey paper maps. These maps were at a relatively coarse grain (small cartographic scale) for the work done at Fraser Experimental Forest, and inconsistencies between map information and actual hypsography were often encountered. In 1995, a contract was let to (1) provide aerial photography of the entire forest, (2) develop 2-meter contour maps, (3) provide geographic information system (GIS) thematic layers, and (4) provide co-registered digital orthophotos at a 2-meter pixel resolution. Simultaneously, 30-meter pixel Landsat Thematic Mapper (TM) satellite imagery was obtained, and the process of georeferencing key research locations on the Experimental Forest through the use of global positioning systems (GPS) was initiated.

The overall plan was to provide geospatial information at the finest level of resolution possible, given budgetary restrictions, and the spatial extent of the Experimental Forest. Two-meter contour information, coupled with 2-meter pixel black-and-white orthophotos, provided the basis for this geospatial infrastructure. The assumption was that information could be aggregated to a coarser level, whereas the reverse was problematic: fine-resolution interactions could not always be reliably disaggregated from coarse-level measurements.

Without the advent of affordable, accurate global positioning system (GPS) equipment, it would have been impossible to implement the research side of this infrastructure. In 1995, point locations could be located with a GPS satellite receiver at a nominal 5-meter r.m.s. accuracy (after differential correction). Currently, the same approximate investment in equipment allows differentially corrected position accuracy on the order of 1 to 3 meters. Because of the remote location and the mountainous terrain, the potential decimeter accuracy of current equipment can not be realized. The ability to collect information on accurately located

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plots, and to integrate this discrete point information with extensive contiguous information, from GIS and satellite imagery, for example, has allowed the application of geostatistical methodology.

Geostatistical techniques have allowed us to interpolate point estimates of forest canopy conditions across landscapes, by integrating spatially correlated predictor variables, such as slope, elevation, and aspect derived from GIS coverages, and multispectral reflectance values obtained from satellite imagery. Geostatistical techniques used include sequential Gaussian simulation and co-conditional turning bands simulation. These are useful in estimating uncertainties in GIS analyses using auto- and cross-correlations in a multivariate spatial context, and disjunctive kriging which allows the conterminous estimation of discrete and continuous distributions of forest canopy conditions across landscapes. The overall goal is to integrate point information on both forest canopy and snowfall accumulation with continuous data to improve the database used for hydrologic predictions.

GPS Survey and Map Data

The contract to obtain spatial data for Fraser Experimental Forest involved five main steps: survey control, aerial photography, stereoscopy, orthorecitfication, and GIS data formatting. Prior to any work, it was determined that the best format for the data was Colorado State Plane coordinates in meters, on the North Zone of the North American Datum 1983 (NAD83), using the Lambert Conformal Conic Projection. All photographic and map products were to provide information for an additional 300-meter buffer zone beyond the Experimental Forest boundary to ensure spatial continuity for any analysis area. Final results were to meet second-order, class I horizontal control survey accuracy standards, with a relative accuracy between points of at least one part in 50,000 (Wolf and Brinker 1994). After completion of the GPS survey, the final minimally constrained adjustment in the network evaluation ratio was one part in 625,000, well exceeding first order accuracy requirements of one in 100,000.

Survey Control and Aerial Photography

The Experimental Forest and surrounding boundary was divided into nineteen rectangular tiles, 4 kilometers in the east-west direction, and two and one-half kilometers in the north-south direction. These tiles partitioned the GIS information into analytically manageable sizes. Sixteen survey control points were established throughout the Experimental Forest and immediately surrounding areas. Precise positions for these horizontal benchmarks were established by satellite (GPS) survey methods, and the intermediate topography filled in photogrammetrically. In two cases, permission had to be obtained from private landowners before benchmarks and photo panels were installed. Two other locations required a day-long hike to set the photo panels and obtain the GPS baselines (see Fig. 1). Upon completion of the aerial photography, all the photo panels were removed.

Aerial photography at a scale of 1:27,500 provided a nominal 60 percent endlap (between adjacent photographs on the same flight line) and a 35 percent sidelap (between adjacent flight lines) between photographs. This resulted in three flight lines of nine exposures each, covering the rectangular area encompassing the Experimental Forest. The photo panels were located so that at least two and sometimes three photo panels were visible in each photograph. Brass

Figure 1.—Aerial photography panel near Byers Peak on west boundary of the Fraser Experimental Forest.

caps, centered on the photo panels, were used to permanently benchmark the location of each control point. These benchmarks will provide horizontal and vertical references for future work, such as real-time differential GPS correction radio links within the Experimental Forest.

Stereoscopy and Orthorectification

The contractor used a stereoscopic plotter to develop the digital elevation models. These, in turn, were used to create topographic sheets with 2-meter contours. Nineteen 1:5000 scale topographic map sheets resulted, each covering a two and one-half- by four-kilometer area. Additional mylar map sheets were created by overlaying the contour lines on the orthophotos, providing simultaneous visual reference for stand delineation and topography.

Orthophotos are corrected to a uniform scale: perspective effects due to terrain relief and photo tip and tilt have been removed. These photographic images were co-registered with each of the nineteen topographic map sheets. The digital orthophotos were provided in ERDAS format with a two-meter pixel resolution in 8-bit gray scale. They have proved invaluable for "heads-up" digitizing from the computer screen, and for stand delineation and location for subsequent field measurement, as discussed below.

The orthoimage is corrected for relief perspective so that there is a constant scale across the image. However, the outward radial lean of objects with vertical relief displacement, such as cliffs or trees, is still a visible distortion, which increases as one moves outward from the center of the photograph. Because several aerial photographs had to be used to develop the orthophoto for each tile, and the edges of the aerial photographs did not match the edges of the map tiles; there are locations on the orthophotos where corners of four aerial photos come together. Such a juncture is visible in the upper center of Figure 2. Care must be taken that junctures such as this do not cause misinterpretation of stand composition and texture when these orthophotos are used for stand delineation.

Figure 2.—A portion of a digital orhtophoto showing forested areas of the Lexen Creek watershed.

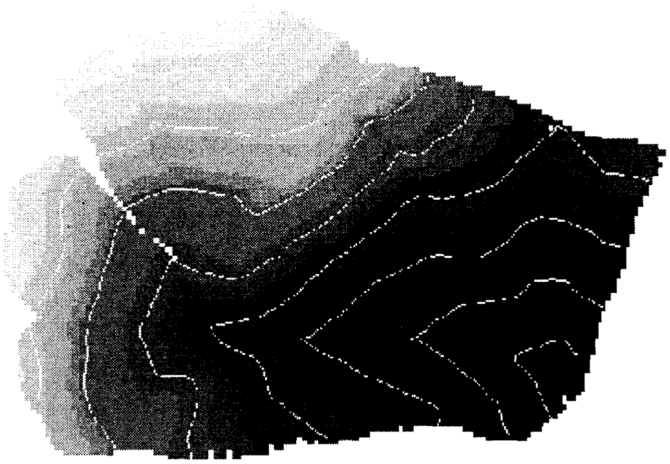

Figure 3.—The same area of Lexen Creek watershed as in Figure 2, showing topography. White lines are 50-meter contours, derived from initial 2-meter contours. Deriving slope and elevation surfaces is a straightforward process from the digital elevation model.

GIS Data Formatting

In addition to the digital orthophotos described above, thematic layers were provided for GIS use. Ten map themes were provided in separate Arc/Info files for each of the nineteen tiles. These thematic layers included hypsography (Fig. 3), hydrography, structures, roads and trails, tree-line, barriers (fences), drainage (bridges, culverts, etc.), map sheet lines, and control points. The hypsography provides the basis for interpolation of a digital elevation model (DEM). In addition to providing direct information on elevation, digital elevation models provide the basis for calculation of continuous slope and aspect information. Hydrography (permanent streams, lakes, and wetlands) provides a useful reference for delineation of riparian vegetation. Roads and trails, as well as hydrographic information, provide useful visual references for orienting an observer to specific locations. Map sheet lines are invaluable for georeferencing point, line, and polygon information from other sources. Control point locations are useful to determine the closest benchmark to an existing or proposed research site or for satellite classification (Fig. 4).

Spatially Referenced Experimental Data

In addition to the spatial information obtained under contract, described above, additional information has been collected on the Experimental Forest, both specific to this particular project and historically as part of long-term research on the Experimental Forest.

Plot-Level Forest Canopy Information

Since 1992, a summer field crew has been measuring forest plots, centered in and surrounding the Lexen Creek watershed of the Experimental Forest. As a first step,

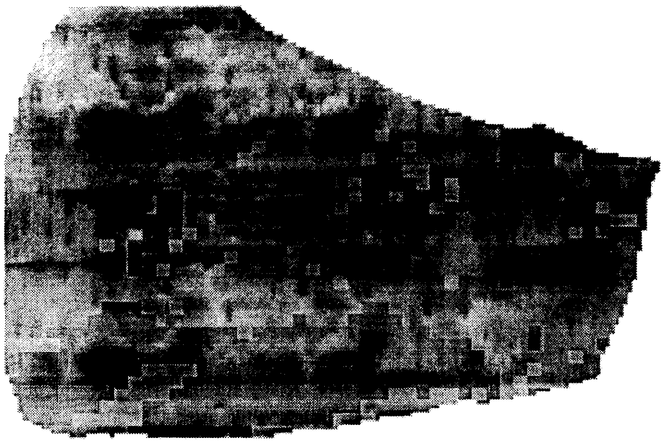

Figure 4.—Unsupervised classification of entire Lexen Creek watershed using Landsat Thematic Mapper satellite imagery showing (from lightest to darkest grey): open ground/bare rock; widely spaced lodgepole pine (*pinus contorta*); mixed lodgepole pine, Englemann spruce (*picea engelmanii*), and subalpine fir (*abies lasiocarpa*); and dense Engelmann spruce/ subalpine fir (darkest grey).

previously measured temporary point sample locations were reestablished, measured, and monumented. In subsequent seasons, these systematically located sample points were augmented by randomly located plots to ensure complete sampling across the 121-hectare first-order watershed (see Fig. 5).

Navigation to Plots Using GPS

GPS location has been critical to this research, first to provide georeferencing of inventory points using differential

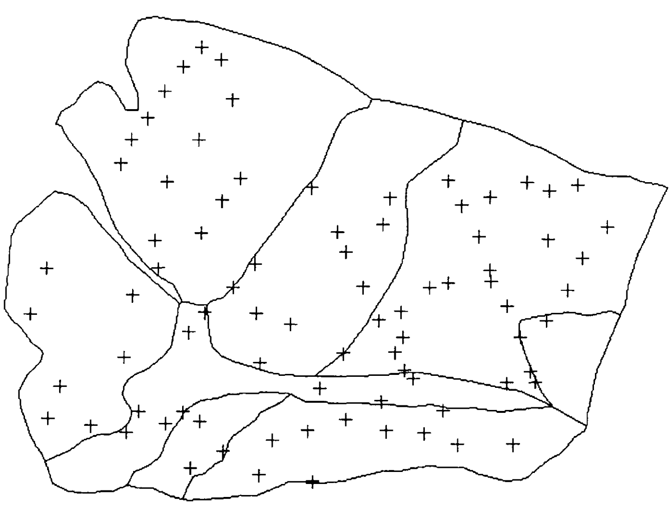

Figure 5.—Global Positioning System (GPS) satellite locations of 82 1/125th hectare plots. Lines delineate stands from the orthophoto in Figure 2.

correction, and, more recently, to navigate to randomly located plots using a Precise Positioning Service P(Y) code GPS receiver. These P(Y) code GPS receivers are made available to federal agencies through the Department of Defense, and receive cryptographically coded signals, which broadcast position information without the additional errors introduced to civilian C(A) code GPS signals. The overall effect is to provide "real-time" location information that is accurate to within a 30-meter Landsat TM pixel. This is particularly useful in remote mountainous areas where real-time broadcast of differential correction information is unavailable or impractical.

This capability allows navigation in the field to a precise location that was previously established in the office through computer analysis of digital spatial information, or through the more traditional method of determining the location of a point on a map on a digitizer tablet. This has been extremely useful in locating sample plots in areas that have been selected through a combination of data sources such as satellite imagery and digital orthophotographs, in conjunction with stereoscopic viewing of aerial photography. The coordinates of the desired plot location can either be obtained from the cursor location on the digital imagery, or from a digitizer table. The coordinates are entered into the P(Y) code receiver, and the field crew can reliably navigate to the selected point location to collect their information.

This is a substantial improvement over traditional forest inventory procedures, where crews relied on coarse topographic and overstory conditions to estimate their location within a stand. Plots were then systematically located along compass lines by pacing a predetermined distance between plots. Thus, plot locations had only nominal certainty with regard to their location within the stand. It was therefore necessary to statistically base inventory information on this "systematic sampling with multiple random starts" methodology, which is generally accepted as only suitable for predicting the mean values of typical forest conditions (Avery and Burkhart 1994). Through GPS location of forest plot location, spatial information can be maintained throughout an analysis, preventing information loss through averaging of plot information (Mowrer 1997).

Snow Course Information

Mountain snowpack accumulation, and subsequent collection and transport of snow melt to supply water for agricultural and urban uses is of considerable economic importance in Colorado and elsewhere in the western USA. Part of the importance of the Fraser Experimental Forest, is its long-term historic data set of snow accumulation and consequent runoff at measured stream locations. Four "snow courses" have been measured for more than forty years. These consist of large loops, beginning and ending at stream flow measurement points (v-notch weirs) at the base of the watershed. Measurements of snow depth and water equivalent are taken at monumented points located 40.24 meters (2 chains) apart throughout the loop. The on-going process of GPS-locating each of these measurement posts will allow the spatial interpolation of water equivalents throughout a watershed using the contiguous GIS information as a function of canopy information measured at point locations.

Geostatistical Analysis

In 1993, the purchase of the first GPS receiver on the Experimental Forest was coincident with the measurement of 82 inventory and randomly added plots across the Lexen Creek watershed. Just being able to visualize the spatial response surface for percent crown cover across this 121 hectare watershed was a great advantage. Mowrer (1994) developed a variogram and a kriged response surface for the watershed. The variogram (or semi-variogram) models the spatial autocorrelation between values of a particular variable at successively greater separation distances. Kriging uses this variance model to estimate the minimum variance combination of weights for adjacent measured values to estimate the value at an unmeasured location (Isaaks and Srivastava 1989)

Mowrer (1996) extended this methodology using sequential Gaussian simulation to develop multiple, equally probable realizations of input to GIS analyses. Sequential Gaussian simulation applied the kriging algorithm to each cell or pixel visited randomly in the area of interest. If the cell had a measured location in it, that value was adopted for the cell. If not, the kriging process was used with the variogram to estimate the set of weights to apply to adjacent measurement points and previously simulated cell values to create a minimum variance estimate for the point in question. A random deviate was then drawn from distribution determined by the kriged mean and variance, and assigned to that cell. This process was repeated as cells were visited randomly until values for the entire area had been estimated.

Mowrer (1997) again extended this approach to estimate the potential areas for old growth across the Lexen Creek watershed by applying the sequential Gaussian simulation algorithm to three variables of interest: mean stand diameter, age of dominant and codominant trees, and percent crown cover. Creating independent realizations of these three variables, and using them as input to a simple GIS analysis to select cells meeting a minimum threshold for each of the three variables, created the *ad hoc* spatial confidence region for potential old growth on the watershed shown in Figure 6. Of particular relevance, this study established that at least 500 realizations of the sequential Gaussian simulation process was necessary to provide stable estimates of the variance.

In the 1997 study, sequential Gaussian realizations were created based on the assumption of spatial independence between variables. In 1998, Mowrer (in press) extended the study through adaptation of the FORTRAN program COSIM (Carr and Myers 1985). The co-conditional simulation algorithm in this program includes spatial correlations through cross-variograms, which provide a model of the spatial covariance between two variables as a function of separation distance. Thus, the co-variogram can be used with the variograms for the individual variables in co-kriging. The Carr and Myers (1985) program uses the "turning bands" algorithm (Journel and Huijbregts 1978) to create random fields that are subsequently conditioned using co-kriging. The results of the *ad hoc* spatial confidence region generated using this algorithm are shown in Figure 7. The conclusion from this study was that the symmetrical and circular artifacts of the process we impossible to justify ecologically.

Figure 6.—Percentiles based on the histogram of 500 realizations from the sequential Gaussian simulation geostatistical uncertainty assessment procedure. Areas above the 90th percentile are shown in medium gray, 95th percentile in dark gray, and 99th percentile in black, representing successively higher levels of certainty for old growth locations.

For this, and other reasons, Mowrer recommended not using this algorithm in generating multiple realizations of forest stand conditions.

An ongoing controversy in the field of GIS, is how to represent different spatial phenomena that may vary continuously in some areas, yet have discrete boundaries in others. Hunner, et al. (in press) investigated the use of the GIS and remote sensing information described above, to explore different geostatistical techniques such as cokriging and disjunctive kriging to interpolate these types of phenomena accurately. Cokriging, described above, has the advantage of using continuously measured information,

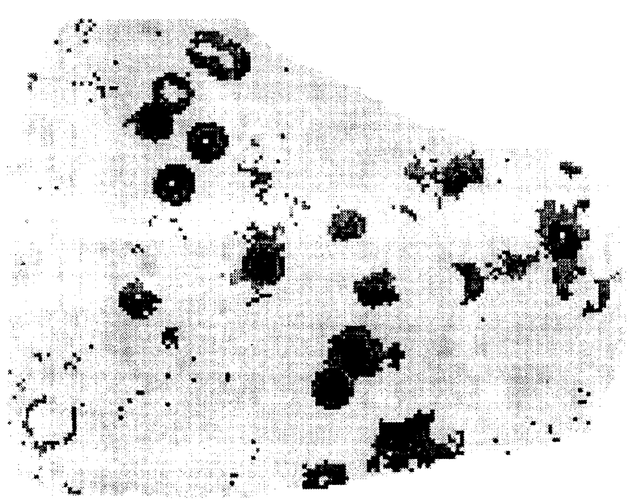

Figure 7.—Ad hoc spatial confidence region, from the same GIS analysis in Figure 6, but using the co-conditional simulation algorithm to create spatially cross-correlated realizations for age and diameter. Results are considered inferior to sequential Gaussian simulation, despite the explicit spatial cross-correlation.

such as that available from GIS and remote sensing, that is spatially cross-correlated with other information measured only at particular point locations. Thus, the more extensive data can be used to improve the estimation of the sparser variables of interest across the entire area. Disjunctive kriging (Rivoirard 1994) provides a non-linear unbiased estimate of conditional probabilities that some value exceeds a cutoff value.

Forest Canopy Effects on Hydrology

Our objective in the work described above is to improve spatial estimates of snowpack water equivalent on the ground on April 1st of each year. This measure provides the basis for estimation of runoff later that spring. Ninety-five percent of the surface water exiting watersheds on the experimental forest originates as melting snowpack. Simple empirical models indicate that the amount of water in the snowpack on April 1 explains 70-95 percent of the variability in annual runoff (Troendle et al., 1998). Canopy interception and subsequent sublimation of snow, which can approach 35 percent of gross precipitation before it reaches the ground, is a major manipulable source of water loss in forested stands (Troendle et al. 1993). Winter interception losses vary with aspect, stand density, species composition, and, to some extent, precipitation amount. Interception losses are therefore quite variable spatially (ibid.). On north-facing slopes, peak water equivalent or the amount of water in the snowpack on April 1st, can be increase by 50 percent through forest removal. On a similar south-facing slope, the increase would only be 20 percent (ibid.). Because of the almost direct relationship between vegetation density and snowpack accumulation, and between snowpack accumulation and streamflow, reliable predictions of steamflow from subalpine forest environments require spatially correct estimations of vegetation and physiography.

Dubrasich et al. (1997) developed estimates of between-tree porosity, based on intensive individual tree sampling in five structurally complex and three structurally simple forest stands in the Pacific Northwest of the USA. Their estimate of porosity treated each tree as a solid object and expanded crown areas from individual plots to volumes per hectare. Between-tree porosity was calculated as the percentage of the total volume space in the stand occupied by stand crown volume.

Conclusions

Obvious extensions of existing research may improve predictive capabilities for forest canopy hydrologic interactions. Modeling the between-tree porosity using geostatistical techniques such as three-dimensional kriging with external drift, or three-dimensional cokriging are two immediate goals. Both of these techniques require that the primary variable of interest, i.e., between-tree porosity, be second-order stationary with a constant mean and spatial covariances that are only dependent on the distance between points. Kriging with external drift does allow for a linear or polynomial trend model. Cokriging has the strength of including cross-variates that are measured more intensively than the variable of interest and improve predictive ability for the primary variable at unmeasured locations. Possibilities for following up Pomeroy and Schmidt's 1993 work on fractal analysis may provide predictive capabilities for within-tree porosity, or interception. The confluence of spatial data, predictive capabilities, and computing power bode well for progress in these areas.

Literature Cited

Avery, Thomas E. and Harold E. Burkhart. 1994. Forest Measurements. McGraw-Hill, New York. 408 pp.

Carr, James R. and Donald E. Myers. 1985. COSIM: A Fortran IV program for coconditional simulation. Computers and Geosciences 11(7): 675-705.

Dubrasich, Michael E., David W. Hann, and John C. Tappeiner II. 1997. Methods for evaluating crown area profiles of forest stands. Canadian Journal of Forest Research 27:385-392.

Hunner, Gerhard, Robin M. Reich, and H. Todd Mowrer. In press. Modeling forest stand structure using spatial statistics, geographic information systems, and remote sensing. In: Proceedings of the Second Southern Forestry GIS Conference, October 28-29, 1998, Athens, Georgia, USA.

Isaaks, Edward H. and R. Mohan Srivastava. 1989. An Introduction to Applied Geostatistics. Oxford University Press, New York. 561 pp.

Journel, Andre and Ch.J. Huijbregts. 1978. Mining Geostatistics. Academic Press, London. 600 pp.

Mowrer, H. Todd. 1994. Spatially quantifying attribute uncertainty in input data for propagation through raster-based GIS. In: Proceedings of GIS '94: the Eighth Annual Symposium on Geographic Information Systems. Polaris Conferences, Vancouver, British Columbia, Canada. Pp. 373-382.

Mowrer, H. Todd. 1996. Incorporating uncertainty into spatial estimates of old-growth subalpine forests using geostatistics. In: GIS Applications in Natural Resources 2, edited by M. Heit, H. Parker, and A Shortreid. GIS World Books, Fort Collins, Colorado, USA. Pp. 178-184.

Mowrer, H. Todd. 1997. Propagating uncertainty through spatial estimation processes for old-growth subalpine forests using sequential Gaussian simulation in GIS. Ecological Modeling 98(1997):73-86.

Mowrer, H. Todd. (In press.) Spatial interpolation of forest conditions using co-conditional geostatistical simulation. In: Integrated Tools for Natural Resources Inventories in the 21st Century, Proceedings of an International Conference on the Inventory and Monitoring of Forested Ecosystems, August 16-20, 1998, Boise, Idaho. General Technical Report, North Central Forest Experiment Station, St. Paul, Minnesota, USA.

Pomeroy, J. W. and R.A. Schmidt. 1993. The use of fractal geometry in modeling intercepted snow accumulation and sublimation. In: Proceedings of the 50th Eastern/61st Western Snow Conference, Quebec City, 1993. Pp. 1-10.

Rivoirard, J. 1994. Introduction to disjunctive kriging and non-linear geostatistics. Clarendon Press, Oxford. 180 pp.

Troendle, Charles A., M.S. Wilcox, and G.S. Bevinger. The Coon Creek water yield augmentation pilot project. In: Proceedings of the 66th Western Snow Conference, Snowbird, Utah, USA. Pp. 123-130.

Troendle, Charles A., R.A. Schmidt, and Manuel Martinez. 1993. Partitioning the deposition of winter snowfall as a function of aspect on forested slopes. In: Proceedings of the 50th Eastern/61st Western Snow Conference, Quebec City, 1993. Pp. 373-379.

Wolf, Paul R. and Russell C. Brinker. 1994. Elementary Surveying, Ninth Edition. Harper Collins, New York. 760 pp.

Spatially Based Forest Inventory Approach for Ejido el Largo, Chihuahua, Mexico[1]

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Abstract—A spatially based forest inventory system is presented for the Ejido El Largo y Anexos, Unidad de Administración Forestal No. 2, El Largo-Madera, Chihuahua, Mexico. Universal kriging/cokriging is used in conjunction with Landsat TM data to spatially model selected forest attributes (basal area, volume, growth rates, fuel loadings, etc.) to a 60 m resolution. These results are compared to conventional methods of analyzing forest inventory data. In addition, techniques for integrating spatial data are presented along with techniques for identifying stand with similar spatial characteristics. Examples of the techniques referred to above are demonstrated using data collected in a recent forest inventory on the Ejido El Largo.

Resumen—Un sistema de inventario basado en un planteamiento de estimaciones espaciales es presentado para el Ejido El Largo y Anexos, Unidad de Administración Forestal No. 2, El Largo-Madera, Chihuahua, Mexico. Kriging y cokriging universal en conjunto con datos Landsat se utilizó para modelar espacialmente varios atributos del bosque (area basal, volumen, crecimiento, cargas de combustible, etc.) a una resolución de 30m. Estos resultados son comparados con aquellos que resultan de utilizar metodos convencionales para analyzar datos de inventarios forestales. Tambien, técnicas para la integración espacial de información se describen en relación con técnicas empleadas para identificar rodales que comparten características similares. Ejemplos sobre la demostración de estas técnicas se presentan utilizando datos de un inventario recientemente realizado en el area del Ejido El Largo y Anexos.

New trends such as the emergence of ecosystem management and the sustainability of ecosystems are rapidly advancing the development of alternative approaches for inventorying and monitoring forest ecosystem resources. Current inventory and monitoring approaches are given more emphasis to the question of integration across scales (e.g., space, time) and among different programs (e.g., processes, resources). Traditional programs, characterized by having a narrower focus, are becoming more comprehensive and integrated from an ecosystem hierarchical perspective. In this evolution, scientists and managers are actively addressing emerging issues concerning the interoperability of inventory and monitoring programs (e.g., sampling designs, data collection processes, quality assurance and quality control protocols, information management systems, statistical data analysis systems, syntheses, and strategies for reporting, etc.). Similarly, though at different paces, land management and environmental institutions are also developing planning strategies for moving toward a unified framework for inventorying and monitoring ecosystem resources.

In North America, the revolution in the development of new approaches to inventory and monitoring forest ecosystem resources is taking place in Canada and the United States. Significant progress is also occurring in Europe, particularly in Scandinavian countries (Finland and Sweden). While a myriad of technological innovations have been occurring abroad, Mexico's institutions have been marginally participating in these scientific and technological advancement processes. For decades, little attention has been given to the problem of modernizing Mexico's human and technological infrastructure for inventorying and monitoring the wealth of its forest ecosystem resources. Presently, Mexico lacks of a scientifically and technically defensible forest ecosystem resource inventory and monitoring program (Varela 1995). Local forest inventory programs, for example, are still single resource oriented, and in most cases they are far from meeting quality assurance and quality control standards and protocols (Aguirre and Reich 1998). Uncertainty in the quality of forest resource inventory data undermines significantly the technical and scientific credibility of forest resource management plans, as well as public confidence and support in our natural resource institutions.

Bringing Mexico's ecosystem resource inventory programs up to speed with the rest of North America would take an unprecedented international cooperative effort of science and technology exchange. Unfortunately, partner institutions abroad have limited human and financial resources to assist in this respect. In response to this situation, however, a number of NAFTA organizations working in partnership have been assisting local forest organizations in northern Mexico to confront a number of the problems referred to above (Aguirre and Reich 1998). For this purpose, a pilot study on inventory and monitoring of forest ecosystem resources was proposed for implementation in 1997 so that project participants could learn and benefit from the results

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of this international cooperative project. This technical paper, for example, is part of the results so far achieved. Specifically, the paper describes the existing local forest inventory approaches and provides a number of technical recommendations for their improvement.

Study Area Location

The pilot study area is situated in the northernmost edge of the Sierra Madre Occidental (Mexico's Western Madrean Mountain Range), directly west of Ciudad Madera, state of Chihuahua (Figure 1). Jurisdictionally, it is part of the Ejido El Largo y Anexos, the largest forest Ejido in Mexico (250,000 hectares). In this region, complex topography and extreme elevational gradients contribute to the diversity of ecosystems themselves. Precipitation ranges from roughly 800 mm/year in the lower elevations to more than 1200 mm/year in the higher elevations, with seasonal precipitation contributions provided by summer monsoons. The region's unique topography, relief, and location explain a large part of its biological richness and diversity. Several dominant ecosystems can be categorized: montane coniferous forests, oak-pine woodlands, wetlands, and agroecosystems (Warshall 1994). This mix of ecological conditions in a relatively compact area leads to a number of diverse and unique biotic communities.

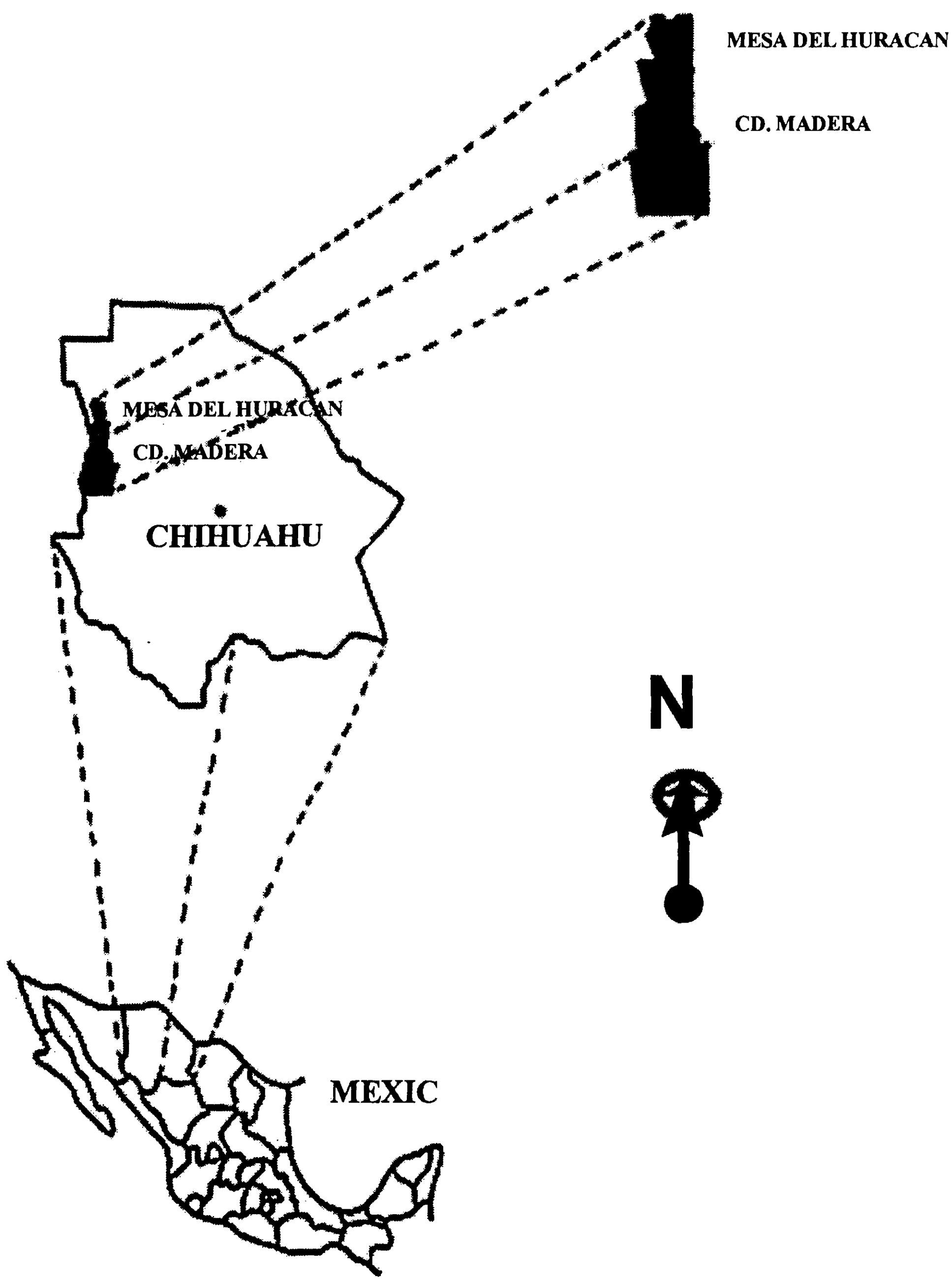


Figure 1.— Location of pilot study area.

As part of Mexico's Ejido System, the pilot study area is communally owned by 1745 stake holders (ejidatarios). In this system of land ownership, ejidatarios usually do not have complete management and planning responsibility for their land. Forest resource management is regulated by policies set forth by the national government. In between the landowners and the government are quasi-public/quasi-private forest management organizations which are required to comply with government regulations while fulfilling the goals of the landowners (who also provide their operating budgets). Timber production is the single most important economic activity and there exist numerous small sawmills throughout the ejido's lands. Historically, these lands have been indivisible and held in common. Recent reforms allow the sale of ejido lands, but the sale of these common lands requires a two-thirds approval by the ejido's general assembly and lands must be transferred as a block, not in parcels (Thoms and Betters 1998). The pilot study area is surrounded by forests and rangelands held under the same land tenure system.

One of the Ejido's Timber Management Units (TMU-2000) which is scheduled for silvicultural treatment in the year 2000 was selected for the purpose of this particular study. TMU-2000 is located at about five kilometers west of Ciudad Madera and covers approximately 650 hectares. Though small in size, it shares many of the ecological features of the other timber management units. Pines (*P. engelmanii, P. durangensis*, and *P. leiophylla*) and oaks are the dominant overstory vegetation. In this study unit, there are also several unidentified species of trees (such as oaks), shrubs, and grasses. As indicated by the local foresters, TMU-2000 has not been harvested for at least 12 years. Most stands are quite heterogeneous in species composition, diameter and height structure, tree ages, stocking level and density, as well as in their growth rates and productivity. Soil fuel accumulation is quite uniform throughout the study area. Considered a healthy forest, TMU-2000 did not exhibit any serious problems of pests and diseases, fires, or livestock overgrazing. Despite its high biological diversity, management practices are focused on the timber resource.

Existing Forest Inventory Approaches

Forest inventories are conducted within this region to comply with Mexican Forest Law and Regulations. Government records indicate that the study area (TMU-2000) was first inventoried sometime between 1986 and 1987. Central to the objectives of this inventory was to determine the forest potential for timber management while protecting other ecological resources. For this purpose, two distinctive inventory approaches were utilized: (1) temporary, fixed-area, concentric circular plots (1000 m^2, 400 m^2, and 80 m^2); and (2) temporary variable radius plots (Van Deusen et al. 1986). Under these approaches, TMUs that had contrasting irregular silvicultural structure (uneven-aged forests) were inventoried using fixed-area circular plots. All stands and substands within TMUs were inventoried (Aguirre and Reich 1998). The level of silvicultural uniformity was the main criterion employed for implementing these two distinctive forest inventory approaches.

For fixed area plots, the information collected on the main plot was limited primarily to individual tree data and general site factors. Saplings by species group were counted in the 400 m^2 plot, while the smallest plot (80 m^2) was used to estimate the number of seedlings, by group of species. In all cases (1000 m^2 plot), trees were measured for diameter at breast height (cm), total height (m), product class, and their health status code was recorded (UCODEFO Largo-Madera 1997). Of these trees, one individual per diameter class was cored for age estimation, and the length of the 5 year and 10 year radial increment measured to the nearest millimeter. For every substand, this information was used to estimate the following parameters by group of species (pine, oaks, and other hardwoods): mean age, diameter, and height, site index, site quality, and growth (diameter, basal area and volume per hectare). Management plans for TMUs were based on this information.

On the other hand, TMUs that had homogeneous forest conditions were inventoried using variable radius plots. Under this approach, only few trees representing the substand average conditions were measured for diameter growth and age (often one or two). Other average tree attributes within the plot (e.g., tree height and diameter, timber product classes, potential silvicultural treatments, trees to be removed in the next cutting cycle, and tree natural regeneration) were visually estimated. No other additional tree information (e.g., tree health, wildlife potential, etc.) and site specific data (e.g., soils, fuels, erosion, vegetation, wildlife habitats, streams, etc.) was collected. Basically, the emphasis was given to the timber component of the substands for timber management purposes. On average, it takes about 10 minutes to measure one inventory plot. Among other aspects, this is the main reason why variable radius plots are quite cost-effective for timber inventories, and therefore highly popular among foresters in Mexico. Field audits have revealed a number of technical inconsistencies in the proper use of variable radius plots (Aguirre and Reich 1998).

Both inventory approaches were based on a systematic sampling design and all forest substands units were sampled. Systematic sampling has the advantage of spreading the sample units uniformly throughout the substand while minimizing travel time, hence reducing the cost of the measurements. Plot and tree level measurements were kept to a minimum. Delineation and mapping of stand units were processes based on aerial photographs (1:20,000). Stand units were further subdivided into substands. Under this methodology, the substand is the smallest unit for silvicultural management purposes. For mapping purposes, the prevailing criterion is only to consider substands units whose size is larger than one hectare, otherwise they are integrated into the area of neighboring substands.

Substands within TMUs are inventoried once every ten years. The inventory takes place one year before the TMU is scheduled for harvesting (UCODEFO Largo-Madera 1994). As an annual activity, it is continuous throughout the year (February to November). Presently, the forest inventory design, as far as objectives and sampling design, has not experienced significant changes with respect to its initial characteristics (Table 1). New aerial photographs (obtained in 1997) are being used to support current inventory efforts (1:20,000, black and white). Sampling intensity has been

Table 1.—Description of Existing Forest Inventory Approaches

Parameters	Homogeneous Forests	Heterogeneous Forests
Forest Type Condition	Regular, Even-Aged	Irregular, Uneven-aged
Species Composition	Few Tree Species	Multiple Tree Species
Target Resource (s)	Timber	Timber
Multiresource Emphasis	None	Minimum
Sampling Frame	Substands	Substands
Sampling Design	Systematic	Systematic
Plot Type	Variable Radius BAF (1.0 and 1.5)	Concentric Circular Plots (1000 m^2, 400 m^2, 80 m^2)
Sampling Intensity	3%	3%
Strategy for Data Analysis	Incipient	Incipient
Strategy for Quality Assurance	None	None
Crews Technical Certification	None	None
Distance between Plots	Variable	Variable
Time Frame	Temporary	Temporary
Plot Traceability	None	None
Resampling Cycle	Every 10 Years	Every 10 Years
Remote Sensing Support	Aerial Photographs	Aerial Photographs
GIS-Support	Incipient	Incipient
Strategy for Information Management	Incipient	Incipient
Strategy for Advancement	None	None
Government Technical Support	None	None

three percent on average, independently of substand size and statistical variability. Recent assessments of these inventory programs have revealed a number of inconsistencies in their sampling design and protocols for field implementation (Aguirre and Reich 1998). Little consideration has been given to data collection of other forest ecosystem resources, the assessment of their status and condition, as well as their ecological significance for developing integrated resource management plans.

Approach Used for Forest Inventory Study

There were a number of adjustments made to the forest inventory approach used for the purpose of this study. One of the most important considerations was to disrupt the least possible amount the prevailing framework of how local technicians plan, design, organize, conduct field measurements, and process the information collected from their forest inventories. Several training workshops and field visits were carried out to improve technical skills and inventory design understanding of foresters and field crews involved in this study. Aspects such as the proper use of variable radius plot sampling techniques and field measurement quality control protocols were highly emphasized in training workshops. The cost-efficiency of alternative sampling designs was also a major factor to take into consideration. Strategies for data analysis using geostatistics and remote sensing support (LANDSAT imagery and digital elevation models) are discussed later in this paper. TMU-2000 was inventoried (Table 2) based on these considerations.

While maintaining the same sampling design, a new plot configuration was utilized for collecting additional ecological information. For this purpose, fixed area plots of different size were nested within the structure of variable radius plot (Figure 2). Under this plot design, saplings were measured using a 50 m^2 plot located at the center of the variable radius plot (main plot). Saplings were defined as trees with a diameter at breast height (DBH) less that 1 cm and greater than 0.5 m in height. Seedlings were measured using 5 m^2 circular plots nested within the 50 m^2 plot. Trees of less than 0.5 m in height were counted as seedlings for assessing natural regeneration by species. In addition, a 1 m transect was randomly located at the center of the 5 m^2 plots for collecting soil and fuel information. In all cases, the center of the main plot was geo-referenced using global positioning systems (GPS). Use of this technology will allow us to keep track of the inventory plots and data in a spatially explicit format using a GIS data base. For all substands, sampling intensity was the same (3%), and plots were systematically distributed.

Table 2.— Summary of Adjustments to Existing Forest Inventory Approach

Descriptor	Existing Approaches	Inventory Study
Forest Condition Type	Dependent	Independent
Species Composition	Dependent	Independent
Target Resource	Specific (Timber)	Flexible
Sampling Frame	Substands	Stand
Sampling Design	Systematic	Systematic
Plot Design	Variable Radius or Fixed Area Circular Plot	Nested: Variable Radius and Circular Plots
Sampling Intensity	3%	Variable
Strategy for Data Analysis	Average Estimates	Spatial Estimation
Strategy for Quality Assurance	Unimportant	Important
Distance between Plots	Fixed	Flexible
Time Frame	Temporary	Temporary
Plot Traceability	Untraceable	Traceable
Resampling Time	Every Ten Years	Flexible
GIS-Dependent	Independent	Highly Dependent
Strategy for Data Management	Unclear	Highly Important
Topographic Support	Maps	DEM
Remote Sensing Support	Areal Photographs	LANDSAT
Strategy for Advancement	Unclear	Highly Important

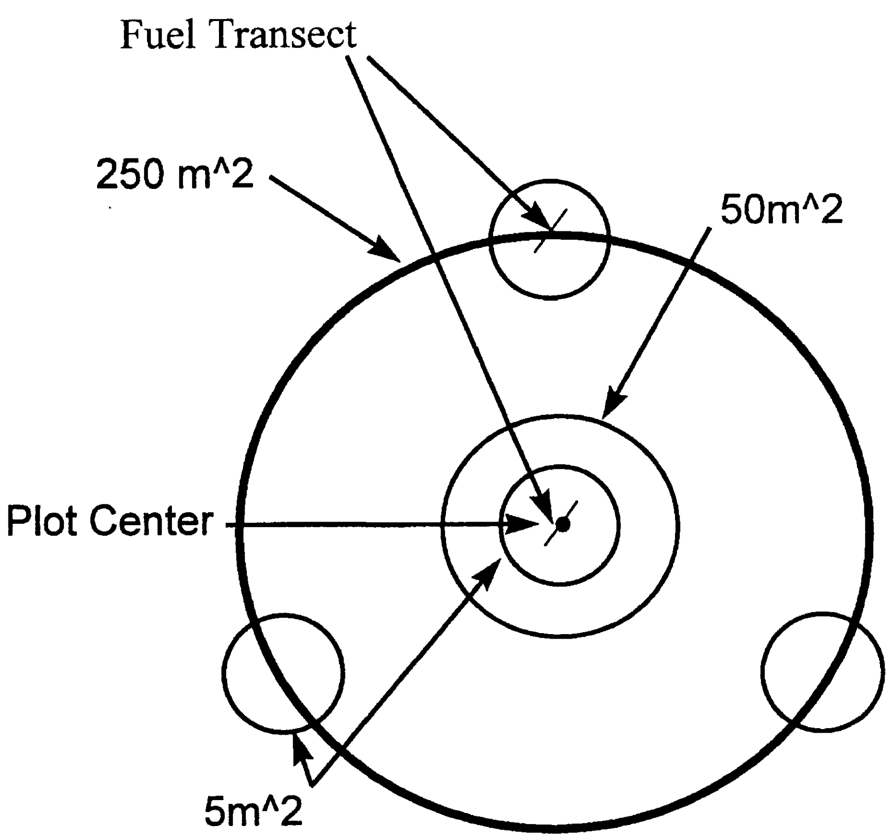


Figure 2.— Plot layout.

Specifically, the following information was collected: saplings (count of all trees, by species, mean height and diameter, and health status); seedlings (count of all individuals, by species, mean height and diameter, and health status), and soil information (e.g., erosion, bare ground, rockiness, depth, woody materials, duff, needles, leaves, etc.). Trees were measured using a basal area factor (BAF) of 0.5, 1, 1.5, 2, 3 and 4. The BAF was chosen such that, on the average there were 7 to 10 in trees on each plot for the stand as a whole. Crews were told not to change the BAF in a substand. Tree measurements included: species, DBH, total tree height, growth, product class, and status (healthy, infected, dead). On every third plot, increment cores were obtained from a representative sample of trees from each diameter class to estimate 5- and 10-year radial growth measured to the millimeter. Information on age of substands was obtained from previous forest inventories. Field measurement protocols and other logistical aspects were detailed in a field inventory manual prepared for the purpose of this inventory study.

Results and Discussion

Forest Inventory

The management unit was fairly homogeneous with respect to species composition and understory vegetation. Elevations ranged from 2100 m to 2449 m and with slopes ranging from 0 to 16 percent. Dominant ecosystems within the study area consist of montane coniferous forests, oak-pine woodlands, short grass prairie, and riparian pine-oak forest. Major tree species include *Pinus durangensis* (43.1%), *Pinus arizonica* (28.8%), and *Pinus engelmanii* (10.3%). Oak (*Quercus*) species occur infrequently throughout the area (9.8%), along with *Pinus leiophylla* (5.4%), and *Pinus ayacahuite* (2.6%).

The management unit was sub-divided into 57 stands and 142 sub-stands based on aerial photography. The number of sample plots in an individual stand ranged from 2 to 63 with a median sample size of 8. Sample sizes for the sub-stands ranged from 2 to 16 with a median of 3. The total sample size was 554 plots. Sample plots were allocated proportional to the size of the sub-stand and systematically within sub-stands.

Table 3 summarizes the variability associated with key variables measured in the survey. The median stand consisted of 165 pine trees per hectare, with a basal area of 9.1 m^2/ha and a volume of 61.7 m^3/ha. The median stand diameter was 29.3 cm. Oaks had a median density of 8 trees per hectare and a basal area 0.5 m^2/ha. The median oak volume was 2 m^3/ha. The oaks had a median stand diameter of 6.5 cm and a height of 2.2 m. Stands had very little understory vegetation, pine or oak regeneration, or woody material (Table 3). Large numbers of shrubs, regeneration, and fuels did occur in some of the more inaccessible portions of the management unit.

Due to the small sample sizes within stands the variability associated with the survey was quite large. Percent sampling errors for individual stands ranged from a low of 2.7 percent for 5 year radial diameter growth to a high of 1270 percent for the number of pine and oak saplings, number of shrubs and shrub volume (Table 3). Half of the stands had percent sampling errors greater than 20 percent for 22 out of 24 variables (92%) measured in the survey. Fourteen out of 24 variables (58%) had median sampling errors exceeding 50 percent, and 11 variables (46%) had median sampling errors exceeding 100 percent.

In most natural resource surveys it is desirable to have percent sampling errors less than or equal to 20 percent for selected key variables such as basal area and volume. To achieve this goal using the current sampling design would require a substantial increase in the number of sample plots. As an alternative, if the sample plots were allocated proportional to the variability within a stand, one could increase the level of precision associated with the survey without having to substantially increase the number of sample plots.

Spatial Modeling

Since every sub-stand was sampled at least twice, the 554 sample plots provide a fairly uniform coverage of the management unit. This is an ideal situation in that geostatistical procedures such as kriging and cokriging can be used to describe how the field data varies spatially throughout the management unit. Figures 3 and 4 depict the spatial variability in basal area per hectare and a hypothetical habitat suitability index for the wild turkey at a 60 m resolution. The habitat suitability index for the wild turkey was developed as a function of the total basal area, and the density of shrubs and oaks. The surfaces were generated using universal kriging (Reich et al. 1998). The large-scale spatial variability was modeled using a trend surface model. Independent variables included various Landsat MS bands (60 m x 60 m resolution), elevation and percent slope. The residuals from the trend surface (small-scale spatial variability) were modeled using kriging. Also, depicted in the figures are corresponding maps of the stand level inventory data. Comparing these two set of figures one can see that the spatially derived surfaces provide more detailed information on the spatial distribution of the variable of interest, unlike the stand level data which provides only a point estimate for an individual stand.

The ability to spatially model field data allows one to integrate the data over any specified geographical region (i.e. stand, management unit, watershed, region, etc.) to obtain a point estimate and associated standard error of prediction (Reich et al. 1998). This is accomplished by integrating the three dimension response surface representing the variable of interest over the area of interest and dividing by the area. Since the spatially modeled response surfaces can be represented as a grid in ARC/INFO, any specified region will contain a finite number of grid cells of uniform size (i.e. 60 m x 60 m). The point estimate of a resource in a given area is obtained by summing the point estimates associated with each cell and dividing by the number of cells in the area. This procedure allows one to change the scale at which one can view a particular resource while keeping track of the error associated with the estimates. It is also possible to develop a cost efficient sampling design for modeling the spatial variability in the population and then use this information to obtain stand level data for purposes of management.

Table 3.—Summary of the variability associated with key variables measured in the survey of the 600 ha management unit in Ejido el Largo, Chihuahua, Mexico. The statistics are based on an inventory of 57 stands using a sample size of 554 plots.

	Point Estimate		95% Sampling Error (%)	
Parameter	**Median**	**Range**	**Median**	**Range**
Tree Level Data				
Conifers				
Basal area (m^2/ha)	9.1	2.3 — 22.7	35.5	13.5 — 635.3
Trees/ha	165.6	22.5 — 471.0	50.6	23.6 — 860.6
Diameter (cm)	29.3	15.6 — 51.5	21.0	9.6 — 218.5
Height (m)	14.5	9.4 — 20.0	21.0	9.7 — 214.1
Volume (m^3/ha)	61.7	14.1 — 247.6	35.2	14.7 — 529.8
5 yr. growth (mm)	12.1	10.2 — 13.8	8.8	2.7 — 279.7
10 yr. growth (mm)	24.9	20.5 — 29.2	7.5	0.8 — 265.2
Seedlings/ha	667.0	0 — 8000.0	141.6	40.0 — 270.6
Saplings/ha	653.6	0 — 5907.0	118.1	36.3 — 1270.6
Oaks				
Basal area (m^2/ha)	0.5	0 — 6.3	106.6	29.0 — 430.3
Trees/ha	7.9	0 — 271.2	113.3	48.2 — 430.3
Diameter (cm)	6.5	0 — 22.7	80.6	21.9 — 430.3
Height (m)	2.2	0 — 11.3	78.6	11.5 — 430.3
Volume (m^3/ha)	2.0	0 — 26.8	110.1	29.6 — 430.3
Seedlings/ha	0	0 — 23231.0	217.1	88.4 — 430.3
Saplings/ha	0	0 — 91.7	204.2	130.2 — 277.6
Shrubs				
Shrubs/ha	4027.8	0 — 25000.0	115.4	36.1 — 1270.6
Volume (m^3/ha)	97.0	0 — 695.6	117.5	14.6 — 1270.6
Fuels				
Duff (tons/ha)	0.02	0.005 — 0.031	48.9	11.5 — 816.8
Litter (t/ha)	0.01	0.004 — 0.015	25.8	6.6 — 256.5
Small wood (t/ha)	0.03	0.01 — 0.043	41.2	8.7 — 545.3
Sound Large Wood (t/ha)	0.0	0.0 —7.5	204.3	117.2 — 244.7
Rotten Large Wood (t/ha)	0.0	0.0 — 12.2	219.4	119.7 — 270.6
All Woody Material (t/ha)	11.6	1.7 — 47.7	96.5	26.3 — 1050.3

In developing a multiple resource management plan it is important to be able to identify regions with similar ecological characteristics. Given a set of response surfaces for key indicator variables it is possible to subdivide an area into a finite number of sub-regions with similar spatial characteristics using a multivariate clustering algorithm developed by the senior author. Figure 5 demonstrates the application of this algorithm using some of the data from this study. The figure depicts ten micro-ecological units that have similar spatial characteristics with respect to the habitat suitability index for the wild turkey, stand density index, 10 year radial diameter growth, and volume. These regions could be considered stands for the purpose of management since they have similar characteristics with respect to the key indicator variables. The definitions of stands using this procedure seems more logical from an ecological point of view then using aerial photographs to delineate stand boundaries based on crown characteristics. These ecological areas could also define the strata for future inventories.

There where some problems associated with developing the response surfaces depicted in Figures 3 and 4. The first was the use of the Landsat MS imagery. Because of the course resolution of the imagery (60 m x 60 m) it was difficult to establish a relationship between the field data and the Landsat imagery. These results are unlike the ones we have obtained using Landsat TM data in which the resolution (30 m x 30 m) closely corresponds to the size of the sample plots (Kallas 1997, Metzger 1997). There was also a six-year difference between the date of the imagery and the forest survey. Best results are obtained when the Landsat imagery coincides as closely as possible to the inventory. The second problem had to do with the placement of the sampling units. Since the sample plots were allocated proportional to the size of the sub-stands, the inventory data did not capture the spatial variability within the management unit. This is especially true of the small-scale spatial variability. The best way to account for this small-scale spatial variability is to use a form of cluster sampling. The distance between subplots should correspond to the desired resolution of the response surfaces (Metzger 1997).

Recommendations

The most significant outcome of this study was identifying the importance of using the proper sampling design. The

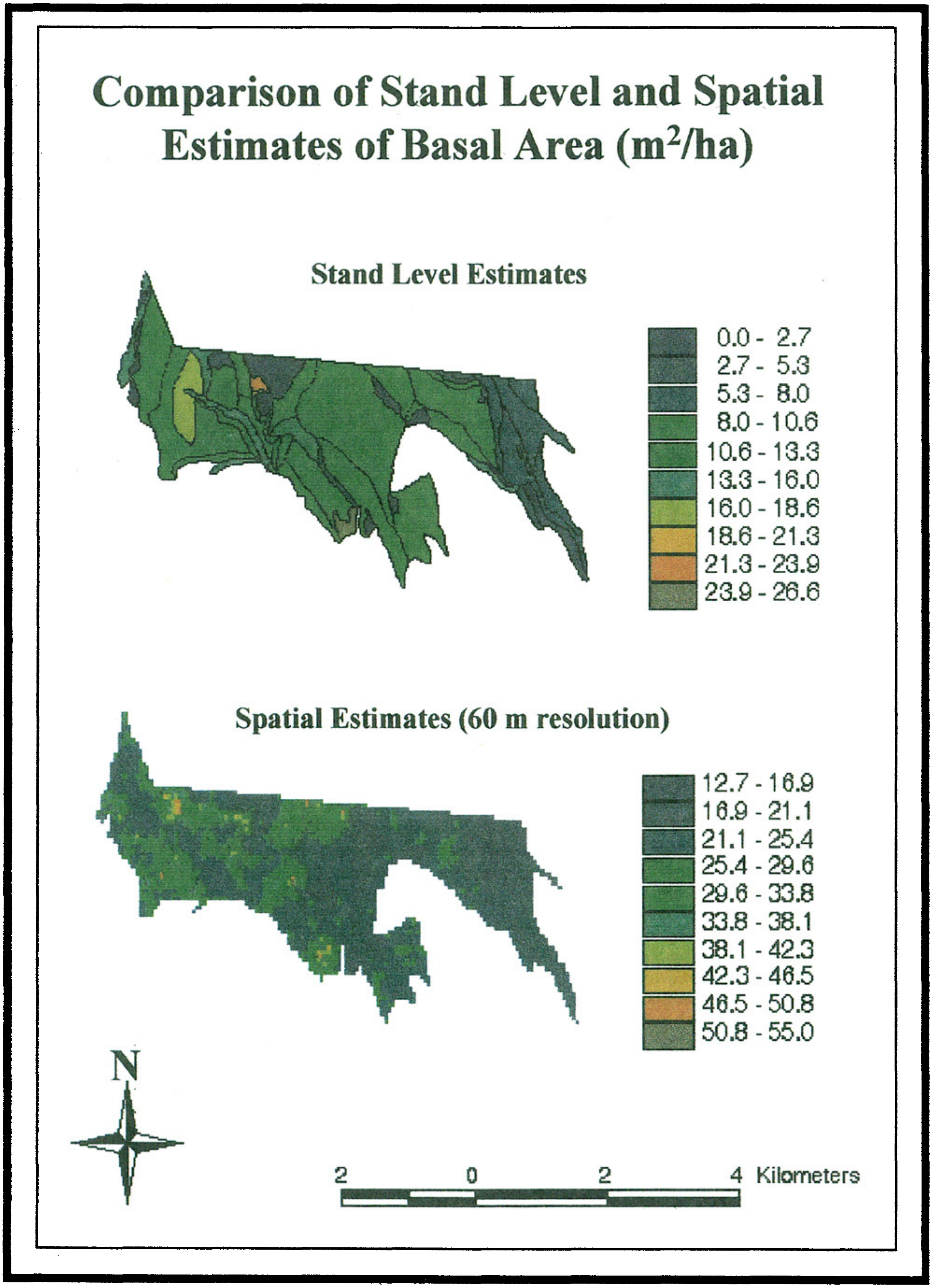
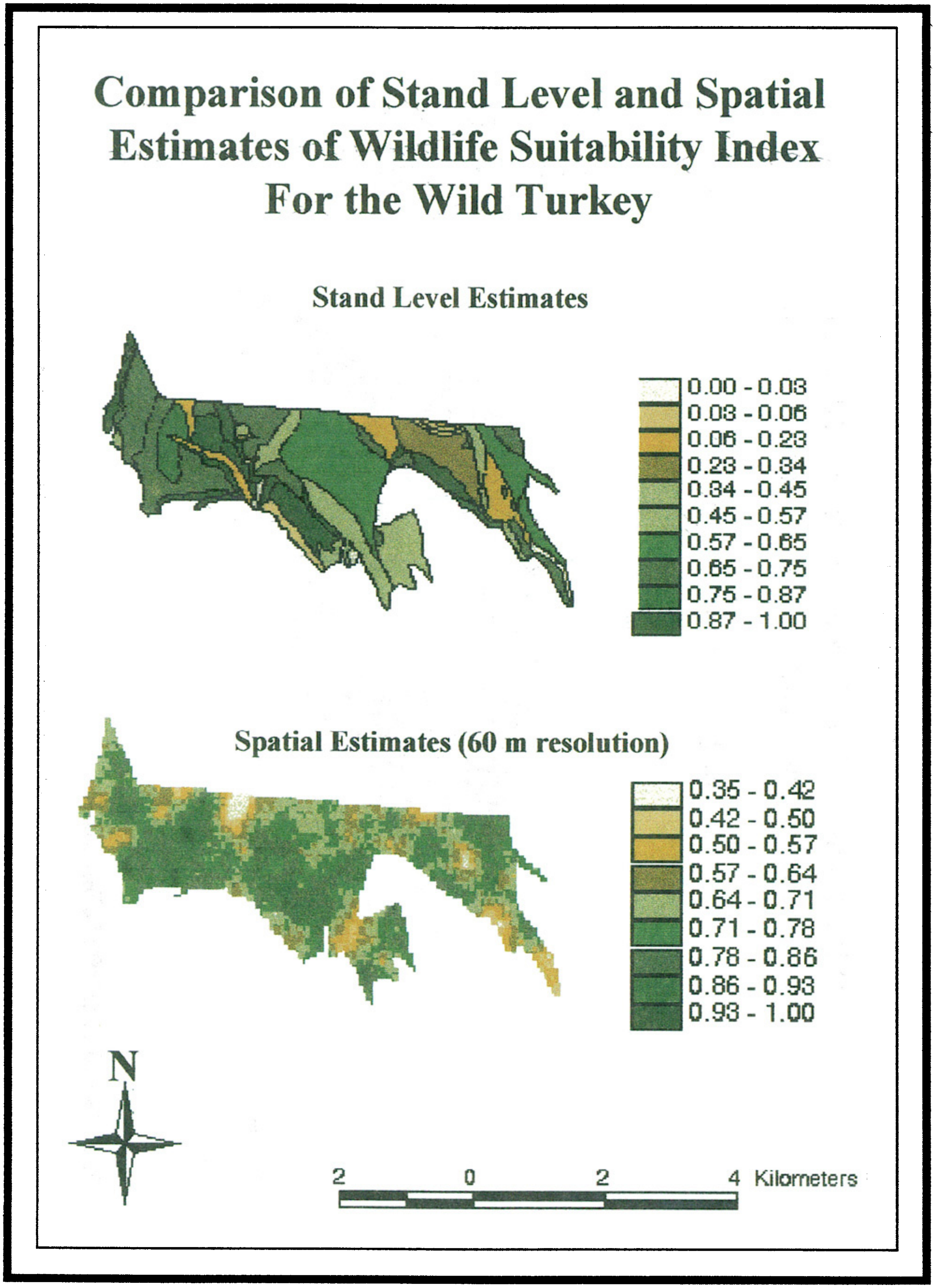

Comparison of Stand Level and Spatial Estimates of Basal Area (m^2/ha)
Stand Level Estimates
0.0 - 2.7
2.7 - 5.3
5.3 - 8.0
8.0 - 10.6
10.6 - 13.3
13.3 - 16.0
16.0 - 18.6
18.6 - 21.3
21.3 - 23.9
23.9 - 26.6
Spatial Estimates (60 m resolution)
12.7 - 16.9
16.9 - 21.1
21.1 - 25.4
25.4 - 29.6
29.6 - 33.8
33.8 - 38.1
38.1 - 42.3
42.3 - 46.5
46.5 - 50.8
50.8 - 55.0
N
2
0
2
4 Kilometers

Figure 3



Comparison of Stand Level and Spatial Estimates of Wildlife Suitability Index For the Wild Turkey
Stand Level Estimates
0.00 - 0.03
0.03 - 0.06
0.06 - 0.23
0.23 - 0.34
0.34 - 0.45
0.45 - 0.57
0.57 - 0.65
0.65 - 0.75
0.75 - 0.87
0.87 - 1.00
Spatial Estimates (60 m resolution)
0.35 - 0.42
0.42 - 0.50
0.50 - 0.57
0.57 - 0.64
0.64 - 0.71
0.71 - 0.78
0.78 - 0.86
0.86 - 0.93
0.93 - 1.00
N
2
0
2
4 Kilometers

Figure 4

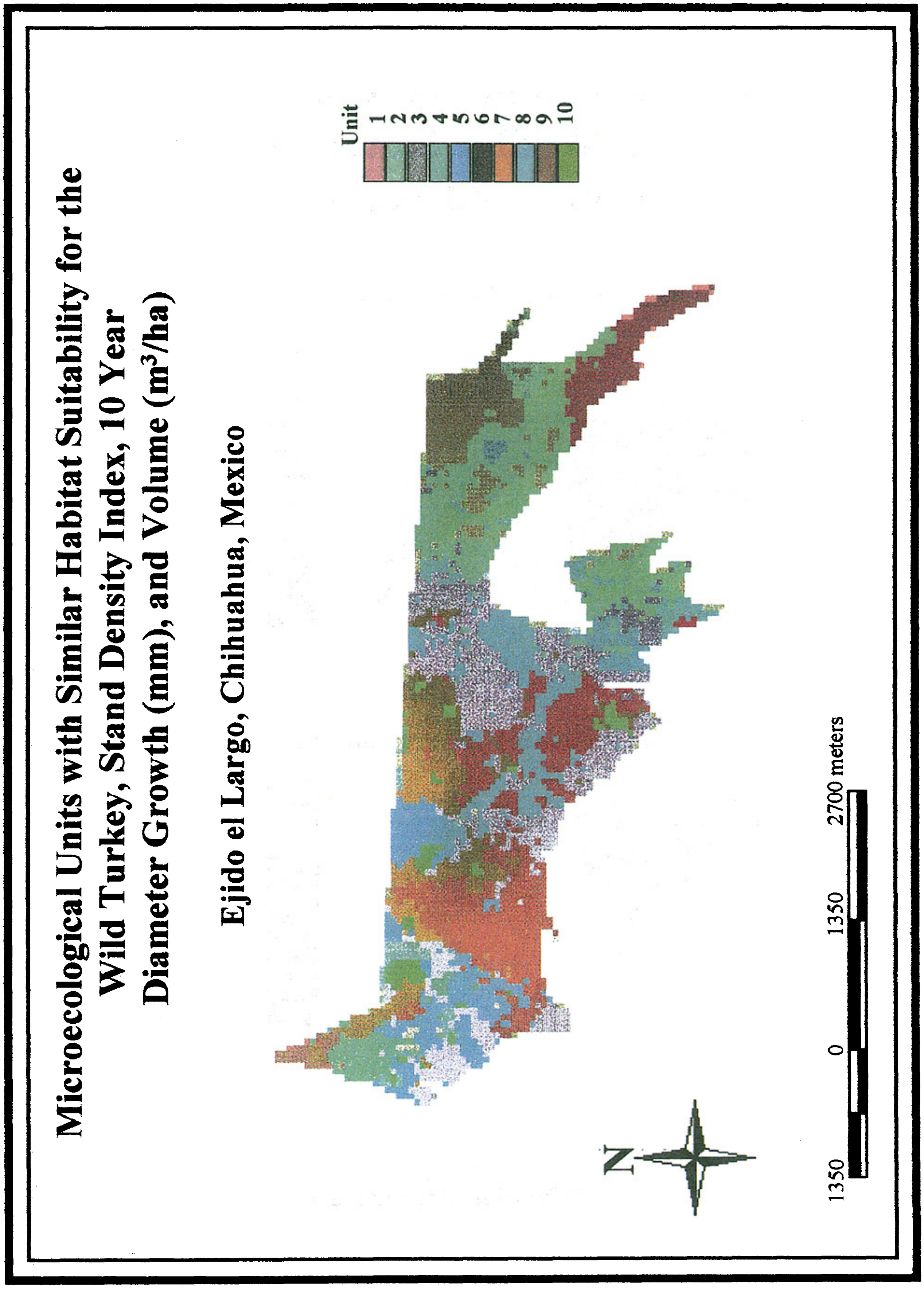

Microecological Units with Similar Habitat Suitability for the
Wild Turkey, Stand Density Index, 10 Year
Diameter Growth (mm), and Volume (m³/ha)
Ejido el Largo, Chihuahua, Mexico
Unit
1
2
3
4
5
6
7
8
9
10
N
1350
0
1350
2700 meters

Figure 5

existing sampling design was not able to account for the small-scale spatial variability in the management unit, or provide precise estimates at the stand or sub-stand level. Some form of cluster sampling should be used to account for the small-scale spatial variability in the management unit. The distance between sub-plots should correspond to the desired resolution of the response surfaces. The cluster plots should be randomly located throughout the area irrespective of stand, or forest type boundaries. One could also use a non-aligned systematic sample. This would introduce some randomness into the location of the clusters while providing full coverage of the study area. It is also important to accurately georeference the clusters so the field data can be accurately related to other information available in the GIS data base. Finally, it is important to have an appropriate GIS infrastructure to support the spatial data (e.g., digital elevation model, digital orthoquads, Landsat TM data, digital radar data, soils data, etc.) required to develop the response surfaces presented in this paper.

If these recommendations are implemented one should be able to model the spatial variability of selected variables to any desired resolution; apply multivariate spatial clustering algorithms to define micro-ecological units with similar spatial characteristics; and spatially integrate the data to any desired resolution (e.g., sub-stands, stands, management unit, counties, watersheds, etc.).

Literature Cited

Aguirre-Bravo, C., and R.M. Reich. 1998. Integrated Inventory and Monitoring for Forest Ecosystem Resources: Northern Mexico Pilot Study. In, Environment Canada's Fourth National Science Meeting, Ecological Monitoring and Assessment Network (EMAN), Quebec City, Canada. 65pp.

Aguirre-Bravo, C., and R.M. Reich. 1998. Assessment of Forest Inventory and Monitoring networks in Northern Mexico: The Ejido El Largo Case Study. In, North American Science Symposium - Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources (This Proceedings).

Kallas, Melanie. 1997. Armillaria root disease on the Black Hills National Forest. Dept. Forest Science, Colorado State University, Fort Collins, CO.

Metzger, Kristine. 1997. Modelling forest stand structure to a ten meter resolution using Landsat TM data. Dept. Forest Science, Colorado State University, Fort Collins, CO.

Reich, R. M. and V. Bravo. 1998. Integrating spatial statistics with GIS and remote sensing in designing multiresource inventories. In: Proceedings of the North American Symposium on Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998. (This Proceedings)

Thoms, C.A., and Betters D.R. 1998. The Potential for Ecosystem Management in Mexico's Forest Ejidos. Forest Ecology and Management, 103:149-157.

UCODEFO No. 2 El Largo-Madera. 1994. Estudio Dasonómico. Ciudad Madera, Chihuahua, Mexico. 250pp.

UCODEFO No. 2 El Largo-Madera. 1997. Aplicación del Método de Desarrollo Silvícola en los Bosques Regulares del Ejido El Largo, Chihuahua, Mexico. Ciudad Madera, Chihuahua, Mexico. 15pp.

UCODEFO No. 2 El Largo-Madera. 1997. Aplicación del Método de Control en los Bosques Irregulares del Ejido El Largo, Chihuahua, Mexico. Ciudad Madera, Chihuahua, Mexico. 25pp.

Varela-Hernández, Sergio. 1995. El Programa de proteción de la Salud Forestal: problemas Actuales, Necesidades, Oportunidades y Perspectivas en la Evaluación y Monitoreo de los Recursos Forestales de México. In, North American Workshop on Monitoring for Ecological Assessment of Terrestrial and Aquatic Ecosystems. Editor: C. Aguirre-Bravo, RM-GTR-284, USDA Forest Service, Fort Collins, Colorado, USA, 305p.

Warshall, P. 1994. The Madrean Sky Island Archipelego: A plenary Overview. Biodiversity and management of the Madrean archipelago: the sky islands of southwestern United States and northwestern Mexico. 1994 Sept. 19-23; Tucson, AZ. Gen. Tech. Rep. RM-GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experimental Station. p 6-17.

Design and Implementation Strategy for the Creation of a Basic GIS Infrastructure for Supporting Forest Ecosystem Resources Inventorying, Monitoring and Management[1]

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Anita Hoover[4]
Johnell Geddes[4]
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Abstract—The organizations in charge of inventorying, monitoring and managing forest ecosystems in Mexico operate with limited human, financial and material resources. In this context, the introduction of new tools and methods to assist them in improving the efficiency and effectiveness of their operations is fundamental. However, this must be done in such a way that: (1) there is little extra demands on their already stretched resources, (2) there is minimum disruption of their day to day activities during the transition period, and (3) the new tools and methods are customized with the aim of achieving a high *perceived usefulness* paired with a high *perceived easy of use*. This paper describes a design and implementation strategy for creating a GIS infrastructure (human resources, hardware, software, and data) that addresses these requirements for a pilot study area in northern Mexico. With respect to data it is important to make the most out to readily available geographic digital data. For the pilot study area the 3-arc second resolution DEM was processed to define "Working Watersheds" to be used as Ecological Accounting Units. 2D and 3D perspectives were created to visualize the spatial relationships between and among these units.

Issues related to the management of ecosystems can be best addressed in the context of "geographic areas" defined by explicit environmental parameters rather than by geopolitical and administrative criteria. In natural resources management, for example, resource planners and managers make little use of ecological principles for delineating management and harvesting units. In most cases, boundaries between forest stands are established to emphasize the operational aspects of timber management and harvesting plans. Management units, under this traditional approach to forest resource management, are treated as if they were independent from the rest of the ecological context (i.e., landscapes, watersheds, etc.). Ecosystem attributes such as connectivity and relationships between and among units and their elements are often ignored for the sake of making resource management plans simpler. In Mexico, for example, planners and managers of ecosystem resources often make little use of ecological principles for delineating resource management units (Thoms and Betters 1998).

Traditional approaches to forest land classification based on a single resource are now coming into question in many parts of the world. Forestry concepts such as "forest stand" and "forest cover type" do not necessarily represent meaningful ecological units (Smith 1986). Such concepts were borrowed directly from the European experience of growing successive tree crops of economically desirable species on the same site for many generations. For implementing ecosystem management, as it is now the trend in many industrialized countries, land resource classification should be based on ecological principles (Boyce and Haney 1997). Various hierarchical land classification systems using ecological principles have been developed for geographical scales ranging from global to local (Bailey 1996). Linking these land classification systems to local plans of resource utilization is fundamental to implementing ecosystem management. At the local level, however, land resource classifications are often not available, and if they are, they need to be revised in order to improve their ecological foundations and utility.

This lack of ecological context has impacted not only the functional integrity of ecosystems, but also the economies and institutions, which depend upon them. More and more we have come to realize that what we manage does not exist in isolation. Instead, it is inherently part of a complex interplay of ecosystems, within which all components are hierarchically linked. At a landscape level, therefore, approaches for mapping the diversity of these different geographical contexts are fundamental for integrating ecological principles to the management of terrestrial ecosystems.

This paper outlines a strategy for the design and implementation of a basic GIS infrastructure (hardware, software, data and people) to support forest ecosystems inventorying, monitoring and management activities under the conditions of limited resources faced by most Forest Administration Units (UAF's) in Mexico. A case study for a forest region in northern Mexico describes how GIS is being

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used for meeting the need to define Ecological Accounting Units using a Digital Elevation Model (DEM) and LANDSAT satellite imagery available for this specific pilot study area. The results of this study are a fundamental part of a North American undertaking on integrated inventory and monitoring approaches for ecosystem resource management in northern Mexico.

Current Challenges

During the 70's and 80's the Mexican federal government subdivided the forested areas in each State into Forest Administration Units (UAF's/UCODEFO's for their acronyms in Spanish). Central to the purpose of these "Units" was to provide technical services for the administration of forest resources. In the early 90's the forest technical services were deregulated allowing the forest owners to contract these services with private companies or certified professionals. Many landowners chose to continue working with the professionals of these Units. Currently, most of these Units face a number of technical and resource limitations:

Work overload—Professionals in these Units are responsible for providing the following technical services: (a) Inventorying of forest resources; (b) formulation and implementation of forest resource management practices (i.e., natural regeneration, thinnings, timber harvest scheduling, wildlife habitats, soil conservation, water quality protection, etc.); (c) monitoring and control of forest pests and diseases; (d) monitoring and control of forest fires, (e) social education and organization for forest resources utilization and conservation; and (f) preparation and presentation of reports and submission of permissions to state and federal regulatory agencies.

Shortage of personnel—Usually there are between three to five professionals working in each Unit, depending on the forest area extent to cover. This forces them to perform more than one role limiting the time available for training and specialization in a single task including the deployment and implementation of new tools and techniques.

Limited budgets—Negotiated each year, budgets are based on a fixed fee charged per cubic meter, with respect to the annual total timber production harvested. Buying a new computer or software most compete with fixing or maintaining vehicles, or controlling fires or pest outbreaks.

Limited material resources—Vehicles, tools, instruments, computers and software are in short supply.

Requirements to meet increasing demands and more strict regulations—While landowners and society impose higher constraints and demands on forest resource management practices, at the same time, state and federal agencies issue and demand the meeting of more strict regulations on the production and conservation of forest ecosystems.

Access to technical and educational resources is limited by Units geographic location—Significant distances must be traveled to have access to libraries, education and training institutions, high-tech facilities, and other professionals in different fields of expertise.

Limited, or no experience, working with large computer systems in general and GIS in particular—Depending on the size (area and personnel), financial resources, and technical leadership, many Units do not have appropriate computer systems to support their day-to-day activities.

Shortage of readily available geographic digital data at the appropriate scale or level of resolution—Mexico's National Institute of Statistics, Geography and Information Systems (ENEGI) and the National Forests Inventory Department work closely to provide geographic data in digital form. However, this information is scarce, and most of the time not at a level of detail required for supporting tactical-level decision making. Currently, the information available at the national level includes: soils and vegetation layers scale 1:250,000 and the Digital Elevation Model at a resolution of 3" of degree (roughly 90 meters per side) per cell.

Strategy for Implementation Design

Given the resource limitations under which most Units in Mexico operate, a design and implementation strategy for the creation of a GIS infrastructure, must address the issues of hardware, software, data and human resources, and must strive to meet the following desirable characteristics: (1) it would impose little extra demands on the already stretched human, financial and material resources; (2) it would provoke minimum disruption of the day-to-day activities during the implementation and transition periods; (3) the new tools and methods would be customized with the aim of providing a high *perceived usefulness* paired with a high *perceived easy of use* as later defined; and (4) it would make the most out of the available geographic digital data.

Design Considerations

Without attempting to be a complete design methodology, the following aspects must be considered when designing a GIS:

Solve the problem, do not fit the problem to a preconceived solution—Because of the technological capabilities of GIS developers can feel compelled to fully exploit these capabilities and this can lead them to apply their preconceived ideas about how to solve a problem. System development efforts that are technology-driven rather than end-user-demand-driven are less likely to succeed (Hutchinson and Toledano 1993). We argue they are also less likely to be perceived as useful as defined below.

Consider the concepts of Perceived Usefulness and Perceived Ease of Use—*Perceived Usefulness* is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance", and *Perceived Ease of Use* (EOU) is "the degree to which a person believes that using a particular system would be free from effort" (Davis 1989). Usefulness and EOU are important factors in determining acceptance and use of information systems. Software developers place a disproportionate amount of emphasis on EOU. In many cases, the intended users have found a product easy to use but have been unconvinced about its usefulness. High EOU with low usefulness is a "toy", low EOU with high usefulness is a "Power User Tool", high EOU with high usefulness is a "Super Tool" (Keil et al. 1995). The goal for a GIS is to be a "Super Tool". Emphasis on improving EOU should be made only after insuring the system has high perceived usefulness.

Clearly identify the client(s) and carefully study the decision making process to be supported—Staying close to the end users during the design and development processes is likely to improve the perceived usefulness of a GIS.

Provide reasonable initial EOU—The findings of Davies and Medyckyj-Scott (1994) point to several desirable characteristic that would improve EOU: (a) comprehensive error messages, (b) on-line help facilities, (c) compliance with national and international interface standards, and (d) customization based on careful consideration of user's needs, avoiding the introduction of inconsistencies with the original software.

Make provisions for effortless and cost-effective future system development—Stand alone GIS can easily become "snapshots" of existing conditions running the risk of becoming outdated shortly after completion (Shiffer 1995b). In UAF's and environmental agencies a GIS will play the role of a DSS, therefore it will be a substantial long-term investment that will require maintenance and future development.

Prioritize user's needs and address them through self-contained modules—A modular design breaks problems into small subproblems and addresses them by specific pieces of software. Modularity improves consistency by always solving problems in the same way, reduces duplication of efforts by facilitating reusability of code, facilitates development, tracking of bugs, system documentation and maintenance (ESRI 1992). Modules provide short-term reachable goals for system development and as self-contained units, they can be created following the established needs' priorities and start supporting operations without waiting for the whole system to be completed.

Involve on-site end users in the design and development processes—This involvement allows them to promptly take charge of adding new information and content to the system.

Provide detailed support documentation for the system's design, development stages and code—This is essential to the autonomy of professional end-users in the maintenance and future development of the system.

Development Considerations

Some aspects to consider in the development of a Geographical Information System are:

Develop the system in short development cycles making extensive use of prototyping—A fundamental assumption of traditional methodologies for systems development is that requirements and specifications can be completely defined during the analysis phase. This is not the case for decision support tools since the user may not fully understand or be able to articulate requirements early in the development cycle. The process of requirements specification for a decision support tool is best characterized as a learning experience which takes place continuously during the development (Chaudhry et al. 1995). This learning is facilitated by short development cycles concentrating in specific modules and quick generation of prototypes. During these cycles interviews with the users insure mutual understanding of needs and the system's capabilities to satisfy them. The interviewing techniques outlined by Scott et al. (1991) can be used as guidelines for these interactions.

This approach also favors the minimization of disruptions of day-to-day activities, and the imposition of significant extra demands on human, financial and material resources. The first development efforts should concentrate on GIS system's functions that: (a) have high priority, (b) are easy to develop, (c) rely on ready available data, and (d) can be implemented as soon as possible. In this way, short-term successful objectives can be achieved providing developers and end-users with experience, and fostering trust and support for further system's development efforts.

Evaluate the available development tools—A GIS system which will be operated by professional users in support of forest inventorying, forest monitoring and management operations will need to integrate extensive GIS functionality. Also, the issues and challenges for the development of this type of systems must be considered when evaluating the software tools for their development. We suggest that they should:

- Offer ample ready-to-use GIS functionality, which is easy to access and customize.
- Facilitate the development of the system following a modular design.
- Provide characteristics of a Rapid Application Development (RAD) tool (refer to Linthicum 1994 for details).
- Support inter-application communications (such as Dynamic Data Exchange (DDE) and/or Object Linking and Embedding (OLE) (refer to Thomas et al. 1995 for details).
- Have low hardware requirements.
- Be low-priced.
- Be easy to learn.
- Allow easy interface customization.
- Be capable of develop applications that comply with national and international interface standards (such as Microsoft Windows).
- Have a broad and rich support base (training books, courses, users groups, journals, 3rd party developers, WWW sites and forums).
- Have continuous development and support from the software's proprietary company and 3rd party developers.
- Have the potential to be used in developing different system components and links as the GIS system is integrated into a Spatial Decision Support System (e.g., simulations, models, databases, client/server architecture).

Make the Most Out of Readily Available Digital Data

The Instituto Nacional de Estadistica, Geografía e Informatica (INEGI) y the Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP) among others, are working intensively to produce thematic layers in digital form. Of the layers available with national coverage, the Digital Elevation Model at a 3-arc second resolution (roughly 90 m per cell side) can be processed to support strategic level and some tactical level decisions. Given that it is in raster format it can be used as a matrix to create spatial models, for example through geostatitiscal analysis. In the next section of this paper we provide examples of how this layer can be processed to extract information that is important to define ecological units and later visualize and query them in 2 and 3 dimensions.

The most expensive and time-consuming activity in creating a fully functional GIS is the creation of the spatial database (Berry 1995). For most of the UAF's this is an activity they cannot afford to carry out in terms of time and money. They are in need of immediate information and results to support their decision-making processes. Hence, it is important to make the most out of readily available geographic digital data. The following are sources of digital data with national coverage in Mexico:

- **Digital Elevation Model (DEM)**. National Institute for Statistics, Geography and Information (ENEGI). 3-arc seconds resolution (roughly 90 m per cell side).
- **Forest vegetation**. National Forest Inventory, National Autonomous University of Mexico (UNAM). Major forest types scale 1:250,000.
- **Soils**. National Forest Inventory, UNAM, National Institute for Forestry, Agriculture and Livestock Research (INIFAP). Major soils units according to FAO classification scale 1:250,000.
- **Satellite Imagery**. UNAM, EROS Data Center United States Geological Survey (USGS). LANDSAT imagery for different dates for the decades of the 70's, 80's and 90's. Resolution of 60 m and 30 m per pixel side.

Definition of Ecological Accounting Units

At different scales, the watershed concept provides a flexible and consistent approach to mapping "geographic areas" for purposes of environmental accounting and ecosystem resource management. For a given hydrological region, or basin, there are a large number of smaller interconnected watershed systems in which many of their physiographic indicators, such as slope, aspect, altitude, soils, morphology, drainage patterns, natural boundaries, and connectivity can be considered as permanent physical attributes. Most importantly, the spatial distribution of these physical attributes is geographically fixed. While these parameters experience change on a geological time scale, their geographic location and dynamics remain almost invariant for centuries for purposes of classification. Because of these permanent qualities, watershed systems provide a consistent geographical framework for purposes of environmental accounting and assessment of ecosystems.

GIS systems have the capability of using DEM data for delineating watershed systems at different levels of resolution. GIS can also be used to define drainage systems and provide tridimensional perspectives of watershed units and their spatial connectivity. Terrain features within each watershed unit, such as aspect, slope, and altitude, can also be effectively mapped for purposes of ecosystem analysis. Remote sensing can provide additional information for purposes of ecological unit design. Watershed units may be analyzed individually, as a group of a larger system, or linked at different scale levels so that situations of resource connectivity and interdependencies are accounted for to improve ecosystem management decisions at the local level. Under conditions of limited resources for GIS analysis, the development of a geographic is essential for meeting multiple needs concerning ecosystem monitoring, assessments, and management.

For a pilot study area watershed units were delineated at different scales for the primary purpose of ecological and environmental accounting. The basic assumption is that watershed features and processes such as aspect, slope, altitude, and hydrology may influence microclimate, soil characteristics, and potential natural communities. Landtypes and landtype phases are often identified within the context of features and processes of each watershed unit. Each watershed unit has a particular ecological and management history. Linked at the landscape level, or at higher spatial scales, these watershed units may have multiple ecological relationships and interdependencies. In a number of ways, each watershed is an accounting unit, and as such, it provides a well defined georeferenced framework for ecological and environmental accounting of how natural and anthropogenic drivers of change are impacting ecosystem resources, processes, and health.

The pilot study area covers a region of roughly 150 km by 50 km around the city of Madera in the northwestern portion of Chihuahua state, Mexico. The DEM at 3-arc second resolution was processed using the BASIN function in the GRID module of ARC/INFO. In this way more than 7,000 watersheds were identified, the smallest measured less than 2 hectares and the largest had more than 4,000 hectares. Later, using a series of GRID hydrological functions the run off flow accumulation patterns (up to six levels) were delineated. For the purpose of display and analysis of this information 2D maps and 3D perspectives were created a different scales: (a) the whole study area, (b) tiles of 20 x 20 km covering the study area, (c) tiles of 10 x 10 km covering the study area, d) tiles of 5 x 5 km covering the study area.

Different levels of detail of the drainage systems are displayed at different scales. For example at the study area scale (roughly 1:500,000) only the main flows of the drainage system are displayed. At smaller scales more detail of the drainage system is shown. The 3D perspectives were created using the GRID and TIN modules in ARC/INFO, as well as the 3D Analyst in ArcView 3.1. These perspectives of the study area and the tiles provided a much clearer picture of the configuration of the each watershed and the relationships existing among them. Also, the drainage systems within each watershed are better appreciated in these perspectives. For examples of these products please visit The Metropolitan State College of Denver GIS web site at **http://clem.mscd.edu/~gis** (click on sample student projects).

The final objective is to compile an "Atlas of Working Watersheds" that incorporates the 2D maps and 3D perspectives and the different scales previously listed. This atlas would be produced at a manageable size (letter size or legal size) to facilitate its use in the field. Currently, LANDSAT MSS images for 1973, 1983 and 1993 are being processed to identify changes in land use. This work has not been completed yet. In the future this type of data will be used to rapidly update vegetation and land use information.

Conclusions

Advances in GIS technology and continuos decrease in hardware costs have made this technology more accessible than ever to a larger group of nonexpert users with limited resources. However, it is still important to use an implementation and development strategy for the creation of GIS infrastructures that increases the chances of a long-term successful application of GIS technology to support inventorying, monitoring and management of natural resources. This paper provides suggestions on points to consider when designing and deploying GIS systems for the conditions faced by most Forest Administration Units in Mexico. The most expensive and time-consuming activity of creating a fully functional GIS is the creation of the spatial database. Hence, it is crucial to maximize the amount of information that can be derived from readily available geographic digital data.

Using GIS the Digital Elevation Model can be easily and rapidly processed to provide information on watershed definitions, drainage systems, slope, aspect, altitude and physiographic configuration. This information constitutes the foundation to delineate Ecological Accounting Units (EAU) to keep track of how natural and anthropogenic drivers of change are impacting ecosystem resources, processes, and health. The creation of 2D maps and 3D perspectives at different scales proved to be extremely helpful in visualizing and understanding the definition of these EAU's and their spatial relationships at different levels of spatial aggregation. Also, the drainage systems are better appreciated in the 3D perspectives and the tiles produced at different scales provide the opportunity to display this information with different levels of detail.

Literature Cited

Bailey, R. G. 1996. Ecosystem Geography. Springer-Verlag, 204 p.

Berry, J. K. 1995. Spatial Reasoning for effective GIS. GISWorld Books. Fort Collins, USA. 198 p.

Boyce, M. S. and A. Haney. 1997. Ecosystem Management. Yale University. 360p.

Chaudhry, S. S.; Salchenberger, L. and Beheshtian, M. 1995. A Small Business Inventory DSS: Design, Development and Implementation Issues. Computers and Operations Research 23(1): 63-72.

Davis, F. D. 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly 13 (3): 132-147

Davies, C. and Medyckyj-Scott, D.1994. GIS Usability: Recommendations Based on the User's View. International Journal of Geographical Information Systems 8(2): 175-189.

ESRI (Environmental Systems Research Institute). 1992. Customizing ARC/INFO with AML Revision 6.1. Environmental Systems Research Institute. Redlands, CA. 840 p.

Hutchinson, C. F. and Toledano J. 1993. Guidelines for Demonstrating Geographical Information Systems Based on Participatory Development. International Journal of Geographical Information System 7 (5): 453-461.

Keil, M.; Beranek P. M. and Konsynski B. R. 1995. Usefulness and Ease of Use: Field Study Evidence Regarding Task Considerations. Decision Support Systems 13: 75-91.

Linthicum, D. S.1994. Radical Development: The Latest Wave of Visual Development Tools Promises Slick Client/Server Database Applications in Record Time. PC Magazine 13(19): 153-210.

Scott, A. C.; Clayton, J. E. and Gibson, E. L. 1991. A Practical Guide to Knowledge Acquisition. Addison-Wesley Publishing Company Inc. New York, USA. 509 p.

Shiffer, M. J. 1995. Interactive multimedia planning support: moving from stand-alone systems to the World Wide Web. Environment and Planning B: Planning and Design 22: 649-664.

Smith, D. M. 1986. The Practice of Silviculture. 8th edition. John Wiley and Sons, New York, New York. USA. 480 p.

Thomas, Z.; Peterson, K.; Petersen, C.; Shields, J.; Greenberg, S.; and Waite, M. 1995. Visual Basic how-to: The Definitive Visual Basic problem-Solver. Costa Madera, The Waite Group.

Thoms, C. A. and D. R. Betters. 1998. The Potential for Ecosystem Management in Mexico's Forest Ejidos. Forest Ecology and Management 103: 149-157.

Evaluación de Diferentes Modelos Auxiliares en Inventarios de Recursos Naturales: Estimación de Áreas[1]

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Resumen—Los inventarios de recursos naturales se enfrentan a una serie de obstáculos que influyen en gran medida en la precisión y por lo tanto en la confiabilidad de los análisis de datos. El diseño de muestreo y el análisis de los datos están muy relacionados; por lo que la decisión sobre un diseño de muestreo para un caso de estudio sugiere la aplicación de un estimador inicial que puede ser mejorado con la aplicación de estimadores de regresión. Estos estimadores usan información auxiliar que tiene relación con la variable bajo estudio.

Las técnicas de muestreo, así como los estimadores usados en los inventarios de recursos naturales han cobrado gran interés en los últimos años. Dentro de las técnicas más recientes está la inclusión de información espacial en el proceso de análisis. Una justificación es que a nivel "macro" es un factor que cobra gran importancia, ya que las zonas donde ocurren los eventos de interés (por ejemplo mayor o menor crecimiento de arboles), están geográficamente localizadas. De ahí que el análisis espacial de los datos tengan un papel clave en el análisis de los datos.

Cuando los recursos se refieren a superficies dedicadas a diferentes recursos (clases), se tienen restricciones en el proceso de estimación ya que los valores deben ser no-negativos, y la suma de todas las áreas debe ser igual a la superficie total de la región en estudio. Si además se incluye información auxilia ry/o espacial, el proceso de estimación, dependiendo del modelo sugerido, podría ser muy complicado al grado de que sería necesario contar con métodos (iterativos) para lograr las estimaciones deseadas.

El objetivo del presente documento es discutir las bondades de tres modelos para estimar áreas dedicadas a "Q" diferentes recursos y a su vez estimar a nivel espacial la ocurrencia de los eventos de interés.

Todas las naciones del mundo se preocupan por conocer cuáles, cuántos y cómo son los recursos con los que cuentan (tierra, agua, biota y humanos entre otros). Se han tratado de hacer catálogos de las especies existentes, establecer su distribución, los limites de su extensión geográfica y la evaluación del número de especies de recursos mayores, como el volumen de madera, la evaluación de la condición de comunidades de praderas para el pastoreo o el número de peces (Boyle, 1995). Además, se preocupan por conocer que tan de prisa se deterioran y cuáles serían los mecanismos para conservarlos. Randall (1985) señala que los recursos poseen dimensiones de cantidad, calidad, tiempo y espacio y que la disminución o agotamiento de los recursos naturales y la sobrecarga de los mecanismos para la asimilación de desechos amenaza seriamente a la supervivencia de la civilización de la tierra.

De tal manera que la cuantificación y evaluación periódica de los recursos naturales es una actividad de gran importancia para su adecuado manejo. Entre otras cosas, permite conocer su dinámica y por consiguiente proponer estrategias de manejo que permitan su conservación. La erosión del suelo, la menor fertilidad, el aumento de la salinización, el agotamiento de las capas freáticas y la deforestación son problemas que están actualmente presentes e interrelacionados, y que han hecho que la contaminación proveniente de los desechos animales, los fertilizantes y los plaguicidas aparezcan en todas partes (Randall, 1985).

Los aspectos que se pueden considerar al evaluar los recursos naturales son variados y dependerán del objetivo que se persiga. Un componente esencial en la cuantificación del recurso tierra es el uso de las superficies que ocupan los objetos de interés, agricultura, silvicultura, fauna, uso residencial e industrial por ejemplo. Tradicionalmente, la cuantificación del uso de las superficies ha sido con el cubrimiento total del área en estudio.

México ha realizado grandes esfuerzos desde 1960 por medio del Inventario Nacional Forestal para cuantificar las superficies que ocupan sus recursos forestales, con el propósito básico de conocer el estatus del recurso, y determinar su dinámica de cambio por la acción del hombre y de la propia naturaleza (Varela, 1995). Para ello se han utilizado fotografías aéreas con cubrimientos totales (Secretaria de Agricultura y Ganadería, 1974; Peña De La, 1989; Varela, 1995) y en los último años se han utilizado, además de lo anterior, técnicas modernas como sensores remotos y sistemas de información geográfica (SARH, 1994).

Si bien estas estrategias permitieron conocer la magnitud de los recursos, también resultaron en grandes erogaciones de dinero. El país, debido a sus grandes limitaciones económicas, debe buscar una nueva estrategia que permita cuantificar los recursos naturales con los que cuenta. Una estrategia factible para reducir los costos es utilizar técnicas de muestreo estadístico. Como es conocido, estas técnicas usan una muestra de tamaño $n < N$ para llevar a cabo las estimaciones deseadas. El valor de "n" se determina de acuerdo a criterios de precisión y confiabilidad deseados en el estudio. De esta manera, se toman datos de ciertas unidades seleccionadas por un mecanismo aleatorio para

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llevar a cabo el análisis de estimación del parámetro deseado de la población, en lugar de llevar a cabo un censo.

Los inventarios de recursos naturales se enfrentan a una serie de obstáculos que influyen en gran medida en la precisión y por lo tanto en la confiabilidad de los análisis de datos. El diseño de muestreo y el análisis de los datos están muy relacionados; por lo que la decisión sobre un diseño de muestreo para un caso de estudio sugiere la aplicación de un estimador inicial que puede ser mejorado con la aplicación de estimadores de regresión. Estos estimadores usan información auxiliar que tiene relación con la variable bajo estudio. La selección de las variables auxiliares que permitan mejorar la estimación es por tanto un aspecto que debe ser considerado cuidadosamente.

Las técnicas de muestreo, así como los estimadores usados en los inventarios de recursos naturales han cobrado gran interés en los últimos años. Cuando los recursos se refieren a superficies dedicadas a diferentes recursos (clases), se tienen restricciones en el proceso de estimación ya que los valores deben ser no-negativos, y la suma de todas las áreas debe ser igual a la superficie total de la región en estudio. Si además se incluye información auxiliar y/o espacial, el proceso de estimación, dependiendo del modelo sugerido, podría ser muy complicado al grado de que sería necesario contar con métodos numéricos (iterativos) para lograr las estimaciones deseadas.

El objetivo del presente documento es discutir las bondades de tres modelos matemáticos para estimar áreas dedicadas a diferentes usos.

Materiales y Métodos

Área de estudio

La presente investigación se desarrolló en el área de influencia del Distrito de Desarrollo Rural III Texcoco (DDR III) del Estado de México. El distrito se ubica en la zona oriente del estado (Fig. 1), se integra de 26 municipios y cubre una superficie de 261,975 ha. En esta zona se ubican algunos de los principales centros urbanos e industriales del estado con una alta tasa de crecimiento poblacional, lo cual repercute fuertemente en los recursos naturales. A esto se debe que el conocimiento de la ubicación y cuantificación de los recursos sea de gran trascendencia. El uso de métodos alternativos a la cuantificación total permitirá que esto se realice con mayor frecuencia lo que repercutirá en un mejor entendimiento de la dinámica de cambio.

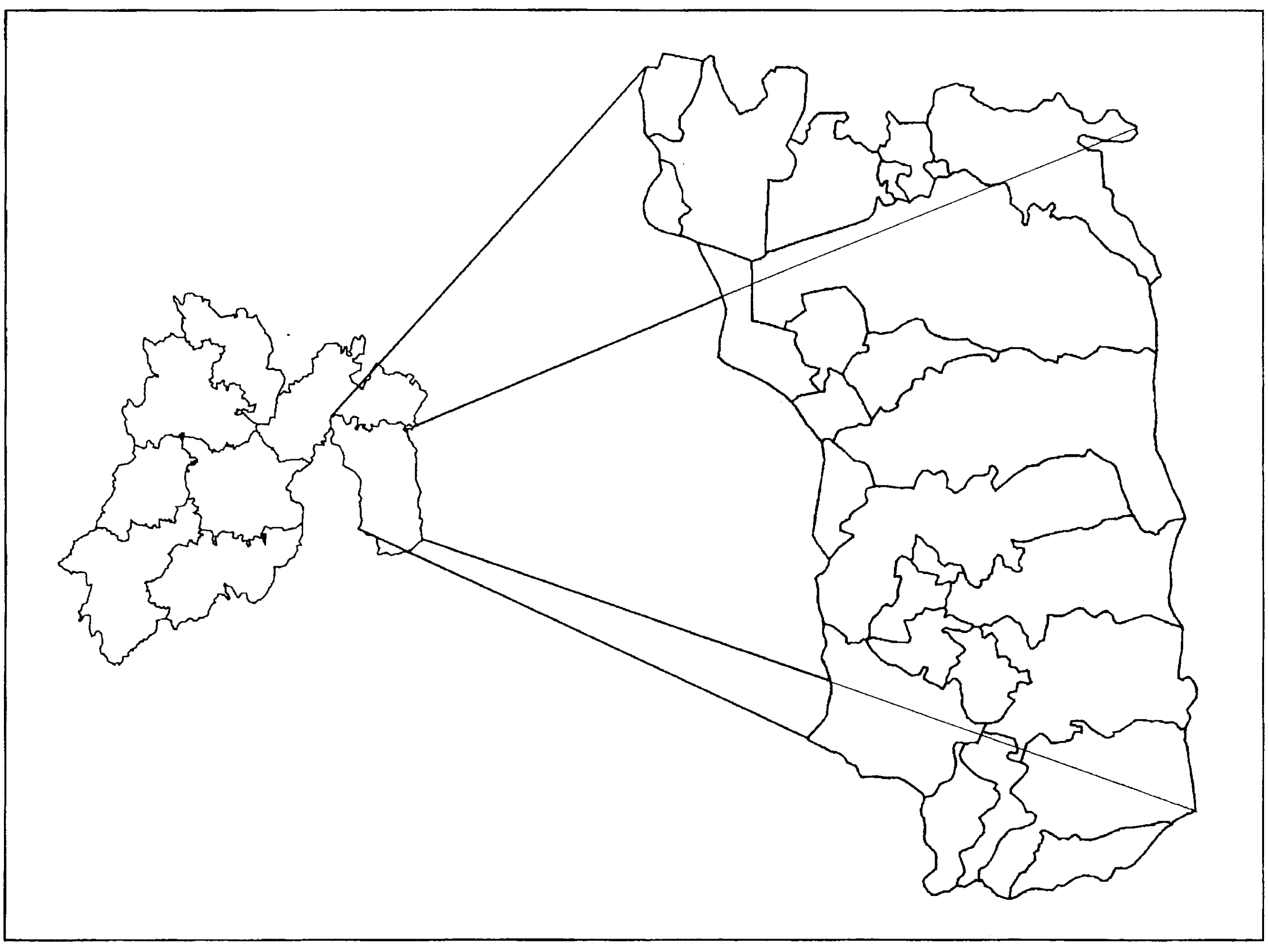

Figura 1.—Localización del Distrito de Desarrollo Rura III del Estado de México.

Modelos Probados

En esta sección se presentan los modelos probados así como los estimadores sugeridos para llevar a cabo esta evaluación. El parámetro de interés es el total de la población (DDR III), el cual es un vector de dimensión q x 1. Con la finalidad de evaluar el efecto de incluir información auxiliar adicional al proceso de estimación, se discute primeramente el estimador de razón usando el tamaño de la unidad de muestreo como variable auxiliar. Posteriormente se presentan los estimadores bajo el modelo de regresión lineal con restricción y el modelo logit multinomial. Para la discusión de los modelos de regresión y logit-multinomial, se usa el enfoque desarrollado por Särndall's et al. (1992) y se extiende al caso multivariado. La notación que se usa en este artículo es la siguiente:

$j = q$ x 1 vector columna que contiene 1 en cada entrada.
N = tamaño de la población.
n = tamaño de muestra.
t_i = tamaño de *i-esima* unidad de muestreo.
π_i = probabilidad de inclusión de la i-esima unidad poblacional en la muestra.
$W' = [w_{i1}, w_{i2}, ...w_{iq}]$ = 1 x q variable aleatoria observable de dimensión q, con $w_{ij} \geq 0$, asociado a la i-esima unidad muestreada.

$w' = \sum_{i=1}^{n} W_i'$ = 1 x q vector de totales (parametro)

W = [W_1, W_2,......Wiq] = N x q matriz poblacional de unidades.

$W_j = \sum_{i=1}^{n} W_{ij}$ total del *j-esimo* componente del vector W'

$x_i' = [1, x_{i1}, \ldots, x_{ik}] = 1 \times (k+1)$ vector de variables auxiliares,

$\sum_s o \sum_{i \in s}$ denota la suma de las unidades en la muestra,

$\sum_u o \sum_{i \in u}$ denota la suma sobre toda la población.

Estimador de razón—En el estimador de razón se incluye el tamaño de la unidad de muestreo, para ajustar las estimaciones por superficie muestreada. En el caso multivariado, el estimador de razón toma la siguiente forma:

$$\hat{W} = N \frac{\sum_s W_i'}{\sum_s t_i}$$

donde cada W_i' es el vector de dimensión q observado en la unidad *i-esima* en la muestra y t_i es el tamaño correspondiente.

La aplicación del estimador de razón en la estimación de un parámetro, es una forma simple de ajustar las unidades de la muestra usando, en este caso, el tamaño de la unidad como variable de ajuste. Una discusión completa del uso del estimador de razón y sus diversas aplicaciones en ciencias forestales se discuten en Srchreuder et al. (1993).

Estimador de regresión multivariado con restricción—Este estimador, incluye una o mas variables auxiliares en el estimador. Suponga que cada unidad de muestreo está ajustada por su tamaño. Es decir, cada componente del vector W_i' está dividido por el valor de t_i. Usando, esta estrategia, la suma de los elementos de cada vector W_i' es igual a uno; razón por la cual exíste una singularidad en la matriz W. Para evitar el tratar esta singularidad, suponga que la matriz W^r incluye solo las primeras $(q-1)$ columnas de W. Ahora suponga el siguiente modelo lineal de regresión multivariado.

$$W^r = XB + E,$$

donde:

W^r= N x (q – 1) matriz de variables dependientes,
X = N x (k + 1) matriz de variables auxiliares,
B = (k + 1) x (q – 1) matriz de parámetros, y
E = N x (q – 1)matriz de errores aleatorios.

Siguiendo las ideas de Särndall's et al. (1992), el modelo que desarrolla el estimador de regresión está dado por

$$E[w_{ij}] = X_j'\beta_j \qquad \text{o} \qquad E[w_i'] = x_i'B,$$

y

$$V[w_i] = \sum_i,$$

para i =1,2,...,N, y j =1,2,...,q – 1, donde β_j es la *j-esima* columna de B y $\sum_i$ es la matriz de varaianzas y covarianzas de W_i. Este modelo se puede ver como la extensión multivariada del modelo dado por Sarndall's et al. (1992) en el capitulo 2.

La estimación de B se lleva a cabo tranformando el modelo a un modelo univariado aplicando el operador *vec* (Christensen, 1987), el cual consiste en poner todas las columnas de la matriz W^r en una sola columna y extender el lado derecho del modelo de manera analoga. Asi, el modelo queda expresado como:

$$W^{rv} = X^* B^v + E^v$$

donde:

W^{rv}= N x $(q-1)$ matriz de variables dependientes,
X^* = Nq x $q(k+1)$ matriz de variables auxiliares,
E^v = $(k+1)q$ x 1 vector de errores aleatorios,
B^v = $q(k+1)$ x 1 vector de parametros.

El estimador de mínimos cuadrados generalizados para B^v es

$$B^v = T^{-1}t,$$
$$= \left[\sum_{i=1}^{N}\left(\sum^{-1} \otimes x_i x_i'\right)\right]^{-1}\left[\sum_{i=1}^{N}\left(\sum^{-1} w_i \otimes x_i'\right)\right]$$

donde "⊗" denota el producto Kronecker (Hocking 1984).

Usando la muestra, T y t, se pueden estimar usando estimadores de Horvitz Thompson [Srchreuder et al. (1993)], los cuales incluyen la probabilidad de selección de la unidad en la muestra como denominador. Así, los estimadores de T y t, son

$$\hat{T} = \sum_s \frac{\left(\sum_i^{-1} \otimes x_i x_i'\right)}{\pi_i} \qquad \text{y} \qquad \hat{t} = \sum_s \frac{\left(\sum_i^{-1} w_i \otimes x_i\right)}{\pi_i}$$

respectivamente. Por lo tanto, usando la muestra es

$$\hat{B}^v = \left[\sum_s \frac{\left(\sum_i^{-1} \otimes x_i x_i'\right)}{\pi_i}\right]^{-1} \left[\sum_s \frac{\left(\sum_i^{-1} w_i \otimes x_i\right)}{\pi_i}\right]$$

Entonces, reacomodando los componentes de $\hat{B}^v$ a su forma original $\hat{B}$ como una matriz de dimensión (k+1) x q, el estimador del vector total W, queda como:

$$\hat{W}^{r''} = \left[\sum_u x_i' \right] \hat{B}.$$

$$\hat{W}^{r'} = \left[\hat{W}_{R1}, \hat{W}_{R1}, ...\hat{W}_{R(q-1)} \right]$$

y para el q – esimo componente del vector W se tiene:

$$\hat{W}_{Rq} = N - \sum_{i=1}^{q-1} \hat{W}_{Ri}.$$

Una discusión mas detallada de estimadores regresión multivariados están dados por Terrazas (1997).

Modelo Logit multinomial—La necesidad de tener restricciones de la forma $W_i' j = 1$ y $\hat{\omega}_{ij} \geq 0$ se pueden evitar asumiendo modelos alternativos a los descritos anteriormente. Un modelo apropiado para el presente caso es el modelo logit-multinomial. bajo este modelo, se asume que

$$E(w_{ji}) = \frac{\exp[x_i^t \beta_j]}{\sum_{j=1}^{q} \exp[x_i^t \beta_j]}$$

Este modelo, tiene la ventaja de que todos sus componentes son no-negativos, y la suma de sus componentes es igual a uno. Es decir,

$$\frac{\exp[x_i^t \beta_j]}{\sum_{j=1}^{q} \exp[x_i^t \beta_j]} \geq 0 \quad \text{y} \quad \frac{\exp[x_i^t \beta_j]}{\sum_{j=1}^{q} \exp[x_i^t \beta_j]} = 1$$

Para estimar B se puede usar mínimos cuadrados ordinarios por lo que se debe minimizar

$$\min_{\beta j} \sum_{i=1}^{N} \sum_{j=1}^{q} \left[w_{ji} - \frac{\exp[x_i' \beta_j]}{\sum_{j=1}^{q} \exp[x_i' \beta_j]} \right]^2$$

Dado que el modelo es no_lineal, se deben usar métodos numéricos, como el de Newton Raphson para su solución. Supongase que la solución está dada por $\hat{B}_{LM}$, donde el subíndice LM indica logit-multinomial. Entonces, los valores predichos para cada w_{ji} son

$$\hat{\omega}_{ji} = \frac{\exp[x_i' \hat{\beta}_j LM]}{1 + \exp[x_i' \hat{\beta}_j LM]}$$

De aquí que el estimador de regresión bajo este modelo para W sea igual a

$$\hat{W}'_{LM} = \left[\hat{W}_{L1}, \hat{W}_{L2}, ..., \hat{W}_{Lq} \right]$$

donde

$$\hat{\omega}_{LMj} = \frac{n}{N} \sum_{i \in s} W_i + \left(1 - \frac{n}{N} \right) \sum_{i \notin s} \hat{W}_i.$$

Notese que el primer componente del estimador, incluye la parte incluida en la muestra, mientras que la segunda, es la parte que no fue incluida en la muestra. Es decir, para estimar el vector w, se debe tener la información auxiliar disponible de todas la unidades de la población.

Datos Utilizados

Para determinar la confiabilidad de los modelos para predecir la superficie fue necesario contar con una base de datos que indicara el total de la superficie para cada tipo de vegetación existentes en el DDR III. Por tal motivo, se utilizó la información del Inventario Forestal Periódico del Estado de México (SARH, 1994). Esta información consistió en una cobertura de ARC/INFO de la vegetación forestal y uso actual del suelo. En la zona se ubican 17 tipos de vegetación (Cuadro 1) que corresponden básicamente a vegetación de clima templado frío. Una descripción de los diferentes tipos de vegetación existentes en el DDR III puede consultarse en las memorias del Inventario Forestal Periódico del Estado de México (SARH, 1994).

La distribución de los tipos de vegetación se muestran en la Figura 2. Por facilidad en el manejo de la información y debido a que la superficie que ocupan es muy pequeña, se decidió agrupar a la vegetación halófita y la vegetación hidrófila en una sola categoría denominada otro tipo de vegetación.

Diseño de Muestreo

Se utilizó un muestreo simple aleatorio. La unidad de muestreo fue un cuadro de 2 Km de lado. Para hacer la asignación de las unidades de muestreo se generó en primer lugar una cobertura de polígono que cubre completamente la zona de estudio en la que cada uno de los polígonos es de forma cuadrada con 2 km de lado. Esta cobertura se interceptó con la cobertura de vegetación de tal forma que para cada

Cuadro 1.—Tipos de vegetación forestal existentes en el DDR III del Estado de México.

Tipo de vegetacion	Superficie
	ha
Bosque de pino cerrado	2,297
Bosque de pino abierto	25,468
Bosque de pino y encino cerrado	31,455
Bosque de pino y encino abierto	3,098
Bosque de encino cerrado	687
Bosque de encino abierto	6,789
Bosque Oyamel cerrado	1,887
Matorral Xerófilo	2,715
Pastizal	35,837
Plantaciones forestales	6,603
Agricultura de temporal	93,835
Agricultura de riego	20,352
Áreas perturbadas	14,656
Áreas sin vegetación aparente	7,233
Vegetación halófita	680
Vegetación Hidrófila	89
Urbano	8,294
Total	261,975

Fuente: Inventario Forestal Periódico. 1994.

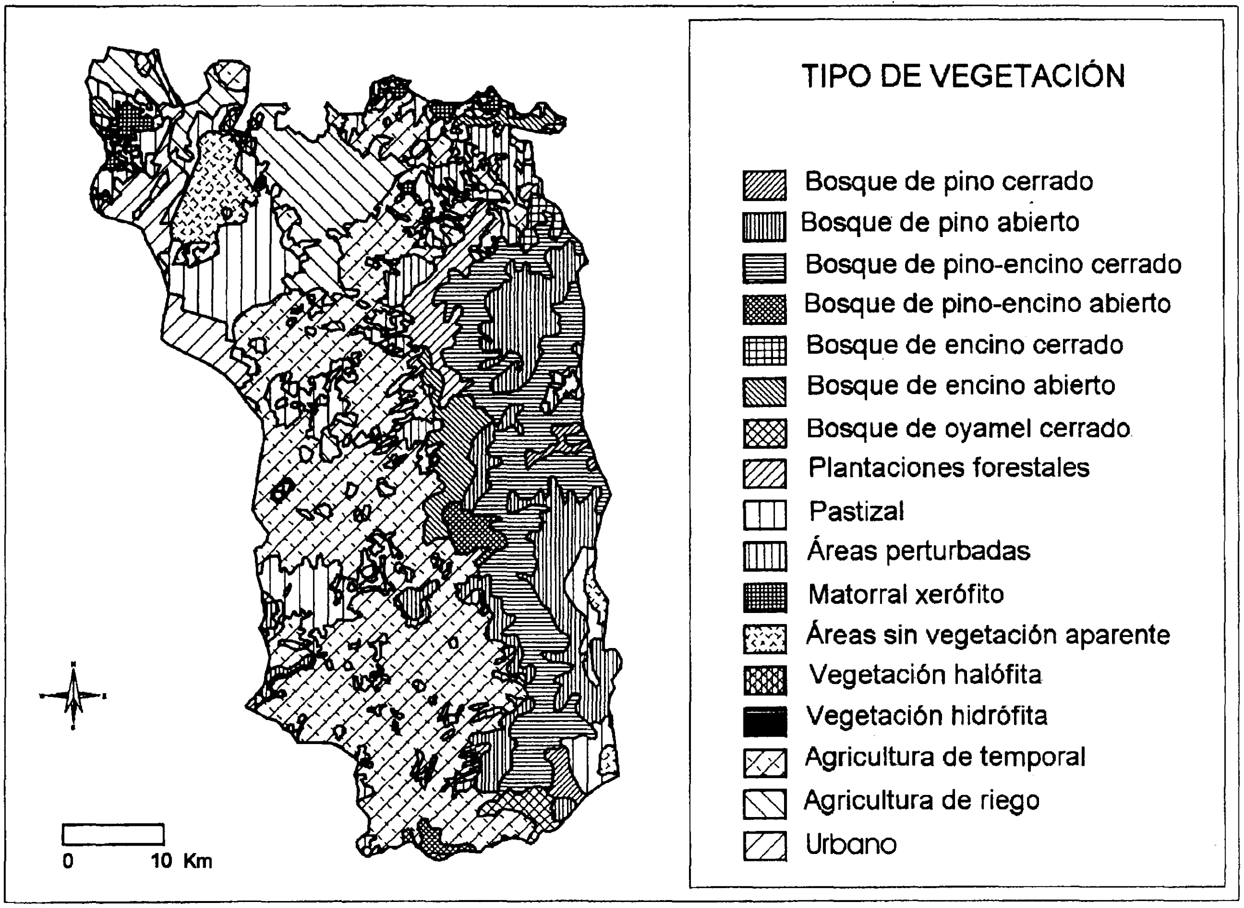

Figura 2.—Distribución de los tipos de vegetación en el DDR III.

unidad de muestreo se obtuvo el tipo de vegetación y la superficie ocupada por ella. La muestra se seleccionó sobre esta última cobertura. El tamaño de muestra fue de 36 unidades y su distribución espacial se muestra en la Figura 3. En unidades incompletas, es decir unidades que caían en los límites del distrito, se consideró únicamente la parte correspondiente al área de interés como se observa en la esquina noroeste de la Figura 3.

Información Auxiliar

El uso de información auxiliar pretende incorporar información que permita mejorar la estimación del modelo. Existe una diversidad de variables que pueden ayudar a estimar el parámetro de interés. Por lo tanto, la decisión sobre que información incluir es un aspecto que requiere especial atención. En el caso específico de estimar el tipo de vegetación existente pueden influir diferentes aspectos entre los que sobresales: terreno, clima, suelo y localización geográfica. Como una primera aproximación se decidió que los aspectos de terreno pudieran evaluarse.

La información auxiliar (de terreno) que se consideró fue la altura sobre el nivel del mar, la pendiente del terreno y la orientación de la pendiente. Esta información se obtuvo del modelo digital de elevación (MDE) generado por INEGI y procesado por el laboratorio de Sistemas de Información Geográfica del Centro de Investigación Disciplinaria en

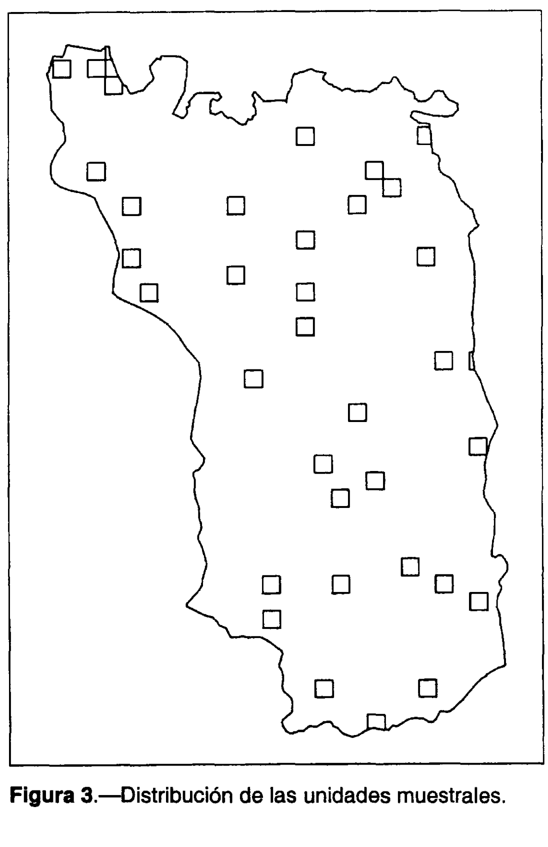

Figura 3.—Distribución de las unidades muestrales.

Conservación y Mejoramiento de Ecosistemas Forestales del INIFAP a una resolución de 3" de arco.

Debido a que la resolución de 3" de arco en la zona de estudio significan celdas de 103 m de lado y las unidades de muestreo tienen 2 Km de lado, es decir, se generan 377 celdas por cada unidad de muestreo y sólo se requiere un valor de altura, pendiente y orientación, se tomó el promedio de las 377 celdas para asignarselo a la unidad de muestreo.

La información utilizada para ajustar los modelos fue: superficie, asnm, pendiente y orientación de la pendiente.

Resultados

Las 36 unidades muestrales seleccionadas, cubrieron una superficie de 13,390 ha lo que significa un 5% del total del DDR III. De las 16 categorías de vegetación consideradas, únicamente 12 quedaron en la muestra. Las categorías no incluidas fueron: encino abierto, encino cerrado, matorral xerófilo y otro tipo de vegetación (que como se comentó, está formada por vegetación halófita e hidrófila). Estas categorías representan solo el 4% de la superficie del distrito por lo que no se considera de gran trascendencia la estimación de sus áreas. Con la finalidad de incluir todas las categorías, la muestra pudiera ser mejorado en trabajos futuros con estrategias de muestreo diferentes a la utilizada.

La superficie estimada para cada categoría de vegetación por cada modelo se muestra en el cuadro 2. Como puede apreciarse la superficie estimada total bajo los tres modelos coincide con la superficie real del DDR III. Por otra parte, se observa que hay una buena aproximación en las superficies estimadas con respecto a la real, principalmente en las categorías con mayor superficie, aunque esta proximidad no esté marcada fuertemente para algún modelo específico. El hecho de que cuatro categorías de vegetación no hayan sido incluidas en la muestra repercute en las estimaciones de los modelos ya que la restricción deque las estimaciones sumen el total de la superficie del distrito, obliga a incluir la superficie de estas categorías faltantes a otras clases.

Es conveniente destacar que el área total del distrito esta dominada fundamentalmente por 5 de las 16 categorías. En el cuadro 3 puede notarse que las cinco primeras categorías forman el 80% de la superficie del DDR III.

Si se comparan las proporciones de la superficie estimada para cada categoría por los diferentes modelos con la proporción de la superficie real del distrito, se observa que la estimación con el modelo de razón tiene una buena estimación en cinco de las catorce categorías, el modelo de regresión lineal con restricciones en cuatro y el logit_multinomial en una. Resalta el hecho que la categoría agricultura de temporal, la categoría con mayor superficie, tiene una proporción cercana a la real usando los modelos de razón y de regresión con restricciones. Lo mismo sucede para la categoría de pastizal, segunda categoría con mayor superficie, con los modelos de regresión y logit_multinomial.

El modelo de razón presentó la mayor desviación en la categoría de pino-encino cerrado con 9% de la diferencia en la asignación de la superficie pero en el resto de las clases la diferencia estuvo abajo del 4% teniendo en cinco categorías diferencias de apenas 1%.

La mayor desviación del modelo de regresión con restricciones fue de 6% en la categoría de pino-encino cerrado seguida por un 4% en pino-encino abierto. En el resto de las categorías la desviación estuvo abajo del 3%.

El modelo L_M tuvo las diferencias más marcadas en las categorías de plantaciones forestales y áreas perturbadas con 12 y 9% respectivamente.

Conclusiones y Recomendaciones

Los modelos probados, muestran algunas discrepancias en las estimaciones realizadas. Sin embargo para las categorías con mayor superficie, los modelos muestran estimaciones similares. Aunque las categorías con menor superficie tienden a tener el mayor porciento de error, se puede deber al hecho de que las variables auxiliares no

Cuadro 2.—Superficie estimada por cada modelo.

Tipo de vegetación	Real	Razón	Lineal restric	Logit mult.
Agricultura de temporal	93,835	98,171	99,736	64,174
Pastizal	35,837	29,192	34,675	40,562
Pino-encino cerrado	31,455	7,985	15,819	24,062
Pino abierto	25,468	28,635	22,092	9,904
Agricultura de riego	20,352	30,168	18,696	14,350
Áreas perturbadas	14,656	19,176	22,496	7,266
Urbano	8,294	18,240	9,494	12,351
Áreas sin vegetación aparente	7,233	5,894	2,866	19,953
Encino abierto (NM)	6,789	0	0	0
Plantaciones forestales	6,603	7,009	11,893	31,435
Pino-encino abierto	3,098	9,698	12,397	15,876
Matorral xerofilo (NM)	2,715	0	0	0
Pino cerrado	2,297	80	333	20,578
Oyamel cerrado	1,887	7,726	11,479	1,464
Otro (NM)	769	0	0	0
Encino cerrado (NM)	687	0	0	0
Total	261,975	261,975	261,975	261,975

NM = No incluido en la muestra

Cuadro 3.—Porcentaje de la superficie total estimada para cada clase por cada modelo.

	Porciento De Superficie				Diferencia		
Tipo De Vegetación	**Real**	**Razón**	**Lineal Restric**	**Logit Mult**	**Razón**	**Lineal Restric**	**Logit Mult.**
Agricultura de temporal	36	37	38	24	1	2	–12
Pastizal	14	11	13	15	–3	1	–1
Pino-encino cerrado	12	3	6	9	–9	–6	–3
Pino abierto	10	11	8	4	1	–2	–6
Agricultura de riego	8	12	7	5	4	–1	–3
Áreas perturabadas	6	7	9	3	1	3	–3
Urbano	3	7	4	5	4	1	2
Áreas sin vegetación aparente	3	2	1	8	–1	–2	5
Encino abierto (NM)	2	0	0	0	0	0	0
Plantaciones forestales	2	3	5	12	1	3	10
Pino-encino abierto	1	4	5	6	3	4	5
Matorral xerofilo (NM)	1	0	0	0	0	0	0
Pino cerrado	1	0	0	8	–1	–1	7
Oyamel cerrado	1	3	4	1	2	–3	0
Otro (NM)	0	0	0	0	0	0	0
Encino cerrado (NM)	0	0	0	0	0	0	0
Total	100	100	100	100			

NM = No incluido en la muestra

proporcionan suficiente información de ellas. Por ello es recomendable ensayar otras variables auxiliares de tipo socio-económico como distancias a poblaciones mas cercanas, número de habitantes en dichas poblaciones; o también variables climáticas como precipitación y temperaturas. Estas variables juegan un papel determinante en la ocurrencia de vegetación regional. A pesar de las deferencias observadas entre los modelos, cabe mencionar que este trabajo es una etapa inicial en la aplicación de estas técnicas de muestreo a inventarios de ares de recursos naturales. Por lo que no se debe descartar este enfoque en trabajos futuros donde se apliquen refinamientos que incluyan otras estrategias de muestreo (con tamaño de muestra aleatorio) y diferentes modelos para aplicar al proceso descrito en este documento.

Literatura Citada

Boyle, T. P. 1995. El uso de inventarios de recursos para la evaluación de amenazas a ecosistemas y la protección del ambiente. *In* Taller norteamericano sobre monitoreo para la evaluación ecológica de ecosistemas terrestres y acuáticos. Rocky Mountain Forest and Range Experiment Station. RM-GTR-284. pp: 217-222.

Christensen, R. 1987 Planed answers to complex questions. New York : Springer Verlag.

Hocking. 1984. The analysis of linear models. Brooks/Cole publishing company Monterey, CA

Peña De La. F., J. L. 1989. Restitución por transparencia (de fotos 1:40 000 a ortofotos 1: 20 000). *In* Congreso forestal mexicano. Tomo I. pp: 395-398.

Randall, A. 1985. Economía de los recursos naturales y política ambiental. LIMUSA, México. 474 p.

Särndall, C.E., Swensson, B., y Wretman, J. 1992. Model assisted survey sampling. New York : Springer Verlag.

SARH. 1994. Inventario Forestal Periódico del Estado de México. 73 p.

Schreuder, H. T., Gregoire, T. G. y G. B. Wood. 1993. Sampling methods for multiresource forest inventory. Wiley and Sons, Inc. USA. 445 p.

Secretaria de Agricultura y Ganadería. 1974. Inventario forestal del Estado de México y Distrito Federal. Subsecretaría Forestal y de la Fauna. Dirección General del inventario Nacional Forestal. México. 57 p.

Terrazas, G.G.H. 1997. Evaluation of projeciton methods to predict Wetlands area sizes: The wetlands inventory of U.S.A. Ph.D. Dissertation. Colorado State University. 150 p.

Varela, H. S. 1995. Problemas actuales, necesidades, oportunidades y perspectivas en la evaluación y monitoreo de recursos forestales en México. *In* Taller norteamericano sobre monitoreo para la evaluación ecológica de ecosistemas terrestres y acuáticos. Rocky Mountain Forest and Range Experiment Station. RM-GTR-284. pp: 68-72.

Determinación de la Degradación Inducida por el Hombre en el Estado de Tlaxcala[1]

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Diego D. Reygadas Prado[3]

Abstract—El presente estudio se llevo acabo aplicando la metodología propuesta por FAO/ISRIC para la evaluación de la degradación inducida por el hombre a través del uso de un SIG (ARCINFO), La citada metodología considera cuatro factores: degradación Biológica, degradación Física, degradación Química y degradación por contaminación, así como cuatro niveles de velocidad en los procesos: ligera, moderada, severa y muy severa.

En el proceso se definieron sistemas terrestres a través de la interpretación de imágenes de Satélite Landsat TM, para posteriormente realizar recorridos de verificación de campo, y entrevistas a productores para evaluar los sistemas de producción y condiciones ambientales. Finalmente se generó cartografía en ARCINFO señalando el estado actual que guarda cada sistema terrestre y las principales causas de degradación para el mismo.

Se observó que entre las principales causas de degradación está el monocultivo de gramineas en algunas áreas y la contaminación de rios y áreas con desechos sólidos, siendo segundo lugar ocupado por la sobre explotación de la tierra y el mal uso de los agroquímicos. Las áreas más degradadas corresponden a la parte sur y centro del Estado.

El disponer de información fidedigna del sector primario se ha convertido en una necesidad primordial, dado que su futuro desarrollo depende de investigaciones que se basarán en la documentación antecedente, tal es el caso de la degradación de suelo, la cual se ha venido incrementando a medida que la población ha generado mayor presión sobre el recurso.

Dicho proceso es comprendido en forma diferencial entre las personas que interactuan con el medio, usuarios técnicos y políticos.

El presente trabajo pretende generar un marco de referencia geográfico homogéneo del estado de Tlaxcala a través de un levantamiento fisiográfico, para evaluar la degradación de suelo y determinar el grado de conocimiento de los procesos degenerativos del suelo por parte de los diversos sectores que interactúan con el recurso generando un banco de información, estableciendo las causas, efectos y alternativas de solución.

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Método

La variedad de paisajes del estado de Tlaxcala puede atribuirse a los cambios de litología, clima y relieve. Consecuentemente el uso actual del suelo es variable y esta en función de las condiciones que se presentan en la zona.

Con base en lo anterior y con la finalidad de generar un marco geográfico que cubriera todo el estado se realizó un levantamiento fisiográfico en el nivel de sistema terrestre, para lo cual se uso la información cartográfica escala 1:250 000 y una imagen de satélite en falso color a la misma escala.

Como primer paso se estatifico el ambiente a través de un levantamiento fisiográfico, para ello se siguió el diagrama de flujo mostrado en la figura 1 que es una adaptación de la metodología propuesta por el Colegio de Postgraduados, esta adaptación es debida a la implementación del uso de sistemas de información geográfica.

La forma como se describe a las unidades fisiográficas esta dividida en dos partes: a) descripción de los sistemas terrestres b) diagrama idealizado de los mismos.

Para la descripción de los sistemas terrestres se tomaron las siguientes convenciones:

- Nomenclatura: El nombre asignado a cada sistema terrestre corresponde a la principal población o accidente orográfico más relevante dentro de su área de influencia.
- Clima: Se indica la precipitación media anual en mm y la temperatura media anual en °C.
- Geología: Se establece en términos de su naturaleza y tipo específico.
- Suelos: Se reporta con base a sus características principales.
- Vegetación y uso actual: Se menciona la vegetación dominante y/o el uso del suelo.

Para llegar a estratificar el ambiente, el método original incluye como un primer paso una interpretación visual de una impresión de un compuesto en falso color de una imagen de satélite de la zona de estudio, lo que requiere cierta capacitación en la interpretación y manejo de las imágenes. Como una alternativa a este proceso se probó realizar diversos compuestos de color que permitieran una mejor interpretación visual, como una ayuda en la posterior clasificación de la imagen.

A través de la operaciones booleanas de capas de información digital de clima, suelo, uso actual del suelo y un posterior recorrido de campo se pudo llegar a la formulación de sistemas terrestres como se consigna en ejemplo de la figura 2.

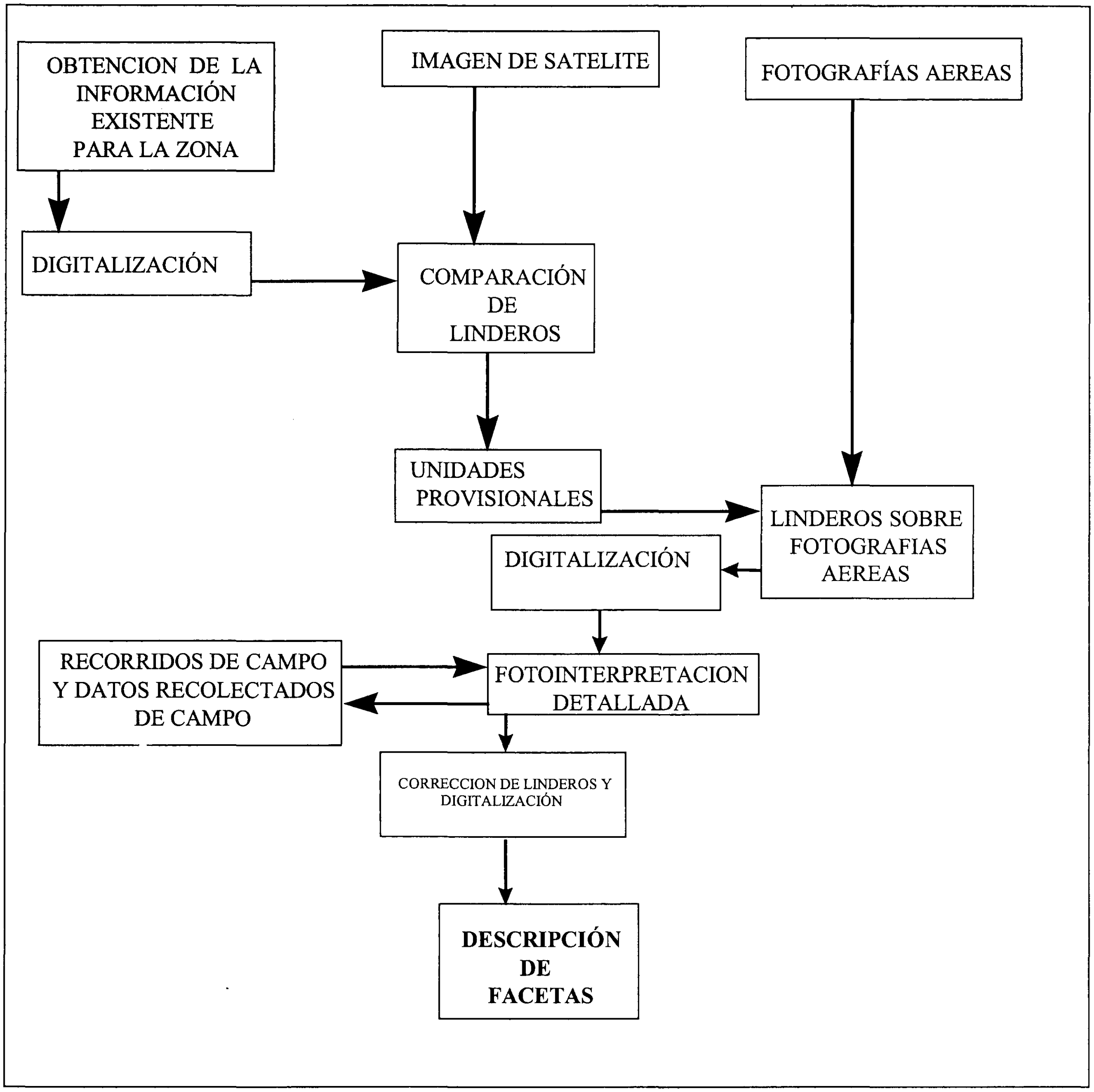


Figura 1.—Diagrama del levantamiento fisiográfico.

Resultados

Se generaron 57 sistemas terrestres para el estado de Tlaxcala, mismos que se localizan de uno a más municipios, encontrándose a través de los recorridos y pruebas de campo, que estos sistemas terrestres son lo suficientemente homogéneos como para considerarse como unidades estructurales básicas para la estratificación del ambiente.

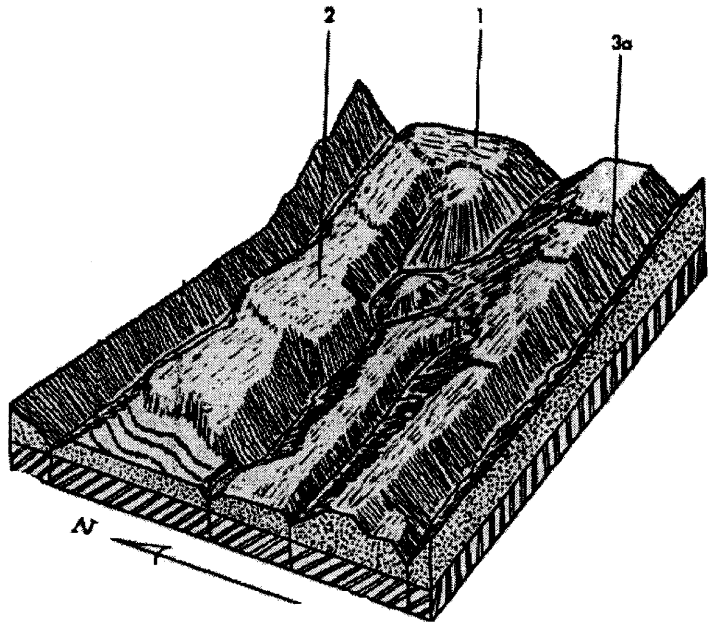
En 46 sistemas terrestres la degradación del suelo se considera como un problema que afecta la producción.

Con base a la información recolectada se generó una caracterización por sistema terrestre de las causas que originan la degradación de suelo, encontrándose que la deforestación el sobrepastoreo y el mal manejo de suelos agrícolas son las responsables del 80% de la degradación de suelos.

Conclusiones

La información digital generada por del INIFAP en su segunda aproximación, es confiable y de calidad suficiente para aplicarse en trabajos cartográficos de determinación de la degradación del suelo inducida por el hombre.

Sistema terrestre Lardizabal .



CARACTERISTICAS
Precipitación:
De 800 a 1000mm °Tmedia 12 a
Geología:
Materiales ígneos, ignimbritas sobre basalto, con fallas y fracturas.
Paisaje:
Volcánico, muy erosionado geológicamente con pendiente dominante perpendicular a las fallas de 40 %
Uso:
Explotación forestal, agricultura de ganadería extensiva.
Suelos:
Profundos con texturas medias.
Vegetación:
Bosque de pino alterado por explotación forestal.
Altitud:
2 600 a 3 msnm.

FACETAS:
L-1: Declive suave con pendientes del 7-10%. Suelos negros ricos en materia orgánica, y de textura media. Vegetación de Pinus, Abiesy Quercus.
L-2: Declive moderado pendientes de 10-18%. Suelos profundos ricos en materia orgánica, con texturas medias en algunas partes se siembra cebada y haba, la vegetación dominante es AbiesQuercuscon estrato herbaceo de zacatonales.
L-3a: Suelos profundos negros y ricos en materia orgánica, textura media, vegetación de asociaciones de Abies Quercus

Figura 2

El estado de Tlaxcala presentan una seria degradación del recurso suelo dominando los procesos de erosión con diferentes grados, velocidades y extensiones.

El fenómeno de degradación del suelo es comprendido en forma diferencial, tanto en causas como en soluciones, por los distintos sectores que interactúan con el recurso.

El causante de la degradación del recurso suelo en la entidad, es el hombre y su interrelación con los recursos naturales, siendo este proceso irreversible en el corto plazo, dentro de las medidas a tomarse destacan por orden de importancia, el manejo forestal.

Bibliografía

FAO 1984 Proteger y Producir; Conservación del suelo para el desarrollo Roma.

FAO/ISRIC 1994 Metodología para la evaluación de la degradación de los suelos. Roma.

Farrel J. G. 1984 The role of trees whitin mixed farmaing sistems of Tlaxcala, México MS Thesis Wildland Resource Science. University of California, Berkeley.

Leon A. R. 1975 El levantamiento fisiográfico y la conservación de suelos Tesis Profesional ENA Cahpingo.

Evaluation of Projection Methods to Predict Wetland Area Sizes[1]

Gerardo H. Terrazas Gonzalez[2]
David C. Bowden[3]
Kenneth Burnhamm[4]

Abstract—This research concerns different methods to estimate projections of wetland area sizes at selected times. These methods address mainly two objectives. One objective is to estimate the total of wetland area sizes at any given time. The other objective is to estimate the amount of change among wetland types between a beginning time, T_B and an ending time T_E, to obtain annual rates of changes (trends). A method developed by W.E. Frayer in collaboration with D.C. Bowden USFWS to address these objectives has been used by the USFWS. The method applies when the sampling units have been measured in two times, T_1 and T_2 with $T_1 < T_2$. A change matrix giving the amount of each wetland at time T_1 that in each wetland type at time T_2 for each sampling unit is computed. Projections are based on an annual rate of change matrix at stratum basis for a time $T_1 < T_2$. This method will be identified as the FBSB estimator.

Methods of evaluating the reliability of FBSB estimator have not been given previously. Variance estimators to evaluate the method using the jackknife and the bootstrap techniques are provided. Direct analytic techniques seem to be very complicated given the complexity of the estimator.

Interest in having projections at an arbitrary time T led to a more general description of the FBSB estimator t include projections for a time $T < T_1$ and for T between T_1 and T_2. Variations in the measurements times T_1 and T_2 among sampling units within stratum and other considerations like the complexity of the FBSB estimator, motivated the use of simpler estimators.

The methods discussed can be classified in methods based on the sum of estimated change matrices and methods based on a product of normalized estimated change matrices. Besides, methods within each class can be based whether the change matrices are on annual basis or observed time period ($T_1 - T_2$) basis. The FBSB estimator is a method that uses a sum of estimated matrices of changes and is based on an annual basis matrix of change's. Two additional estimators are provided in this paper and then compared to the FBSB method. The first is a modification of the FBSB estimator that uses the average of the change matrices of the sampling units within stratum using the ratio estimator to calculate the projections to a desired time T (FBUB estimator). The second method uses a product of normalized change matrices (transition matrices) based on the observed period ($T_1 - T_2$); and then linear interpolation to estimate the projections at a desired time T is applied (CNTM estimator).

Because the estimates for the totals were not statistically insignificant, the selected method was the CNTM estimator since it is the simplest to apply.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Aerial Sketch Mapping Surveys the Past, Present and Future[1]

Timothy J. McConnell[2]

Abstract—Aerial sketch mapping has been used as a detection and monitoring tool, over large geographical areas, for over fifty years. Mexico, Canada and the United States share a common need, sketch mapper expertise. Aerial survey data is only as good as the sketch mapper. The leadership of the Forest Health Monitoring Program in the United States for standardization and support of aerial sketch mappers can serve as a model for improving the quality and quantity for aerial surveys in all three countries.

Since the advent of forest land management, specialists have looked for methods to document changes in forest ecosystem health over large areas. Aerial sketch map surveys have become the most efficient and cost effective method of detecting visible forest change events over a large geographical area since the 1950's.

Definitions

An aerial sketch map survey consists of using an aircraft with a trained observer to systematically fly over a forested area to detect visible changes in the forest, such as mortality, defoliation and blowdown. Once detected, while in the air, the affected area is drawn on a map, then attributed with the appropriate information. Upon landing, a draft map product is already completed. For this paper, the words "sketch mapper", "observer", "sketch map observer" and "aerial observer" are synonymous and "aerial sketch map survey", "aerial survey" and "survey" are also synonymous.

There are two primary types of aerial surveys: the overview or general survey and the specific or detailed operational survey. The overview aerial survey is more of a landscape level assessment capturing a multitude of forest change events. A high wing airplane is generally used, along with a map with a scale of 1;250,000 to 1:100,000. An example of this type of survey would be the annual aerial surveys conducted once a year in the western United States. A specific or operational aerial survey covers a smaller geographical area and focuses on one to a few special events. A specific aerial survey may be conducted either by airplane or helicopter, along with a map scale of 1:100,000 to 1:24,000. An example would be the aerial surveys in southeastern United States to sketch map areas with recent mortality by southern pine beetle. Southern pine beetle may be conducted four to seven times a year, depending on the number of bark beetle generations a year.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Words of Caution—Just as in any other form of forest ecosystem inventorying and monitoring, the use of proper techniques and qualified personnel are very important to the success of that method. Conducting an aerial survey from an aircraft is difficult and challenging work. It must be planned, conducted and completed by well qualified aerial observers.

Past complaints about aerial survey data usually stem from the lack of experience, training or attitude of the aerial sketch map observer. *"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 same way. For this reason sketchmapping should be regarded more as an art than as an exact science.... 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, 1983.)

An aerial sketch map survey requires not only qualified, motivated sketch mappers, but a great deal of mission planning to insure that the data collected is valuable, the survey is cost-effective and that above all, it is completed in a safe manner.

Forest change event signatures must be visible from the air. Extreme wind throw or abundant bark beetle caused mortality are easily seen from the air, while light adelgid infestations or very light defoliation from larval feeding on foliage is likely to not be visible. Therefore, the signature and visible thresholds for various damaging agents must be understood and taken into account in the planning process.

Other complaints can be found related to the fact that the users of the data did not understand the scope, scale or intent of the aerial survey that produced the data.

Qualifications for a Sketch Mapper Observer

The cost of sending one or two observers up in an aircraft gets more expensive every year. Valuable forest health monitoring money can be wasted easily by sending less than qualified sketch mappers up in to the air. When using aircraft in natural resource management, an aviation management program is a must, and is frequently forgotten in fledgling aerial survey programs. Qualified sketch mapping aerial observers must be able to:

1. Read maps proficiently so they can track the aircraft position, navigate the aircraft and locate the affected area on the ground and on the map. (If you don't know where you are, you can't draw a polygon on the map accurately.)

2. Have good eye sight and normal color perception.
3. Identify forest disturbance agent signatures, which usually come in the form of foliage color change or tree crown or canopy texture change.
4. Draw or sketch the affected area on to a map (of appropriate scale) the way it appears (shape) on the forest below. A small affected area on the ground may be only a point on the map, where a large affected area will be delineated with a polygon. (Good sketch mappers don't draw large area circles because they don't accurately represent most affected areas.)
5. After the affected area has been marked or delineated on the map, it must be attributed with the causal agent, host and a relative intensity or tree count of damage.

Other valuable qualities of a good sketch mapper include:

- Having a working knowledge of forest insect and diseases, and their hosts indigenous to the survey area.
- Having a sincere interest in flying a sketch map mission.
- Being able to control motion sickness.
- Having the ability and experience to plan an aerial survey mission.
- Having on the ground field experience in the survey area.
- Having knowledge of meteorology and weather, especially in the survey area.
- Having the ability to be a team player.
- Depending on the aptitude of the observer, 50 to 200 hours of training time in an aircraft.

Other Important Aerial Survey Variables—Besides the observers, there are many other variables that can contribute to the quality of information collected. A sketch mapper must be familiar with the conditions and methods that affect the quality of the survey. These include:

- Timing the survey to observe the forest change event at its optimum visible signature. This may mean waiting for the damaged foliage to turn red or flying the area before the damaged foliage has been washed away by rain or wind.
- Timing the survey to have the best light. High sun angle is very important, so best light is at noon in the summer months in North America. Cumulus clouds can create dark shadows causing a monochromatic view that is less than acceptable, where an even, high cirrus cloud cover can be beneficial.
- Fly the survey at the appropriate altitude above ground level to be able to detect the signatures of interest.
- Fly the survey at a speed that is slow enough to allow the sketch mapper to locate and identify the signature, draw the area as it appears in the forest canopy onto the map and attribute the point or polygon, yet fast enough to be safe and cost-effective.
- Turbulent air can make an observer anxious and uncomfortable and be the cause of reduced concentration to do the work.

There are many other variables that can affect the quality of an aerial survey. Some of them include; the type of aircraft, the attitude and ability of the pilot, other air traffic, radio communication, terrain, and smoke haze. Even with all these variables, aerial survey data has value in tracking trends, providing quick response information, providing annual information over large areas and can serve as the first phases of a multi-stage sampling scheme.

The Past

A Little History

In 1919, Gordon Hewitt recommended using aircraft for forest insect detection after flying mosquito breeding areas in parts of British Columbia. In 1920, an open cockpit hydroplane was used to survey a spruce budworm infestation in parts of Quebec and Ontario. Another early attempt to survey forest insect damage from the air was made by J.M. Miller, over the Sierra National Forest, in California, in 1925, in an open cockpit airplane. In 1930, the Bureau of Entomology used a Forest Service airplane to survey bark beetle outbreak areas of Yellowstone National Park. In 1931, F.P. Keen, from the Portland Forest Insect Laboratory and C.S. Cowan, Chief Fire Warden of the Washington State Fire Association conducted the first recorded aerial survey of a forest insect outbreak in the two northwest states, when they delineated a hemlock looper outbreak in southwest Washington. In 1947, the annual aerial survey program was instituted by the Bureau of Entomology and Plant Quarantine, US Department of Agriculture and cooperators from the States of Washington and Oregon and the Weyerhaeuser Timber Company.

The pioneers of the modern aerial survey, when it began in Portland, Oregon, were: W.J. Buckhorn, a seasoned entomologist and John F. Wear, a young research forester and pilot, just out of graduate school after World War II.

The More Recent Past

Other aerial survey attempts and program developments occurred in the fifties and sixties in the United States. Early attempts to develop programs share much of the same challenges as today's program efforts, such as; (1) qualified observers, (2) budgets than can cover costs for aircraft, (3) suitable map bases for sketch mapping, and (4) suitable aircraft and qualified pilots. Within the USDA Forest Service, most Forest Health Protection groups and conduct aerial surveys. Ten years ago, some of these groups had no aerial survey program or so small a program that only an occasional event was flown. Some expected satellite technology of the 1970's to replace the "old fashioned" aerial survey. Without the interest and expertise, some regional programs lost their ability to conduct aerial surveys. In recent years the National Forest Health Monitoring Program (FHM) in the United States, has provided leadership in the form of support and funding to rebuild expiring programs, as well as helping to fund ongoing programs in the USDA Forest Service, Forest Health Protection.

In Canada, as recently as 1996, the Canadian Forest Service, Forest Insect and Disease Survey Unit (FIDS) conducted the annual overview survey across much of Canada. They processed and digitized the survey data, which was used by both the federal agency and the provincial forest health specialists. Some of their other services were: diagnostics, providing historical trends in pest populations based on a 50 year record, and, providing annual national, regional and provincial pest damage summaries. The FIDS unit also conducted ground truthing, other special surveys and maintained permanent sampling stations. Due to down sizing, program reviews and philosophical changes at the federal level, most provinces, like British Columbia, must now conduct both their overview and operational aerial surveys. (personal communication with Tim Ebata)

In Mexico, aerial surveys have been conducted in many states, at both the state and federal level. The USDA Forest Service has assisted Mexico with aerial survey training a number of times, twice in the 1980's; in 1990, in cooperation with Forest Health Protection and La Secretaria de Agricultura y Recursos Hidraulicos (SAHR) of the Mexican government and in cooperation with USDA Forest Service, Forest Health Protection and La Secretaria de Medio Ambiente Recursos Naturales y Pesca y Protectora de Bosques (SEMARNAP) and PROBOSQUE of the State of Mexico, in Metepec, March, 1998.

The Present

Currently, there are many aerial sketch mapping programs in North America. In all three countries, the universal challenge remains the same, the ongoing struggle to find highly qualified sketch mappers.

In Canada, the Province of British Columbia is faced with the challenge of developing a cadre of qualified sketch mappers, since the service and product is no longer furnished by the Canadian Forest Service. Aerial overview surveys are now required by the Forest Practices Code (FPC), to provide licensee land managers and District Managers with information on forest health conditions. Aerial overview surveys are now conducted by Ministry of Forests regional and district personnel or qualified contractors (who are often retired FIDS observers). The Ministry of Forests, Forest Practices Branch has developed a training package, including workbook, video and other teaching aids to help train new observers. The Province of Ontario still maintains support of FIDS, who conduct aerial surveys for the province, as well as the ground plot based work. (personal communication with Gordon Howse) Some provinces, like Saskatchewan, only fly to sketch map specific insect outbreaks in support of suppression activities.

Across Mexico, state forest health specialists are currently developing a program or building on past aerial survey experiences to improve their aerial survey programs. As in the United States, programs are at various levels of evolution, depending on the states' funding levels, sketch mapper expertise, forest management direction, terrain, insects and diseases and vegetation. There is a strong interest in building programs and gathering quality data. Mexico's diverse forests and terrain makes for unique challenges in each state. Of the three countries, Mexico is the first to hold national aerial survey training sessions, in cooperation with USDA Forest Service Forest Health Protection.

Presently, in the United States, the states, and the USDA Forest Service continue to conduct aerial surveys, while sharing the same ongoing challenges of adequate funding and sketch mapper expertise. Because many aerial survey programs have similar interests, several issues have been worked on together. One issue, aviation safety, has been addressed the past three years with the development of the Natural Resource Aerial Survey Aviation Safety and Management (AS2M) training course. Another issue, information sharing, has been addressed with the formation of the Aerial Survey Technical Working Group in November, 1996, to provide field level input to the Washington, D.C. Office and Staff Directors regarding issues of interest to the various aerial survey programs. The goals of this working group are: (1) ensure safe aerial survey programs, (2) to conduct each program in the most cost efficient and highest quality manner to meet customers needs, and (3) to communicate information about aerial surveys to appropriate audiences in a timely manner. This working group has become a sort of support group for sketch mappers of all agencies. At the 1998 meeting, a British Columbia representative attended and shared the British Columbia training package. This working group meets annually and welcomes sketch mappers from any country or agency.

A major supporter of aerial surveys in the United States is the Forest Health Monitoring Program. FHM has become a national leader in mentoring new aerial survey programs and assisting ongoing programs. The FHM understands the importance of aerial survey programs in the United States and the importance of collecting aerial survey data for local, regional and national needs. FHM has become an additional primary customer of aerial survey data. While realizing aerial survey limitations, FHM sees value in the vast information gathered each year and over past years (historical). Recently, it has taken on the challenge of bringing the many and varied programs to a common goal of implementing national aerial survey standards for sketch mapping and geographic information system (GIS) processing. These standards include; mapping and reporting a defined set of tree damage types (including mortality and defoliation), damage severity and damage pattern. This national, regional and state combined effort to implement aerial survey standards was done so that each local program could still meet their needs, yet tier to the national level, so all combined data could be utilized. This example of cooperation, for the good of all programs, can serve as a model to other countries. This cooperation has also resulted in support for improving data quality as well as standardizing shared data. And the agreed upon method to improve the quality of aerial surveys was to support sketch mapper training, certification and annual preseason "calibration and conformity" sessions.

The Future

With the growing interest in forest ecosystem resource status and change at national and global scales, aerial surveys can provide rapid and low cost per area assessments of disturbance events that can complement other data. As stated in this symposium's notice, all three North American countries are reassessing and redirecting their inventory and monitoring programs, making this a golden opportunity to coordinate efforts to enhance the quality, interoperability and availability of aerial survey data and information. With the understanding of the value, as well as the limits of large geographical aerial surveys and the importance of well qualified aerial sketch map observers and programs, our three countries can work together to capture and share data on a continental scale.

What is currently developing in the present will be the ground work affecting the future opportunities for quality and shared information. Additional training is planned between the USDA Forest Service, Forest Health Protection and Mexico's SEMARNAP sketch mappers in the northwest United States in 1999. Geographical positioning system (GPS), GIS and digital map base technology are being utilized to develop computerized sketch map tools. With little written information available about aerial survey protocol, Forest Health Monitoring and Forest Health Protection are sponsoring the writing of a national procedures guide to conducting aerial surveys. This guide would be of value to sketch mappers in all countries that conduct aerial surveys.

Conclusions

Again, aerial survey data is only as good as the sketch mapper. All three countries have similar ongoing needs for sketch mapper expertise, suitable map bases and safe aerial survey programs. Standardization needs to be implemented internationally. Forest Health Monitoring Program, states and USDA Forest Service will strive to be leaders in North America to ensure that sketch maps surveys are a quality method of detection and monitoring of forest ecosystem resources. Now is the time for Mexico, Canada and the United States to work together to share methods, expertise, and develop a strategic plan to conduct aerial surveys across the forests of this continent in a standardized and quality manner. Each year that a forest is not surveyed, potential valuable information on forest change is lost forever. Using Forest Health Monitoring's example and assistance, this can be accomplished.

Literature Citations

Eaton, C.B., 1942. The adaptation of aerial survey methods to the forest loss survey. USDA Bureau of Entomology and Plant Quarantine, Berkley, CA., unpublished report.

Klein, W.H., S.Tunnock, J.G.D. Ward and J.A.E. Knopf. 1983. Aerial sketch mapping. USDA Forest Service, Methods Application Group, Ft. Collins, CO. 15 p.

McConnell, T.J. (ed.). 1995. Proceedings aerial pest detection and monitoring workshop. USDA Forest Service, Northern Region, Forest Pest Management, Rpt. 95-4. 103 p.

Miller, J.M., 1926. Report of aerial photography as a method of mapping yellow pine areas to show losses caused by bark beetles. Forest Insect Laboratory, Stanford University, CA. (ms.).

Ministry of Forests, 1997. Aerial overview surveys, forest insects and diseases training program, Participant's Guide, British Columbia Forest Service, version 1.1, 71 p.

Unknown, History of the use of aircraft in Forest Service work, USDA Forest Service, Region 1, Missoula, MT. 9 p.

Wear, J.F. and W.J. Buckhorn, 1955. Organization and conduct of forest insect surveys in Oregon and Washington, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, 40 p.

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Aplicación de la Percepción Remota en los Inventarios de Áreas Subtropicales[1]

Eduardo Javier Treviño Garza[2]

Abstract—Existen una amplia gama de aplicaciones de las tecnicas de percepcion remota en los inventarios de ecosistemas. Las areas subtropicales cubiertas por bosques templado secos y matorrales de diversos tipos requiere el uso de materiales obtenidos mediante la percepcion remota como fuente directa de informacion correlacionada directamente con paramentros obtenidos en campo o como herramienta para formar estratos de vegetacion de caracteristicas similares.

Los regimenes hidricos irregulares, las condiciones micro - climaticas particulares y la influencia de las actividades humanas favorecen una gran heterogeneidad dentro de las comunidades vegetales y son determinantes en la diversidad de especies presentes.

En este trabajo se discutiran las aplicaciones de la percepcion remota para el monitoreo de los cambios de uso del suelo, el uso de la misma en inventarios considerados de niveles multiples y su aplicacion para determinar las diversas calidades de sition en bosques semiaridos.

El area en donde se realizó este trabajo se localiza entre los 250004 y los 2401143744 de latitud norte y los 9802142244 y los 99 0584 0144 de longitud oeste, dentro de la llamada Planicie Costera del Golfo Norte y la Sierra Madre Oriental. En ella se desarrolla una vegetacion compuesta por matorrales xerofilos de los tipos Submontano y Espinoso Tamaulipeco, asi como algunas comunidades templadas formadas por bosques de, pino, encino y enciono - pino.

En esta region se han utilizado imagenes de satelite multitemporales y multeispectrales, asi como fotografias aeras para realizar los propositos antes descritos. El monitoreo de los cammbios de uso del suelo se ha realizado a lo largo de un periodo de 23 años utilizando para el efecto el procesamiento digital de imagenes LANDSAT del sensor conocido como barredor multiespectral (MSS) asi como del mapeador tematico (TM).

Dentro de los inventario en niveles podemos considerar los inventarios multietapico y multifasicos. Para la realizacion del primero se utilizó una imagen de satelite para estratificar la vegetacion templada de la subtropical. Sobre cada uno de los estratos diferenciados se extendio una red de muestreo considerando bloques de 1 km. En el caso del multifasico se utilizo una imagen de satelite y dos juegos de fotografias aereas a diversas escalas tomadas con un periodo 1 mes de diferencia para tratar de correlacionar la informacion extraida de cada material con la inforemacion levantada en campo.

En la cartografia de la calidad de sitio de *Pinus cembroides* se utilizo la informacion contenida en un Sistema de Informacion Geograafica como medio de estratificacion digital automatica sobre una imagen de satelite.

Dentro de los resultados se mostrara el indice y tendencias de cambio del uso del suelo y la vegetacion a traves del tiempo, la pertinencia del uso de la percepcion remota en la planeacion y ejecucion de los inventarios forestales, ams como las ventajas de utilizar la informacion cartografica existente almacenada en un Sistema de Informacion Geografica como herramienta de estratificacion dentro de un proceso de clasificacion digital de imagenes.

Las áreas subtropicales secas se locaclizan en el sur de Estados Unidos y el Norte de México. Se caracteriza principalmente poseer una vegetación compuesta por matorrales xerófilos de poca altura y cobertura y en las montañas se presentan bosques. Los regímenes hídricos irregulares, las condiciones micro - climáticas particulares y la influencia de las actividades humanas permiten el desarrollo de un paisaje complejo formado por una gran heterogeneidad de las comunidades vegetales las cuales poseen una riqueza y diversidad de especies tanto vegetales como animales.

La vegetación provee a los habitantes de estas áreas de materiales para construcción o para ser usados en la combustión, así como plantas medicinales.

De manera general esta vegetación es usada como área de pastoreo extensivo para el ganado. El incremento en las necesidades de la población en materia de alimentos ejerce sobre estas regiones subtropicales una fuerte presión que ocasiona que se destruya la vegetación para ser transformadas parte de estas superficies al uso agrícola o ganadero intensivo.

Existen una amplia gama de aplicaciones de materiales obtenidos mediante la percepción remota en los inventarios de ecosistemas. En las áreas subtropicales cubiertas por bosques templado secos de escasa productividad y matorrales de diversos tipos se requiere el uso de estos como fuente directa de información. La cual puede ser correlacionada directamente con parámetros obtenidos en campo o pueden ser usados como herramienta para formar estratos de vegetación de características similares.

Antecedentes

La utilización de imágenes de satélite para la cartografía de la vegetación es una de los más importantes campos de aplicación de la percepción remota. Imágenes de satélite han sido utilizadas por ejemplo, para la cartografía de bosques (Carneiro, 1978; Beaubien, 1979; Bryant et al., 1980; Keil et al., 1987, Benson & De Gloria, 1985), para el reconocimiento de rodales y la identificación de diversos tipos de bosque (Woodcock & Strahler, 1980; Mayer & Fox III 1981; Hafker & Philipson, 1982 Fiorella et al. 1993; Congalton et. Al. 1993), así como para actualizar los mapas de vegetación en

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áreas de vegetación arbustiva (Kelly & Hill (1987), Mc Daniel, R. K., R. H. Hass (1982), Ringrose et al . (1990) y Treviño, E. (1992).)

Otro campo de aplicación del procesamiento de imágenes de satélite se encuentra en regiones con una vegetación tropical o subtropical baja. Mc Daniel & Hass (1982) utilizaron exitosamente imágenes multiespectrales para determinar las condiciones de una asociación vegetal Mezquite - Pastizal.

Las imágenes de satélite pueden cubrir un importante campo de aplicación, dada la posibilidad que tienen para observar los cambios ocurridos en la vegetación y a la capacidad de estos sensores de poder representar periódicamente área geográfica determinada.

A continuación se presentara de manera general las aplicaciones de la percepción remota realizadas en la Facultad de Ciencias Forestales de la Universidad Autónoma de Nuevo León.

Nuestra área de influencia comprende le centro sur de los estados mexicanos de Nuevo León y Tamaulipas. Esta se localiza entre los 26°00´ y los 24°00´ de latitud Norte y los 98°00´ y los 100 °00´ de longitud Oeste, dentro de la llamada Planicie Costera del Golfo Norte y la Sierra Madre Oriental. En un rango altitudinal entre los 0 y 3700 msnm.

En la región se presenta un clima (A) C(x') (w») a(e) (semicalido subhúmedo extremoso) considerando la clasificación de Köppen modificado por García con una precipitación pluvial entre 400 y 1850 mm/año alcanzando valores promedio de aproximadamente 810 mm/año se presentan precipitaciones irregulares todo el año, considerando el mes de septiembre como periodo de lluvias antecedido por un período de sequía estival los meses de julio y agosto. La temperatura media anual es de 22.4C. Con temperaturas extremas superiores a los 40°C en verano e inferiores de 0°C en invierno. La oscilación diaria de la temperatura puede ser superior a los 15°C. En invierno debido a la influencia de masas de aire polar continental se presentan descensos bruscos de la temperatura (heladas) por debajo del punto de congelación.

Los suelos de la región según la clasificación de FAO son Xerosol, Fluvisol, Regosol, Castañozem, Phaeozem y Rendzina.

La vegetación de la región es preponderantemente arbustiva y se puede diferenciar básicamente en tres tipos de matorral:

- Matorral Submontano distribuido en colindancia con la Sierra Madre Oriental en el predominan el especies con alturas entre los 3 y los 6 m, predominando *Helietta parvifolia* (Barreta), *Diospyrus palmeri* (Zapotillo), *Cordia boissieri* (Anacahuita). *Castela texana* (Chaparro amargoso), *Celtis pallida* Granjeno), *Acacia rigidula* (Chaparro prieto).
- Matorral Espinoso Tamaulipeco, comunidad de baja cobertura, dominado por especies espinosas de 2 a 4 metros de altura entre las que se encuentran *Acacia rigidula* (Chaparro prieto),*Acacia farnesiana* (Huizache), *Cordia boissieri* (Anacahuita), *Diospyrus pallmeri* (Zapotillo). En localidades con suelos someros, se presentan asociación de especies de baja altura (0.6 a 1.5 m) compuesta por *Leucophyllum texana* (Cenizo), *Porlieria angustifolia* (Guayacan), *Karwinskia humboldtiana* (Coyotillo)
- Mezquitales comunidades que se desarrollan en suelos profundos, en las que se presenta una asociaciones de especies espinosas compuesta por *Prosopis glandulosa* (Mezquite), *Acacia rigidula* (Chaparro prieto), *Castela texana* (Chaparro amargoso), *Cercidium floridum* (Palo verde).

En la Sierra se encuentran bosque mixtos de Pino encino, de 10 a 18 m de altura compuestos en su mayoría por *Quercus polymorpha, Q. fusiformis, Q.laceyi Q. affinis y Pinus pseudostrobus,y P. teocote* y bosques de encino con alturas de 8 a 15 m de alto *dominado por Quercus polymorpha, Q. mexicana, Q. fusiformis.* En las riveras de los ríos se desarrollan bosques de galería dominados por *Taxodium mucronatum*, *Populus mexicana* y *Salix Nigra* entre otros.

Dentro de las actividades económicamente importantes en la región se cuentan las practicas agrícolas, debido a la baja precipitación en su mayoría las áreas reciben riego. El cultivo de cítricos es de importancia económica, a pesar de cubrir un área menor que los cultivos anuales de maíz, frijol, sorgo y trigo.

Se utilizaron imágenes de satélite LANDSAT obtenidas por dos tipos de sensores del Barredor multiespectral (MSS) correspondientes a los años de 1973, 1980 y 1986 y del sensor mapeador temático (TM) de los años 1988, 1992, 1994, 1996 y 1998. De la misma manera se han utilizado fotografías aéreas convencionales a diferentes escalas, así como imágenes obtenidas por un sistema de videografía sencillo el cual se ha instalado en equipo aéreo del Gobierno del estado de N. L. La compra de estos materiales y la infraestructura necesaria para su proceso y análisis ha sido financiada por proyectos de investigación patrocinados por la Sociedad Alemana para la investigación (DFG), la Sociedad Alemana para la cooperación técnica (GTZ) el Gobierno del estado de Nuevo León y el Consejo Nacional de Ciencia y Tecnología de México (CONACyT), Este ultimo y el Fondo Méxicano para la conservación de la Naturaleza A. C. han patrocinado de la manera los trabajos de levantamiento de información en campo.

Para el procesamiento digital de las imágenes se utiliza el paquete ERDAS (Earth Resources Data Analysis Software) IMAGINE® y ERDAS 7.5., para la formación de un Sistema de Información geográfica se utiliza el Programa ArcInfo® en sus versiones para estación de trabajo y computadora personal.

Metodología Aplicada

Dinámica de cambios de uso del suelo

Se han realizado para el determinar la dinámica en los cambios de uso del suelo un análisis multitemporal de Imágenes de Satélite. Estas imágenes fueron procesadas para lograr un registro geográfico entre ellas. Para determinar el grado de remoción de la vegetación se procesó la información contenida en cada imagen aplicando un análisis de componentes principales. La clasificación se realizó utilizando la información contenida en los dos primeros componentes principales, estos datos fueron procesados utilizando un algoritmo de formación de grupos en los cuales se fijó como 16 el limite máximo de clases a separar.

Los resultados de cada clasificación fueron validados utilizando como referencia los resultados obtenidos en una interpretación visual de imágenes de satélite impresas y de fotografías aéreas. Las clases obtenidas fueron ordenadas en 4 clases temáticas finales. Estas fueron a) agricultura, b) vegetación, c) agua y sombras, d) suelo desnudo.

Inventario Forestal

Dentro de los inventario forestal de grandes extensiones se ha empleado las imágenes de satélite para estratificar la vegetación utilizando una interpretación visual de las mismas, así como de fotografías aéreas.

Por otra parte se han aplicado inventarios de varios niveles entre los que podemos considerar los inventarios multietapico y multifásicos.

Para la realización del primero se utilizó una imagen de satélite para estratificar la vegetación subtropica considerando bosques templados secos y matorrales. Sobre cada uno de los estratos diferenciados se extendió una red de muestreo considerando bloques de 1 km. por 1 km. Estas unidades de muestreo consideradas Unidades Primarias de Muestreo (UPM). De ellas se seleccionaron al azar un numero determinado. En cada UPM se seleccionaron sitios de manera aleatoria considerados como Unidades Secundarias de Muestreo (USM). Con este mustreo se puede obtener la variabilidad dentro tanto dentro de las UPM como entre estas.

En el caso del multifásico se utilizó una imagen de satélite y dos juegos de fotografías aéreas a diversas escalas tomadas con un periodo 1 mes de diferencia para tratar de correlacionar la información extraída de cada material con la información levantada en campo. Siguiendo la siguiente secuencia metodológica:

1. Estratificación utilizando un SIG
2. Selección de sitios en Imagen de Satélite
3. Selección de sitios en Fotografías aéreas vuelo alto (Fotointerpretación)
4. Selección de submuestra en fotografías aéreas vuelo bajo (Fotogrametría)
5. Inventario de campo

Cartografía de Calidades de Sitio

En la cartografía de la calidad de sitio de *Pinus cembroides* se marco como objetivo el aprovechar la información contenida en la cartografía de la vegetación y uso del suelo existente, para definir y actualizar la cartografía de las comunidades de *Pinus cembroides* un utilizando Sistema de Información Geográfica.

Los bosques de pino piñonero (*Pinus cembroides*) son importantes en la región debido a la producción de la semilla, la cual se comercializa con fines alimenticios.

El área de estudio se encuentra localizadas en el sur del estado de Nuevo León, México. Para esta región se ha elaborado de manera sistemática un Sistema de Información Geográfica conteniendo entre otros temas una cubierta digital con la información de la carta de uso del suelo y vegetación generada por el Instituto Nacional de Estadística Geografía e Informática por medios fotogramétricos y de fotointerpretación en la década de los setentas.

Se realizó un análisis en esta cubierta para determinar todas las áreas de *Pinus cembroides* considerando los polígonos de bosque de pino que cumplieran con los criterios de distribución de la especie.

Esta información se utilizó como datos adicionales en el procesamiento digital de una imagen de satélite LANDSAT TM obtenida en julio de 1994. Esta imagen se clasifico utilizando un método supervisado considerando únicamente las superficies forestales, para ello la imagen fue procesa utilizando los datos contenidos en el Sistema de Información Geográfica para obtener una mascara forestal

Resultados

Dinámica de Cambios de Uso del Suelo

En el año de 1973 las Areas abiertas (áreas agrícolas, de pastizales y suelo desnudo) ocupaban aproximadamente el 20 % de la superficie del municipio según el análisis de los resultados obtenidos al considerar la cartografía de la vegetación y uso del suelo, así como el mapa obtenido usando procesamiento digital de las imágenes.

El año de 1983 se construyó la presa José López- Portillo (Cerro Prieto) la cual incrementa las superficies del municipio cubiertas por cuerpos de agua, (correspondiendo al área de riego entre un 1 y un 4 %) Las superficies abiertas reportadas en la tabla muestran un incremento de 16.76% en 19 años (1973 a 1992) y de 17.23 en 21 (1973-1994). En 1988 las superficies agrícolas se encontraron cubiertas por agua, nubes o sombras producidas por las secuelas del Huracán Gilberto, que azoto la región.

La superficie ocupada por vegetación se redujo en un 12.28 % entre 1973 y 1988 con una taza de perdida anual de 0.81%, y en un 10.03 % entre 1988 y 1994 lo que equivale a una perdida en superficies de 1.25%. Considerando esto se puede observar que con el paso del tiempo se incrementa la taza de remoción de la vegetación.

Tabla 1:—Uso del Suelo de los años 1973, 1988 y 1994 obtenidos de la clasificación digital de imágenes LANDSAT.

	1973	%	1988	%	1994	%
A. abiertas	63,700	22.18	55,259	19.24	109,175	38.00
Vegetación	221,453	77.09	185,935	64.72	157,118	54.69
Agua	2,098	0.73	12,026	4.19	2,538	0.88
Suelo desnudo			19,165	6.67	18,435	6.42
Nubes			4,768	1.66		
Sombras			10,122	3.52		

Se puede corroborar efectuando un análisis espacial de la distribución de la vegetación que en algunos casos es suspendido el uso de algunas superficies abiertas a actividades agrícolas o pecuarias, debido principalmente a la baja producción de las tierras de agricultura de temporal (secano) ó al mal manejo de los pastizales. Estas superficies son ocupadas por diferentes etapas de sucesión de la vegetación. Los secuencia de los cambios observados son:

Vegetación primaria - Area agrícola - vegetación secundaria
Vegetación primaria - Pastizal - Vegetación Secundaria
Area agrícola - vegetación secundaria
Pastizal - Vegetación Secundaria.

Considerando el total de las superficies abiertas a través del tiempo podemos aseverar que el porcentaje de vegetación que no ha sufrido de una remoción total a través del tiempo se limita a menos de un 40% de la superficie total del municipio, y se restringe a áreas con difícil acceso en las montañas y en lomerios con suelos someros. La figura 1 muestra la distribución de la vegetación en el municipio en 1973 y 1994.

Inventario Forestal

Se determino para la zona de estudio el área ocupada para cada una de las clases a ser consideradas en el inventario de vegetación utilizando la interpretación visual de imágenes de satélite, a continuación se presenta la relación clase - área.

Clase	Superficie en hectáreas
Bosque	13,533.83
Matorral cerrado	303,532.72
Matorral abierto	33,364.24
Pastizal	1,066.60
Areas Agrícolas	41,501.23
Areas sin vegetación aparente	2,954.45
Total de área considerada	395,953.07

Para el bosque se levantaron 7 Unidades Primarias de Muestreo y 20 Unidades Secundarias de Muestreo en ellos se registraron 5683 individuos y en el matorral se le levantaron 12 Unidades Primarias de Muestreo y 36 Unidades Secundarias de Muestreo en ellos se registraron 16383 individuos. En total se determinaron 340 especies pertenecientes a 61 familias.

Cartografía de calidades de sitio.

Los resultados de la clasificación muestran la distribución espacial de los bosques de *Pinus cembroides* según su densidad., los bosques cerrados y densos se distribuyen básicamente en las laderas con exposición sur y sudoeste.

Las superficies estimadas para las diferentes clases se presentan en la tabla 2, predominan en el área los bosques semidensos, ocupando un 45% del área de estudio.

Tabla 2.—Superficies estimadas en la clasificación digital.

Clase	Hectareas	Porcentaje
Cerrado	7,148.312	33.30
Denso	1,502.688	7.00
Semidenso	9,753.875	45.44
Abierto	2,789.438	12.99
Suelo	272.562	1.27
Totales	21,466.875	

Conclusiones

La utilización de imágenes de satélite ha permitido demostrar la influencia del hombre y sus actividades en la región, la cual se ve reflejada en algunos casos en la destrucción total de la vegetación con fines agrícolas, estando sujeta las superficies remanentes a una constante degradación, causada principalmente por actividades pecuarias que afectan la vegetación por el ramoneo y pastoreo de ganado bovino y caprino, sin excluir las actividades de recolección de leña y madera para construcción realizadas por los pobladores, estas actividades producen efectos irreversibles en la composición y estructura vegetal (Heiseke y Foroughbakhch 1985, 1990 Jurado, E. y Reid, N. (1989).

El clima es determinante en la evolución de las actividades humanas en la región, varios años de lluvias escasas producen el abandono de áreas abiertas a actividades agrícolas lo que ocasiona que se inicien procesos de revegetación los cuales presentan varias tendencias tanto en patrones de estructura como de composición de vegetación.

El procesamiento digital de imágenes es útil para determinar los impactos relacionados con los cambios de uso del suelo. En este trabajo se utilizó una clasificación no supervisada. Por una parte ésta se aplicó a la información derivada un análisis de los componentes principales de los datos originales de las imágenes, éste análisis reduce la dimensionalidad de los datos, reduciendo la heterogeneidad de la respuesta espectral de la vegetación y permite realizar la clasificación de manera semi - automática. Éste mismo análisis por otro lado se utilizó sobre datos originales de las imágenes, en los cuales se trabajo sobre áreas especificas sometidas a riego. Esto permitió el trabajar solo con pocas clases temáticas considerando sus diversas clases espectrales. Para el análisis de grupos con datos obtenidos del ACP se trabajo con un máximo de 16 clases utilizando una imagen completa, en cambio con los datos originales se tuvo que considerar 27 clases para poder clasificar todas las variantes espectrales. Ambos métodos presentan sus ventajas, la variación se presenta principalmente en tiempos de preparación del material para el proceso.

Los resultados obtenidos muestran el incremento en las superficies ocupadas por agricultura y la evolución del pasaje. El Monitoreo de estos cambios aunado a investigaciones que se realizan paralelamente a este trabajo permitirá modelar el desarrollo a futuro de esta región.

Los materiales provenientes de la percepción remota han demostrado su utilidad con respecta a la distribución de la muestra en la realización de Inventarios forestales y de la vegetación. El uso del inventario multietapico permitió concentrar la muestra y por ende reducir costos en el levantamiento de la información de campo.

El muestreo multifasico permitió correlacionar la información contenida en diversos materiales para reducir el numero de muestras levantadas en campo.

En el campo del manejo de los recursos naturales es cada día más frecuente la implementación de Sistemas de Información Geográfica con el fin de tener a disposición la información necesaria para la toma de decisiones. Esta información proviene en su mayoría de cartografía antigua que no refleja en ocasiones la magnitud de los problemas. La periodicidad de la toma de imágenes desde el espacio es la solución a los problemas de actualización de la información, Los analistas de imágenes deben utilizar la información contenida en el Sistema de Información Geográfica, para establecer criterios objetivos que faciliten el proceso digital de imágenes y por ende la generación de nueva información.

El estratificar la vegetación, para formar grupos homogéneos, es una practica usual en la elaboración de inventarios forestales, al aplicar este método sobre la información contenida en las imágenes de satélite se logra el objetivo de reducir la variabilidad de los datos y aumentar la eficiencia en el muestreo (selección de áreas de entrenamiento).

Una desventaja al formar estratos la constituye la posibilidad de incluir de manera errónea un objeto en un grupo que no le corresponde. El manipular digitalmente la información que contiene los criterios de estratificación (en este caso la cubierta digital de vegetación), elimina en cierta medida la subjetividad individual del analista, por ser más sencillo aplicar los criterios de separación de los estratos a través de un programa de computo, que hacerlo interpretando directamente los datos.

La ventaja de la estratificación pre - clasificación es el trabajar solo con las clases de interés, facilitando el análisis de los resultados al concentrar la atención en áreas especificas y por otro lado el aprovechar la información existente para las zona, aunque esta se encuentre desactualizada.

El conocimiento de la dinámica de uso de los recursos naturales de una región permite por un lado, optimizar la utilización de los recursos sin destruirlos, evitando así la perdida de la diversidad biológica y la aceleración de los procesos de desertificación y posibilita por otro el aumentar el bienestar de los pobladores de la región.

Literatura Citada

Beaubien, Jean.(1979) : Forest type mapping from Landsat digital data. Photogrammetric Engineering and Remote Sensing, Vol. 45, No. 8, pp 1135-1144.

Benson, A. S., De Gloria, S. D. (1985) : Interpretation of Landsat thematic mapper and multispectral scanner data for forest surveys. Photogrammetric Engineering and Remote Sensing, Vol. 51, No. 9, pp 1281-1289,.

Bryant, E., Dodge, A. G., Warren, S. D. (1980) : Landsat for practical forest type mapping: A test case. Photogrammetric Engineering and Remote Sensing, Vol. 46, No. 12, pp 1575-1584.

Carneiro, C.M.R. (1978) : Forest cover mapping from Landsat-MSS Data by analoge and computer assisted thecniques in the Federal Republic of Germany. Dissertation, Forstwissenschaftliche Fakultät, Freiburg.

Congalton, R.G., Green, K., and Teply, J. 1993. Mapping Old Growth on National Forest and Park Land in the Pacific Northwest from Remotely Sensed Data. Photogrammetric Engineering and Remote Sensing Vol. 59, No. 4, pp 529-535.

Fiorella, M., and Ripple, W.J. 1993. Determining Successional Stage of Temperate Coniferous Forest with Landsat Satellite Data. Photogrammetric Engineering and Remote Sensing Vol. 59, No. 2, pp 1383-1380.

Foroughbakhch, R. y Heiseke, D. (1990) Manejo Silvícola del matorral, raleo, enriquecimiento y regeneración controlada. Fac. de Ciencias Forestales, U.A.N.L., Linares N.L. México. Reporte Científico No. 19. 28 pp

Hafker, W., Philpson, W. R. (1982) : Landsat detection of hardwood forest clearcuts. Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 5, pp 779-780.

Jurado, E. y Reid, N. (1989) Influencias de factores edaficos, topográficos y perturbación sobre el matorral espinoso tamaulipeco en Linares, N.L. Fac. de Ciencias Forestales, U.A.N.L. México. Reporte Científico No. 10. 29 pp

Mayer, K., Fox Iii, E. L. (1981) : Identification of conifer species grouping from LANDSAT digital classifications. Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 11, pp 1607-1614

Treviño Garza, E. J., 1992 «Verwendung von Satellitenaufnahmen zur Vegetationkartierung am Beispiel der Region «Sierra Madre Oriental» in Nordostmexiko». Göttinger Beiträge zur Land- und Forstwirtschaft in der Tropen und Subtropen, Heft 68, 150 p. ISBN 3-88452-724-X

Treviño, E. (1992).Verwendung von Satellitensufnahmen zur Vegetationskartierung am Beispiel der Region Sierra Madre Oriental in Nordostmexiko.Gottinger Beitraege zur Land und Forstwirtschaft in den Tropen und Subtropen, Goettingen, Germany, Heft 68, 119 pp. ISBN 3-88452-724-X

Treviño, E., Akça, A. Navar, J, J. Jiménez, O. Aguirre (1996) Detection of Land Use Changes by Satellite Imagery in the Municipality of Linares, N.L., Memories of the Fifth International Conference on Desert Development, Texas Tech University. Loobok, TX . 7 pp

Real Time AVHRR Detection of Forest Fires and Smoke in Mexico Between January and June 1998[1]

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Abstract—Using satellite imagery, the whole forest regions of Mexico are extensively studied to monitor fires and smoke during the 1998 biomass burning season. The spatial and temporal distribution of fires are examined. Although most of Mexico suffered from forest fires, the largest number of correlated pixels are located in the states of Chiapas (4,394, only during May), Durango (4,363, March to June), Jalisco (3,414, January to March and May), Guerrero (2760, March-May) and, Oaxaca (2093, April-May). The largest number of fires occurred in May and haze and smoke covered most of the country, the Gulf of Mexico and the southern part of the United States.

We propose a multispectral detection method that operates in real time. It works on the imagery received before sunrise and after sunset. A flag is shown together with fire coordinates. At present the method depicts all kind of biomass burning including controlled straw and stubble burning for agricultural purposes.

Forest fires occur in Mexico every year between December and August during the dry season. Usually forest fires peak on April (Rodríguez-Trejo, 1996). Data for the period 1980-1997 indicate a yearly average of 6,837 forest fires with a damaged surface of 223,114 ha, i.e., about 33 ha/fire. More than 80% of forest fires correspond to shrubs and scrubs (SEMARNAP, 1998). Although most of forest fires (97%) are due to human negligence or deliberate action, however natural calamities such as hurricanes or the El Niño/Southern Oscillation (ENSO) events contribute to accumulate enormous amounts of dry organic matter. These conditions are associated on the next year to a temporal drought now called La Niña (SEMARNAP, 1998). In fact, Table 1 data shows that the largest number of forest fires occur the year after ENSO events. The previous maximum number of fires for the period 1980-1997 happens to be 1988.

The necessary and sufficient conditions for the development of forest fires were provided by the ENSO event of 1997-98, considered as the most intense of this century, namely: A very severe drought in most of the country associated to out of records high temperatures and strong winds. Maximum temperature for Mexico during the 1998 dry season was higher than the maximum temperature for the period 1941-1997. The burning for agricultural purposes produced also many uncontrolled fires. In spite of the different actions taken to reduce the forest fires risk, the final balance from January to June, indicates 14,302 fires affecting 583,664 ha (0.4% of the total forest surface). 73% corresponded to grazing land, shrubs and scrubs. 27% corresponded to forest burning in different degrees (i.e., 0.3% of the total forest surface). The average is 40.81 ha/fire, that is about 20% higher than the average for the period 1980-1997.

Satellite data have been used increasingly during the past few years to examine burning in remote places. One of the primary sensors on board the NOAA series of polar orbiting satellites is the Advanced Very High Resolution Radiometer (AVHRR). This scanning instrument acquires data in five spectral channels, one in the visual range (0.58 £ l £ 0.68 mm), one in the near infrared range (0.725 £ l £ 1.1 mm) and three in the thermal range (3.53- 3.93, 10.3-11.3 and 11.5 – 12.5 mm). Data are sensed by all five channels simultaneously. The instrument has full resolution of 1.1 km at nadir.

Although fire detection using satellite data comes back to 1977 when Croft (1977, 1978) presented views of agricultural burning in central Africa, the theory of fire monitoring using channel 3 was developed by Dozier (1981) and Matson et al., (1987). At present improvements on fire detection

Table 1.—Forest fires in Mexico, 1980-1997*

Year	Number of fires	Area covered (ha)	Area / Fire (ha)
1980	4,242	110,709	26
1981	2,740	67,228	25
1982**	5,599	137,669	25
1983**	6,087	272,000	45
1984	6,120	236,032	39
1985	4,386	152,224	35
1986**	8,482	290,815	34
1987**	9,263	287,347	31
1988	10,492	518,286	47
1989	9,946	507,471	51
1990	3,443	80,400	23
1991**	8,621	269,266	31
1992**	2,829	44,401	16
1993	10,251	235,020	23
1994**	7,830	141,502	18
1995**	7,860	309,097	39
1996	9,256	248,765	27
1997**	5,163	107,845	21

*Dirección General Forestal, Subsecretaría de Recursos Naturales. SEMARNAP, 1998
**ENSO events

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.
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methods are made introducing temperature thresholds outlined for channel 3 temperatures with respect to channel 4 temperature (Christopher et al., 1998). Similarly, a technique to estimate satellite-derived burning areas is now in use (Cahoon et al., 1992). In what follows we present a multispectral method of forest fire detection. The method aims a more complete description of burning and smoke identification, geolocation, and area estimation. This method is applied for detection of the 1998 Mexican forest fires. All AVHRR channels are used in order to have a more complete description of burning and the smoke plume

Data and Methods

Since April 1994 we have in operation a real-time NOAA polar-orbiting satellite ground receiving station. The AVHRR LAC images from NOAA-12 and NOAA-14 are used in this analysis to map fires and smoke.

A) Fire Dectection

To locate forest fires it is necessary to determine the geographical coordinates from any pixel in the image located by its row, or scan line number S and within the scan line by its column, or pixel number P. The geolocation process, i.e., the identification of the values of W (longitude) and N (latitude) for each pixel (S,P) is electronically made through a third order polynomial function.

Channels 1 and 2 data identify smoke loading and surface characteristics. Channel 3 data provide information during night on fires as "hot spots" (Matson et al., 1987). Surface temperature in the fire neighborhood is determined using channels 4 and 5 data.

Several detection schemes are used, however, these methods are dependent on local conditions, a method applicable over the Amazon was developed by Kaufman et al. (1990), recently this method is improved by Christopher et al. (1998). The method here used is adapted to local features. A pixel is classified as fire if the following conditions are met:

1. $T3 \geq T3_{min}$, where T3 is the AVHRR channel 3 temperature, $T3_{min}$ @ 299 K. It ensures that false hot pixels are counted as biomass burning.
2. $T3 \geq T4 + 10$, where T4 is the AVHRR channel 4 temperature. It ensures that the hot bare soils are not confused as fire pixels.
3. Albedo $A1 <$ Albedomax (2-4%), this is a masking procedure to avoid pixels having a high albedo due to clouds and ground features. This condition is applied to NOAA 12 images received both near to sunset and sunrise.
4. $268 < T4 < 303$ K, this condition discriminates false "hot points" such as water, water clouds over land, hot rocks, active volcanoes, etc.

B) Image Composition

Forest fires points overlay on a visible image (channel 1 + channel 2). Channel 2 offers more ground features and it is more transparent to aerosol. The combination of both channels produces a compensated image with a clear smoke plume over ground features.

Since fires can be considerably smaller than the maximum resolution (~1.1 km by 1.1 km) the data set needs to be corrected in order to obtain subpixel size high-temperature sources. Other necessary correction is the removal of water bodies temperatures initially identified as "hot points" determined with channel 3 data.

The number of pixels with forest fires is distributed for each month in a matrix array. Each row number corresponds to the day of the month and the column number contains its geographical coordinates distributed by states.

Finally, a multispectral data set is constructed containing all forest fires and the smoke detected in Mexico from January to June 1998.

Results

The total number of pixels per month and state is shown in Figures 1 to 6. It is noticeable that from January to April the total pixel average per month was from 27 to 90, however for May it went to 652 to decay in June to 100.

The first five places for the maximum number of fires per state is shown in Table 2. Whereas the temporal forest fire distribution from January to June 1998 is shown in Table 3.

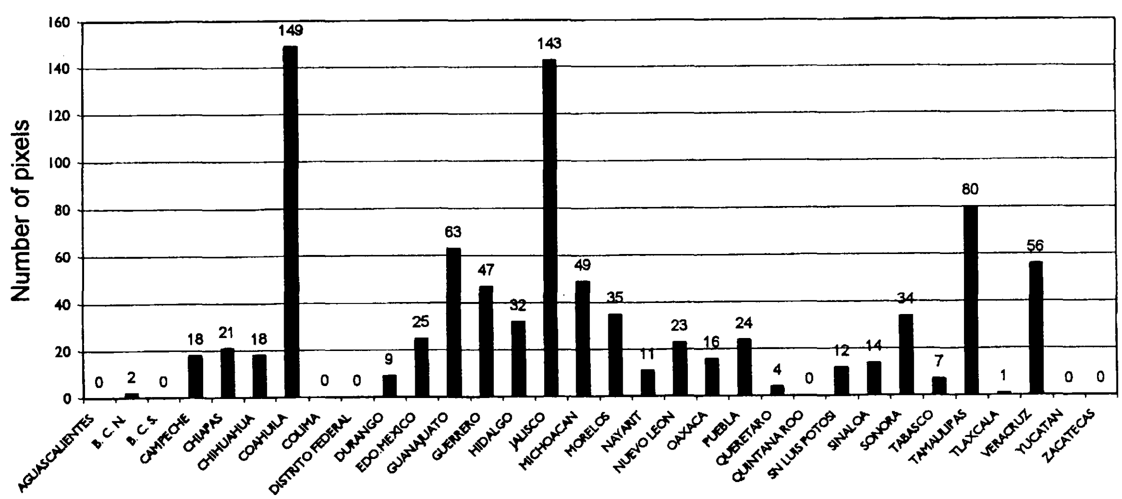

Figure 1.—Forest fires per state detected on real time using AVHRR channel 3 data. January 1998

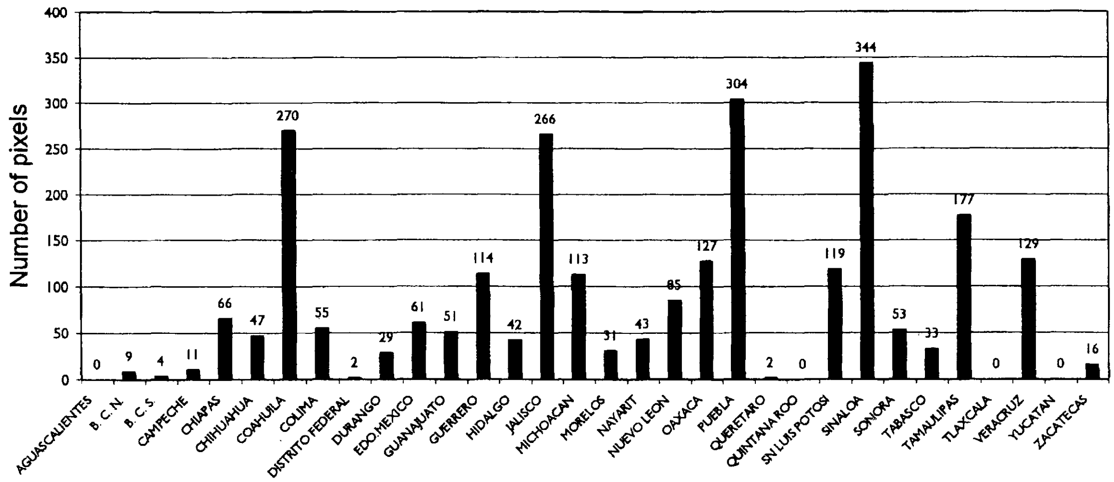

Figure 2.—Forest fires per state detected on real time using AVHRR channel 3 data. February 1998

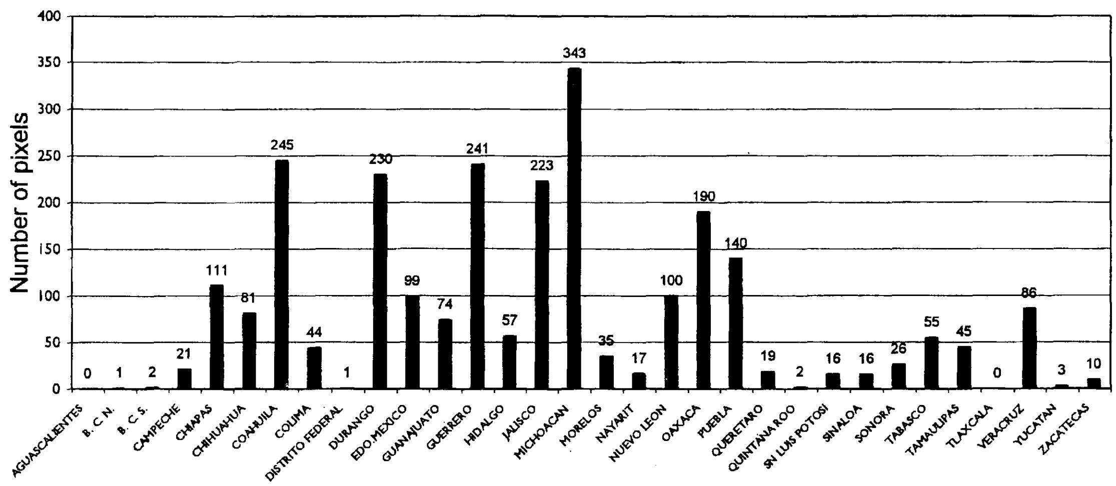

Figure 3.—Forest fires per state detected on real time using AVHRR channel 3 data. March 1998

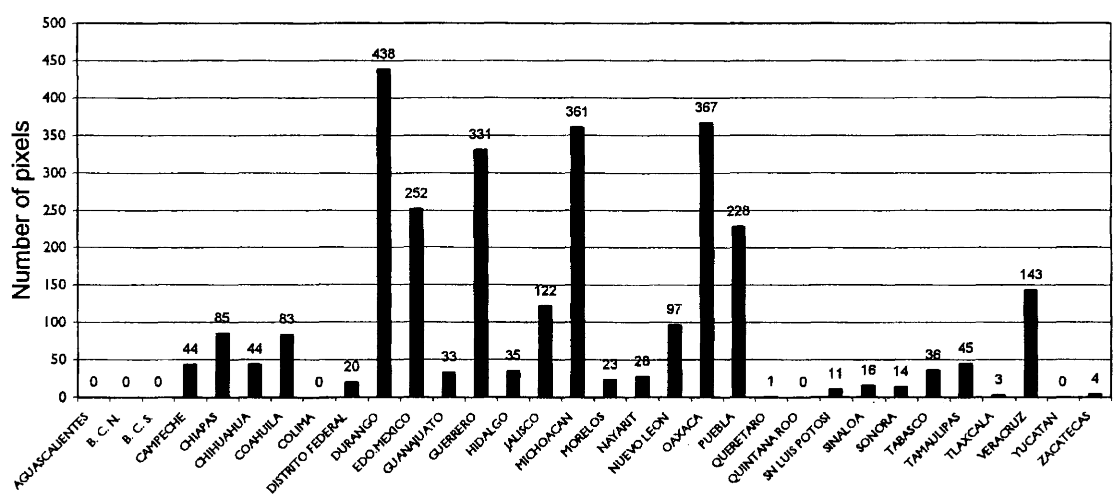

Figure 4.—Forest fires per state detected on real time using AVHRR channel 3 data. April 1998

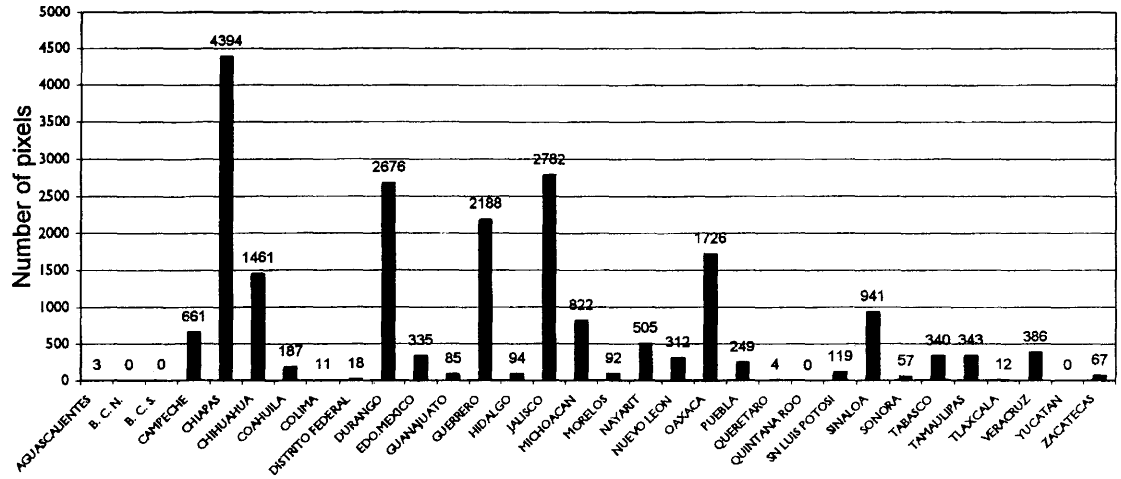

Figure 5.—Forest fires per state detected on real time using AVHRR channel 3 data. May 1998

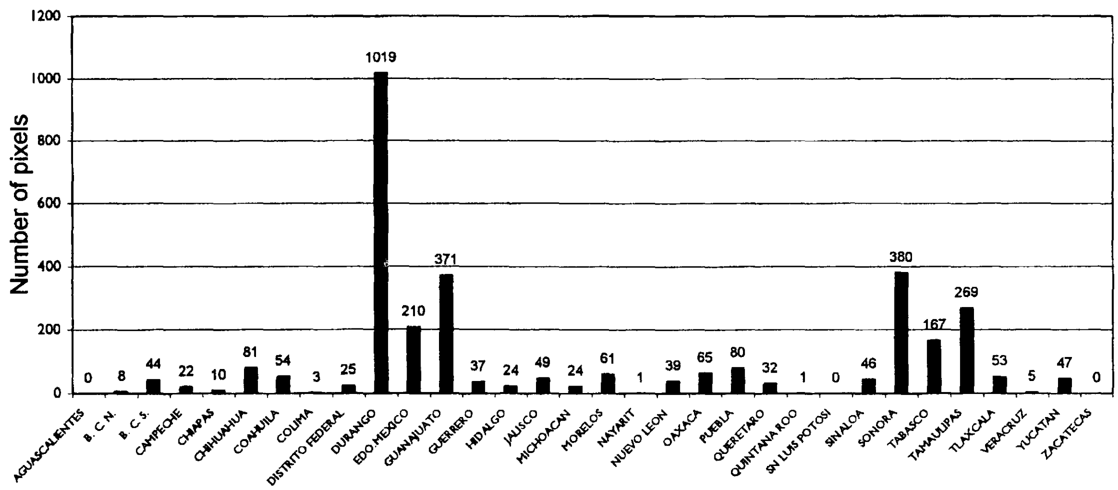

Figure 6.—Forest fires per state detected on real time using AVHRR channel 3 data. June 1998

Table 2.—Maximum number of fires per state during the 1998 dry season.

January		February		March		April		May		June	
No. of Pixels											
Coahuila	149	Sinaloa	344	Michoacán	343	Durango	438	Chiapas	4,394	Durango	1,019
Jalisco	143	Puebla	304	Coahuila	245	Oaxaca	367	Jalisco	2,782	Sonora	380
Tamaulipas	80	Coahuila	270	Guerrero	241	Michoacán	361	Durango	2,676	Guanajuato	371
Guanajuato	63	Jalisco	266	Durango	230	Guerrero	331	Guerrero	2,188	Tamaulipas	269
Veracruz	56	Tamaulipas	177	Jalisco	223	Edo. de México	252	Oaxaca	1,726	Edo. de México	210

Table 3.—Temporal distribution of forest fires during the 1998 dry season.

Month	Total number of pixels
January	893
February	2,603
March	2,533
April	2,864
May	20,870
June	3,227
Total	32,990

The geographical distribution of all the detected forest fires in Mexico determined from AVHRR data from January to June 1998 is shown in Figure 7.

Figure 8 shows a composite image depicting fire points and the haze and smoke layer originating in the Southeast from Mexico and Central America spreading over the Gulf of Mexico. Smoke trajectories are conformed according with the wind pattern. Figure 9 shows the alignment of smoke plumes from fires detected on February 28, 1998 where wind blows northeast.

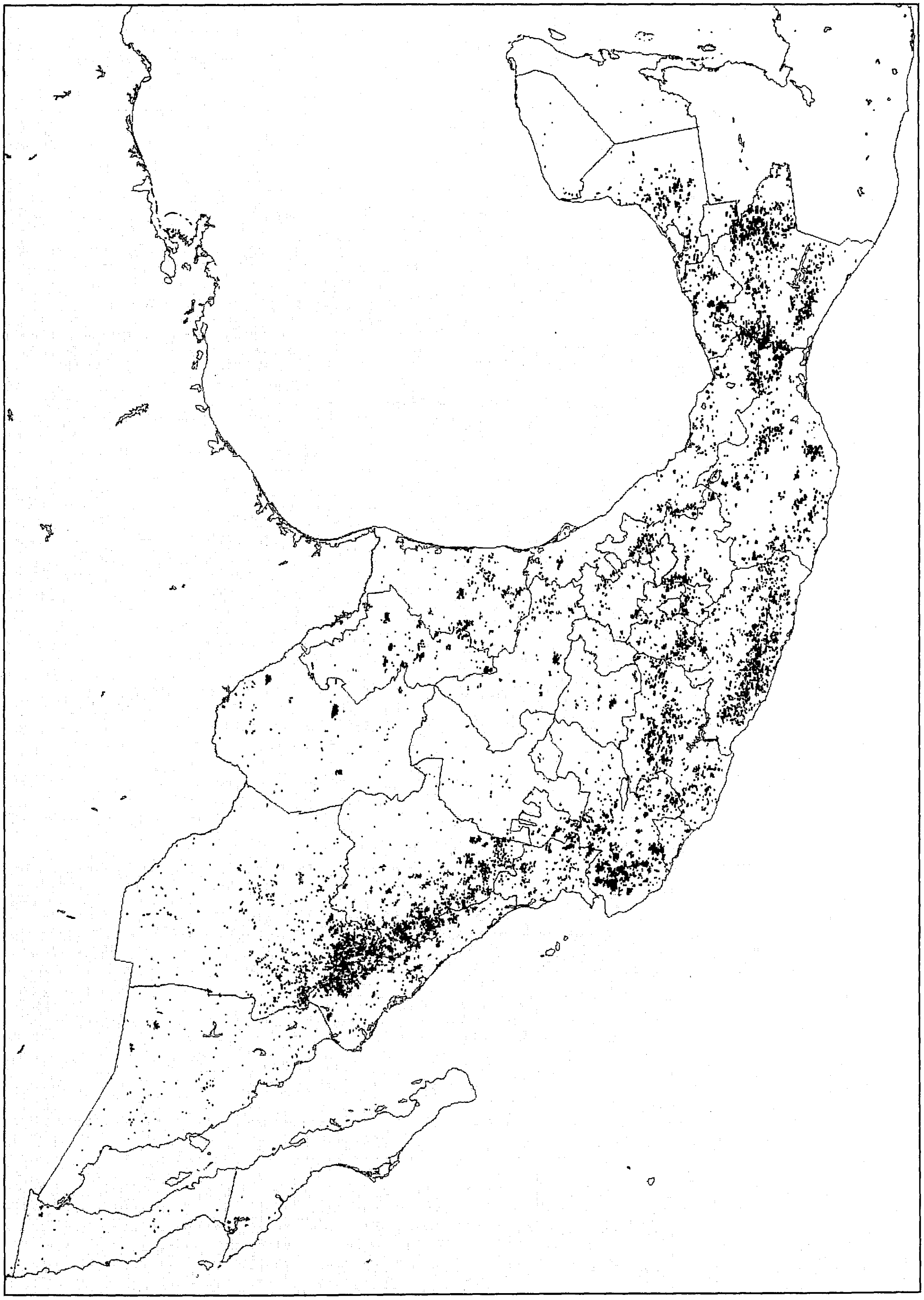

Figure 7.—Geographical distribution of forest fires in Mexico detected from AVHRR data. January to June 1998

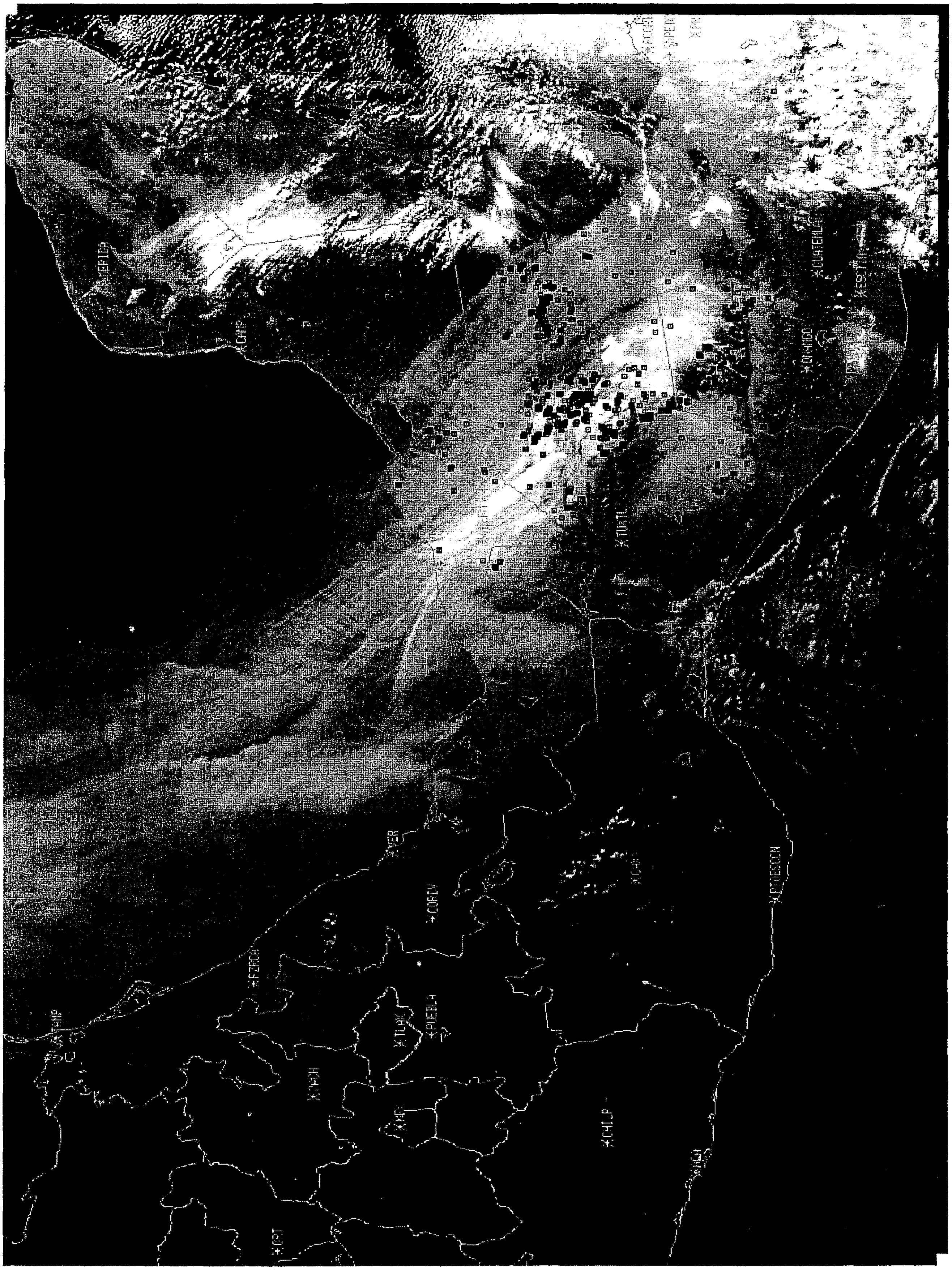

Figure 8.—Composite image (AVHRR channels 1 + 2, 3 and 4) showing forest fires (dot points) and the smoke layer spreading over the Gulf of Mexico. May 8, 1998.

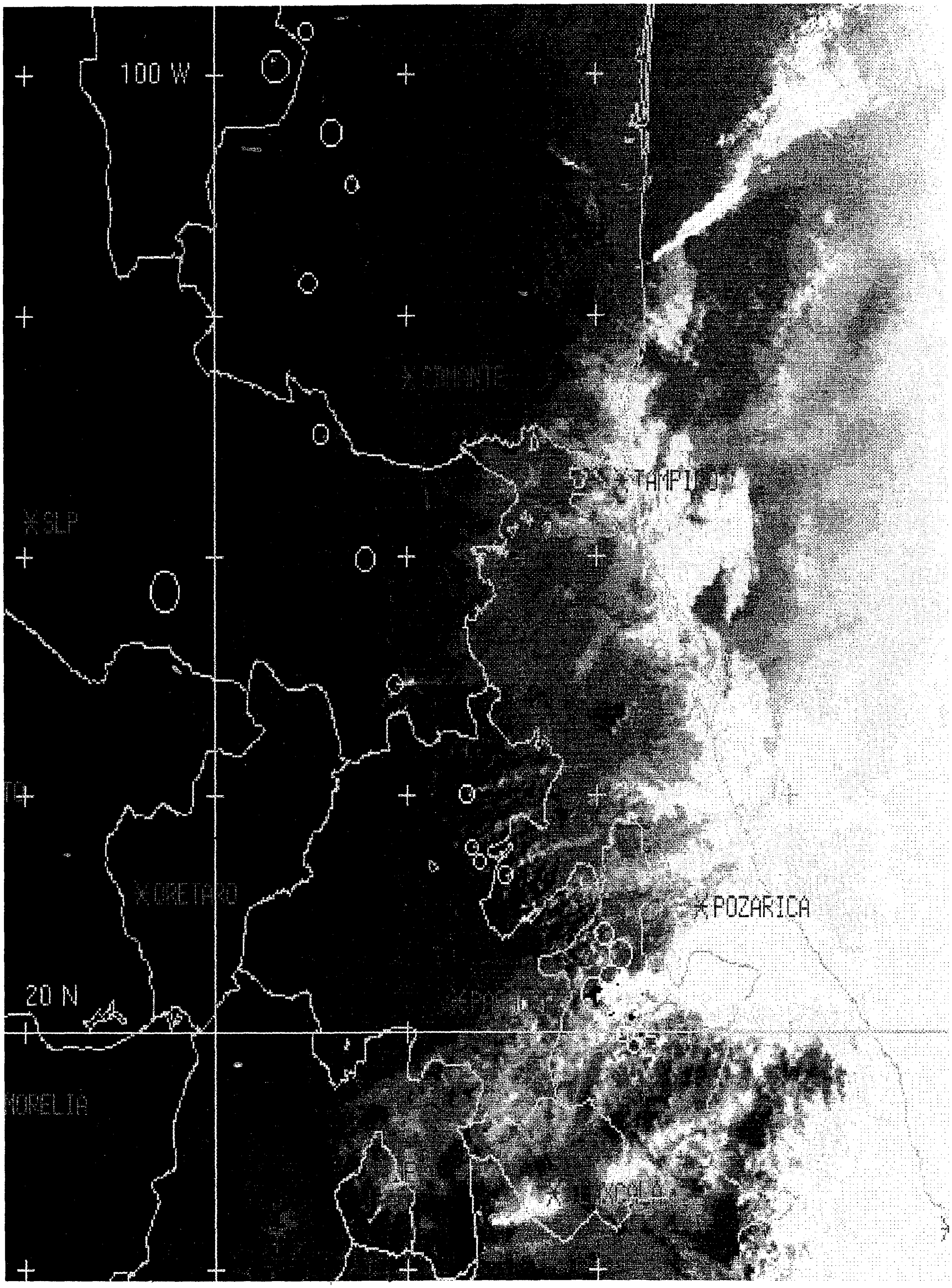

Figure 9.—Composite image (AVHRR channels 1 + 2, 3 and 4) showing forest fires (circles) and the alignment of the smoke plumes in NE direction. February 26, 1998.

Conclusions

1. From January to June 1998 were recorded in Mexico 14,302 fires affecting 583,664 ha (0.4% of the total forest surface). 73% corresponded to grazing land, shrubs and scrubs. 27% to forest burning in different degrees (i.e., 0.3% of the total forest surface). The average is 40.81 ha/fire, that is about 20% higher than the average for the period 1980-1997.

2. A unique AVHRR data set containing the geographical and temporal distribution of burning for Mexico (January-June, 1998) is now ready for analysis and assessment of the impacts on the biodiversity and the effects of smoke on the regional radiation balance.

3. The largest number of fires occurred in the states of Chiapas, Durango, Jalisco, Guerrero, and Oaxaca.

4. Burning reached a maximum in May covering most of the country. The smoke reached the Gulf of Mexico and the southern part of the United States.

5. The forest fire detection method is now operational, it works on real time basis.

Acknowledgments

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References

Cahoon, D.R. Jr., Stocks, B., J., Levine, J.S., Cofer III, W.R., and Chung, C.C., (1992): Evaluation of a Technique for Satellite-derived Area Estimation of Forest Fires. *J. of Geophys. Res.*, 97 D4, 3805-3814.

Christopher, S.A., Wang, M., Berendes, T.A., Welch, R.A., and Yang, S.K., (1998): The 1985 Biomass Burning Season in South America: Satellite Remote Sensing of Fires, Smoke, and Regional Radiative Energy Budgets. J. Appl. Meteorology, 37, 661-678.

Croft, T.A., (1977): *Nocturnal images of the earth from space* (Order Number 68197) (Reston, Virginia: U.S. Geological survey). Cited in Cracknell, A.P., *The Advanced Very High Resolution Radiometer (AVHRR)*. Taylor and Francis, London, pp. 534

Croft, T.A., (1978): Night-time images of the Earth from Space. *Scientific American*, 239, No. 1, 68-79. Cited in Cracknell, A.P., *The Advanced Very High Resolution Radiometer (AVHRR)*. Taylor and Francis, London, pp. 534

Dozier, J., (1981): A method for satellite identification of surface temperature fields of subpixel resolution. *Remote Sensing of Environment,* 11, 221-229.

Kaufman, Y.J., Tucker, C.J., and Fung, I. (1990): Remote sensing of biomass burning in the tropics. *J. Geophys. Res.*, 95, 9927-9939.

Matson, M., Stephens, G., and Robinson, J. (1987): Fire detection using data from the NOAA-N satellites. *Int. J. of Remote Sensing,* 8, 961-970.

Rodriguez-Trejo, D. (1996): Incendios Forestales. Universidad Autónoma de Chapingo y Mundi-Prensa, México. pp 167-170.

Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP) (1998): Los incendios forestales en México, 1998. 36 pp.

ECADS—A Multi-Resource Database and Analytical System for Ecosystem Classification and Mapping[1]

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Abstract—ECADS is an acronym for the "Ecosystem Characterization and Description System," a series of PC-based relational databases and analytical software for multi-scale ecological assessments. Specifically, the system contains databases for multi-intensity sampling of various ecosystem components (e.g., vegetation, soil, streams, wildlife, and topography) at the site or plot scale. Ecosystem analysis programs are also included to access such data and produce standard reports, statistical summaries, and resource value interpretations for plots or plot groupings (i.e., classifications). Program outputs may be used to describe different types of classifications (e.g., existing vegetation, potential vegetation, soil, and stream types) in a series of databases; these in turn, are linked to another series of databases which describe digital thematic maps. Because ECADS is hierarchically designed, map attributes can be rapidly updated using site-level inventory data and ecological classification information. This functionality makes ECADS a powerful tool for integrated ecological assessments and land use planning.

Assessment of landscape condition, health, or integrity involves the description of biotic and abiotic variability over multiple spatial scales (Jensen et al. 1998). Additionally, environmental processes that control patterns of species and community distributions must be described (Margules and Austin 1991). Such characterizations of ecosystem pattern-process relations require consistency in the information used to describe field sites, ecological classifications, and ecological mapping units (Jensen et al. 1996). Accordingly, consistent database structures and analytical systems are required for natural resource information if they are to be used efficiently in landscape evaluation (Margules and Austin 1991, FGDC 1998, Ford et al. 1994, 1997).

A common obstacle to many ecological assessment efforts is the lack of standard systems for the collection, storage, and analysis of natural resource information (National Research Council 1994, RISC 1983). For example, vegetation and other environmental data from most ecological studies are rarely collected in a similar manner; as a result, their use is limited in broad-level assessments of ecosystem health or condition (Bastedo and Theberge 1983, Stolgren and Quinn 1992). Collecting data without standard protocols also inhibits coordinated analysis of resource information between disciplines, and commonly increases costs because repeated visits to sampling sites often are required for multi-disciplinary analysis.

In 1985, the Ecology Staff of the USDA-Forest Service, Northern Region, recognized the need to develop a standard set of sampling procedures, databases, and analytical systems for multi-disciplinary use in the inventory and monitoring of vegetation patterns. The sampling methods and related computer software developed by this group were called ECODATA (Keane et al. 1990) and were subsequently expanded to include other resource information such as soil and stream data (Jensen et al. 1994) on a USDA-Forest Service mainframe computer platform. To facilitate ECODATA's use by a wider audience, this system was modified to operate on a PC-based platform. This revision was named the Ecosystem Characterization and Description System (ECADS). In this paper, we present a brief description of the database design, functionality, and some of the analytical capabilities of ECADS.

System Overview

ECADS is designed to facilitate efficient storage and summarization of natural resource data for multi-scale ecological assessments and land use planning. To meet this objective, various databases and analytical programs have been constructed to optimize the flow of field site or plot information into ecological classification summary tables (Fig. 1). These classification tables, in turn, are linked to map tables which provide summary information for mapping units within a geographic information system (GIS). Knowledge-based systems (e.g., EMDS, see Reynolds et al. this proceeding) utilize map-level information from ECADS

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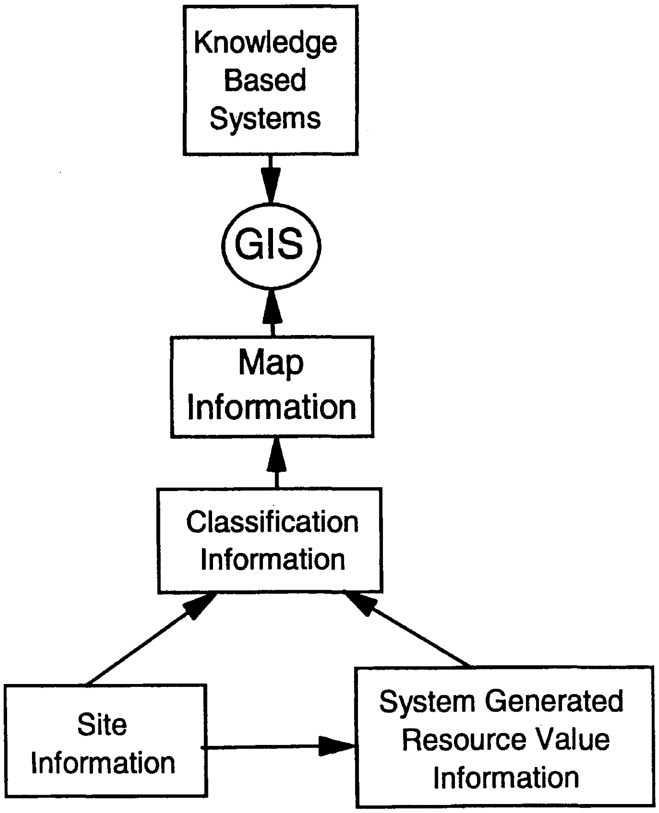

Figure 1.—Basic Components of ECADS.

in a GIS environment to develop resource interpretations appropriate to multi-scale ecological assessment objectives through a progressive series of data reduction steps (Fig. 1). These steps are as follows:

1. basic, measured site data may be transformed into interpreted resource value information (e.g., forage values, hiding cover, diversity indices);
2. measured or interpreted site data are summarized into appropriate classification taxa (e.g., stream types, existing vegetation cover types, soil types);
3. the composition of classification taxa within a mapping unit are used to describe its average resource values or other selected attributes; and
4. knowledge-based systems may be linked in a GIS environment with map summary table output by ECADS to facilitate further interpretation of measured or derived resource information.

Site Information

A number of customized data entry forms are included in ECADS for the entry of site-level information in appropriate relational database structures (Fig. 2). The database design used in ECADS is highly flexible, and allows users to input data according to their local needs by basic information categories. For example, users may choose to describe foliar cover of plant species by rapid visual estimation (i.e., ocular, plant list), intensive replicated sampling of microplots (i.e.,

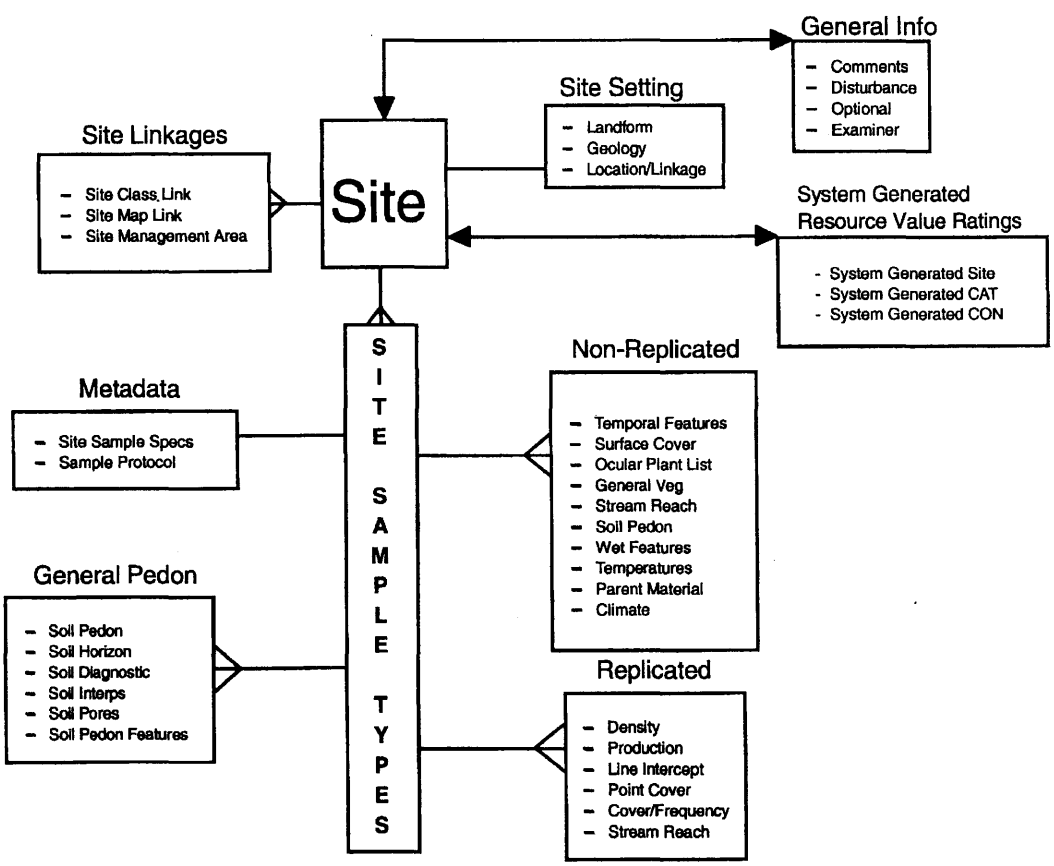

Figure 2.—ECADS Site-Level Data Table Design.

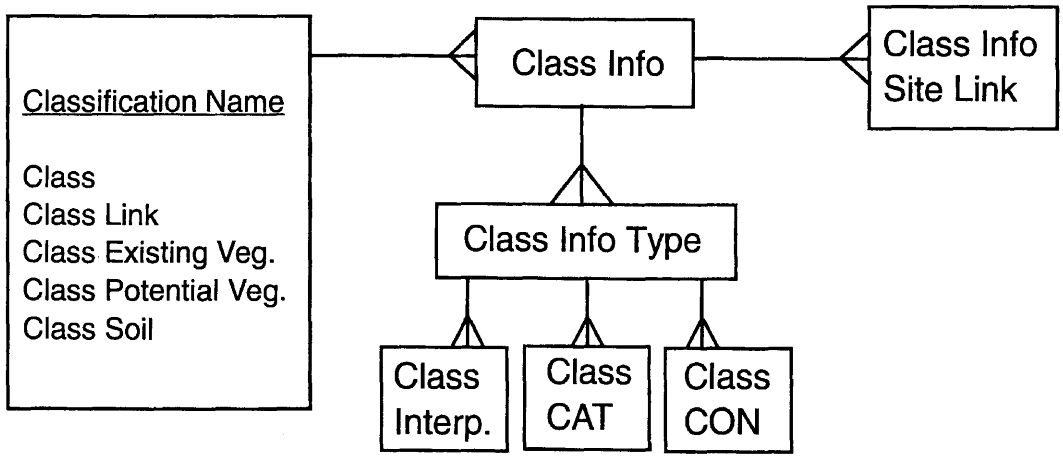

Figure 3.—ECADS Classification Data Table Design.

cover/frequency), or line transects (i.e., line intercept), dependent on study needs. The flexible design of ECADS site-level data entry forms and associated tables allows the user to select appropriate methods for sampling based on purpose, accuracy, and precision requirements as well as cost and personnel experience criteria. Accordingly, these forms and tables may be used to accommodate many integrated inventory and monitoring needs.

Classification Information

Classification information (Fig. 3) is grouped into two basic components in ECADS— classification name and classification information. The classification name component represents a set of lookup tables that associate hierarchical naming structures (as appropriate) to a primary classification name table. Examples of classification types that fit a hierarchical structure include: soils, potential vegetation, existing vegetation, geology, and landforms. Data concerning each classification name are stored in a series of tables that are linked to a primary classification information table.

The classification information component of ECADS (Fig. 3) is structured in a manner similar to the table design used for site-level information. For example, a given classification record is first identified in the Classification Information table. Multiple sets of information are associated to a classification record by the Class Info Type table which tracks the type, source, and date of information. Actual data concerning a classification are stored in three generic table structures that, in turn, are linked to the Class Info Type table (Fig. 3). The Class Interp table is used to store general use and limitation ratings (e.g., road suitability, erosion hazard class); the Class Cat table provides summary statistics for categorical variables (e.g., code type, rank, and frequency of occurrence); and the Class Con table provides summary statistics for continuous variables (e.g., mean, min, max, variance). These three tables can be populated directly by the user, or through an automated summary of specified site records by the Class Summary Program (see Analytical Software and Utilities).

Map Information

The data tables used to store information concerning uniquely labeled polygons (e.g., watersheds, vegetation stands) and ecological mapping units (e.g., soil, potential vegetation) in ECADS are presented in Figure 4. The Map Sample and associated tables are used to store field observations for each polygon. For example, the Map Composition table provides information on the composition of different ecological classifications (e.g., soil, existing vegetation, and stream types) within a polygon, and the Map Settings table describes the environmental setting (e.g., elevation, aspect, slope relations) of a given classification within a polygon.

The Map Info table and its associates (Fig. 4) provide summary information for a uniquely labeled polygon or ecological mapping unit. Population of data into these tables is accommodated through three different options: direct

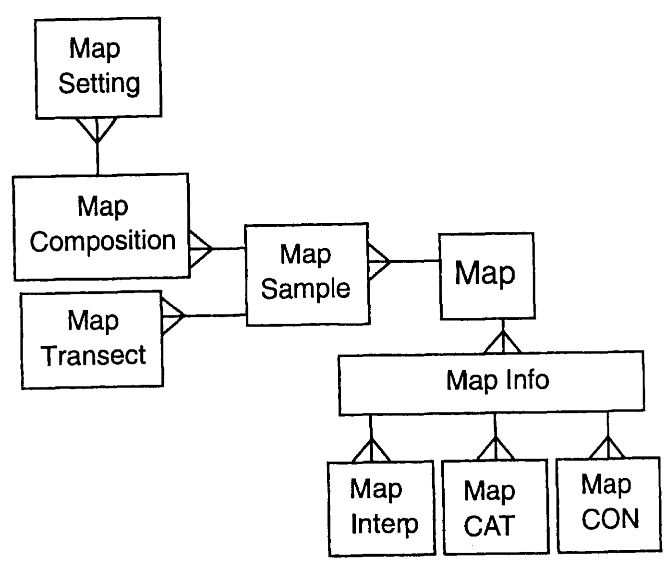

Figure 4.—ECADS Map Data Table Design.

entry by the user, system-generated summaries from classification information tables, and system-generated summaries from user- specified site record files. Attribute summaries based on classification information are calculated by the Map Summary Program (see Analytical Software and Utilities) and are facilitated through linkages between the Map Composition and Class Information tables. Summaries from site record files are also calculated by the Map Summary Program, and allow the user to generate map-level information based on selected sites known to occur within a polygon or mapping unit. Selected attributes from the Map Information tables of ECADS can also be converted to a dBASE format by the Map Summary Program for subsequent use by knowledge-based systems in a GIS environment (Fig. 1).

Analytical Software and Utilities

A variety of analytical programs (Table 1) and customized utilities (Table 2) were developed for ECADS to perform efficient, standard analysis of natural resource data by land managers and scientists (e.g., ecologists, soil scientists, biologists, hydrologists). Most of these programs were originally written in FORTRAN 77 language for execution on main frame computer systems by the ECODATA system of the USDA-Forest Service (Jensen et al. 1994). These programs have subsequently been rewritten to ANSI C language for execution on IBM-compatible micro computers for ECADS. Data management utilities are written in Object-Pal language and provide customized extensions of functionality included in PARADOX. Each analysis and utility program is run interactively by the user through a set of standard Windows 95 based menu queries that specify details of program execution. Output may be viewed on screen, directed to a printer, stored in external text files, or used to populate appropriate database fields in ECADS.

Conclusions

ECADS represents a relational database and analytical software system useful to multi-scale ecological assessments and ecosystem management. Earlier versions of this system (Keane et al. 1990) were designed primarily for integrated vegetation inventory and monitoring. Additions to the system were subsequently made to facilitate other resource characterization needs (Jensen et al. 1991, 1994). In its current form, ECADS provides a PC-based platform for integrated environmental effects analysis of multi-resource information (e.g., soil, water, vegetation, geology) commonly collected by various land management agencies.

The design and functionality of ECADS was optimized to facilitate the efficient summarization of site-level data by ecological classifications and related mapping units for subsequent analysis by knowledge-based systems (e.g., EMDS, see Reynolds et al., this proceeding) in a GIS environment. This functionality is of particular importance to many land management agencies, universities, and non-government organizations involved in multi-scale ecological assessments and land use planning. Accordingly, representatives from such groups have been actively involved in the development, testing, and use of ECADS (e.g., USDA-Forest Service, USDA-Natural Resources Conservation Service, USDI-National Park Service, U.S. Environmental Protection Agency, The Nature Conservancy, and various universities). For example, ECADS was used extensively in the recent multi-agency landscape ecology assessment of the Columbia River Basin (Jensen et al. 1997).

Migration of the data structure, utilities, and analytical software contained in ECADS to a platform-independent environment (e.g., JAVA) on the Internet is planned for future development of the system. This activity will undoubtedly increase the accessibility and use of ECADS in future years. Detailed descriptions and computer software for ECADS are available from the authors on request.

Table 1.—Analytical Package of ECADS

Analysis Programs	Description
Strata	Community analysis package used in developing ecological type classifications. Produces site and plant species cover summary reports, and similarity matrices.
Data Formatting	Formats species and site data for Canonical correlation/ correspondence and ordination software package.
Forage	Calculates forage values based on measured biomass and forage value preference ratings provided by the user.
Diverse	Calculates various plant species diversity indices (e.g., Shannon-Weiner index) for a site based on user specified layer heights.
Soil	Generates soil properties for user defined, fixed depth, and genetic horizon layers. Summarizes soil layer properties and summarizes soil pedon properties within a classification.
Class Summary	Calculates summary statistics for user-specified Òtegorical and continuous variables based on site record files.
Map Summary	Calculates summary statistics for user-specified categorical and continuous variables based on site record files or Class Info Summary data.

Table 2.—System Utilities of ECADS

Utility	Description
Developer Tools (Password Protected)	
Table Manager	Generates and edits individual tables and attributes. Provides table/attribute specifications (e.g., type, size, description).
Form Manager	Defines customized forms (e.g., navigation, data entry, program execution) and their associated tables.
Create Tables	Works with conversion in Table Manager to update underlying database structure.
Attribute Mapper/Code Mapper	Tools used to track crosswalks of data between different struc tures (e.g., ECADS and ECODATA).
System Managers (Password Protected)	
Validation Manager	Establishes parent/child relations and assigns user access level (i.e., national, regional, local) for the addition and editing of validation codes.
Species Manager	Identifies the type of coding system to be used in plant species validation (e.g., NRCS plants, TNC).
User Tools	
Query IDs/Build IDs	Queries the database to construct site or plot files for input into analytical programs.
Report Manager	Prints multiple copies of previously generated customized Field Forms for data collection.
Import/Export	Archives/restores data and combines datasets between stand alone desktops.
On-Line Help	Uses RoboHelp functionality to describe system components and their intended uses.
Program Command/Record	Provides easy retrieval of stored summary attribute options consistently used in analyses.

Acknowledgments

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Literature Cited

Bastedo, J.D.; Theberge, J.B. 1983. An appraisal of inter-disciplinary resource surveys (ecological land classification). Landscape Planning. 10: 317-334.

Federal Geographic Data Committee. 1998. Content Standard for Digital Geospatial Metadata-2.0, Federal Geographic Data Committee Secretariat, U.S. Geological Survey, Reston, Virginia.

Ford, R.; Sweet, M.; Votava, P. 1997. An object-oriented database for cataloging, archiving, and disseminating spatial datasets and FGDC-Compliant Metadata. Proceedings of 1997 International Society for Photogrammetry and Remote Sensing Workshop, October 1997, Boulder, CO.

Ford, R.; Running, S.; Nemani, R. 1994. Large scale terrestrial ecosystem modeling, IEE Computational Science and Engineering. 1(3): 32-44.

Jensen, Mark E.; McNicoll, Cecilia H.; Prather, Martin. 1991. Application of ecological classification to environmental effects analysis. Journal of Environmental Quality. 20: 24-30.

Jensen, M.E.; Hann, W.; Keane, R.E.; Caratti, J.; Bourgeron, P.S. 1994. ECODATA—a multiresource database and analysis system for ecosystem description and evaluation. In: Jensen, M.E.; Bourgeron, P.S., eds. Volume II: Ecosystem management: principles and applications. Gen. Tech. Rep. PNW-GTR-318. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR: 192-205.

Jensen, Mark E.; Bourgeron, Patrick; Everett, Richard; Goodman, Iris. 1996. Ecosystem management: a landscape ecology perspective. Journal of the American Water Resources Association. 32: 203-216.

Jensen, Mark; Goodman, Iris; Brewer, Ken [and others]. 1997. Biophysical environments of the basin. In: Quigley, Thomas M.; Arbelbide, Sylvia J., tech. eds. An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins: Volume 1. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest research Station. 335p.

Jensen, M.E.; Crespi, M.; Lessard, G. 1998. A national framework for integrated ecological assessments. In: Cordel, H. Ken; Bergstrom, John C., eds. Integrating social sciences with ecosystem management: human dimensions in assessment policy and management. Sagamore Press, Champaign "Urbana", IL.

Keane, R.E.; Jensen, M.E.; Hann, W.J. 1990. ECODATA and ECOPAC: analytical tools for integrated resource management. Compiler. 4: 24-35.

Margules, C.R.; Austin, M.P. 1991. Nature conservation: cost effective biological surveys and data analysis. Melbourne, Australia; CSIRO.

National Research Council. 1994. Rangeland health: new methods to classify, inventory, and monitor rangelands. National Academy Press, Washington, DC. 182p.

RISC. 1983. Guidelines and terminology for range inventories and monitoring. Report of the Range Inventory Standardization Committee. Society of Range Management, Denver, CO.

Stohlgren, T.J.; Quinn, J.F. 1992. An assessment of biotic inventories in western U.S. National Parks. Natural Areas Journal. 12: 145-154.

Knowledge-Based Approach to Watershed-Scale TMDL Assessment[1]

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James Andreasen[4]
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Abstract—The Ecosystem Management Decision Support (EMDS) system is an application framework for knowledge-based decision support of ecological landscape analysis at any geographic scale. The system integrates geographic information system and knowledge base system technologies to provide an analytical tool for environmental assessment and monitoring. The basic objective of EMDS is to improve the quality and completeness of environmental assessments and the efficiency with which they are performed. The USDA Forest Service and Environmental Protection Agency have cooperatively developed an EMDS knowledge base for assessment and monitoring of ecological states and processes in 6th code watersheds. The knowledge base evaluates watershed processes, patterns, general effects of human influence, and specific effects on salmon habitat.

The Total Maximum Daily Load (TMDL) program, Section 303(d) of the Clean Water Act, identifies sources of pollution remaining after end-of-pipe discharges are regulated and applying the best available technology. Remaining sources of pollutant are termed non-point sources (NPS). Under requirements of the Act, States develop lists of waters that do not meet State water quality standards, even after point sources of pollution have installed required levels of pollution control technology. States must establish priority rankings based on severity of pollution and beneficial uses of water bodies, such as recreation or fishing, and must develop TMDLs for waters on the lists. TMDLs specify amounts of pollutants that need to be reduced to meet State water quality standards and allocate pollution control responsibilities among pollution sources in a watershed. The U.S. Environmental Protection Agency (EPA) has established a five-step approach to setting TMDLs: (1) identify waters requiring TMDLs; (2) priority ranking and targeting; (3) develop TMDLs; (4) implement control actions; and (5) assess control actions.

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Conventional TMDL development is carried out on individual stream reaches by analyzing impaired conditions. Conventional methods for TMDL analysis cannot address the spatial and temporal scales required to: (1) establish adequate reference conditions for NPS parameters; (2) estimate the predictive capabilities of scale relations for spatially continuous ecoregions; (3) project likely scenarios of water quality change due to changes in land use, cover, or climate; (4) relate monitoring technologies and standards to defined ecoregional scales; and (5) establish schedules for TMDL development that are ecologically meaningful and compatible with Federal Agency responsibilities under the Endangered Species Act.

The EPA Office of Research and Development and the Forest Service (U.S. Department of Agriculture) are cooperatively developing new analytical techniques for landscape-scale TMDL assessment, using knowledge-based processing of landscape databases that enable environmental managers to make better decisions. The objectives of this study were to design a knowledge base as a logical framework for assessment of 6th code watershed condition and illustrate its application in landscape analysis with the Ecosystem Management Decision Support (EMDS) system (Reynolds 1999a; Reynolds and others 1997a, 1997b).

Materials and Methods

NetWeaver Knowledge Bases

This section summarizes key concepts and constructs related to design and use of NetWeaver knowledge bases (Stone and others 1986). Reynolds (1999b) gives a more detailed description of the technology as implemented in EMDS. Formally, a knowledge base is a meta database that provides a specification for interpreting information. Knowledge bases in this sense effectively are cognitive maps of the elements in a problem domain and the logical relations among those elements. In the context of watershed assessment, for example, the elements of the problem are typically ecosystem states and processes related to vegetation structure and composition, water quality, stream flow properties, etc.

The primary structural element of a knowledge base as implemented in NetWeaver is the network whose function is to evaluate a proposition. The key attribute of a network is its truth value, which is a measure of the degree to which the proposition is true, based upon the state of logically antecedent conditions. NetWeaver networks are recursive insofar as a network may be evaluated in terms of other networks. For example, the network for **watershed processes** (Figure 1) is evaluated in terms of its logically antecedent networks **hydrologic processes, erosion processes**, and **fire processes** (hereafter, NetWeaver objects are identified in bold type). Thus, the proposition that watershed processes are within a suitable range of reference conditions is true to the degree that the propositions associated with its logically antecedent networks are true. The network architectures under **hydrologic processes, erosion processes,** and **fire processes** define the manner in which these networks are evaluated in turn and so on.

Logical operators in NetWeaver such as AND and OR are fuzzy logic operators. That is, they perform fuzzy math operations that propagate truth values, derived at the level of data links, upward through the logical structure of a knowledge base. Zadeh (1965, 1968) presented basic concepts of approximate reasoning with fuzzy logic. Subsequent concept papers (Zadeh 1975a, 1975b, 1975c) elaborated on the syntax and semantics of linguistic variables, laying the foundation for what has become a significant new branch of mathematics. Fuzzy logic is concerned with quantification of set membership and associated set operations.

Data links (graphically illustrated as rectangles in figures) essentially are elementary networks. Like networks, data links may evaluate a proposition, yielding a truth value (although data links do not necessarily evaluate anything). The primary distinction between networks and data links that yield truth values is that data links only evaluate data rather than a logical expression of antecedent conditions. Data links evaluate a proposition by comparing the value of a data item, or the result of a mathematical expression involving one or more data items, to an argument that defines the conditions under which the proposition is considered true. An argument may test for a simple true/false condition as in classical rule-based systems based on bivalent logic, or an argument may be a fuzzy membership function that tests an observed value's degree of membership in a fuzzy subset (Kaufmann 1975, Zadeh 1992). A fuzzy membership function provides an explicit mathematical expression for testing an observation's degree of affinity for the concept represented by the fuzzy subset.

Problem Domain

Given the objectives of the EPA water quality assessment program discussed in the introduction, the primary knowledge base topics included in design were watershed processes, watershed patterns, general effects of human influence, and specific effects of human influences on aquatic species (Table 1). A key decision, made early in the design process, was that the method of assessment be sufficiently general for application in any geographic region. This design criterion was implemented by constructing all fuzzy membership functions as dynamically-defined functions of data representing standards. That is, all fuzzy membership functions in the knowledge base are defined by standards input during analysis. All data are evaluated by comparison to standards for which we conceptually distinguish three basic types: reference conditions representing attributes of unmanaged watersheds, management standards set by resource management agencies such as the USDA Forest Service, and regulatory standards set by regulatory agencies such as the EPA.

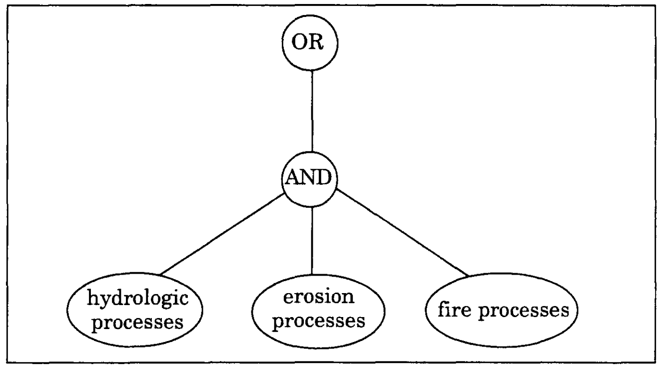

Figure 1.—Network for watershed processes. The truth of the proposition that watershed processes are within a suitable range of conditions depends on the degree to which its three premises, represented by the networks, hydrologic processes, erosion processes, and fire processes, are true.

Knowledge Base Application in EMDS

Major components of the EMDS system (Reynolds 1999a) include the NetWeaver knowledge base system, the EMDS Arcview application extension, and the Assessment system (Figure 2). This section briefly summarizes system structure and function in terms of system level objects, their methods, and relations. More detailed descriptions of the system are provided in Reynolds (1999a) and Reynolds and others (1997a, 1997b).

The NetWeaver knowledge base system (Reynolds 1999b) is composed of an engine and a graphic user interface for knowledge base developers that provides controls for designing, editing and interactively evaluating knowledge bases (Figure 2). Primary components of the EMDS Arcview application extension are the DataEngine and MapDisplay objects that customize the Arcview environment with methods and data structures required to integrate NetWeaver's knowledge-based reasoning schema into Arcview (Figure 2). The Assessment system is a graphic user interface to the NetWeaver engine for EMDS application end-users that

Table 1.—Primary networks in the knowledge base for assessing watershed condition.

Network name	Proposition evaluated by network
watershed processes	Watershed processes are within acceptable ranges.
watershed patterns	Watershed patterns are within acceptable ranges
human influence	Aggregate effects of human influence are within acceptable ranges.
aquatic species	Likelihood of longterm viability of aquatic species is good.

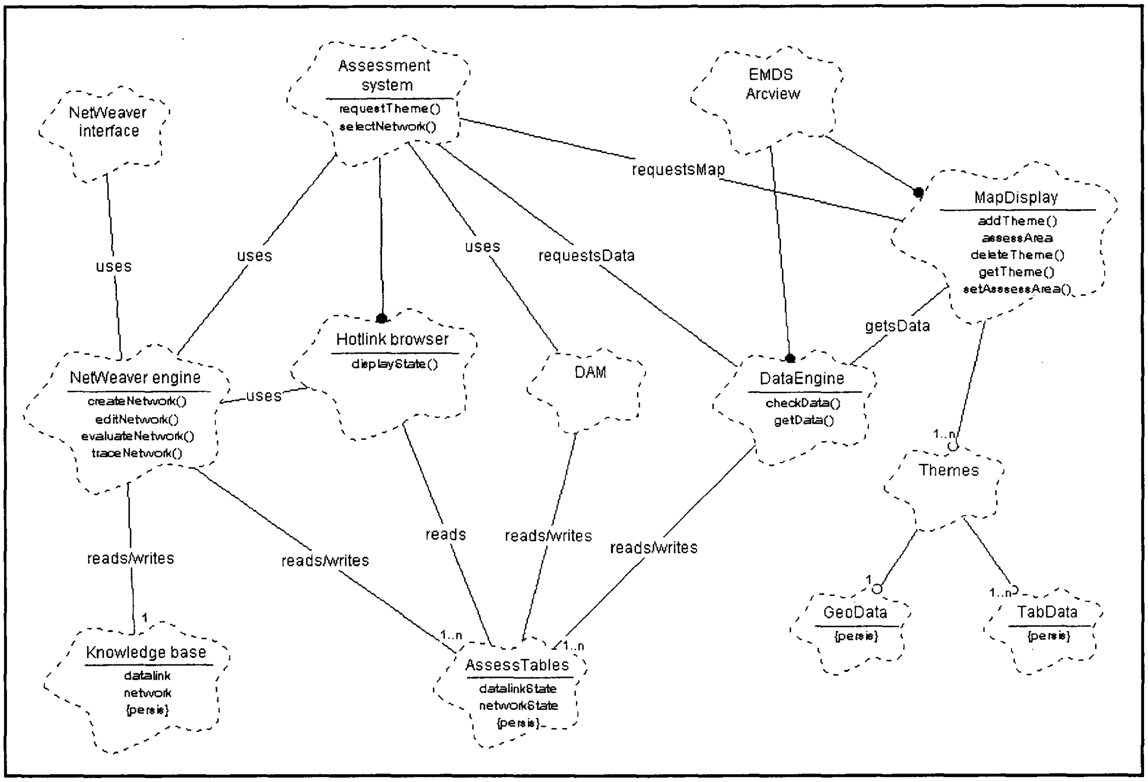

Figure 2.—System level object diagram of EMDS system. Lines indicate object relations and annotations on lines indicate primary nature of the relation ("uses" indicates a general relation in which several to many methods of the used object are relevant). Text items within objects of the form "xxx ()" indicate object methods. Only key methods are shown for each object.

controls setup and running of analyses, runtime editing of knowledge bases, and display of maps, tables, graphs, and evaluated knowledge base state related to analyses.

Results

The primary networks for assessing watershed condition are **watershed processes, watershed patterns, human influence,** and **aquatic species**. Each network evaluates a specific proposition about the state of watershed condition (Table 1). An example analysis of erosion processes in a portion of the Columbia River Basin was performed to illustrate landscape application of the knowledge base for watershed condition in EMDS (Figure 3). The Assessment system (Figure 2) was used to specifically select the **erosion processes** network (Figure 1) for evaluation in our example. In general, the Assessment system can be used to select any combination of networks for analysis. Map output shows the computed truth value for the proposition that erosion processes are within a suitable range of conditions for each 6^{th} code watershed in the assessment area selected for this example.

Partial evaluations, based on currently available data, can be performed in EMDS. Truth values for **erosion processes** in the map output (Figure 3) only reflect a partial evaluation of the network because data values for volumes of mass wasting and debris avalanche are missing in our example (Table 2). Ecological assessments frequently are broad in conceptual scope, requiring evaluation of possibly numerous and diverse data. Consequently, several to many data elements needed for complete evaluation of a knowledge base or any of its components may be missing at the

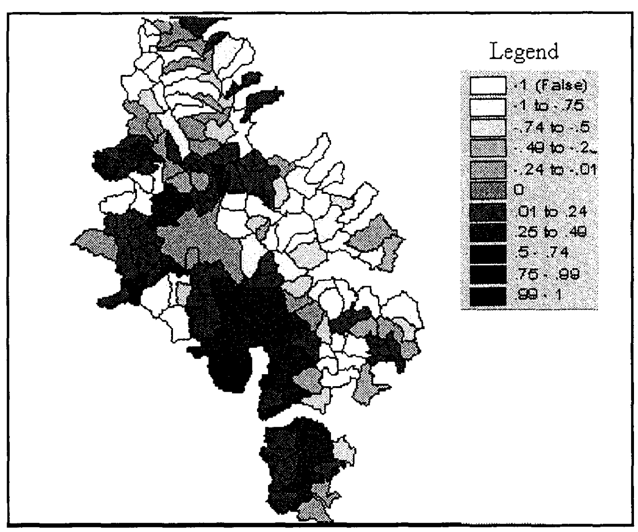

Figure 3.—Truth value map for the proposition that erosion processes in 6th code watersheds are within a suitable range of reference conditions.

Table 2.—Propositions associated with networks antecedent to the erosion processes network.

Network name	Proposition
erosion processes	Erosion processes are within suitable ranges.
surface erosion	Amount of surface erosion is within a suitable range.
mass wasting	Amount of mass wasting is within a suitable range.
debris avalanche	Amount of debris avalanche is within a suitable range.
sediment delivery	Amount of sediment delivery is within a suitable range.

start of an assessment. In our example, complete evaluation of erosion processes requires data values for volumes of surface erosion, sediment delivery to streams, mass wasting, and debris avalanche, but only the first two data elements were available at the time of analysis. However, given the set of knowledge base objects and their logical organization within the knowledge base, the NetWeaver engine computes the relative influence of missing data (Figure 4).

Finally, the Hotlink browser (Figure 2) provides a means to examine details underlying an evaluation, by allowing the user to view the evaluated state of the knowledge base for any landscape feature selected on a truth value map (Figure 5).

Discussion

Application of fuzzy logic to natural resource science and management is still relatively new. General areas of application include classification in remote sensing (Blonda 1996), environmental risk assessment (Holland 1994), phytosociology (Moraczewski 1993a, 1993b), geography (Openshaw 1996), ecosystem research (Salski and Sperlbaum 1991), and environmental assessment (Smith 1995, 1997). More specific applications include catchment modeling (Anonymous 1994), cloud classification (Baum et al. 1997), evaluation of plant nutrient supply (Hahn et al. 1995), soil interpretation (Mays et al. 1997, McBratney and Odeh 1997), and land suitability for crop production (Ranst et al. 1996).

The knowledge base for evaluation of watershed condition was designed for general application. The architecture is such that the knowledge base should be applicable in any geographic region with no more than minor adaptation. Specification of standards as data to be read from a database is an important ingredient of this general applicability. Clearly, our approach to a general solution begs the question, "Where do specifications for reference conditions come from?" We suggest the following approach. For any geographic region or subregion, the vegetation potential of unmanaged watersheds is conditioned by geographic and climatic factors (Whittaker 1975). Widely available synecological analysis tools such as detrended correspondence analysis (Hill and Gauch 1980) provide a basis for arranging watersheds along geographic and climatic gradients, and identifying groupings indicative of reasonably separable vegetation potentials in the absence of management. Most resource management agencies have sufficiently detailed GIS coverages to identify watersheds that have experienced little or no management, and the attributes of such watersheds can be used as reference conditions.

The knowledge-based reasoning schema of NetWeaver uses an object- and fuzzy logic-based propositional network architecture for knowledge representation (Reynolds 1999b). The system facilitates evaluation of complex, abstract topics such as water quality that depend on numerous, diverse subordinate conditions because NetWeaver is fundamentally logic based. The object-based architecture of NetWeaver knowledge bases is conducive to incremental, evolutionary design of complex knowledge representations (Booch 1994) which has been recognized as crucial to successive design of complex systems (Gall 1986). The propositional network architecture of NetWeaver knowledge bases allows both the ability to evaluate the influence of missing information and the ability to reason with incomplete information (Reynolds and others 1997a, 1997b).

Use of fuzzy logic in NetWeaver affords significant practical advantages over Bayesian belief networks (Ellison

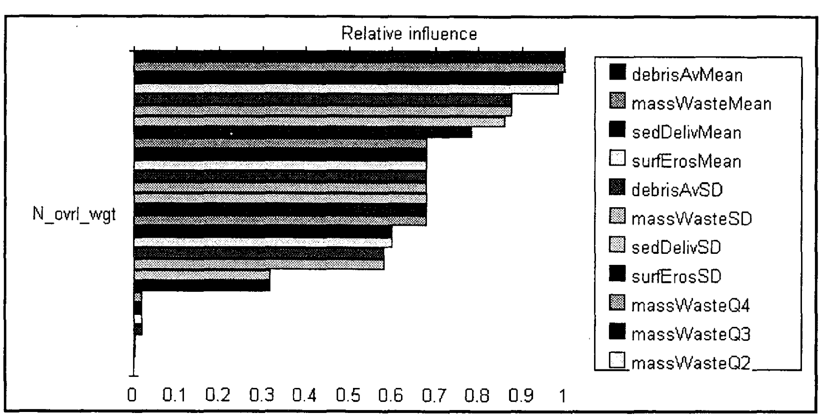

Figure 4.—Relative influence of missing data with respect to completing an analysis of erosion processes.

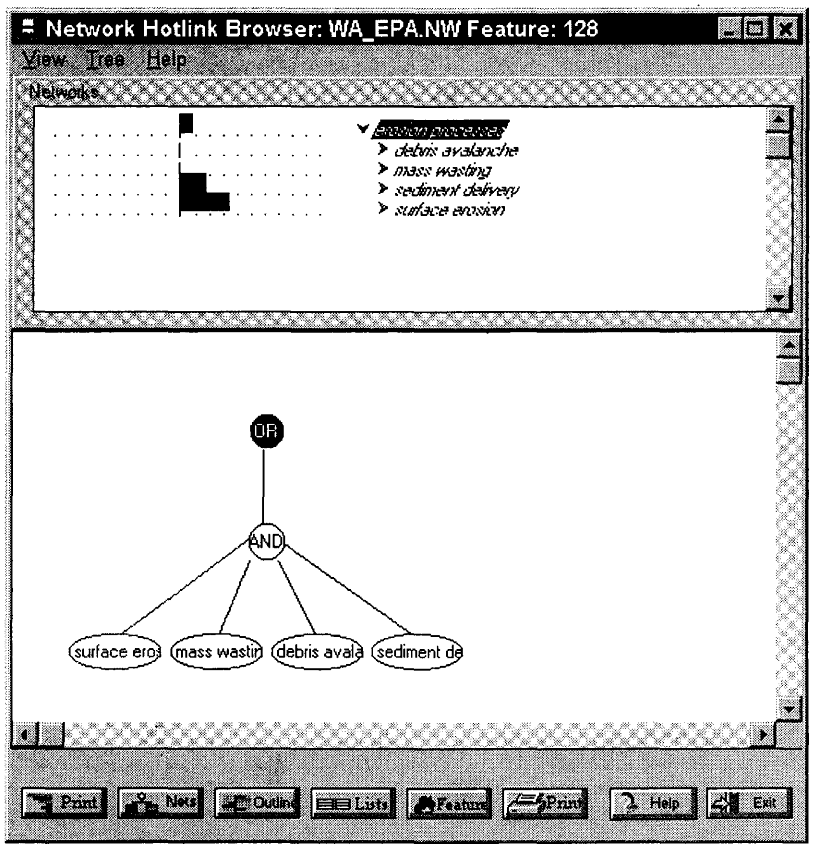

Figure 5.—The EMDS NetWeaver browser displays the evaluated state of a knowledge base for selected landscape features in EMDS map outputs.

1996, Howard and Matheson 1981) and classical rule-based knowledge representations that depend on bivalent (e.g., yes/no or true/false) logic (Waterman 1986, Jackson 1990) in the context of knowledge bases that are conceptually broad and that include a wide variety of topics. Bayesian belief networks work well on narrow, well-defined problems, and may be preferable to fuzzy logic networks when conditional probabilities of outcomes are known. However, Bayesian belief networks are difficult to apply to large, general problems because the number of conditional probabilities that must be specified can quickly become extremely large as the conceptual scope of a problem increases. In such situations, model design not only becomes difficult to manage, but many probabilities will not be well characterized and will therefore need to supplied by expert judgment, thus negating much of the value to be gained by a more statistically-based approach to knowledge representation. Similarly, the number of rules required in a bivalent logic knowledge base increase to unmanageable levels as soon as the model designer attempts to account for shades of outcomes such as poor, fair, good, excellent, *etc*. These arguments should not be taken to infer that fuzzy logic networks are inherently superior to other forms of knowledge representation. On the contrary, the various methods just discussed may be highly complementary to one another. In particular, we believe that fuzzy logic networks are ideally suited as logical frameworks for integrating model results from a variety of analytical systems such as simulators, linear programs, Bayesian belief networks, and rule bases.

Conclusions

A knowledge-based approach to landscape analysis for TMDL assessment was shown to be quite feasible with application of the EMDS system despite the broad conceptual scope of the problem domain. The complete knowledge base has large data requirements, but any combination of networks, representing subsets of the full knowledge base, may be selected for analysis. Key advantages of a landscape analysis based on fuzzy logic networks as implemented in NetWeaver and used in EMDS include the ability to reason with incomplete information, and the ability to evaluate the influence of missing information. Fuzzy-logic based landscape analysis may be most useful for construction of logical frameworks within which a wide variety of analytical results can be effectively integrated into a single, coherent analysis.

Literature Cited

Anonymous. 1994. Fuzzy logic applied to catchment modelling. Water & Wastewater International 9:40-45.

Baum, Bryan A.; Tovinkere, Vasanth; Titlow, Jay; Welch, Ronald M. 1997. Automated cloud classification of global AVHRR data using a fuzzy logic approach. Journal of Applied Meteorology 6:1519-1526.

Blonda, P.; Bennardo, A.; Satalino, G.; Pasquariello, G. 1996. Fuzzy logic and neural techniques integration: an application to remotely sensed data. Pattern Recognition Letters 17:1343-1347.

Booch, G. 1994. Object-oriented analysis and design. New York: Benjamin/Cummings Publishing Company. 578 p.

Ellison, A. M. 1996. An introduction to Bayesian inference for ecological research and environmental decision-making. Ecological Applications 6:1036-1046.

Gall, J. 1986. Systematics: how systems really work and how they fail. Ann Arbor, MI: The General Systematics Press. 342 p.

Hahn, A.; Pfeiffenberger, P.; Wirsam, B.; Leitzmann, C. 1995. Evaluation and optimization of nutrient supply by fuzzy logic. Ernahrungs-Umschau 42:367-375.

Hill, M. O.; Gauch, H. G. Detrended correspondence analysis: an improved ordination technique. Vegetatio 42:47-58.

Holland, J. M. 1994. Using fuzzy logic to evaluate environmental threats. Sensors 11:57-62.

Howard, R.; Matheson, J. 1981. Influence diagrams. Pages 721-762 in Howard, R., and Matheson, J,, eds., Readings on the principles and applications of decision analysis, Volume II. Menlo Park, CA: Strategic Decisions Group.

Jackson, P. 1990. Introduction to expert systems. Addison-Wesley Publishers. Reading, MA. 526 p.

Kaufmann, A. 1975. Introduction to the theory of fuzzy subsets. Volume 1. Fundamental theoretical elements. New York: Academic Press. 416 p.

Mays, M. D.; Bogardi, I.; Bardossy, A. 1997. Fuzzy logic and risk-based soil interpretations. Geoderma 77:299-309.

McBratney, A. B.; Odeh, I. O. A. 1997. Application of fuzzy sets in soil science: Fuzzy logic, fuzzy measurements and fuzzy decisions. Geoderma 77:85-91.

Moraczewski, I. R. 1993a. Fuzzy logic for phytosociology 1. Syntaxa as vague concepts. Vegetatio 106:1-12.

Moraczewski, I. R. 1993b. Fuzzy logic for phytosociology 2. Generalizations and prediction. Vegetatio 106:13-27.

Openshaw, S. 1996. Fuzzy logic as a new scientific paradigm for doing geography. Environment & Planning A 28:761-767.

Ranst, E. Van; Tang, H.; Groenemans, R.; Sinthurahat, S. 1996. Application of fuzzy logic to land suitability for rubber production in peninsular Thailand. Geoderma 70:1-12.

Reynolds, K. M. 1999a. EMDS users guide (version 2.0): knowledge-based decision support for ecological assessment. Gen. Tech. Rep. PNW-GTR. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. (in press).

Reynolds, K.M. 1999b. NetWeaver for EMDS version 2.0 user guide: a knowledge base development system. Gen. Tech. Rep. PNW-GTR. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. (in press).

Reynolds, K.; Saunders, M.; Miller, B.; Murray, S.; Slade, J. 1997a. An application framework for decision support in environmental assessment. Pages 333-337 in: GIS 97 Conference Proceedings of the Eleventh Annual Symposium on Geographic Information Systems. Vancouver, BC. February 17-20, 1997. Washington, DC: GIS World.

Reynolds, K.; Saunders, M.; Miller, B.; Slade, J.; Murray, S. 1997b. Knowledge-based decision support in environmental assessment. Pages 344-352 in: Resource Technology 97 Conference Proceedings Volume 4. ACSM 57th Annual Convention. ASPRS 63rd Annual Convention. Seattle, WA. April 7-10, 1997. Bethesda, MD: American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping.

Salski, A.; Sperlbaum, C. 1991. Fuzzy logic approach to modelling in ecosystem research. Lecture notes in computer science XX:520-527

Smith, P. N. 1995. A fuzzy logic evaluation method for environmental assessment. Journal of Environmental Systems 24:275-279.

Smith, P. N. 1997. Environmental project evaluation: a fuzzy logic based method. International Journal of Systems Science 28:467-471.

Stone, N. D.; Coulson, R. N.; Frisbie, R. E.; Loh, D. K. 1986. Expert systems in entomology: three approaches to problem solving. Bulletin of the Entomological Society of America 32, 161-66.

Waterman, D. A. 1986. A guide to expert systems. Addison-Wesley Publishers, Reading, MA. 419 p.

Whittaker, R. H. 1975. Communities and ecosystems. New York: MacMillan Publishing. 385 p.

Zadeh, L. A. 1965. Fuzzy sets. Information and Control 8:338-353.

Zadeh, L. A. 1968. Probability measures of fuzzy events. J. Math. Anal. and Appl. 23:421-427.

Zadeh, L. A. 1975a. The concept of a linguistic variable and its application to approximate reasoning. Part I. Information Science 8:199-249.

Zadeh, L. A. 1975b. The concept of a linguistic variable and its application to approximate reasoning. Part II. Information Science 8:301-357.

Zadeh, L. A. 1975c. The concept of a linguistic variable and its application to approximate reasoning. Part III. Information Science 9:43-80.

Zadeh, L. A. 1992. Knowledge representation in fuzzy logic. Pages 1-25 in: An introduction to fuzzy logic applications in intelligent systems (R.R. Yager and L.A. Zadeh, eds.). Boston, : Kluwer Academic Publishers. 356 p.

Standard Forest Sampling Designs and Their Analysis Using TabGen[1]

Charles T. Scott[2]
Scott D. Klopfer[3]

Abstract—Three standard sampling designs have been used for forest monitoring through the years. Simple random sampling typically is applied for small areas. Stratified random sampling often is used in mid-scale assessments when the forest areas are delineated on maps. Double sampling for stratification generally is used only for extensive surveys when strata sizes must be estimated on aerial photographs. Remote sensing (satellite imagery) can be used for stratified random sampling at larger scales, potentially reducing sampling error. The program TabGen was written in Visual Basic 2.0 to analyze surveys using each of these designs. TabGen reads files of survey data that have been expressed on a per-hectare basis. The user then selects the row and column categorical variables and the attribute of interest (continuous variable). Tables of means, totals, and areas are produced, including 95% sampling errors for each cell. Users can define multiple filters to control what data are included/excluded from each table.

Most forms of forest monitoring are based on sampling designs so that results are unbiased and of known precision. The three most commonly used designs are simple random sampling, stratified random sampling, and double sampling for stratification. The designs are listed in order of increasing efficiency but also increasing complexity. However, each is designed to provide estimates of forest-resource attributes and their precision.

These monitoring results generally are provided in the form of one- and two-way tables. For example, a key table might be change estimates for abundance by species and size class. The statistical reports of the Forest Inventory and Analysis (FIA) units of the USDA Forest Service are compilations of such tables. Although we regularly use such tables, the forest survey and sampling literature describes sampling designs and alternative estimators for a single attribute of interest rather than for tables of them.

Software for generating these tables has not been widely available. A FORTRAN program called FINSYS (Forest Inventory System) was developed in the early 1960's and was updated in the early 1980's (Born and Barnard 1983). However, the batch processing mode was retained in the revised version, so it has not been used widely. Survey sampling software packages are available but have not been well accepted by natural resource analysts largely because they focus on human population surveys. General statistical packages also are widely available but using them to develop resource tables and their variances requires considerable statistical and programming knowledge. Spreadsheets can be used to generate tables for simple sampling designs, but variance estimators are much more difficult; thus, resource managers likely would use the data without knowing the reliability of the estimates.

During a study with Mead Paper Corp. that combined monitoring with geographic information systems (GIS), the need for an interactive forest-resource analysis program became clear. The program TabGen was written to meet that need. In this paper, we describe TabGen and discuss the estimation procedures it uses.

Estimation Methods

Typically, estimators are derived for a single attribute of interest, such as total biomass of a forest. When estimating tables, one may be interested in estimating biomass by species group and diameter class. The estimation process and the attribute of interest are the same in each cell but different conditions are placed on the attribute of interest in each table cell. For example, if a tree is not of the first species and not in the first diameter class, its biomass is not summed into the first table cell (Cochran 1977, p. 142-144).

With simple random sampling, plots (sampling units) are located randomly across the population (sampling frame). The simple average of the plot values is computed for each cell along with the simple variance. The sample size is the same for each cell because each plot contributes to the estimate even if the only information is that the plot does not belong to the cell. This is a common source of misunderstanding (Scott 1999).

For stratified random sampling, the population is divided into homogeneous areas of known size. Each stratum in treated as a simple random sample, so the strata means and variances are computed in the same manner. To estimate the overall mean, each strata mean is multiplied by its stratum weight (proportionate area in each stratum) and summed. The variance of the overall mean is computed as the sum of each strata variance multiplied by the square of its stratum weight (Cochran 1977).

Double sampling for stratification is similar except that stratum weights are estimated rather than known. In forestry applications, the weights typically are estimated using a large sample of points on aerial photographs (Bickford 1952). Each point is classified into a stratum and weights are estimated as the proportion of photo points falling in each stratum. The estimation process is the same as for stratified random sampling except that a variance term is

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added to account for the errors in the stratum weights (Cochran 1977). The formulas for all three designs for the estimation of two-way tables are given in Scott (1999). When stratum weights are known, the double sampling for stratification estimators simplify to the stratified random sampling estimators, which simplify to the simple random sampling estimators when there is only one stratum.

Program TabGen

TabGen produces two-way tables for any of the three sampling designs described. Written in Visual Basic 2.0, the program allows the user to create tables in a point-and-click environment. The current version of TabGen is described here, though work has begun on a more general version that will handle FIA data.

Program Inputs

Currently, TabGen reads a flat file for each of the following: plot (sampling unit) data, site-index trees, regeneration, overstory trees, and fields common to both regeneration and overstory trees. Other files can be substituted, though a hierarchy of one plot file and one or more files with multiple observations per plot is assumed. Each file has a header record containing a label for each data field. Each data record is comma delimited and has the plot number, observed data, and any calculated data, e.g., trees per hectare, biomass per tree, and diversity index. TabGen reads a variable library (dictionary) that describes the variables that are read from each file, whether they are continuous or categorical, and, if the latter, the labels for each category. The names of any per-unit-area fields must start with a "#" symbol, so that TabGen knows which field to multiply all the other fields on that record by to put them on a per-hectare basis.

TabGen also reads a control file that contains the stratum weights, the total area in the population, and a list of plots that will be included in the analysis. This list allows the analyst to include only the subset of plots of interest. GIS software can be used independently to select a subarea of interest, compute the areas by stratum and identify the plots within, and then create the control file with zeros following the plot numbers for those plots outside the area of interest. All files are assumed to be in the same directory as the control file.

Program Execution

Once the input files are created, the first step in running TabGen is to select the control file. The next step is to select

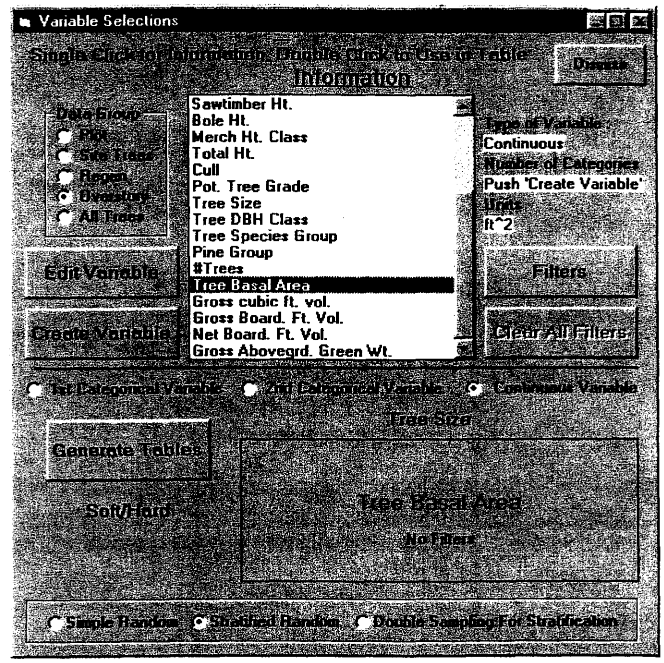

Figure 1.—Form to select table variables, to create and edit new ones, and to add filters.

the variables to be presented in a table. TabGen reads the variable library and presents the form in Figure 1. When a file type is selected, the variable list is presented. The user selects two categorical attributes for row and columns variables, and then a continuous attribute for the body of the table. The design of the table is shown at the bottom right.

Once the table is setup, the Generate Tables button is hit, and one (plot) or two files (plot and one other) are read to generate the tables (Fig. 2). The results can be viewed as:

1. The percent or total area in each table cell.
2. The mean or total of the attribute of interest in each cell.
3. The ratio of the attribute total to the area estimate for each cell.
4. The mean of individual observations (generally on a per-tree basis).
5. The number of plots "falling" in each cell.

The 95% sampling errors (confidence limits) are computed for each cell using the estimators for the design indicated in Figure 1 (simple random sampling, stratified random sampling, or double sampling for stratification). The user hits a button to display the sampling errors for the table. Hitting

Soft/Hard	Poletimber	Sawtimber	Total
Softwoods	0.6	1.2	1.8
Hardwoods	34.9	42.6	77.5
Total	35.5	43.8	79.3

Figure 2.—Mean basal area (ft²/acre) by species group and size class.

the same button switches back to the estimates, so it is easy for resource managers to determine the reliability of the estimates.

Program Options

TabGen has several additional features that allow the user to customize how the data are estimated and presented. The Modify Values function allows the user to rescale table values by dividing each by 1,000 to put the values on a per-thousand basis. The user also can input a value to multiply or divide by to convert values to dollars, for example.

The user also can create categorical variables from continuous ones by assigning ranges to categories, such as converting diameter to 5-cm classes. Existing categorical variables can be transformed into new variables by collapsing the full set of categories into a smaller set by combining classes, for example, when categories have too few values to stand alone in a table. Any created variable can be edited later, e.g., change class labels.

In small populations, some strata may have insufficient numbers of plots to stand alone. TabGen allows the user to collapse the strata in any fashion. To aid in choosing which strata to collapse, stratum weights and sample sizes are displayed for original and collapsed strata.

TabGen's powerful filtering feature allows users to create tables that meet their needs. Filters can be defined to exclude observations with specified values of one or more attributes to be excluded from a table. The user selects the variable, defines ranges of its values, then checks which ranges will be used in estimates. For example, the user can select Species and then define two ranges-one for softwoods and one for hardwoods. A filter labeled "Softwood Only" would have only the first range checked. A second filter labeled "Hardwood Only" would have the second range checked. Multiple filters can be created for each variable (Fig. 3). Filters can be used to create a series of two-way tables as a way of forming three-way tables, such as one table for poletimber, another for sawtimber, and one with both. Filters also can be used in combination, for example, applying the "Softwood Only" and "Sawtimber Only" filters simultaneously to yield a table containing only softwood sawtimber trees. Filters can also be used to ignore plots with missing or suspect values, such as computing average site index only on those plots where site index was observed. Filters give users tremendous power to create tables that meet their needs.

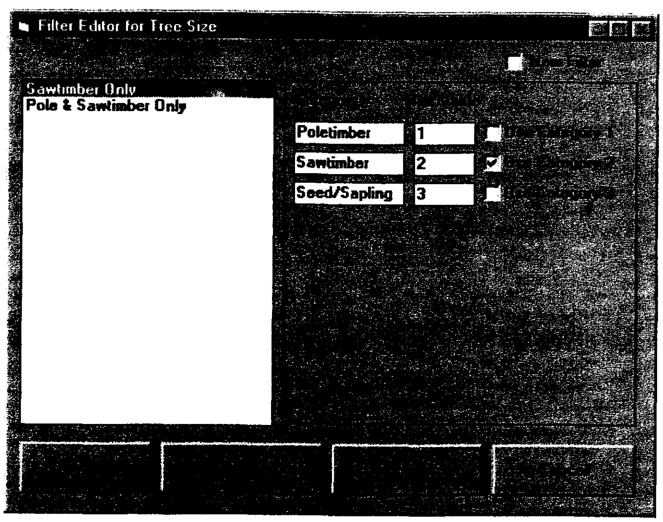

Figure 3.—Form to create, edit, delete, and apply filters for a variable. The Sawtimber Only filters for Tree Size is displayed.

The primary output of TabGen is the on-screen displays of the tables and their sampling errors, but any table can be printed to the default printer. Tables also can be sent to a comma-delimited text file suitable for importing into spreadsheets or word processors for additional formatting or for generating graphics. TabGen can generate a plot summary file for the current attribute. The summary file can be used in other analyses apart from TabGen or as an additional input field by attaching it to the input plot file.

Summary

TabGen generates two-way tables using the correct estimators and produces 95% sampling errors for each cell in the tables. Written in Visual Basic 2.0, the current version allows users to create tables using all available data in a point-and-click environment. TabGen has been tested on Windows 9+ and NT. Tables can be refined through the use of variable editing and filtering features. The program also works in conjunction with a GIS to produce tables for subareas of the population. Thus, it should prove a powerful tool for quickly and easily exploring monitoring results.

Although written for a specific study with Mead Paper Corp., TabGen is public domain software and can be modified for other applications. Copies of TabGen and sample data sets are available from the author.

Acknowledgments

The development of TabGen was supported by Mead Paper Corp. through a cooperative agreement with the USDA Forest Service, Northeastern Research Station. We thank our reviewers: Tom Frieswyk, Pat Miles, and Larry Royer, all with the Forest Service.

Literature Cited

Bickford, C. Allen. 1952. The sampling design used in the forest survey of the Northeast. Journal of Forestry 50(4):290-293.

Born, David J.; Barnard, Joseph E. 1983. FINSYS-2: Subsystem TABLE-2 and OUTPUT-2. General Technical Report NE-84. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 133 p.

Cochran, William G. 1977. Sampling Techniques. John Wiley & Sons, New York. 428 p.

Scott, Charles T. 1999. Estimating two-way tables based on forest surveys. *In* Hansen, Mark H.; Burk, Thomas E., eds. Integrated tools for natural resources inventories in the 21st century - an international conference on the inventory and monitoring of forested ecosystems. Gen. Tech. Rep. NC-. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. In press.

Necesidades de Monitoreo para el Manejo Forestal Sustentable de los Bosques de Coniferas del Norte de Mexico[1]

José Návar[2]

Resumen—El Manejo forestal sustentable es un proceso dinámico que inicia con la medición de criterios e indicadores que definan tendencias del manejo forestal presente. Los primeros 5 criterios y sus 27 indicadores del Proceso de Montreal fueron revisados al nivel de la unidad de manejo para determinar lagunas de información y definir las metodologías apropiadas para su monitoreo. Para este propósito se revisaron los planes de manejo de 3 ejidos forestales del Estado de Durango y uno del Estado de Nuevo León. Se encontró que los planes de manejo reunen como promedio un 60% de los 27 indicadores, de los cuales 17 se encuentran explícitos y 7 cuentan con menos del 25% de la información requerida. Las metodologías de monitoreo de las normas oficiales mexicanas se describen para 2 de estos 7 indicadores. Para 3 indicadores, sin normas oficiales, se recomiendan metodologías aceptadas por la comunidad científica. Se hacen algunas sugerencias para incrementar la precisión en la medición de otros indicadores.

Abstract—The sustainable forest management is a dynamic process which initiate with the monitoring of criteria and indicators which define tendencies of the state of forests. The first 5 criteria and their 27 indicators of the Montreal Process were reviewed at the management unit scale to determine information drawbacks and to define the appropriate methodologies for monitoring. For this report, I reviewed the forest management plans of 3 ejidos of the State of Durango and one of the State of Nuevo Leon. Information of the forest management plans meets, as an average, 60% of the 27 indicators, of which 17 are fully explained and 7 of them consider only 25% of the information requested. The methodologies adopted by the mexican official standards for 2 of these 7 indicators are described. For 3 other indicators, without official standards, I recommend monitoring methodologies accepted by the cientific community. The report briefly explains several suggestions to increase the level of precision in the monitoring of several other indicators.

La rápida transformación de los bosques del mundo tiene sus orígenes en causas políticas, económicas y sociales (Comisión Brundtland, 1987; UNCED, 1992; FAO, 1997), donde el incremento de la población, la descentralización, privatización, la liberación internacional del comercio, etc. han jugado un papel preponderante. Con los escenarios futuros sobre el crecimiento de la población mundial y las caracteristicas presentes del manejo de los recursos naturales se prevee que la perdida de biodiversidad (Mittmeier, 1993), la desertificación (Mainguet, 1994), la deforestación (FAO, 1997) y el cambio climático (Conway et al. 1994) se vean acelerados en el futuro no muy lejano.

El manejo sustentable nace como un concepto para detener la rápida transformación de los recursos naturales cuya filosofía se basa en utilizar los recursos naturales para satisfacer las necesidades presentes sin comprometer la capacidad productiva de los ecosistemas para satisfacer las necesidades de las generaciones futuras (Comisión Bruntland, 1987). Aunque este concepto había sido utilizado desde el siglo XIX en el norte de Europa y retomado en la decada de los 1970's, no fue sino hasta 1992 cuando la Conferencia de la Naciones Unidas proveió los marcos conceptuales para poner en práctica este concepto filosófico. En el sector forestal nacieron los Principios Forestales de la Agenda 21 de la reunión sobre Medio Ambiente y Población de Río de Janeiro (UNCED, 1992).

Los criterios e indicadores para la ordenación forestal sustentable se definen en el reporte 'Directrices de la ITTO para el Manejo Sustentable de los Bosques Tropicales' (ITTO, 1992) y se expande a los Procesos de Helsinki, Montreal, Tarapoto, Lepaterique, etc como continuación de los Principios Forestales de la Agenda 21. Los criterios e indicadores son herramientas para evaluar cambios o tendencias en la condición de los bosques en los contextos ecológico, económico y social (ISCI, 1996). Para el Proceso de Montreal se definieron y acordaron, en el Acuerdo de Santiago, 7 criterios y 67 indicadores, los cuales se han estado integrando a niveles nacionales (FAO, 1997).

Existen intentos por parte del Centro de Investigaciones Forestales (CIFOR) para determinar la factibilidad de operativizar los criterios e indicadores de varios procesos al nivel de la unidad de manejo. Las unidades de manejo son las rutas críticas en la ejecución de las prácticas de monitoreo para lograr los objetivos de la ordenación forestal sustentable. En México, no se ha observado esta factibilidad a la escala mencionada y este trabajo intenta hacer una revisión de la información concentrada en los planes de manejo para detectar el número y los niveles de información contenida en los primeros 5 criterios del Proceso de Montreal y hacer sugerencias de metodologías de monitoreo para aquellos indicadores no evaluados por los manejadores forestales.

Materiales Y Metodos

Los planes de manejo forestal de 4 ejidos del norte de México fueron evaluados para determinar los niveles de información explícitos de los primeros cinco criterios del Proceso de Montreal. La evaluación se realizó de una manera objetiva con el procedimiento siguiente. La información

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requerida por el indicador y totalmente explícita en el plan de manejo se le otorgó una calificación de 100. La información contenida en el plan de manejo pero no explícita de acuerdo con el indicador tuvo una calificación de 75. La información contenida parcialmente en el plan de manejo sin reunir el requisito del indicador le fue otorgada una calificación de 25 o 50, dependiendo del nivel de la información. Información no concentrada en el plan de manejo y requerida por el indicador fue dada una calificación de 0. Indicadores no relevantes fueron considerados no cuantificables.

Las metodologías de monitoreo de los indicadores no evaluados en los planes de manejo son brevemente discutidos. Estas fueron revisadas de las normas oficiales mexicanas. Para los indicadores que no tuvieron norma, se sugieren otras metodologías aceptadas por la comunidad científica.

Resultados Y Discusión

En el Cuadro 1 se reportan los indicadores de los primeros 5 criterios del Proceso de Montreal evaluados en los cuatro ejidos. Las observaciones mostraron que 2 de los 27 indicadores de los 5 criterios observados no aplican a la unidad de manejo forestal de los bosques de México. El primero se refiere a la superficie de bosque afectada por contaminantes resultantes de la actividad industrial e incremento poblacional de las metrópolis. El segundo por la acumulación de sustancias tóxicas persistentes resultantes de la deposición de residuos industriales. Ninguna de estas actividades es relevante por ahora para los bosques de coníferas del norte de México.

Los indicadore completamente explícitos variaron entre ejidos. De los 27 indicadores, 10 son completamente explícitos en los planes y programas de manejo, mientras que 15 cuentan con más del 75%, 3 con el 50% y 7 con menos del 25 de la información requerida por los indicadores. Los criterios favorecidos con la información son el 1 y 2 y los menos favorecidos fueron los criterios 4 y 5. Los promedios totales de información variarion desde 47 hasta 67, con un promedio general de 60% y una desviación estándar de 37%.

Necesidades de Estandarización de Metodologías de Monitoreo de Los Indicadores

La necesidad de estandarizar las técnicas de medición de los criterios e indicadores del Proceso de Montreal radica en el concepto filosófico del manejo sustentable. La medición continua de los perímetros deberá mostrar tendencias que indiquen cambios potenciales hacia el acercamiento, alejamiento o no cambio del manejo forestal actual en comparación con el manejo forestal sustentable (expreado

Cuadro 1.—Resultados de la información de los planes de manejo de cuatro ejidos del norte de México que contienen los indicadores de los primeros 5 criterios del Proceso de Montreal.

Criterio	Indicador	Aspecto o Indicador	Ejido 1	Ejido 2	Ejido 3	Ejido 4
1	1A1	Area por Tipo de Bosque	100	100	100	100
1	1A2	Area por Clase de Edad	50	25	100	100
1	1A3	Areas Protegidas (IUCN)	100	100	100	100
1	1A4	Areas Protegidas, Etapa Sucesional	100	50	100	100
1	1A5	Fragmentación por Tipo de Bosques	100	75	75	75
1	1B1	Número de Especies Dependientes del Bosque	75	50	75	100
1	1B2	El Estado de las Especies Forestales	100	100	100	100
1	1C1	Número de Especies de Corto Rango Espacial	100	100	100	100
1	1C2	Poblaciones de Especies de Amplio REspacial	50	25	50	75
2	2A	Area Forestal Bajo Producción	100	100	100	100
2	2B	Existencias Reales Maderables y No Mad.	75	75	75	75
2	2C	Plantaciones con Esp Nativas y Exoticas	100	50	75	100
2	2D	Remoción Maderable y Sustentable	75	75	75	100
2	2E	Remoción NoMaderable y Sustentable	50	25	50	50
3	3A	Areas Boscosas Afectadas Var. Historica	75	50	75	100
3	3B	Area Boscosa afectada por Contaminadntes	**	**	**	**
3	3C	Area Disminuida de Componentes Biologicos	0	0	0	0
4	4A	Area Forestal con Erosión	100	50	100	100
4	4B	Area Forestal bajo Protección	100	100	100	100
4	4C	Caudal Desviado del Histórico	0	0	0	0
4	4D	Area con Materia Orgánica Disminuida	25	0	50	50
4	4E	Area Compactada por Actividades Antrópicas	25	25	50	50
4	4F	Caudales Desviados en Diversidad Biológica	0	0	0	0
4	4G	Caudales Desviados en Charac. Fisicas	0	0	0	0
4	4H	Bosques con Acumulación de S.Toxicas	**	**	**	**
5	5A	Biomasa Total del Ecosistema	75	75	75	75
5	5B	Contribución al Balance Total del CO_2	25	25	25	25

1.- Conservación de la Diversidad Biológica (A-Ecosistemas, B-Especies, C-Genética); 2.- Mantenimiento de la Capacidad Productiva de los Ecosistemas Forestales; 3.- Mantenimiento de la Salud y Vitalidad de los Ecosistemas Forestales; 4.- La Conservación y Mantenimiento de Suelos y Aguas; 5.- El Mantenimiento de la Contribución de los Bosques a los cíclos globales del Carbono.

**Indicadores no relevantes para los bosques de coníferas del norte de México.

por la estabilidad de los ecosistemas forestales). La definición de la variación temporal, estimada de mediciones consecutivas, es la clave para la estandarización de técnicas de medición. Mediciones de parámetros con bajos niveles de precisión y con diferentes tecnologías oscurecen las variaciones temporales y por lo tanto la efectividad de las practicas implementadas para definir el grado de sustentabilidad.

Problemas Metodologías en la Evaluación de Indicadores

Inventarios forestales. Los inventarios forestales realizados en los bosques del norte de México proveen la base de la información para la mayoría (aproximadamente 19 de los 27) de los indicadores discutidos y por consiguiente forman la base fundamental de la aplicación del manejo forestal sustentable. Los inventarios realizados para cuantificar vegetación adolecen de debilidades en precisión y grado de sistematización. Por ejemplo, en un bosque del noroeste de México se observaron intervalos de confianza porcentuales en las existencias reales del orden de 54 hasta 75%. Considerando que los volúmenes de corta se encuentran aproximadamente en el 30% de las existencias reales totales, con los niveles de precisión estimados no se explica si el porcentaje de remoción es el total del bosque o un porcentaje menor a este. En otro bosque del norte de México se observaron incongruencias del orden del 40% en la estimación de las existencias reales en inventarios forestales realizados en tres diferentes fechas de observación, con tres diferentes metodologías de medición (Fig. 1).

Los inventarios forestales son difíciles de estandarizar en cuanto al número, tamaño, forma y distribución de los sitios de muestreo porque las condiciones de los bosques son muy heterogeneas y los niveles de factibilidad económica son variantes. Sin embargo, los niveles de precisión deseados en cada caso deberían ser uniformes y estos deberían concentrarse en dígitos menores al volumen de remoción para poder observar cambios temporales en las variables del manejo sustentable de ecosistemas forestales. Para que el monitoreo de vegetación y otras variables sea económicamente factible, se recomienda observar diferentes dimensiones, formas, y distribución de sitios de muestreo en la elaboración de metodologías que cumplan con los requisitos de precisión y factibilidad económica.

La cosecha sustentable de productos forestales. El concepto de sustentabilidad o de cosecha sustentable descrita en el criterio 2 del Proceso de Montreal debe de ser mas explícitamente definido. Pero si se considera la descripción de la Comisión Brundtland (1987) y la UNCED (1992) como la utilización presente y futura de los recursos forestales, la cosecha sustentable de productos forestales debe ser igual a la tasa de crecimiento o incremento, de los bosques (Vanclay, 1994, 1995). Existen algunas de estas tecnologías para los bosques de coníferas del norte de México (Aguirre, 1987; Torres-Rojo, 1992) pero se han concentrado a bosques uniespecíficos y regulares. Algunas aproximaciones se han realizado por Návar et al. (1996, 1998) para bosques irregulares y bajo manejo (Fig. 2). Para la implementación de estas herramientas se han desarrollado tecnologías para el establecimiento de sitios permanentes de muestreo (Alder y Synnott, 1992) y existe la técnica de análisis troncales para pináceas pero para latifoliadas aun no se han definido

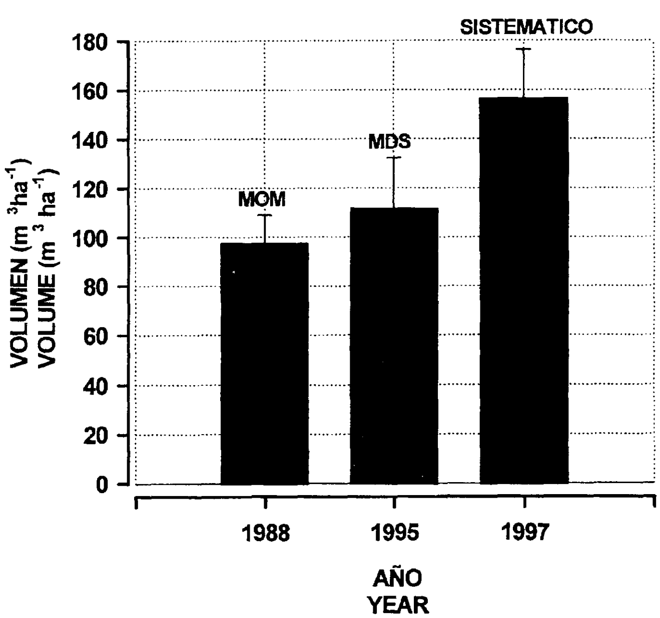

Figura 1.—Existencias reales estimadas en tres fechas con tres metodologias de inventarios forestales.

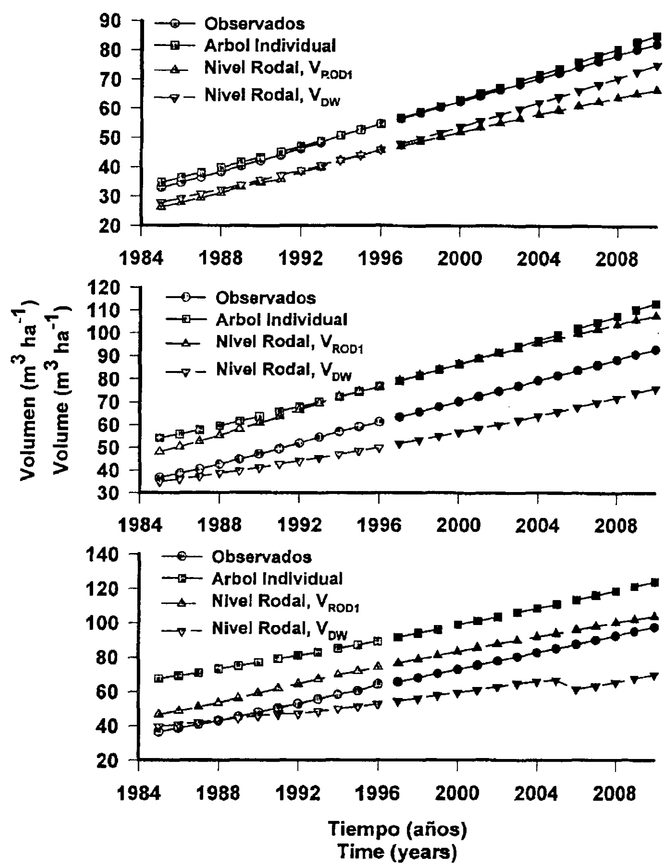

Figura 2.—Ajuste de tres modelos de crecimiento para tres rodales de coniferas del norte de Mexico.

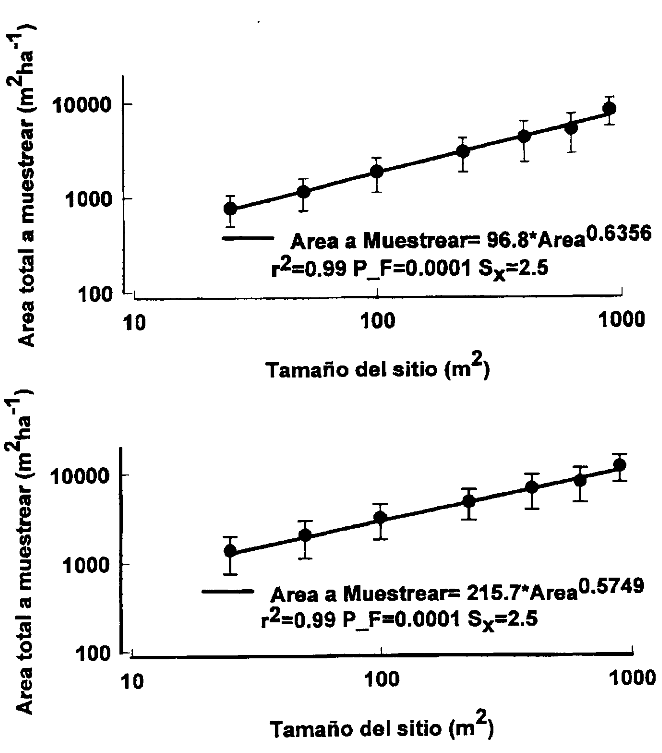

Figura 3.—El area total a muestrear y las dimensiones de los sitios para evaluar la regeneracion natural en bosques de coniferas del norte de Mexico.

estrategias secundarias a los sitios permanentes de muestreo que sean factibles al manejador forestal.

Regeneración. La cosecha sustentable incluye la restauración de los bosques naturales por regeneración natural y este parámetro se ha evaluado consistentemente con diferentes tecnologías de medición en diferentes partes del mundo, i.e los trabajos de Higò et al. (1995); Shelton y Murphy (1994); Lahde (1991); Sutomo y Pratiwi (1988) o los trabajos de Koskela et al. (1995); Little et al. (1994); Tomback et al. (1993); Chrosciewicz (1988) para evaluar el efecto de algunos tratamientos silvícolas y de los incendios forestales, respectivamente, en la regeneración natural. A este respecto, Estrada et al. (1999) observaron la necesidad de evaluar este parámetro con metodologías desarrolladas localmente y sugirieron otras potencialidades de monitoreo (Fig. 3).

Planes de Manejo Forestal

Caudales. Información sobre los caudales y sus desviaciones históricas no existen en los planes de manejo. El crecimiento de las masas forestales (expresado como incremento en volumen, área basal, o estructura diamétrica) y la remoción de árboles (expresado como una reducción en la densidad, área basal o volumen residual) controlan la escorrentía o caudales temporales o anuales de las cuencas forestales (Hibbert, 1967; Swank et al., 1988) (Fig. 4). La construcción de caminos forestales para la extracción, las operaciones de arrime, carga y descarga alteran también los

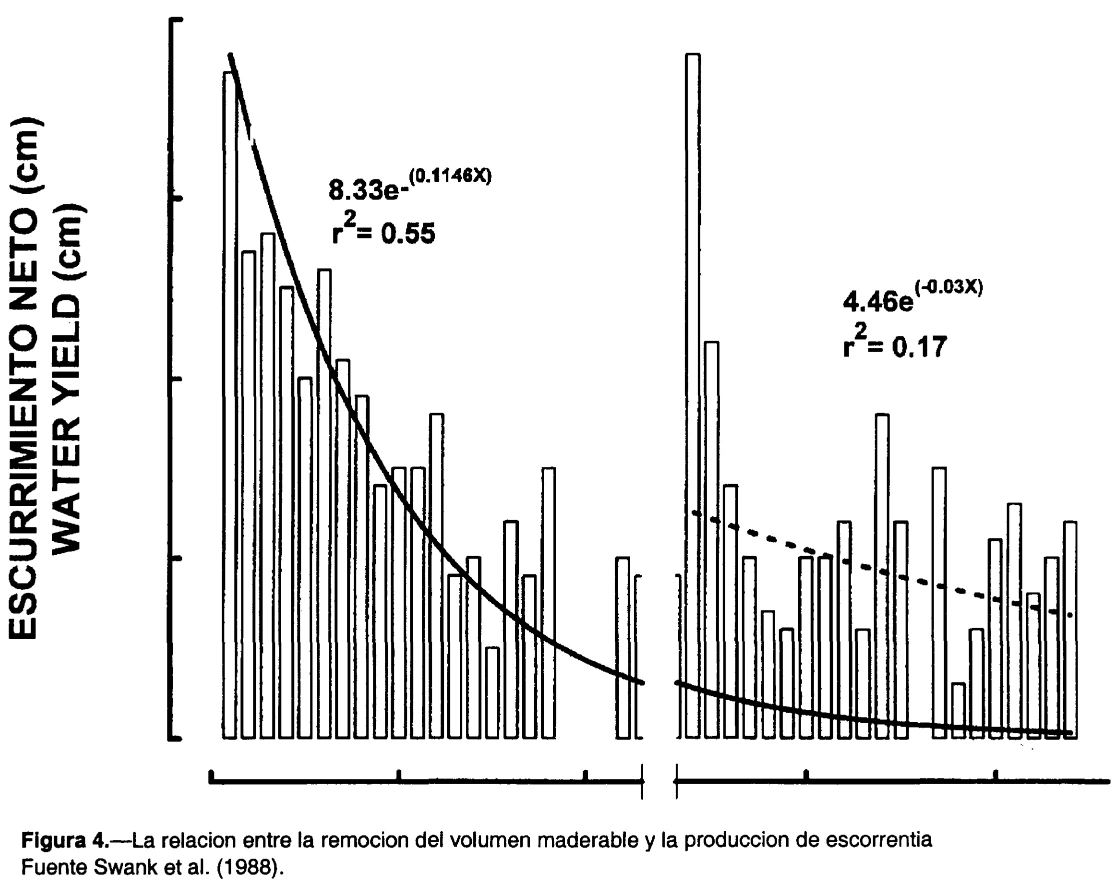

Figura 4.—La relacion entre la remocion del volumen maderable y la produccion de escorrentia Fuente Swank et al. (1988).

caudales (Brown, 1988). Los incendios forestales controlan también la producción de escorrentía superficial y puede incrementar la erosión de suelos (Alanís et al., En Prensa) (Fig. 5) y parece ser el resultado de la eliminación parcial del mantillo orgánico (Fig. 6). Otros disturbios ocasionados por actividades antropogénicas como el sobrepastoreo en terrenos forestales ha sido relacionado con las reducciones en la infiltración y los incrementos de la escorrentía en otras cuencas (Thurow et al. 1988; Wood et al. 1989; Takar et al. 1990). Por estas razones, los caudales deben de medirse para reunir los requerimientos del indicador 3 del criterio 4.

La metodología desarrollada por La Comisión Nacional del Agua, CNA, (descrita similarmente en Linsley et al., 1988) se recomienda para evaluar los caudales de los bosques bajo manejo al nivel de la unidad. Esta se realiza por la medición del área transversal del cauce y la velocidad de la corriente. Con el uso del molinete o correntómetro, la velocidad del caudal se mide en sitios que reunan las condicionantes de estabilidad, sección transversal homogenea y pendiente consistente en una sección del cauce. La velocidad de la corriente es medida normalmente a 0.2 y 0.8 de la base del cauce o cuando el nivel del agua es poco profunda a 0.6 de la base del cauce en distancias discretas transversales a la corriente (Linsley et al. 1988; Shaw, 1988).

La técnica de medición de corrientes descrita produce estimaciones con un error del 10% (Wilson, 1990). Los errores causados por mediciones puntuales en periodos de tiempo consecutivos pueden ser mayores porque los caudales varían en función de la intensidad de la lluvia, humedad antecedente de los suelos, y factores que controlan la evapotranspiración y la percolación profunda. Por estas razones, la CNA realiza mediciones dos veces diarias (8:00 a.m y 14:00 p.m) y en periodos lluviosos a escalas de tiempo menores. En lluvias intensas, cuando los caudales son significativos, la medición de la velocidad se sustituye por la medición de la altura del nivel del agua en un punto de referencia previamente instalado. Para esto se necesita calibrar la relación descarga - altura del nivel del agua y requiere de mediciones continuas.

Calidad de agua de los caudales. Las remoción y las operaciones de remoción de árboles controlan también la calidad del agua de los caudales (Brown, 1988). Actividades humanas como el sobrepastoreo, los incendios forestales y las descargas municipales en los cauces alteran también la calidad de los recursos hidrológicos de las cuencas forestales. La calidad (expresada por el pH, oxígeno disuelto y conductividad eléctrica) debe de ser medido para cumplir con el indicador 7 del criterio 4.

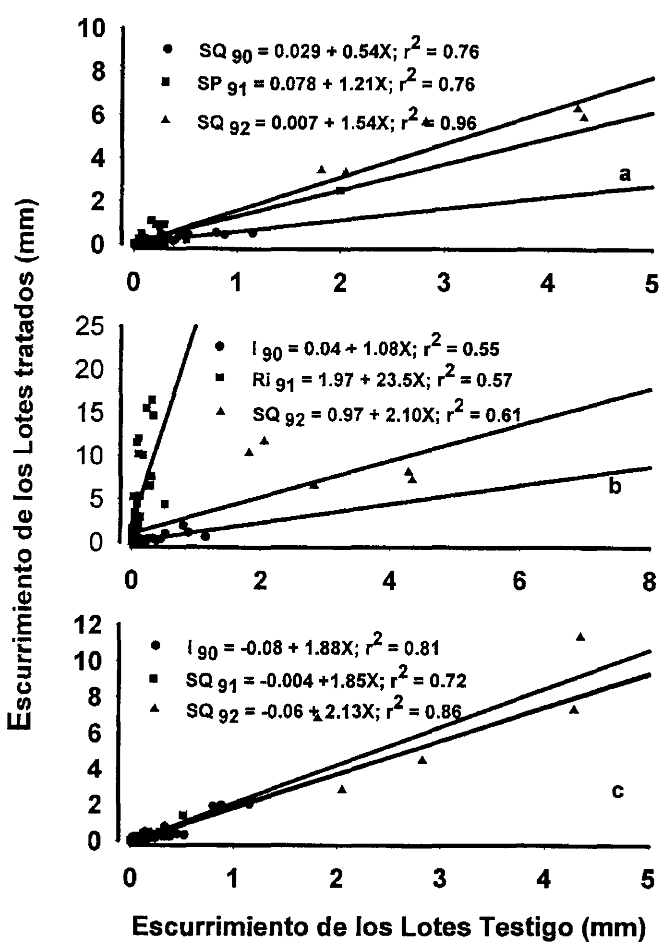

Figura 5.—La relacion entre lotes testigo y lotes tratados con quemas prescritas.

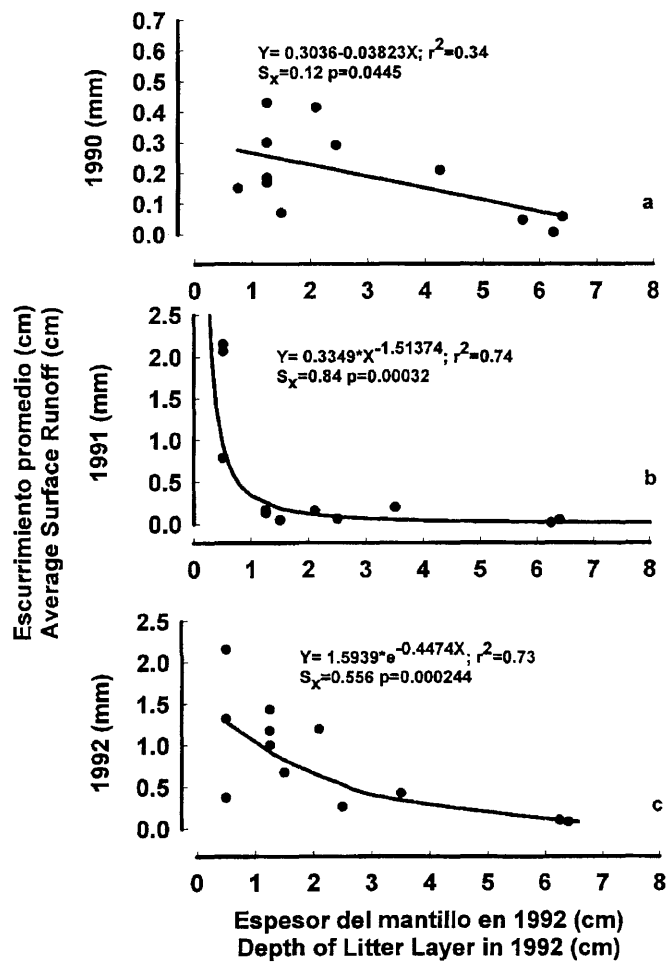

Figura 6.—Las relaciones entre escurrimiento superficial y la profundidad del mantillo organico.

La metodología utilizada por la Comisión Nacional del Agua para la toma de muestras y el análisis químico de las mismas debe de usarse como el estándar de referencia en México. Las muestras de agua se toman de súbito del centro de la corriente, a una profundidad de entre 0 y 30 cm con envases de plástico de 4 l de capacidad, para el análisis de conductividad eléctrica y pH. Para el oxígeno disuelto se utilizan botellas Winkler de 300 ml en las cuales se fija el oxígeno en campo con 2 ml de sulfato de manganeso y 2 ml de solución de álcali yoduro azida de sodio. Para la determinación de la conductividad eléctrica se realiza por el método Electrométrico (NMX-AA93-1984) con un conductivímetro YSI modelo 32, con límites de detección de 1 mmho cm^{-1}. El pH se mide con el analizador de iones Cominng 250, con límites de detección de 0.01 pH y se realiza por el método MA-FQ-28 descrito en la norma Mexicana NMX-AA-8-1980. Para el oxígeno disuelto se utiliza el método Winkler modificación Azida descrito en la norma Mexicana NMX-AA-12-1980.

Contenido de materia orgánica de los suelos. La materia orgánica de los suelos forestales es la reserva principal del nitrógeno, fósforo, azufre y gran parte del boro y molibdeno en suelos templados (Bohn et al. 1993). La materia orgánica proporciona también la energía necesaria de los microorganismos del suelo. Forma un flujo y reserva importante de carbono en los suelos forestales. Esta también contribuye a la formación de agregados y a la estabilidad estructural de los suelos y por consiguiente mejora las relaciones suelo-agua-aire del ecosistema (Hillel, 1982). La materia orgánica amortigua eficientemente los cambios de temperatura del suelo, absorbe la energía cinética de las gotas de lluvia (Morgan, 1990) y aisla al suelo de la energía solar directa (Hillel, 1980, 1982). Por estas y otras razones este factor se recomienda medir dentro del indicador 4 del criterio 4.

Los suelos forestales presentan frecuentemente una capa de mantillo orgánico sobre el suelo mineral y este puede ser medido simplemente por su espesor en una área específica, calibrado por el método del peso o volumen de muestras de mantillo orgánico redistribuidos en la superficie de colecta. Suelos minerales forestales sin cobertura de mantillo orgánico deberan ser medidos por su contenido de materia orgánica. Los métodos de Wakley-Black y Schollenberger se encuentran disponibles para la determinación de carbono orgánico. El primero consisten en combustión húmeda de la muestra de suelo con dicromato de potasio en un medio acido y titulación con sulfato ferroso (Page et al. 1989).

Compactación de los suelos. La compactación de los suelos es una medida del grado de empacamiento de las partículas de suelo y puede ser afectado en suelos forestales por actividades antropogénicas como el sobrepastoreo (Thurow et al. 1988; Wood et al. 1989; Takar et al. 1990), arrastre de torcería (Rothacher, 1970) y la apertura de caminos de extracción. Otros factores indirectos como la disminución de materia orgánica, contenido y movilización del sodio pueden controlar el grado de compactación de los suelos. Este factor afecta la germinación de semillas y penetrabilidad de las raíces de las plántulas dentro de los suelo, las tasas de escorrentía o infiltración, la aireación, intercambios de temperatura, gases y agua dentro de los suelos (Hillel, 1980, 1982; Klute, 1987). Por esta razón este parámetro físico de los suelos forestales debe de ser medido como indicador del manejo forestal sustentable dentro del criterio 4, indicador 5.

El penetrómetro es el equipo utilizado para medir el grado de compactación de los suelos. La densidad aparente de los suelos es también un indicador del grado de compactación. Los métodos del cilindro, excavación, del terrón y por radiación (Blake y Hartge, 1987) se encuentran disponibles para medir la densidad aparente de los suelos forestales. La presencia de gravas y raíces dificulta la medición de este parámetro y los métodos del cilindro y de excavación podrían ser recomendados para este propósito. El primer método requiere de la colección de una muestra de suelo con un volumen conocido, pesar, secar en estufa a 105 °C hasta obtener peso constante y pesar de nuevo. Para este propósito se debe de calibrar las dimensiones del cilindro para obtener el mejor estimador (Fig. 7). El número de muestras a obtener de suelos forestales debe de ser grande, considerando que para suelos agrícolas se requieren 17 con un 95% de certidumbre y un 1% de precisión (Návar, 1996).

Biomasa forestal total. Los bosques desempeñan un papel preponderante en el cambio climático porque almacenan cantidades importantes de carbono en la biomasa aérea (fustes, ramas y hojas), subsuelo (raíces) y suelo (materia orgánica) (Brown et al. 1996; Brown, 1997). El intercambio de carbono entre la vegetación y la atmósfera se realiza a través de la fotosíntesis, la respiración y en suelos a través de la descomposición de la materia orgánica. Cuando los bosques son perturbados por incendios o malos sistemas de manejo o cambios de uso del suelo existe una transferencia neta de carbono hacia la atmósfera. Por el contrario cuando los bosques se mantienen creciendo o se reforestan áreas desprovistas de vegetación, el ecosistema se convierte en un sumidero, almacén, de carbono. Estos procesos contribuyen en la reducción o incremento del CO_2 atmosférico y por consiguiente en el cambio climático global (Schimel et al. 1995). Por esta razón, el criterio 5, indicador 1 considera la

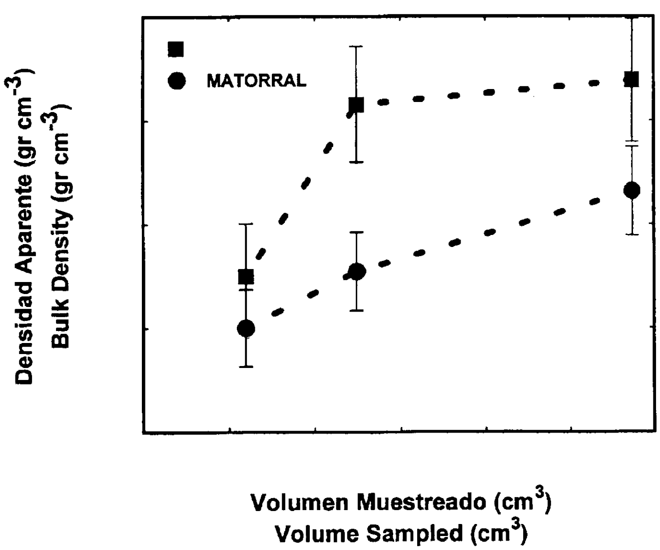

Figura 7.—La relacion entre la dimension del cilindro y la densidad aparente en dos suelos.

biomasa total como un parámetro importante del manejo forestal sustentable.

La secuestración del bióxido de carbono se puede estimar con información disponible sobre la biomasa forestal, i.e., los volúmenes maderables totales de algunos bosques bajo manejo del norte de México (tomado de Contreras et al. En Revisión) y su crecimiento (tomado de Návar et al. 1998) y haciendo algunas suposiciones en cuanto a una biomasa foliar constante, contenido de C en la biomasa maderable y contenido de CO_2 en C de acuerdo con USCSP (1994), algunos bosques del norte de México secuestran aproximadamente 25.7 ton ha^{-1} de CO_2 compensado, para un período de 10 años. Esta metodología presenta incertidumbres en: (i) la estimación del volumen maderable total por árbol (aproximadamente un 25%), (ii) la transformación de volumen maderable en materia seca, (iii) la transformación de la materia seca en carbono y (iv) la transformación del carbono en bióxido de carbono. Por esta razón, se deben estandarizar metodologías para la estimación de la contribución de los bosques al balance total del bióxido de carbono. Las metodologías propuestas por Brown et al. (1996) podrían preliminarmente ser utilizadas en la estimación de este parámetro. Otro parámetro que necesita estimaciones es el CO_2 capturado y almacenado en los suelos y presenta mayor problemas. Brown (1997) estimó que la cantidad almacenada en los suelos es 1.5 mayor que el CO_2 almacenado en la biomasa aérea.

Conclusiones

Los planes de manejo revisados de 4 ejidos indicaron que la información contiene el 60% de los indicadores de los 5 primeros criterios del Proceso de Montreal. De los 27 indicadores, 2 no son aplicables en esta etapa a los bosques del norte de México y 7 no se monitorean en los programas de aprovechamiento de los bosques. Por esta razón se describen metodologías de monitoreo para los 5 indicadores adicionales dentro de las cuales 2 se encuentran oficialmente dentro de las normas mexicanas.

Literatura Citada

Aguirre-Bravo C. 1987. Ph.D. Dissertation. Colorado State University. Fort Collins, Colorado.

Alanís-Morales, H.E., Návar, J., y Jurado, E. 1998. Relación entre quemas prescritas y el escurrimiento superficial de un rodal de pino en Madera, Chihuahua. En Prensa en Agrociencia.

Alder, D., and Synnott, T.J. 1992. Permanent sample plot techniques for mixed tropical forest. Oxford Forestry Institute, Tropical Forestry Pap. 25. 124 p.

Blake, G.R. and Hartge, K.H. 1987. Bulk Density In: Klute, A. Editro. 1987. Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Part 1. 2nd Edition. ASA SSSA. pp 336-375.

Brown, W.G. 1988. Forestry and Water Quality. OSU Book Stores Inc. Corvallis, Oregon.

Brown, S., Sathaye, J., Cannell, M., Kauppi, P.E. 1996. Management of forests for mitigation of greenhouse gas emissions. In: R.T. Watson et al. Climate Change 1995: Impacts, adaptations and mitigation of climate change: scientific analysis. Contribution of working group II to the second assessment report of the IPCC. Cambridge University Press. Cambridge UK. pp 773-798.

Brown, S. 1997. Los bosques y el cambio climático: el papel de los terrenos forestales como sumideros de carbono. Actas del XI Congreso Mundial Forestal. Vol 1. pp 107-121.

Brown, S., Lim, B., and Schlamadinger, B. 1998. Evaluating approaches for estaimating net emissions of carbon dioxide from forest harvesting and wood products. Meeting Report. IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories. Dakar, Senegal. May 1998.

Chrosciewicz, Z. 1988. Jack pine regeneration following postcut burning under seed trees in central Saskatchewan. For. Chronicle 64(4): 315-319.

Clutter, J.L., J.C.Forston, L.V.Pienaar, G.H.Brister, and R.L.Bailey. 1983. Timber Management: a quantitative approach. John Wiley and Sons, New York. 349 p.

Comision Brundtland, 1987. Reporte sobre el estado de los recursos naturales de la Tierra. ONU. Rome Italy.

Contreras, J., Návar, J. y Estrada, C. 1998. Modelos de volumen para *P. durangensis* y *P. Teocote* de Durango, México. En Prensa en Investigación Agraria: Sistemas y Recursos Forestales.

Conway, T., P. Tans, L. Wetermen, 1994. Atmospheric CO_2, records from sites on the NOOAA/CDML air sampling network. In: Trends '93. A compendium of data on global change. Carbon Dioxide Informational Laboratory.

DeBano, L.F. 1991. The effect of fire on soil properties. Proceedings on Management and Productivity of Western Montane Forest Soils. USDA. Forest Service. General Technical Report INT-280. Boise, ID, USA. p. 151-156.

Estrada-Marquez, C., Návar, J. y Contreras, J. 1999. Eficiencia de disenos de muestreo para evaluar la densidad de la repoblación natural en bosques de coníferas en Durango, México. En Prensa en Agrociencia.

FAO, 1997. The state of the world forest resources. FAO, ROME, Technical Bulletin.

Hewlett, J.D. 1982. Principles of forest hidrology. The University of Georgia Press Athens, Georgia. 183 p.

Hibbert, A.R. 1967. Forest treatment effects on water yield. Proc. Int. Symp. For. Hydrol. 527-543. Penn. State University. Pergamon Press, Toronto.

Higo, M., Shinohara, A. and Kodama, S. 1995. The regeneration behavior of major components species in the secondary forest dominated by *Pinus densiflora* and *Quercus serrata* in central Japan. For. Ecol. and Manag. 76: 1-10.

Hillel, D. 1980. Introduction to soil physics. Academic Press Inc. USA. 364 p.

Hillel, D. 1982. Introduction to soil physics. Academic Press Inc. New York, USA.

ISCI, Intergubernamental Seminar on Criteria and Indicators for Sustainable Forest Management. August 19-22, 1996. Helsinki.

ITTO. 1992. Report on the working party on certification of all timber and timber products. Document PCM, PCF, (XIV)/3 Rev. 1. Yokohama.

Koskela, J., Kuusipalo, J. and Sirikul, W. 1995. Natural regeneration dynamics of Pinus merkusii in northern Tailand. For. Ecol. and Manag. 77: 169-179.

Klute, A. 1987. Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Part 1. 2nd Edition. ASA SSSA.

Lahde, E. 1991. *Picea abies*-dominated naturally established sapling stands in response a various cleaning-thinnings. Scandinavian J. For. Res. 6(4): 399-508.

Linsley Jr. R.K., Kohler, M.A., and Paulhus, J.H. 1988. Hidrología para Ingenieros. McGraw Hill. México.

Little, R.W., Peterson, D.L., and Conquest, L.L. 1994. Regeneration of subalpine fir (Abies lasiocarpa) following fire: effects of climate and other factors. Can. J. For. Res. 24: 934-994.

Mainguet, M. 1994. Desertification: Natura Background and Missmanagement. 2nd Edition Springer Verlag. Berlin, Germany.

Morgan, R.P.C. 1990. Soil erosion and conservation. Longman Scientific & Technical. Essex, U.K. 298p.

Návar, J., Jiménez, P.J., Domínguez, P.A., Aguirre, O.A., Galván, M. y Paez, A. 1996. Predicción del crecimiento de masas forestales irregulares en base a las distribuciones diamétricas den el sureste de Sinaloa, México. Investigación Agraria: Sistemas y Recursos Forestales 5(2): 213-229.

Návar, J., Corral, S, Contreras, J. 1998. Perspectivas preliminares para el modelaje del crecimiento de bosques irregulares bajo manejo de pino de Durango, México. Primero Congreso Latinoamericano IUFRO, Valdivia, Chile. Noviembre de 1998.

Návar, J. 1996. Manual de Física de Suelos. Inédito. Facultad de Ciencias Forestales, UANL. Linares, N.L., México.

Page, A.R. 1989. Methods of Soil Analysis. Part 2. Chemical Analysis. Agronomy Part 2. 2nd Edition. ASA SSSA.

Schimel, D., Enting, I.G., Heimann, M., Wigley, T.M.L., Rayneud, D., Alves, D., and Seigenthaler, U. 1995. CO2 and the carbon cycle. In: Houghton et al, Climate Change 1994 radiative forcing of climate change and the evaluation of the IPCC IS92 emission scenarios. Cambridge University Press, Cambridge, UK. pp 35-71.

Shelton, M.G. and P.A.Murphy. 1994. Loblolly pine regeneration and competing vegetation 5 years after implementing uneven-aged silviculture.Can. J. For. Res. 24: 2448-2458.

Shaw, E. 1988. Hydrology in Practice. 2nd Edition. International. London. UK.

Sutomo, S. and S. Pratiwi. 1988. Composition and stocking of natural regeneration in a virgin and logged-over forest at Kintap, South Kalimantan. Buletin Penelitian Hutan. No. 501: 1-12

Swank, W.T., Swift, L.W., and Douglass, J.E. 1988. Streamflow changes associated with forest cutting, species conversions, and natural disturbances. In Forest Hydrology and Ecology at Coweeta. Eds. W. T. Swank and D.A. Crossley Jr. Springer Verlag. New York 297-312 pp.

Takar, A.A., Dobrowlski, J.P., and Thurow, T.L. 1990. Influence of grazing, vegetation life-form, and soil type on infiltration rates and interrill erosion on Somalion rangeland. Journal of Range Management 43(6): 486-490.

Thurow, T.L., Blackburn, W.H., and Taylor, C. A.Jr. 1988. Infiltration and interril erosion response to selected livestock grazing strategies, Edwards Plateu, Texas. Journal of Range Management 41(4): 296-302.

Tomback, D.F., S.K.Sund, and L.A.Hofmann. 1993. Post-fire of *Pinus albicaulis*: height-age relationships, age estructure, and microsite characteristics. Can. J. For. Res. 23: 113-119.

Torres-Rojo, J.M. 1992. SIMBUS. Simulador de Manejo para los Bosques de la Unidad Santiago.

UNCED, 1992. United Nations Congress on Environment and Development. Rio de Janeiro Brazil. Cambridge Univesity Press.

USCSP. 1994. Guidances for Vulnerability and Adaptation Assessments, Washington, D.C.

Vanclay, J. K. 1994. Modelling Forest Growth and Yield: Applications to Mixed Tropical Forests. CAB International. Tucson, AZ. USA.

Vanclay, J.K. 1995. Growth models for tropical forests: A synthesis of models and methods. Forest Science, 41: 7-42.

Wilson, B.N. 1990. General Hydrology. Lecture Notes. Oklahoma State University. Stillwater, Oklahoma.

Wood, J.C., Blackburn, W.H., Pearson, H.A., and Hunter, T.K. 1989. Infiltration and runoff water quality response to silvicultural and grazing treatments on a longleaf pine forest. Journal of Range Manegement 42(5): 378-381.

Estudio de los Suelos Forestales del Desierto de los Leones Distrito Federal[1]

Juana Ma. Castro Servín[2]

Resumen—La declinación que presenta en la actualidad el bosque de Oyamel (*Abies religiosa*) del Parque Cultural y Recreativo Desierto de los Leones en el Distrito Federal (PCyRDL-D.F.), se debe a diversos factores bioticos y abioticos tales como: la contaminación ambiental producida en la Ciudad de México, la falta de manejo forestal del bosque, la excesiva extracción de agua de los mantos acuíferos, plagas y enfermedades, entre otros.

El PCyRDL tiene gran importancia para los habitantes de la Cd. De México, ya que representa una fuente de bienes y servicios, área de recarga de mantos acuífero, purificación de agua y aire, hábitat para infinidad de organismos; así como, un lugar para el desarrollo de trabajos científicos de diversa índole. Algunos de estos estudios han sido realizados por el Instituto Nacional de Investigaciones Forestales (INIF) en los ochentas y en fechas recientes por el Centro Nacional de Investigaciones Disciplinarias en Conservación y Mejoramiento de Ecosistemas Forestales (CENID-COMEF).

Al respecto, sobresalen las investigaciones edafológicas, en las que además de la determinación de las propiedades físicas y químicas del suelo, se ha estudiado los contenidos de metales pesados tóxicos en el mismo.

En el presente estudio los resultados de cinco muestreos estaciónales durante los años de 1984, 1985, 1991, 1992 y 1993; de las siguientes localidades del PCyRDL: Cementerio, Convento, Cañada de San Miguel, Agua de Leones y Cruz de Cólica.

Las muestras de suelo se tomaron a diferentes profundidades en cada uno de los 30 sitios y posteriormente se analizaron en el Laboratorio de suelos del CENID-COMEF siguiendo las técnicas particulares para suelos forestales (Jackson, 1982). En el caso particular de metales pesados se utilizó como extractante ácido dietilen triamino penta acético (DTPA), y se cuantificaron en un espectrofotómetro de absorción atómica.

Los resultados de las propiedades químicas del suelo muestran que durante los ciclos de muestreo los contenidos de pH, materia orgánica, capacidad de intercambio cationico y fósforo han disminuido en relación al primer año en tres de los sitios establecidos, excepto en los ubicados en Cementerio y Cruz de Cólica, los cuales están ubicados el primero en la parte baja y el segundo en la alta no encontrando una variación significativa. La relación de carbono nitrógeno, indica que la cantidad de materia orgánica del suelo no esta siendo incorporada al mismo. En el caso de magnesio y potasio su concentración ha ido aumentando durante los años siguientes significando que éstos elementos no están disponibles para la planta.

En el caso de los metales pesados, estudio iniciado en los noventas, los resultados nos indican que las concentraciones más elevadas de cobre, zinc, fierro, plomo, cromo y cadmio se detectaron en la parte baja, lo contrario sucedió en la parte alta las concentraciones son menores. El aluminio determinado fue mayor en los sitios Agua de Leones y Cruz de Cólica los cuales se localizan en la parte alta del parque.

Los problemas de urbanismo, contaminación y de uso inadecuado de los recursos naturales en México, específicamente en el Parque Cultural y Recreativo Desierto de los Leones, Distrito Federal (PCyRDL-D.F.), han dado como resultado un marcado desequilibrio en sus ecosistemas naturales, poniendo en serio peligro algunas especies vegetales arbóreas como el oyamel (*Abies religiosa)*, el cual presenta daños por el impacto que en diferentes aspectos ejerce el área metropolitana. El PCyRDL, tiene gran importancia para los habitantes de la Ciudad de México, ya que representa una fuente de bienes y servicios recreativos, educativos, culturales, es un área de recarga de mantos acuíferos, purificación de agua y aire, hábitat para infinidad de organismos y para el desarrollo de trabajos científicos de diversa índole.

En el parque, se han realizado varias investigaciones que abordan el problema de la declinación y muerte del bosque de oyamel desde diversos puntos de vista; en ellas se han evaluado mediante estudios interdisciplinarios: la geología superficial, edafología y microbiología de los suelos; así mismo se han realizado estudios que evalúan el efecto de los oxidantes fotoquímicos en el follaje del arbolado; así como los contenidos de metales pesados en los suelos y la caracterización nutricional del follaje (Reyes, et al., 1984; Romero, 1986; Castro, 1986; Alvarado, et al., 1991; Castro, et al., 1993, 1995 y 1996; López y Rivera, 1995; Castañeda, et al., 1995).

Sin embargo, con todas las investigaciones realizadas aún no se conoce con exactitud que es lo que realmente genera el deterioro del bosque; ya que en él inciden una serie de factores como son: la presencia de masa de aire contaminado proveniente de la Cd. de México, ésto aunado a la excesiva extracción de agua de los mantos acuíferos, así como la presencia de plagas y enfermedades pudieran ser en su conjunto las causas de los síntomas de deterioro del bosque (Alvarado, *op. cit.*)

El presente trabajo tiene como antecedente, los muestreos realizados por (Castro, *op. cit.*), para conocer los cambios que durante estos años se han registrado en las propiedades químicas del suelo del PCyRDL-DF Castro, et al., *1995 (op. cit.*). El objetivo fue recopilar la información de cinco años de muestreo de suelos y relacionar los resultados obtenidos para definir algún índice de cambio en las propiedades químicas del mismo.

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Materiales y Métodos

Localización y descripción del área de estudio

El parque, está ubicado en la Delegación Cuajimalpa De Morelos, Distrito Federal, al suroeste de la Cd. de México, a una altitud que va de los 2,800 a los 3,800 msnm (Fig. 1). El clima predominante, según Köppen modificado por García (1981), es templado subhúmedo con lluvias en verano; la precipitación media anual es de 1,354 mm; la temperatura mínima es de 8.4 °C y la máxima de 12.7 °C; con vientos dominantes del noroeste y noreste, lo que corresponde a un clima C (W_2) (b) ig.

Los suelos son profundos , ricos en materia orgánica, textura migajón-arcillo-arenoso a arcillo-limosa; según la clasificación del Insituto Nacional de Estadística Geografía e Informática (INEGI), se trata de regosoles éutricos.

La vegetación corresponde a bosque de *Abies* y de *Pinus*, en los que predominan las siguientes especies: *Abies religiosa* Schl. *et.* Cham., *Pinus patula* Schl. *et.* Cham., *P. Hartwegii* Lindl., *Quercus laurina* HBK., *Q. mexicana* HBK y *Q. microphylla* Neé. Otras especies presentes son: *Prunus serotina* Ehrh ssp. *capuli* (Cav) Mcbaugh., *Alnus firmifolia* Fern., *A. jorullensis* HBK, *Arbutus glandulosa* Mart. & Gal., *Buddleia cordata* HBK y *B. parviflora* HBK.

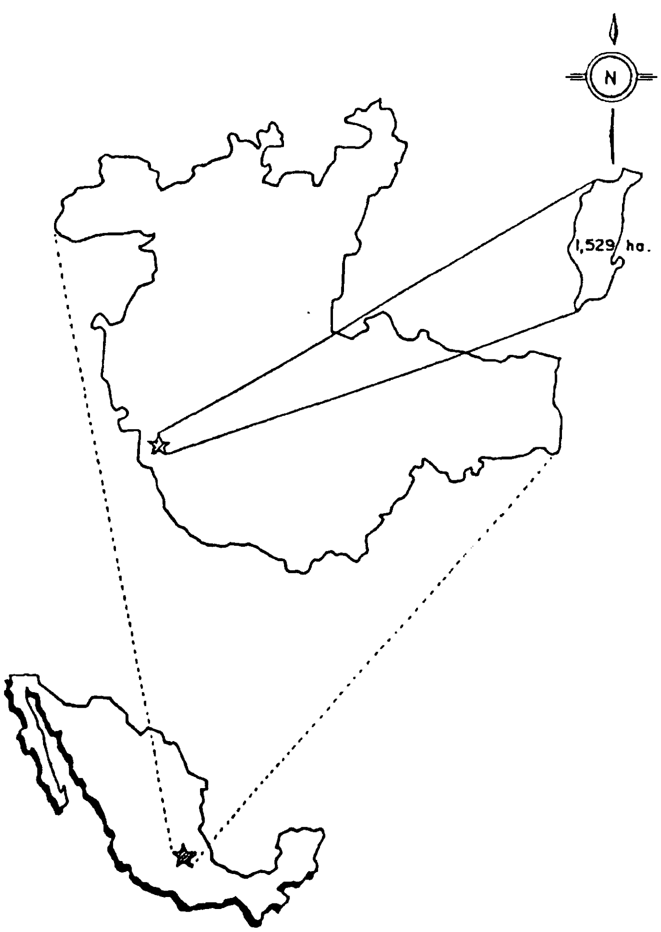

Figura 1.—Ubicación del área de estudio del Parque Cultural y Recreativo Desierto de los Leones.

Trabajo de Campo

El área de muestreo se definió con base en los mapas edafológicos y de vegetación del INEGI. Se realizaron muestreos de suelos estacionales en los años de 1984, 1985, 1991 1992 y 1993 en cinco sitios permanentes del PCyRDL.

Localización de los sitios permanentes de muestreo:

a) Cementerio, con una plantación de *Pinus ayacahuite* Ehr., *P. patula* SChl. *et.* Cham., *P. radiata* Don. y *P. montezumae* Lam. establecida en 1986. Exposición norte y altitud 2,980 msnm.

b) Convento, con una vegetación de *Abies religiosa.* Exposición noroeste y altitud 2,920 msnm.

c) Cañada de San Miguel, con una vegetación dominante de *A. religiosa*. Exposición noroeste y altitud 3,180 msnm.

d) Agua de Leones, con vegetación predominante de *Pinus sp*. Exposición noreste y altitud 3,320 msnm.

e) Cruz de Cólica, bosque de *Pinus*. Exposición «Zenital» y altitud 3,600 msnm.

En cada área se ubicaron tres sitios en un transecto de 50 metros lineales, ubicándolos al norte, centro y sur. Se obtuvieron muestras de suelos de un kilogramo cada una, en un principio los muestreos fueron en perfiles, a partir del año de 1992 solo se tomaron muestras a dos profundidades 0-15 y 15-30 cm.

Trabajo de Laboratorio

Las muestras de suelo se procesaron en el laboratorio de suelos del Instituto Nacional de Investigaciones Forestales (INIF), actualmente CENID-COMEF en Coyoacán, D. F. utilizando los métodos analíticos de Lim y Jackson (1982), a dichas muestras se les realizaron los siguientes análisis: pH, materia orgánica, nitrógeno, capacidad de intercambio cationico, fósforo y cationes intercambiables (Ca, Mg, Na y K), los minerales analizados fueron aluminio, plomo, fierro, zinc, manganeso, cobre, cadmio y cromo (Al, Pb, Fe, Zn, Mn, Cu, Cd y Cr), los cuales fueron extraídos con ácido dietilentriamino penta acético (DTPA). Para su cuantificación se utilizó un espectrofotómetro de absorción atómica

Resultados y Discusión

En el presente estudio se consignan y discuten los resultados correspondientes a las propiedades químicas del suelo más significativas para los ciclos anuales de los sitios permanentes de muestreo.

En los sitios Cementerio y Convento ubicados en la parte baja del parque, en el primero se estableció una plantación de especies de pino en 1986 y en el segundo se tiene una vegetación dominante de oyamel, se observó una disminución progresiva en los contenidos de materia orgánica, capacidad de intercambio cationico, Ca y P; así por ejemplo la M.O. disminuyó de 23.4% a 10.5% (Figs. 2 y 3). Lo contrario se presenta en las concentraciones de Mg y K, las cuales tienden a aumentar en el suelo. Asimismo, las concentraciones de N y Na permanecieron constantes. Estos mismos cambios se presentan en los sitios Cañada de San Miguel y Agua de Leones ubicados en la parte intermedia del parque y Cruz de Cólica que se localiza en la parte alta (Cuadros 1 al 5).

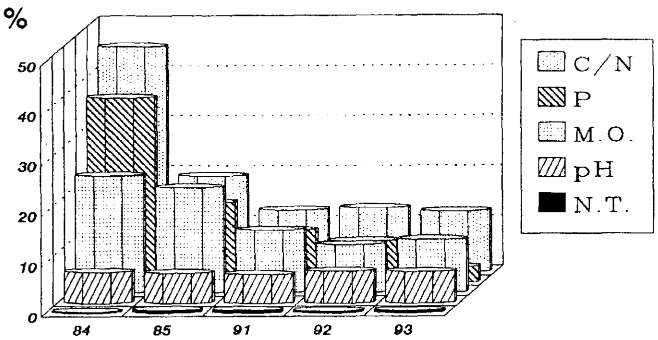

Figura 2.—Sitio Cementerio características químicas del suelo.

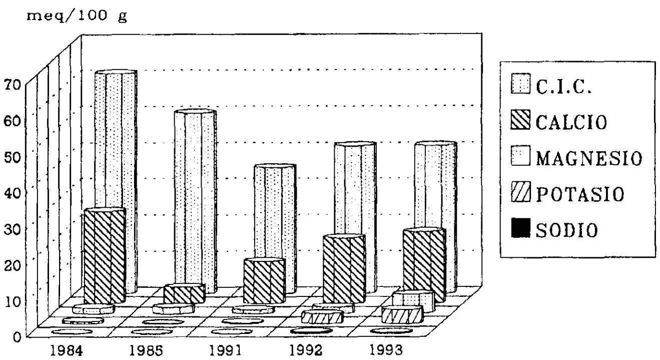

Figura 3.—Sitio Convento características químicas del suelo.

En el caso de los metales pesados el análisis de éstos se inicio a partir de 1991 por lo que solo se están tomando tres años de muestreo de suelos para cada uno de los sitios; se discuten los resultados correspondientes a los elementos más significativos que son: Al, Pb, Fe, Zn, Mn y Cr.

En el Cuadro 6 se resumen los resultados obtenidos, sobresalen los sitios Agua de Leones y Cruz de Cólica con valores superiores a las 100 ppm de aluminio (Figs. 4 y 5). Con respecto a los metales el Pb y Cr han aumentado paulatinamente en los cinco sitios permanentes, lo contrario sucede con el Fe, Zn y Mn cuyos valores han bajado, en el sitio Cementerio el fierro disminuyó de 139.6 ppm a 29.8 ppm (Fig. 6).

La reducción de la materia orgánica en los sitios evidencia que no se está incorporando al suelo por presentar alta relación carbono nitrógeno; sin embargo, a partir de 1991 la integración es rápida pero la perdida es mayor (Cuadro 1 al 5). El pH, importante indicador de humificación que otorga la acidez en el suelo, tiende a aumentar en la mayoría de los sitios en una proporción de 0.1 a 0.5 décimas, lo cual indica la no descomposición del material vegetal y la baja proporción de C.I.C., Ca y P.

Las altas concentraciones de plomo se deben a que este metal pesado se encuentra en las partículas de la atmósfera y se acumula en el suelo por causas naturales, en el caso particular de los sitios muestreados se considera que las concentraciones determinadas se deben a causas antropogénicas, ligadas principalmete a ambientes urbanos

Cuadro 1.—Promedios de características químicas de los suelos del desierto de los leones en el ciclo 1984.

A	B	E	F	pH	M.O.	N_2T	C / N	C.I.C	Ca	Mg	Na	K	P
			H_2O		*- - percent - -*			*- - - - - - - - - - meq / 100 g - - - - - - - - - -*					%
1	Pt	N	2980	6.2	23.4	0.3	45.2	47	28.5	1.3	0.1	0.6	37
2	O	NW	2920	5.8	21.3	0.6	20.6	61	25.7	1.7	0.1	0.7	23
3	O	NW	3180	6.0	12.3	0.5	14.3	43	9.0	2.5	0.2	0.6	24
4	P	NE	3320	6.2	18.3	0.3	35.4	47	16.8	2.0	0.2	0.7	25
5	P	Zenital	3600	5.5	28.1	1.0	16.3	57	15.1	1.7	0.3	0.7	24

Cuadro 2.—Promedio de características químicas de los suelos del desierto de los leones en el ciclo 1985.

A	B	E	F	pH	M.O.	N_2T	C / N	C.I.C	Ca	Mg	Na	K	P
				H_2O	*- - percent - -*			*- - - - - - - - - - meq / 100 g - - - - - - - - - -*					%
1	Pt	N	2980	6.0	21.0	0.6	19.3	62	26.5	2.8	0.2	0.1	15.9
2	O	NW	2920	5.9	14.5	0.6	14.7	50	4.7	1.9	0.1	0.1	4.6
3	O	NW	3180	6.2	11.5	0.5	14.4	56	2.6	1.4	0.1	0.12	14.0
4	P	NE	3320	6.0	17.2	0.6	15.8	53	4.9	2.9	0.1	0.2	15.4
5	P	Zenital	3600	5.3	26.4	1.1	14.0	55	10.4	1.0	0.3	0.4	26.1

Cuadro 3.—Promedios de características químicas de los suelos del desierto de los leones en el ciclo 1991.

A	B	E	F	pH	M.O.	N_2T	C / N	C.I.C	Ca	Mg	Na	K	P
				H_2O	*- - percent - -*			*- - - - - - - - - - meq / 100 g - - - - - - - - - -*					%
1	Pt	N	2980	5.7	12.5	0.6	12.5	35	22.8	2.2	0.2	0.3	10.5
2	O	NW	2920	5.9	4.9	0.3	8.7	35	11.8	1.2	0.2	0.3	9.7
3	O	NW	3180	5.4	11.0	0.6	11.6	56	11.2	2.2	0.3	0.2	17.4
4	P	NE	3320	5.5	6.9	0.9	4.6	51	11.2	0.8	0.4	0.1	21.1
5	P	Zenital	3600	5.4	8.2	0.6	8.5	58	5.3	0.6	0.4	0.4	27.8

Cuadro 4.—Promedio de características químicas de los suelos del desierto de los leones en el ciclo 1992.

A	B	E	F	pH	M.O.	N_2T	C / N	C.I.C	Ca	Mg	Na	K	P
				H_2O	- - percent - -			- - - - - - - - - - meq / 100 g - - - - - - - - - -					%
1	Pt	N	2980	6.3	9.6	0.4	12.9	38	21.2	1.6	0.3	2.7	8.0
2	O	NW	2920	6.0	10.0	0.3	20.3	41	18.3	1.9	0.5	2.8	9.0
3	O	NW	3180	5.9	16.4	0.6	16.0	48	19.8	2.1	0.3	2.5	9.3
4	P	NE	3320	5.3	28.6	0.5	15.1	40	10.8	1.7	0.5	2.6	9.0
5	P	Zenital	3600	5.5	12.4	0.5	14.2	38	7.2	0.8	0.6	2.7	8.7

Cuadro 5.—Promedio de características químicas de los suelos del desierto de los leones en el ciclo 1993.

A	B	E	F	pH	M.O.	N_2T	C / N	C.I.C	Ca	Mg	Na	K	P
				H_2O	- - percent - -			- - - - - - - - - - meq / 100 g - - - - - - - - - -					%
1	Pt	N	2980	6.2	10.5	0.5	12.2	40	23.5	4.5	0.5	3.3	3.1
2	O	NW	2920	5.7	14.3	0.5	16.6	41	20.0	5.4	0.4	4.0	3.0
3	O	NW	3180	5.5	15.7	0.6	15.2	43	10.3	3.1	0.5	3.7	3.5
4	P	NE	3320	5.0	14.4	0.6	13.9	38	8.7	0.9	0.6	3.5	3.0
5	P	Zenital	3600	5.0	10.4	0.4	15.1	34	5.0	1.6	0.5	3.2	1.3

A= Sitios: 1) Cementerio, 2) Convento, 3) Cañada de San Miguel, 4) Agua de Leones y 5) Cruz de Cólica
B = Vegetación dominante: Pt = Plantación de pino, O = Oyamel y P = Pino
E = Exposición F = Altitud en (msnm)

Cuadro 6.—Contenidos de metales pesados en los suelos del desierto de los leones en los ciclos 1991 (a), 1992 (b) y 1993 (c)

A	B	E	F	AÑOS	pH	Al	Pb	Fe	Zn	Mn	Mg	Cu	Cd	Cr
						- - - - - - - - - - - - - - - - ppm - - - - - - - - - - - - - - - -								
1	Pt	N	2980	a	5.7	33.6	27.0	139.6	27.5	57.9	2.2	1.3	0.5	0.1
				b	6.3	32.5	55.1	29.1	6.4	2.4	1.5	0.7	0.5	0.6
				c	6.2	35.9	56.0	29.8	6.6	2.6	4.5	1.1	0.5	0.6
2	O	NW	2920	a	5.9	53.7	14.7	96.4	4.6	12.6	1.4	1.1	0.2	0.1
				b	6.0	50.1	51.7	77.1	5.5	3.4	1.9	0.9	0.2	1.3
				c	5.7	59.7	57.9	79.9	4.4	2.8	5.4	0.6	0.2	1.0
3	O	NW	3180	a	5.4	117.1	6.7	73.6	3.9	7.9	1.0	0.3	0.1	0.1
				b	5.9	42.1	46.3	27.0	7.0	3.2	2.2	0.6	0.4	0.5
				c	5.5	58.9	52.0	35.4	7.9	2.5	4.1	0.4	0.3	0.6
4	P	NE	3320	a	5.5	128.2	9.0	55.6	4.1	5.2	0.9	0.5	0.1	0.1
				b	5.3	131.0	50.2	26.5	4.4	3.2	1.5	0.3	0.1	1.1
				c	5.0	141.1	61.0	18.9	4.8	3.1	1.3	0.3	0.1	1.0
5	P	Zenital	3600	a	5.4	81.9	7.8	73.6	7.1	3.4	0.5	0.5	0.1	0.1
				b	5.5	82.5	48.5	19.3	2.6	3.8	1.1	0.2	0.1	0.9
				c	5.0	135.5	54.1	17.4	2.9	3.8	1.6	0.2	0.1	0.5

A = Sitio: 1)Cementerio, 2) Convento, 3) Cañada de San Miguel, 4) Agua de Leones y 5) Cruz de Cólica
B = Vegetación dominante: Pt = Plantación de pino, O = Oyamel y P = Pino
E = Exposición F = Altitud en (msnm)

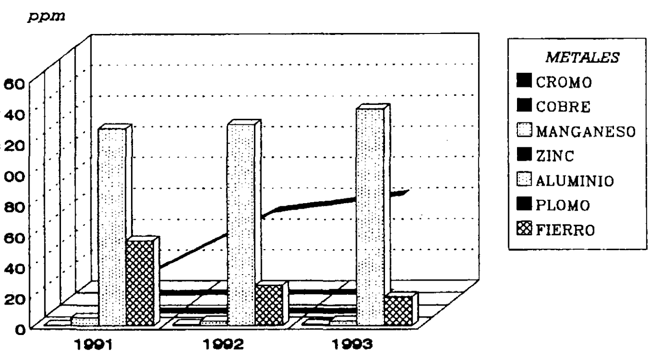

Figura 4.—Sitio Agua de Leones contenido de metales pesados.

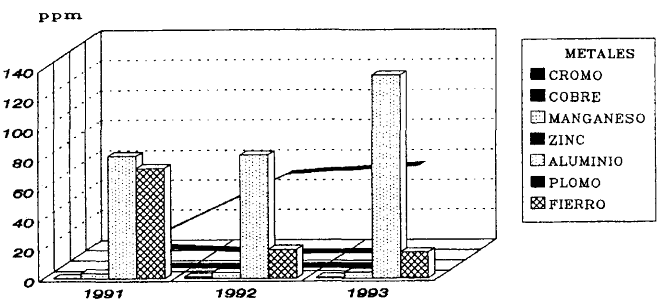

Figura 5.—Cruz de Cólica contenido de metales pesados.

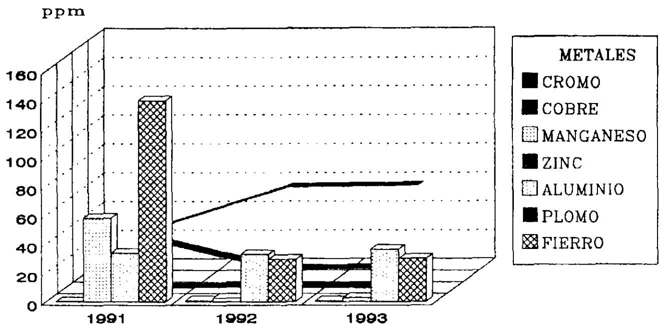

Figura 6.—Sitio Cementerio contenido de metales pesados.

(Elliott, et al., 1986) y la exposición del lugar ya que es ahí donde llegan y se retienen los vientos procedentes de la Cd. de México, por lo que es frecuente encontrar altas concentraciones de otros elementos como cromo.

El aluminio es un elemento no requerido por la planta, pero al acumularse en el suelo puede causar su aluminización, en todos los sitios va aumentando a excepción de Cañada de San Miguel en donde disminuyo (Fig. 7). El aluminio está en altas concentraciones en Agua de Leones y Cruz de Cólica, en donde el pH a presentado una baja de 6.2 a 5.0 y de 5.5 a 5.0 respectivamente, en estas condiciones se presenta el fenómeno de intercambio de iones hidrógeno por aluminio y éste por reacciones propias del suelo sustituye al magnesio.

Se nota que las características del suelo, así como el amortiguamiento del mismo en relación al pH puede influir en la solubilidad y lixiviación de algunos metales pesados como Fe, Zn y Mn que han ido disminuyendo paulatinamente en los cinco sitios permanentes de muestreo del parque.

Conclusiones y Recomendaciones

1. Los contenidos de M.O., C.I.C., Ca y P han disminuido en el suelo paulatinamente desde 1984 hasta 1993 en todos los sitios. Cuando las concentraciones de aluminio y fierro son elevadas exceden grandemente a la de los iones fosfato (PO_4) formando fosfato insoluble, disminuyendo las cantidades de fósforo en el suelo, se puede reducir la división celular y por lo tanto afectar el crecimiento de la planta.

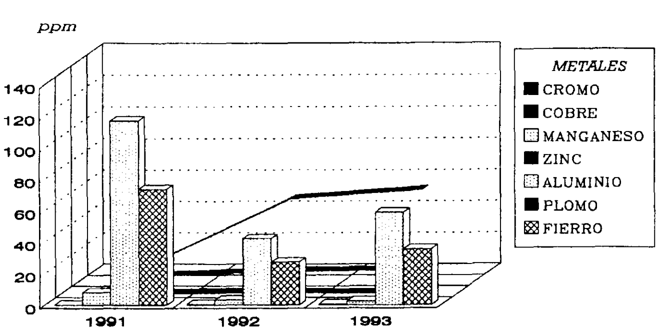

Figura 7.—Sitio Cañada de San Miguel contenido de metales pesados.

2. Las concentraciones de Mg y K se han acumulado, presentando mayor cantidad en el ultimo año de muestreo en los cinco sitios.

3. El pH es factor importante en la disponibilidad o solubilidad de los elementos, tiene influencia en los contenidos de aluminio en Agua de Leones y Cruz de Cólica, así como en la disminución de Fe, Zn y Mn en todos los sitios del parque.

4. El plomo, elemento que se ha acumulado en el suelo de los sitios muestreados, indica que es inmóvil, al igual que otros elementos como el mercurio y el oro pero puede presentar solubilidad a pH ácidos.

5. Si el aluminio puede sustituir al magnesio en ciertas condiciones, ésto indica que no está en forma disponible para la planta y que se acumule en el suelo.

6. La distancia de la fuente de origen de los contaminantes ambientales, la exposición, la altitud y el tipo particular de vegetación del área, tienen relación con la concentración de metales pesados presentes en el suelo.

7. Con base en los datos recabados de propiedades del suelo y contenidos de metales pesados se puede detectar su toxicidad o deficiencia en la vegetación en función de sus contenidos. Se propone Hacer un estudio comparativo del suelo y concentraciones de metales pesados tóxicos en la vegetación.

Bibliografía

Alvarado, D. Bauer, & Galindo, J. 1991. Declinación y muerte del bosque de oyamel (*Abies religiosa*) en el sur del valle de México. Agrociencia Vol. 1 (3): 130- 140.

Castañeda, G. M. Y., López, L., & Velázquez, M. A. 1995. Efecto de tratamientos de fertilización sobre algunos síntomas de declinación en una plantación de oyamel. In Memorias: I Congreso Mexicano sobre Recursos Forestales. Soc. Mex. Rec. For. A. C., U. A. A. A. N., Saltillo, Coah. p. 52.

Castro, S. J. M., 1987. Estudio Microbiologico de los suelos del Parque Cultural y Recreativo Desierto de los Leones, D. F. In Memorias: Primera Reunión Científica Forestal y Agropecuaria CIFAP-D. F. México. 10 p.

Castro, S. J. M., González, K. V. & Hernández, T. T. 1993. Determinación preliminar de algunos metales pesados en los suelos del Desierto de los Leones. In Memorias: I Congreso Mexicano Sobre Recursos Forestales. Soc. Mex. Rec. For. A. C., U. A. A. A. N., Saltillo, Coah. México. p 59.

Castro, S. J. M., González, K. V. & Hernández, T. T. 1995. Metales pesados en los suelos del Desierto de los Leones, Distrito Federal. Rev. Cien. For. En México. Vol. 20 (77): 101-111.

Castro, S. J. M., González, K. V. & Hernández, T. T. 1996. Metales pesados en los suelos del Desierto de los Leones. In Memorias: Primera Reunión Científica Forestal. México, D. F. p 10.

Elliott, H. A., Liberati, M. R. & Huang, C. P. 1986. Absorción competitiva de metales pesados en los suelos Jour Envirn Qual. 15 (3): 214-219.

García, E. 1981. Modificaciones al sistema de clasificación climatica de Köppen.

Lima, C. H. & Jackson, M. L. 1982. Dissolution for total element analysis. In: Page, A. L., et al. (Eds.). Methods of Soil analysis. Madison, Wisconsin. USA. pp. 1-12.

López, L. M. A. & Rivera, A. 1985. Caracterización nutrimental de follaje de oyamel en proceso de declinación. In Memorias: II Congreso Mexicano de Recursos Forestales. Soc. Mex. Rec. For. A. C. Chapingo, México. p. 50.

Reyes, C. R., Castro, S. J. M., Camargo, C. T. & Castro, S. J. M. C. 1984. Estudio de los suelos Forestales en el Parque Cultural y Recreativo Desierto de los Leones. Informe técnico. Inedito. 12 p.

Romero, C. J., 1986. Estudio de reconocimiento de los suelos Forestales del Parque Cultural y Recreativo Desierto de los Leones. Tesis profecional UNAM Zaragoza México. 78 p.

Inventario y Monitoreo del Recurso Micológico en los Bosques Templados[1]

Marisela C. Zamora Martínez[2]

Resumen—Los hongos son organismos heterótrofos con un papel relevante en el equilibrio de los diferentes ecosistemas en los que ellos se desarrollan; ya que contribuyen de manera importante en la formación del humus y en la remineralización del debris remanente. Además en el caso particular de los hongos ectomicorrizógenos desempeñan funciones ecológicas vitales para el desarrolla de las poblaciones vegetales, como son la facilitación del intercambio e energía entre los sistemas por arriba del suelo y el edáfico; la organización de la trayectoria y de la velocidad de la sucesión vegetal; así como la promoción y alteración de nichos.

Por otra parte los hongos silvestres son un recurso forestal no maderable con importancia socioeconómica para las comunidades rurales; ya que a partir de la recolecta de las especies comestibles, éstas obtienen un ingreso alternativo durante una temporada del año, o bien integran los hongos a su dieta diaria. Razón port la cual resulta importante la realización de inventarios de la diversidad fúngica; así como el monitoreo de la producción natural, para con la información generada se puedan elaborar programas de manejo sustentable de las poblaciones naturales.

Las comunidades de macromicetos pueden ser estudiadas de diferentes maneras, mediante aproximaciones micocenológicas, micoflorísticas, ecológicas, fitocenológicas y geográficas. En el presente trabajo se revisan los criterios utilizados por diversos autores para el diseño de parcelas de muestreo de hongos en relación al Tamaño, uniformidad y representatividad; así mismo, se discuten otros aspectos importantes en el inventario y monitoreo de las poblaciones de hongos, como son la frecuencia y duración de las evaluaciones con base en objetivos particulares, y se presentan los métodos más importantes que a la fecha se han descrito para el análisis cuantitativo y cualitativo de las micocenosis.

Por último a manera de ejemplo se muestran algunos datos de tipo fenológico y de monitoreo de la producción de carpóforos obtenidos a partir del seguimiento durante cuatro años en bosques de coníferas de la Región Central de México.

Los hongos son organismos heterótrofos con un papel relevante en el equilibrio de los diferentes ecosistemas en los que ellos se desarrollan; ya que contribuyen de manera importante en la formación de humus y en la remineralización del debris remanente. Además en el caso particular de los hongos ectomicorrizógenos, desempeñan funciones ecológicas vitales para el crecimiento de las poblaciones vegetales.

Por otra parte, los hongos silvestres son un recurso forestal no maderable con importancia socioeconómica para las comunidades rurales; ya que a partir de la recolecta de carpóforos comestibles, éstas obtienen un ingreso alternativo durante una temporada del año, o bien enriquecen con proteína su dieta diaria al incorporar los hongos a la misma.

Tanto la importancia ecológica, como la socioeconómica, justifican por sí mismas la realización de inventarios de la diversidad fúngica; así como el monitoreo de la producción natural, para que la información generada sirva de base para la elaboración de planes de manejo sustentable de las poblaciones fúngicas silvestres, en particular las de uso comestible.

Al respecto, en el presente trabajo se revisan los diversos criterios utilizados por diferentes autores para el diseño de parcelas de muestreo de hongos en relación al tamaño, uniformidad y representatividad; así mismo se discuten otros aspectos importantes en el inventario y monitoreo de las poblaciones de hongos, como son la frecuencia y duración de las evaluaciones con base en objetivos particulares y se presentan los métodos más importantes que a la fecha se han descrito para el análisis cualitativo y cuantitativo de las micocenosis. Por último se presentan datos fenológicos y de producción obtenidos a partir del muestreo permanente durante cuatro años en bosques de coníferas localizados en tres estados del centro de México.

Funciones de los Hongos en los Ecosistemas

Los hongos son los organismos heterótrofos que concentran mayor cantidad de nutrimentos en un ecosistema, ésto debido a su capacidad enzimática par mineralizar el litter. Se pueden distinguir tres grupos funcionales, a saber:

a) Saprobios, organismos descomponedores de materia orgánica capaces de degradar la celulosa, la hemicelulosa y la lignina; su función en los ecosistemas es la formación del humus y la remineralización del debris remanente.

b) Biótrofos, hongos que forman asociaciones mutualistas con las raíces de diversas plantas, o con algas verdes (líquenes). Sus funciones son de tipo ecológico, las cuales consisten en la facilitación del intercambio de fotosíntatos y elementos nutritivos entre los sistemas aéreo y edáfico; la promoción y alteración de nichos; además actúan como reguladores de la trayectoria y la velocidad de la sucesión vegetal. Desde el punto de vista fisiológico participan de manera importante en la mineralización de elementos poco disponibles en el suelo para las plantas, como son el fósforo, el nitrógeno, el azufre y el potasio; además son mediadores e integradores, ya que a través del transporte de agua y nutrimentos regulan la tasa fotosintética; como resultado del crecimiento de las hifas, modifican la permeabilidad y estructura del suelo; aumentan la sobrevivencia de las

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plántulas al incrementar la superficie de absorción de agua (crecimiento hifal) y mediante la protección física y química contra el ataque de diversos patógenos.

c) Necrótrofos, hongos parásitos cuyas funciones ecológicas son el reciclaje de materia orgánica, la creación y la alteración de nichos.

Importancia Económica de los Hongos

En México durante la temporada de lluvias (junio septiembre) la recolecta de hongos comestibles es una actividad que representa para los habitantes de las zonas templadas y templado-frías una fuente alternativa de ingresos, los cuales son un complemento para el gasto familiar, y en ocasiones es el principal ingreso, ésto debido a su alta rentabilidad.

Así es muy común observar en los mercados regionales, sobre todo del centro de México, una gran diversidad de especies expuestas para su venta, su precio varía en función de la oferta y la demanda; aunque en términos generales oscilan entre los $20.00 (dos dólares) y los $80.00 (ocho dólares), lo que representa en ingresos por temporada para un recolector de $10,000 (mil dólares).

Al respecto, sobresale la recolecta comercial del "hongo blanco de pino" o "matzutake americano" (*Tricholoma magnivelare*), cuya producción total se exporta a Japón, generando una derrama económica del orden de un millón trescientos mil dólares (temporada, 1996). Las ganancias para un buen recolector por temporada (tres meses)es de $500.00 - $1800.00 (cincuenta - ciento ochenta dólares).

Otro mercado importante para los hongos mexicanos es el europeo, así por ejemplo en 1996 se exportaron 3,390 Kg de carpóforos frescos con un valor de ochenta y seis mil dólares.

Aspectos Metodológicos Para el Muestreo de Hongos

Las técnicas de muestreo para los hongos (macromicetos) se basaron en sus inicios en los inventarios de vegetación; sin embargo, un error en la aplicación de los métodos fitoflorísticos para el estudio de las comunidades fúngicas consiste en no considerar la distribución en "parches" de los carpóforos de algunas especies (O'Dell, *et. al.*, 1996).

En este sentido los principales problemas en el estudio de las comunidades de macromicetos, en comparación con los estudios de vegetación son:

- La innaccesibilidad de las estructuras vegetativas, en particular el micelio.
- El corto período de vida de los carpóforos
- La marcada periodicidad y las fluctuaciones espaciales y temporales de los carpóforos.
- La diversidad de las funciones ecológicas que presentan los hongos.
- Problemas de tipo taxonómico, éstos son relevantes sobre todo en países como México donde existen pocos taxónomos especialistas en taxa difíciles de determinar.

Antes de mencionar algunos de los diferentes tipos de muestreo que se han propuesto para la realización del inventario y monitoreo de los hongos, en particular de los macromicetos, se definirán dos conceptos importantes para el estudio de los mismos (Arnolds, 1992):

a) Micocenosis o comunidad fúngica, hongos que crecen en una fitocenosis y su ambiente, independientemente de su tamaño y grado de heterogeneidad, en términos de explotación y preferencias de sustratos.

b) Micosinusias, parte estructural de una micocenosis, especies que pertenecen al mismo grupo trófico, presentan igual periodicidad en la producción de carpóforos y ocupan el mismo microhábitat.

Arnolds (*op. cit.*) presenta cinco diferentes aproximaciones metodológicas para el estudio ecológico de los hongos, a saber: micocenológica, micosinusial, micoflorística, autoecológica y la geográfica.

Las aproximaciones micocenológicas comprenden los inventarios de todos los hongos (carpóforos) presentes en un rodal, o en un hábitat previamente seleccionado con base en repetidos muestreos cualitativos y cuantitativos en parcelas seleccionadas. Los primeros trabajos de este tipo se realizaron en los años 30s.

Sí la investigación comprende solamente a una parte de la comunidad fúngica, por ejemplo los hongos que se desarrollan en un microhábitat o un grupo funcional en particular (los hongos ectomicorrizógenos de la especie *Pinus teocote*); entonces, la aproximación será de tipo micosinusial.

Las investigaciones micoflorístico-ecológicos comprenden el estudio de la micoflora en áreas relativamente extensas, con una cubierta vegetal heterogénea; lo que permite generar listados de especies que tiene como ventaja el incluir taxa que crecen en hábitat muy reducidos.

Las aproximaciones autoecológicas se refieren a estudios de uno o pocos taxa fúngicos en relación a su rango ecológico o preferencia por una comunidad vegetal en particular.

Por último, los trabajos de tipo geográfico hacen referencia al registro de la presencia de las especies fúngicas de una región sobre un mapa detallado de la vegetación vegetación presente en la misma, dichos mapas pueden o no incluir datos de tipo ecológico. Estos trabajos son escasos; sin embargo, representan una fuente de información muy valiosa para el diseño de programas de manejo sustentable de hongos; ya que permiten conocer la distribución actual de las especies fúngicas y a través del uso de sistemas de información geográfica, se puede determinar áreas con potencial para el desarrollo de las especies consideradas.

Un ejemplo de la generación de mapas de distribución de especies de hongos es el estudio realizado por Reygadas, *et. al.* (1997) en bosques de pino-encino del estado de Hidalgo, México; en el cual se presenta la distribución conocida y las áreas con potencial para el crecimiento de la especie *Tricholoma magnivelare*.

Selección de Parcelas de Muestreo

La mayoría de los estudios se basa en el análisis de un número reducido de parcelas grandes de muestreo, seleccionadas con base en criterios de homogeneidad, área mínima y representatividad; sin embargo, éstos son difíciles de determinar. Así por ejemplo, en el caso de la homogeneidad, para un momento en particular los carpóforos presentes representan sólo parte de las especies que crecen en una localidad específica; además el carpóforo no constituye una entidad estructural distintiva.

La definición del área mínima en el caso de los hongos se dificulta debido a que el número de especies se incrementa a medida que se aumenta el tamaño de la parcela de muestreo, en respuesta a la periodicidad y fluctuaciones espaciales de los carpóforos. Winterhoff (1984) atribuye el constante aumento en el registro de especies fúngicas a medida que crece la superficie de muestreo al gran tamaño que tiene el micelio (se han medido anillos de hasta 50 m de diámetro), a la ocurrencia en grupos de muchas especies, a la rareza de muchas especies y a la exclusión mutua entre micelios de diferentes especies.

Con base en lo antes expuesto se sugiere tomar en cuenta al momento de definir el número de parcelas de muestreo los siguientes aspectos: sí se trabaja en hábitats homogéneos, es decir con vegetación uniforme, se podrá establecer un número reducido de parcelas (mínimo de cinco); cuando se trate de hábitats heterogéneos el número de parcelas deberá ser mayor. Con respecto al tamaño autores como Winterhoff (*op. cit.*) y Barkman (1987), sugieren para el caso de bosques y asociaciones arbustivas el establecimiento de parcelas con una superficie de 1,000 m^2, y en pastizales el tamaño propuesto es de 500 m^2

Tipos de Análisis

Una vez definidos el número y tamaño de las parcelas de muestreo, es importante determinar el tipo de estudio, y por tanto de análisis de la información, que se pretende realizar; básicamente se deberá seleccionar entre uno cualitativo, en el cual se tiene como objetivo la elaboración de listados de las especies presentes en la zona de estudio, es decir el trabajo es taxonómico. En este caso el principal problema al que se enfrenta el investigador es de tipo taxonómico par la definición de complejos de especies para los cuales hay poca bibliografía especializada.

El segundo enfoque es cuantitativo, las medidas más usadas son el conteo de carpóforos, la frecuencia (porcentaje de parcelas en las cuales una especie está presente o ausente) y la biomasa. La frecuencia refleja el área colonizada por una especie, por lo que es un indicador de la distribución; la biomasa de los carpóforos puede representar, al menos de manera parcial, los cambios en la reserva de energía de un hongo; mientras que el número de carpóforos nos permite conocer la variación anual de la productividad en una especie.

La desventaja de utilizar como unidad de muestreo a los carpóforos es que se desconoce que proporción de éste se correlaciona con la extensión del micelio o con la actividad del sustrato, cabe señalar que estos últimos tienen mayor significado ecológico que el carpóforo.

La cantidad de carpóforos se expresa de las siguientes formas:

a) Abundancia o densidad, número actual de carpóforos presentes en una parcela, se considera una superficie estándar de 1,000 m^2, es muy laborioso.

b) Peso y tamaño, permite determinar la productividad de manera directa al recolectar todos los carpóforos presentes en una parcela y pesarlos en seco o en fresco; sin embargo, es un método destructivo y muy laborioso.

c) Sociabilidad, constituye una medida del arreglo espacial de los carpóforos la cual puede ser en grupos, al azar, o aislados.

Frecuencia espacial, representa el número de parcelas en el que una especie está presente, es de poco valor diagnóstico.

Frecuencia y Duración de los Muestreos

La definición del tiempo que debe durar un monitoreo de las poblaciones silvestres de hongos en una localidad específica; así como de la frecuencia con que se lleven a cabo los muestreos, tiene que considerar los diferentes tipos de variación temporal en la producción de carpóforos, lo cual conlleva regularmente a establecer muestreos muy frecuentes en períodos largos de tiempo. Ésto trae como consecuencia que los monitoreos del recurso micológico resulten costos en lo que se refiere a horas/hombre de trabajo.

Las visitas a las parcelas de muestreo serán con intervalos cortos de tiempo entre ellas debido a la existencia de especies con carpóforos de corta duración, es decir que viven pocos días, tal es el caso de los géneros *Boletus* y *Suillus*; a diferencia de algunas especies del grupo de los Gasteromycetes que pueden sobrevivir de uno a cuatro meses (Arnolds, 1992).

La periodicidad es un carácter específico, sobre todo en las regiones templadas, que influye la presencia o ausencia de algunas especies fúngicas; así en términos generales la fructificación es temprana en hábitats con alta humedad tanto en el suelo como en el aire. La periodicidad también varía a nivel regional, en los países del norte por lo regular las especies fructifican a finales del verano; en tanto que en el Mediterráneo lo hacen entre el invierno y la primavera.

Otro factor determinante al momento de establecer la duración de un estudio de monitoreo de hongos son las variaciones en la producción de carpóforos entre un año y el siguiente, éstas pueden ser cuantitativas o cualitativas, en el caso de las últimas hay especies que no producen carpóforos en uno o más años, esta ausencia de carpóforos además de ser una característica propia de la especie también responde a condiciones de tipo meteorológico (presencia o ausencia de lluvias y variaciones de temperatura), productividad del litter y la vitalidad del arbolado y la sucesión vegetal, sobre todo cuando se presentan cambios ambientales drásticos como un incendio.

Los tres factores antes descritos condicionan que los trabajos de monitoreo e inventario de hongos se deban realizar con muestreos muy frecuentes, semanales o mensuales, y en períodos de al menos cinco años; Arnolds (op. cit.) considera que después de seis años de muestreos en parcelas con una superficie de entre 500 y 1,000 m^2 se alcanza a determinar el 75% de las especies fúngicas que se desarrollan en la localidad de estudio.

Manejo de los Datos de Campo

Como resultado de que el muestreo se realice durante varios años, en numerosas parcelas y con visitas muy frecuentes, la comparación entre diferentes estudios es muy difícil; ya que los tamaños de parcelas, las periodicidad de muestreo y la duración de las investigaciones, generalmente son muy heterogéneas.

En estudios individuales las mediciones sintéticas más importantes son:

a) Densidad máxima de esporocarpos, se le considera una aproximación de la capacidad potencial de fructificación de una especie; se calcula para cada estudio de manera independiente a la frecuencia y duración de la investigación.

b) Densidad total de esporocarpos, es un parámetro usado para comparar parcelas , sus resultados dependen de la duración e intensidad del muestreo. Una forma de minimizar los efectos de la duración e intensidad del muestreo es calcular para cada especie el porcentaje del número total de carpóforos de todas las especies identificadas en una parcela.

c) Densidad promedio anual de carpóforos, depende de la frecuencia de muestreo

d) Frecuencia total temporal, número de visitas en las cuales una especie es observada; depende de la duración, la distribución de las visitas; así como de la periodicidad y persistencia de las especies fúngicas.

La comparación de resultados obtenidos entre parcelas se hace fundamentalmente através del grado de presencia vs. el porcentaje de parcelas en el cual una especie está presente, lo cual determina el grado de fidelidad. El segundo criterio importante en la comparación entre parcelas es una medida promediada de la abundancia.

En lo que se refiere al uso de análisis numéricos, en los estudios micológicos se emplean los utilizados en los análisis de vegetación tales como los análisis de correlación; sin embargo, los análisis numéricos complejos han sido poco usados, debido a lo relativamente pequeños que son los juegos de datos disponibles.

Con respecto a México son pocos los trabajos de inventario y monitoreo de hongos silvestres que se han realizado, se pueden citar los de Villarreal y Guzmán en los bosques de coníferas del Cofre de Perote, Veracruz (1985, 1986), en la misma zona Villarreal (1995); Bandala *et. al.* (1991) en la misma región, pero que adiciona un área de muestreo en el bosque mesófilo de montaña.

El autor del presente documento ha realizado investigaciones de monitoreo en los bosques de pino-encino de la región sureste del estado de Hidalgo durante seis años (1993-1998) de hongos en seis parcelas permanentes de muestreo y en bosques de *Abies* se han monitoreado tres parcelas durante tres años (1996-1998). Como resultado de estos muestreos se han elaborado cuadros fenológicos (reproductivos) para 40 especies fúngicas comestibles, entre ellas Tricholoma magnivelare; además de contar con los datos de biomasa (peso fresco) para cada una de ellas.

Zamora-Martínez y Nieto De Pascual (1995), monitorearon la productividad de las especies fúngicas desarrolladas en dos parcelas de muestreo permenente establecidas en una plantación de árboles de navidad en un bosque de pino localizado en el sureste del Distrito Federal, México, determinándose una producción de 65 Kg/Ha para un período de dos temporadas de lluvias.

Consideraciones Finales

Dada la importancia ecológica y socioeconómica de los hongos es de gran relevancia implementar los trabajos de monitoreo e inventario de sus poblaciones silvestres que por un lado nos permitan conocer la diversidad y potencial productivo del recurso micológico, y por otro contar con la información básica indispensable parar proponer programas de manejo sustentable de sus poblaciones silvestres que garanticen el fomento y conservación del recurso.

Así mismo es indispensable fomentar el intercambio de experiencias entre los micológos y el resto de profesionistas relacionados con el estudio y aprovechamiento de los recursos forestales con el propósito de uniformizar los métodos de estudio, a fin de poder en el futuro comparar los resultados obtenidos en ecosistemas similares.

Por último, es necesario hacer conciencia en los tomadores de decisiones de la importancia de financiar un mayor número de estudios a mediano plazo de inventario y monitoreo de hongos silvestres; ya que sólo de esta manera se podrán obtener datos confiables en cuanto producción, fenología reproductiva y distribución de las diferentes especies fúngicas con importancia ecológica y/o económica.

Bibliografía

Arnolds, E. 1992. The analysisi and classification of fungal communitie with special to macrofungi. In: Winterhoff, W. (de) 1992. Fungi in vegetation science. p. 7-47.

Bandala, V. M., G. Guzmán, D. Murrieta y F. Tapia. 1991. Producción de los hongos comestibles en los bosques de Veracruz. In Memorias del IV Congreso Nacional de Micología. Tlaxcala, México. p. 69.

Barkman, J. J. 1987. Methods and results of mycocoenological research in the Netherlands. In G. Pacioni (de). 1987. Studies on fungal communities. University of l'Aquila Italy. p. 7-38.

O'Dell, T., J. E. Smith, M. Castellano & D. Luama. 1996. Diversity and conservation of forest fungi. General. Technical Report PNW-GRT-371. Forest Srvice. USD.

Reygadas, P. D., F. Moreno, S. y M. C. Zamora -Martínez. 1997. Distribución conocida y potencial de *Tricholoma magnivelare* en el estado de Hidalgo. In Memorias del VI Congreso Nacional de Micología. Tapachula, Chiapas, México.

Villarreal, L. y G. Guzmán. 1985. Producción de los hongos comestibles silvestres en los bosques de México I. Rev. Mex. Mic. 1: 51-90

Villarreal, L. y G. Guzmán. 1986. Producción de los hongos comestibles silvestres en los bosques de México III. Rev. Mex. Mic. 2: 259-277

Zamora-Martínez, M. C. & C. Nieto De Pascual, P. 1995. Natural production of wild edible mushrooms in the southwestern rural territory of Mexico City, Mexico. Forest Ecology and Management 72 (1995): 13-20.

Winterhoff, W. 1984. In: R. Knapp (de). 1984. Sampling methods and taxon analysis in vegetation science. p. 227-248.

Area Natural Protegida Cerro de la Estrella Descripcion y Diagnostico[1]

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En 1989, se inició un estudio del Cerro de la Estrella que en esas fechas tenía la connotación de Parque Nacional. Este estudio se realizó para sentar las bases para realizar acciones que permitieran rescatarlo del abandono e inadecuado uso en que se le tenía. El estudio realizado permitió que se iniciaran trabajos de recuperación a partir de 1990, como una primera actividad el estudio sirvió como base para la promulgación del Decreto expropiatorio del 30 de mayo de 1991, en el cual se establece que el Cerro de la Estrella es una zona prioritaria de preservación y conservación del equilibrio ecológico y la declara zona sujeta a conservación ecológica en su modalidad de Area Natural Protegida. En este decreto se incluyen un poco más de 143 hectáreas, expropiándose únicamente terrenos de propiedad privada.

El Cerro de la Estrella se encuentra ubicado en la parte oriente del Valle de México que comparte la problemática ambiental del resto de la zona urbana: a) desorden en el crecimiento y b) la carencia de áreas verdes.

El área total del Cerro de la Estrella tiene una superficie aproximada de 200 Has, se localiza hacia la porción suroriental del centro de la ciudad de México y constituye un semiarco en conjunto con el volcán Yuhualixqui, volcán Xaltepec, Cerro Tetecón, cerro Tecuautzi y volcán Guadalupe. Este lugar ha constituido un espacio importante no sólo ecológicamente, sino también como parte de los procesos históricos y culturales de la zona, y actualmente por ser una de las pocas reservas ecológicas ubicadas en la Cd. de México.

Los usos de este lugar parten de dos aspectos: Ecología y Sociedad. El Cerro de la Estrella fue lugar de los primeros asentamientos del Valle de México; en él se realizaron y se realizan actividades agrícolas, se ha utilizado como espacio mítico y sagrado, dentro de la cosmovisión religiosa de la población y en últimas fechas se ha agregado otra función, la actividad recreativa, como consecuencia de la falta de espacios y áreas verdes que el individuo busca como forma de reencuentro con la naturaleza.

El Cerro se encuentra constantemente amenazado por el crecimiento de la mancha urbana. De las 1100 has decretadas como Parque Nacional en 1938, existen sólo alrededor de 200 con características de reserva ecológica, las cuales están sufriendo una serie de procesos que alteran gravemente el hábitat, a causa de la urbanización, la contaminación, la deforestación, la erosión del suelo y el exterminio de la flora y la fauna nativas. Asimismo, otros problemas de carácter social y político han llevado al Parque la corrupción y la delincuencia.

Desde 1990 se han realizado trabajos de reforestación, con especies que se han considerado adecuadas a la zona, pero que no han seguido un plan de manejo bien estructurado.

Con base en lo anterior, se planteó como una primera fase una serie de objetivos encaminados a detectar y analizar esta problemática a fin de detener las prácticas inadecuadas para la población usuaria y el ambiente. En esta primera fase se obtendrá un diagnostico, que permitirá desarrollar el Plan de Manejo adecuado para el área.

Para elaborar el diagnóstico se integró un grupo interdisciplinario que ha estado trabajando los siguientes aspectos:

Factores Físicos:
- Geología
- Suelos

Factores Bióticos:
- Vegetación
- Fauna

Factores Sociales:
- Aspectos Socioeconómicos
- Aspectos culturales

Con los resultados obtenidos y respetando las conclusiones de cada uno de los especialistas, se conjunto la información que será manejada a través de Sistemas de Información Geográfica para elaborar el diagnóstico de la zona y derivar el Plan de Manejo.

Geología: De los fenómenos significativos en el cerro se presentan seis fracturas, tres de las cuales presentan la función de fallas-fracturas, que representan un serio problema para todo tipo de actividades humanas.

El cerro se compone principalmente de basaltos, tobas, conglomerados de tobas-basaltos y de cenizas interestratificadas con arenas, gravas y fragmentos de basalto, con diferentes grados de intemperismo.

Suelos. Se ha dividido al cerro en 4 zonas de acuerdo a su pendiente: Zona de pendiente suave (2 al 10%), zona de pendiente moderada (10 al 30%), zona de pendiente fuerte (30 al 45%) y zona de pendiente pronunciada (mayor de 45%).

La zona de pendiente pronunciada abarca la parte alta y abrupta del cerro y ha sido gravemente alterada por la

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carretera asfaltada. Los suelos predominantes son litosoles, los cuales son mas susceptibles a la erosión hídrica y coluvial, riesgo que se ha visto acentuado al retirar la vegetación y exponerlos directamente a los agentes de degradación.

La zona de pendiente fuerte circunda a la anterior, tiene suelos de mayor desarrollo con gran cantidad de materia orgánica, proveniente principalmente de las gramíneas de la zona, son suelos de la unidad cambisol asociados a algunos litosoles.

La zona de pendiente moderada, presenta suelos de mayor evolución, de la unidad cambisol, tienen gran cantidad de material arcilloso que en el horizonte C presentan alta compactación y baja permeabilidad, los suelos son en general de fertilidad moderada a alta y de gran capacidad para almacenar cationes y agua. Estos suelos se dividen en dos: de alteraciones moderadas y los de alteraciones severas, los primeros se ubican en la parte norte del cerro y presentan áreas con remoción de la cubierta vegetal; las alteraciones severas se observan en la parte sur y son resultado de actividades agrícolas y actividades humanas (deportivas, basureros, urbanizaciones).

La zona de pendiente suave es aquella que se localiza por debajo de los 2300 msnm, presenta suelos andosoles, que poseen alta capacidad de retención de humedad, que se libera lentamente, sus principales limitantes son su alta erodabilidad y alta fijación e inmovilización de fósforo, ocasionando graves deficiencias de este nutriente

Vegetación y uso del suelo. En este rubro es muy difícil separar la vegetación del uso del suelo ya que se encuentran mezcladas y en estrecha relación, se aprecian cinco zonas bien definidas. Una zona de bosque cultivado principalmente de *Eucaliptus* spp y de *Cupressus* spp, que cubre aproximadamente 70 has, y que son resultado de sucesivas reforestaciones, y una pequeña plantación de *Pinus radiata* de 1.5 has.

Se presenta también una zona de pastizales de aproximadamente 30 has, presenta algunos elementos arbóreos, principalmente Eucaliptos y pirules (*Schinus molle*).

La zona agrícola que es de aproximadamente 35 has y que se dedican exclusivamente a la producción de maíz.

La zona degradada que abarca 11 has, se localiza en la zona sur. Esta área esta formada por basureros y dos campos de futbol.

La zona habitada que implica asentamientos humanos de distintas dimensiones y que se han ido consolidando con el tiempo.

Fauna. Actualmente el Cerro sufre procesos de alteración avanzada. No presenta ecosistemas naturales y se encuentra rodeado por áreas urbanizadas, esto ha repercutido en las poblaciones de animales silvestres, no así en los animales comensales del hombre como roedores (rata gris *Rattus norvergicus*, rata negra *Rattus rattus*, ratón doméstico *Mus musculus*), perro (*Canis familiaris*), gato (*Felis domestica*), gorrión inglés (*Passer domesticus*), paloma común (*Columba livia*) y plagas de insectos. Actualmente la fauna nociva compite fuertemente con la fauna silvestre, de la que se lograron registrar 3 especies de reptiles, 22 de aves y 18 de mamíferos, entre los que destacan la lagartija común (Sceloporus gramicus), la primavera (*Turdus rufopalliatus* y *T. Migratorius*), el cardenal (*Cardinalis cardinalis*), el murciélago polinífero (*Leptonycteris* sp.), el murciélago insectívoro (*Tadarida macrotis*), el ratón de campo (*Reithrodontomys megalotis*).

Aspectos socioeconómicos y culturales. Este es un aspecto relevante dentro de la importancia del Cerro de la Estrella, y es el que mayormente ha influido en el deterioro del Area.

Los primeros asentamientos humanos se remontan a 1500 a de C., entre 400 y 100 a. De C. Es cuando se establecen los primeros templos, en la parte superior del Cerro encontramos una pirámide, el primer asentamiento en el cerro corresponde a lo Culhuas, que posteriormente en 1430 son conquistados por los mexicas y se convierte en Señorío. El cerro adquiere gran importancia ya que aquí se celebraba la ceremonia del Fuego Nuevo cada 52 años que era el símbolo divino que indicaba que se habían superado los días aciagos que precedían la destrucción del mundo e iniciaba un nuevo ciclo.

A partir del siglo XVII y hasta 1925 el área se utilizó para practicas agrícolas y cacería. A partir de esta fecha se le dio la condición de área recreativa y en 1938 se convirtió en Parque Nacional.

A mediados del siglo XVIII se inicia un periodo religioso que persiste hasta nuestros días y fue la aparición de una imagen de Cristo lo que originó que se iniciara la tradición de la escenificación de la Pasión de Cristo, que persiste hasta la fecha.

En la actualidad el cerro tiene usos agrícolas, deportivos, de convivencias sociales, cultural por la visita a la pirámide y al museo que se encuentra en la zona.

Con respecto a la posesión de la tierra, se tenía mezcladas tierras comunales, tierras ejidales y tierras particulares, a partir del decreto de 1991 143 has se destinan a un área de reserva ecológica y el resto del cerro es comunal (aprox. 50 has) y zona urbana el resto.

Diagnostico

Con estos antecedentes se puede observar que aunque el diagnóstico en primera instancia pueda resultar sencillo, las relaciones que guarda el cerro con el entorno lo hacen muy difícil.

En un diagnostico preliminar se han podido delimitar cuatro zonas:

1. Zona con limitaciones muy severas
2. Zona con limitaciones severas
3. Zona con limitaciones moderadas
4. Zona sin limitaciones

Zona con limitaciones muy severas

Se encuentra ubicada en la cima del cerro y a lo largo de las fracturas. En esta área es donde se aprecia la mayor actividad faunística. En su parte nororiental se encuentran dos fallas fracturas que continúan hacia un asentamiento urbano en la base, y por donde bajan dos canales de escurrimiento con gran cantidad de piedras, grava y arena; en la ladera norte el basamento de la pirámide se esta erosionando severamente.

La cima del cerro presenta la pérdida irrecuperable de parte de la pirámide, como consecuencia de la movilización y arrastre excesivo de los materiales que la sostienen, esta situación representa un peligro constante para los asentamientos humanos de las partes bajas.

La vegetación que se encuentra en esta zona no ha sido la apropiada para las pendientes de más de 45% y el tipo de suelo, lo que ha contribuido a los procesos de erosión.

Zona con limitaciones severas

Esta zona circunda totalmente a la cima, presenta una topografía abrupta y de difícil acceso, conglomerados volcánicos de fácil arrastre, litosoles de alta erodabilida y vegetación que aporta residuos orgánicos de lenta degradación y que no retiene el suelo.

Esta zona puede subdividirse en cuatro áreas. La ladera oeste-norte es la mas transitada, ya que es el paso hacia la pirámide y presenta un camino asfaltado y una gran catidad de senderos con distintas intensidades de alteración.

La ladera este es la receptora de los materiales provenientes de la cima, el disturbio antropogénico es poco evidente.

La ladera sur es afectada por incendios continuos que causan la pérdida total de la vegetación. Desprotegiendo al suelo e induciendo la erosión.

La ladera oeste tiene una gran afluencia de personas porque esta zona posee una gran cantidad de cuevas.

La afluencia constante de usuarios a esta zona, la vegetación inadecuada y los incendios provocados inciden seriamente sobre el suelo. La degradación se revierte contra los visitantes, ya que los accesos se tornan mas escabrosos y resbaladizos.

Zona con limitaciones moderadas

Se distribuye irregularmente en el norte, ocupa la porción central y sur del Cerro de la estrella.

Aunque en esta zona hay intensa actividad diversificada, se considera de restricción moderada debido a su pendiente, que tiene materiales geológicos consolidados y suelos profundos.

Esta ha sido el área que ha tenido mayor atención en cuanto a reforestaciones efectuadas con especies mas adecuadas, pero también es la que presenta la mayor presión humana y urbana, por lo que debe ser sujeta a un manejo mas estricto, para evitar que se pierda por la urbanización.

Zona sin limitaciones

Esta zona colinda con los limites poniente y norte del área natural. Es una zona de pendientes suaves, suelos profundos y aunque aquí se realiza la actividad agrícola más intensa, esto no ha dañado de manera importante la zona.

Conclusiones

Con la información derivada de la descripción y el diagnóstico, se propondrán actividades tendientes a recuperar el Area Natural Protegida del Cerro de la Estrella, dentro del marco de un Plan de Manejo, que permita integrar el manejo ecológico del área y que contribuya al desarrollo social y cultural del área.

El Cerro de la Estrella tiene un fuerte impacto en la comunidad, es una importante y la mas grande área verde del Oriente del Distrito Federal, y reviste un fuerte patrimonio histórico y monumental

Bibliografia

Cayeros, R. M. C. 1981. Arboles y arbustos cultivados en la Cd. De México. Tesis, Fac. de Ciencias. UNAM.

Ceballos, G. Y C. Galindo. 1984. Mamíferos Silvestres de la Cuenca de México. MAB-UNESCO-Ed. Limusa.México.

CETENAL. 1977. Carta Edafológica y Geológica. SPP. México.

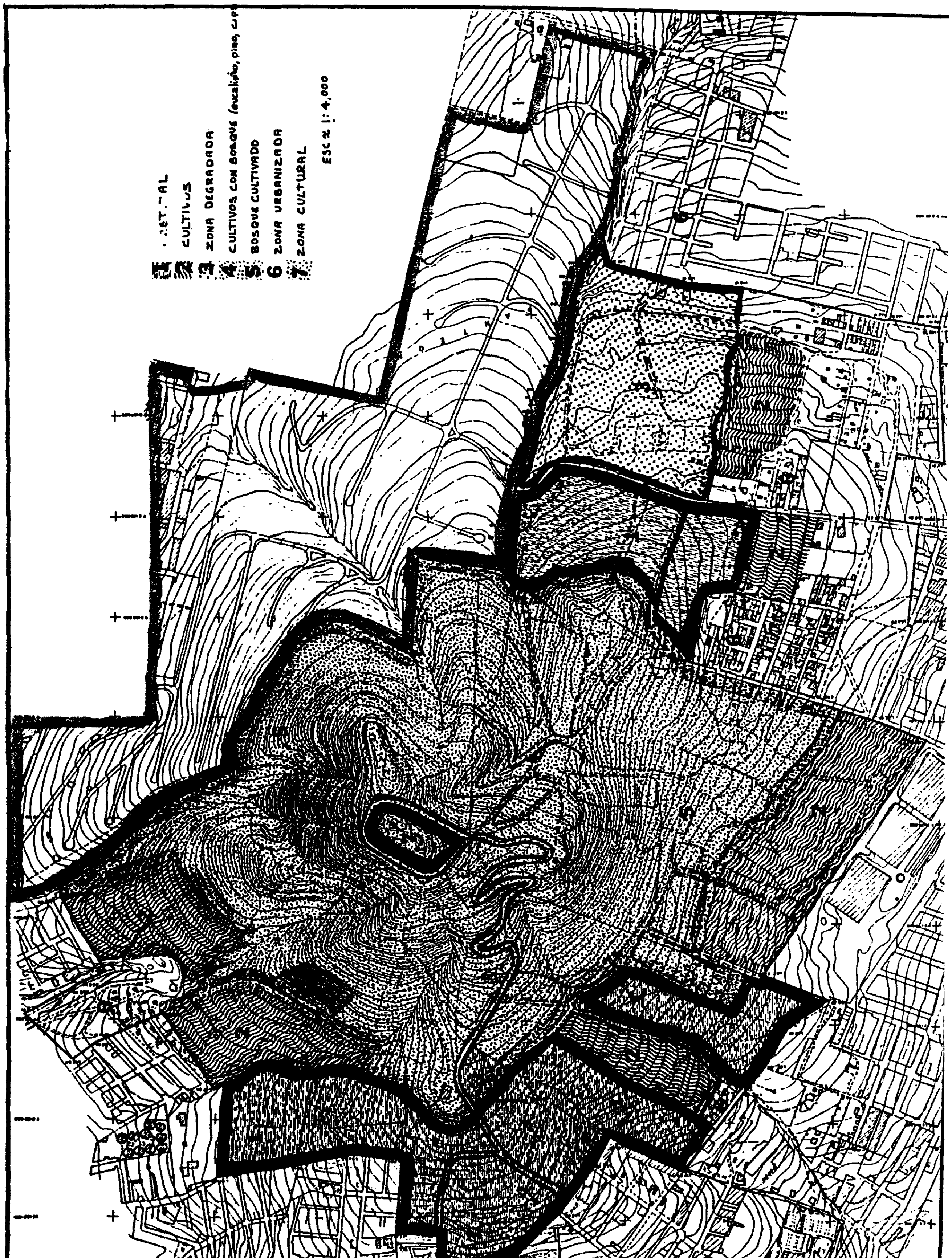
CETENAL. 1984. Carta Urbana y de Construcción. SPP. México.

Garay, M. R. E. 1975. Morfología de la Región Volcánica Chimalhuacán-Cerro de la Estrella/Sierra de Santa Catarina y Fracturas del Fraccionamiento Los Olivos, Delegación Tláhuac. Tesis. Facultad de Filosofía y Letras. Colegio de Geografía. UNAM.

Lugo, H.J. 1984. Geomorfología del sur de la cuenca de México. Serie Varia. T.I. Num. 8. Instituto de Geografía. UNAM.

Rzedowski. J. 1994. La Vegetación de México. Limusa. México.

Ramírez-Pulido, J., M.C. Britton, A. Perdomo y A. Castro. 1986. Guía de los mamíferos de México. UAM-Iztapalapa. México.


CULTIVOS
3 ZONA DEGRADADA
4 CULTIVOS CON BOSQUE
5 BOSQUE CULTIVADO
6 ZONA URBANIZADA
7 ZONA CULTURAL
ESC 1: 4,000

Inventarios Integrados y Monitoreo en Ecosistemas Forestales. Caso de Estudio: Ex-Lago de Texcoco[1]

Francisco Becerra-Luna[2]

Resúmen—El área de influencia del ex-lago de Texcoco, ubicada al Oriente del Valle de México, comprende varios ecosistemas forestales en dos zonas bien diferenciadas: La **Zona Federal**, área plana de 10 mil hectáreas de lo que fue el espejo de agua y la **Cuenca Tributaria**, área de topografía variable de 144 mil hectáreas, integrada por las cuencas de 11 ríos que anteriormente depositaban sus aguas en el lecho del Lago de Texcoco. A través de los Siglos, el deterioro de los ecosistemas forestales de dicha cuenca, propició erosión hídrica y grandes avenidas de los 11 ríos, que inundaban algunas colonias de la Ciudad de México y de su área conurbada con los municipios del oriente del Estado de México.

La explosión demográfica experimentada en el Area Metropolitana de la Ciudad de México a partir de la década de 1930, trajo la necesidad del drenaje projundo, conlo cual el Lago de Texcoco se empezó a desecar, propiciando condiciones de insalubridad para la población, razón por la cual, el Gobierno Mexicano decidió desecar de manera definitiva, el espejo de agua del Lago de Texcoco, derivando dichas aguas, junto con los escurrimientos de los 11 ríos tributarios, hacia el río Tula en el Estado de Hidalgo.

Obras de ingeniería hidráulica para la corrección de las cuencas y otras acciones, permitirían el establecimiento de plantaciones forestales para revertir el deterioro ambiental en la Cuenca Tributaria la recuperar los terrenos desecados del lecho del lago mediante el establecimiento de un bosque artificial que permitiera actividades recreativas y de esparcimiento para la población del Area Metropolitana de la Ciudad de México.

La estrategia eliminó el problema de las inundaciones, pero propició altos niveles de evaporación y de erosión eólica que contribuyeron a aumentar considerablemente las fuertes tolvaneras provenientes de los llanos de Apan Hgo., las cuales azotaron cruelmente por muchos años (y todavía afectan) a la Ciudad de México durante la época de sequía, la cual incluye a la época invernal con la cual se combina, propiciando el problema adicional de graves enfermedades respiratorias, oculares y gastrointestinales entre sus habitantes.

Por otra parte, el establecimiento de un bosque artificial en el lecho del ex-lago resultó ser una tarea poco menos que imposible debido a las características de los suelos salino-sódicos que afloraron una vez que el lago fue desecado, por lo cual, la idea original que prevaleció por varios años, fue cambiada por la del establecimiento de una cubierta vegetal con especies halófitas nativas con buenas probabilidades de éxito.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

[2]Doctor en Ciencias Forestales. Investigador Titular del INIFAP-CENID*COMEF. México, D.F.

[3] Información tomada de Cruickshank 1995, a menos que se especifique otra fuente.

Antecedentes

Desde la época precortesiana, la cuenca del Valle de México ha sido económica, social y políticamente la región más importante del país y de Mesoamérica. Localizada en la parte más alta, hacia el sur del Altiplano Mexicano y con una forma parecida a la paleta de un pintor, está ubicada entre los paralelos 19° 02' y 20° 12' y los meridianos 98° 15' y 99° 00' al Oeste del Meridiano de Greenwich. La superficie de esta cuenca está repartida entre los Estados de México, Hidalgo, Tlaxcala, Puebla y el Distrito Federal y, de acuerdo con levantamientos recientes, totaliza una superficie de 9,600 Km^2 (Cruickshank, 1995).

También desde siempre, el Lago de Texcoco ha sido el cuerpo de agua más importante del Valle de México, constituyendo una parte fundamental del sistema de funcionamiento hidrológico de toda la cuenca. Como tal, al desecarse, dió lugar a una serie de tensiones ambientales que desembocaron en un serio deterioro ecológico, como son la desertificación de los terrenos ocupados y circundantes y la creación de un foco de insalubridad que llegó a representar un grave peligro para la salud de la población de la Ciudad de México y de los municipios conurbados del Estado de México.

A través de la Historia, Texcoco ha sido escenario, causa y efecto de graves problemas en todo el Valle de México, mismos que han preocupado por varias décadas al Gobierno Mexicano. Por esta razón, en 1971, la entónces Secretaría de Recursos Hidráulicos (SRH), formuló el Plan Lago de Texcoco que estableció una serie de programas, acciones, proyectos y obras de rescate de la región. Con el paso de los años, el Plan Lago de Texcoco fue finalmente transferido a la Comisión Nacional del Agua (C.N.A.), la cual depende actualmente de la Secretaría del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP).

Importancia del Proyecto[3]

Entre los impactos Sociales-Económicos-Ambientales que el desarrollo de la zona oriental del Valle de México ha propiciado, se pueden enlistar múltiples prejuicios como: las inundaciones, el abastecimiento de agua, la desecación del Lago de Texcoco y el impacto en su area de influencia, la explosión demográfica y la expansión de la mancha urbana e industrial de la Ciudad de México, la deforestación, la pérdida de suelos, la desaparición de areas verdes y de lagunas, el abatimiento de los recursos hidráulicos subterráneos, el comportamiento irregular de la hidrología manifestada en corrientes torrenciales, el desequilibrio de los ecosistemas que integran la cuenca, con el consiguiente deterioro ambiental del Valle de México.

Problemática

Los problemas que actualmente inciden en el Valle de México son el resultado de una empecinada alteración del ambiente regional y de sus recursos naturales a causa de diversos factores entre los que se pueden enlistar:

a) la explosión demográfica y la expansión de la mancha urbano-industrial, que ya rebasa cualquier límite razonable de tamaño, para hacer posible un control ordenado y equilibrado de su desarrollo;

b) la desertificación provocada por la deforestación, denudación y erosión de los suelos; la desaparición de areas verdes y lagos; la deshidratación de los acuíferos y la ruptura de la estructura del suelo;

c) el comportamiento irregular de la hidrología, manifestado por la torrencialidad de las corrientes, su poder erosivo y los picos de sus avenidas cada vez más pronunciados y,

d) el desequilibrio ecológico en los ecosistemas que integran la cuenca tributaria. Todo ésto reflejado en una creciente alteración de la biósfera (suelos, agua y aire), con muy serias consecuencias previsibles para la salud y la vida de todos los seres que habitan la región (Fig. 1 y 2).

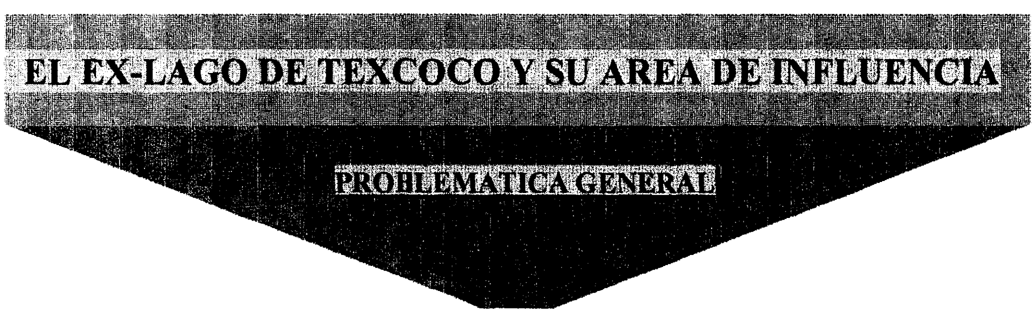
Este conjunto de conflictos conforma un proceso de degradación en apariencia incontenible del ambiente del Valle de México, manifestado en hundimientos del suelo y del subsuelo, los cuales provocan agrietamientos y fallas que desarticulan todas las obras y servicios urbanos, con la consecuente afectación de cualquier tipo de edificación; inundaciones constantes y, paradójicamente, problemas de abastecimiento de agua potable en algunas zonas del area metropolitana, todo lo cual contribuye a hacer de ésta, un lugar cada vez más peligroso e inhabitable para la mayoría de sus habitantes, especialmente, si no se aplican de manera inmediata programas de protección, restauración y conservación en el ambiente regional de todo el valle.

El Plan Lago de Texcoco de la Comisión Nacional del Agua

Debido a la amplitud y diversidad de acciones y obras que implicó la integración del Proyecto Lago de Texcoco, fue indispensable dividir el programa en tres etapas: los trabajos de la primera corresponden a infraestuctura; los de la segunda a obras de aprovechamiento y los de la tercera a conservación y operación.

I. En la primera etapa se consideraron y llevaron a cabo obras urgentes de infraestructura hidráulica y de cobertura vegetal, que eliminarían la degradación ambiental y los efectos ostensiblemente peligrosos para la salud de los habitantes de la zona conurbada, como las "tolvaneras", tormentas de polvo y detritus con agentes patógenos que durante los primeros meses de cada año azotaban y cubrían totalmente el conglomerado urbano, haciendo a los habitantes víctimas de enfermedades oculares, respiratorias y digestivas.

Dado que la superficie que constituyó el espejo de agua del ex-lago es cruzada por dos grandes cauces de desagüe (Río de la Compañía y Río Churubusco), era necesario su encauzamiento, control y regulación para evitar inundaciones en diversas areas del valle y de la Ciudad de México. Además, el lago recibia la afluencia de 11 ríos de la vertiente



EL DESARROLLO DE LA ZONA ORIENTAL DEL VALLE DE MEXICO HA PROPICIADO LOS IMPACTOS SIGUIENTES:

SOCIO-ECONOMICOS

- **EXPANSION DE LA MANCHA URBANA E INDUSTRIAL DE LA CAPITAL**
- **EXPLOSION DEMOGRAFICA**
- **PROBLEMAS EN EL SUMINISTRO DE AGUA POTABLE**
- **PERFORACION SIN CONTROL DE POZOS**
- **SOBREXPLOTACION DE MANTOS ACUIFEROS**

Figura 1.—Impactos Socio-Económicos generados por el desarrollo del oriente del Valle de México.

EL EX-LAGO DE TEXCOCO Y SU AREA DE INFLUENCIA

PROBLEMATICA GENERAL

EL DESARROLLO DE LA ZONA ORIENTAL DEL VALLE DE MEXICO HA PROPICIADO LOS IMPACTOS SIGUIENTES:

AMBIENTALES

- **ABATIMIENTO DE RECURSOS HIDRAULICOS SUBTERRANEOS**
- **HUNDIMIENTOS DEL SUELO**
- **COLAPSOS EN INSTALACIONES Y CONSTRUCCIONES**

- **CAMBIO DE USO DEL SUELO**
- **DEFORESTACION**
- **CORRIENTES TORRENCIALES**
- **EROSION (AGUA Y AIRE)**
- **COMPORTAMIENTO IRREGULAR DE LA HIDROLOGIA**
- **INUNDACIONES**
- **DESAPARICION DE AREAS VERDES Y LAGUNAS**
- **DETERIORO INCONTENIBLE**
- **RUPTURA DEL EQUILIBRIO DE LOS ECOSISTEMAS DE LA CUENCA**

Figura 2.—Impactos Ambientales generados por el desarrollo del oriente del Valle de México.

montañosa oriente, lo que hizo necesario realizar obras de control a fin de evitar inundaciones en numerosos pueblos y tierras de cultivo de la cuenca.

Los trabajos de conservación de agua y suelo incluidos en el manejo de la cuenca, deben ser continuados para regular el funcionamiento hidrológico de la misma. En cuanto a la Zona Federal, desde el inicio del programa se fijó como objetivo su restauración ecológica para convertirla en un gran pulmón para toda la zona metropolitana de la Ciudad de México.

II. La segunda etapa estribó fundamentalmente en reforzar y consolidar el objetivo de la primera fase, para lo cual se desarrollarían en toda la superficie disponible de la Zona Federal del ex-lago de Texcoco, una amplia area boscosa con parques de venados, criaderos de caballos, actividad piscícola, parques recreativos familiares, deportes acuáticos y atletismo. Esta etapa comprendia la terminación de la autopista Peñón-Texcoco con todas sus estructuras y obras complementarias, incluyendo las de mitigación ambiental, así como las del arco norte del periférico de la Ciudad de México, que junto con el camino Peñón-Texcoco mejorarían de manera notable las comunicacones para el Proyecto y para toda la región circundante. Adicionalmente, se proseguirían las obras de riego de San Bernardino y otras que incrementasen el intercambio de agua tratada por el agua potable que es bombeada desde su acuífero y que se utiliza en el riego agrícola.

III. La última etapa está constituida por las acciones de operación, conservación y seguimiento de los trabajos relacionados con el manejo de la cuenca montañosa, lagos, canales, plantas de tratamiento y caminos construidos. El Proyecto Lago de Texcoco de la CNA, es el primer modelo de recuperación ambiental del país, si se considera que es uno de los refugios más significativos para las aves migratorias en invierno y un sitio destinado a la reproducción de la fauna local, lo que la convierte en una zona de importancia y de prestigio internacional, ya que por su entorno y cercanía a la capital del país - la ciudad más grande del mundo - le confieren a esta zona un gran potencial recreativo y turístico.

Conclusiones

Como se puede observar, los trabajos realizados por el Proyecto Lago de Texcoco, dependiente de la CNA, se han enfocado al control de las tolvaneras que afectaban la salud de una parte de los habitantes del D.F. y de las áreas circunvecinas al ex-lago de Texcoco; a propiciar la recarga de acuíferos para tener una mayor capacidad de suministro de agua con fines agrícolas, ganaderos e industriales, así como al control del avance de la desertificación para lograr una recuperación y el mejoramiento del ambiente en favor de los habitantes.

Por otra parte, los problemas ecológicos e hidrológicos de la cuenca del Valle de México incluyen varios aspectos que desde un ambiente externo al mismo proyecto, influyen directa o indirectamente en el mismo; por ejemplo, la dinámica poblacional cuya distribución insuficientemente planificada origina presiones en los límites del área física del proyecto provocando invasiones que han repercutido en la construcción de las obras. Por esta razón, es recomendable el Ordenamiento Territorial, tanto en el D.F. como en la Zona Conurbada del Estado de México.

Finalmente, se debe insistir en destacar que los grandes problemas del Valle y de la Ciudad de México son: la sobreexplotación de los mantos de agua subterráneos y los consiguientes hundimientos del subsuelo con el riesgo de colapsos muy costosos de instalaciones, de construcciones y de los servicios de la Zona Metropolitana. A causa de la perforación de pozos sin control, últimamente se ha acelerado el problema de los hundimientos del subsuelo.

El Proyecto de Investigacion Del Inifap-Cenid*Comef

Las áreas de estudio

La Zona Federal—Los terrenos del ex-lago de Texcoco, conocidos como Zona Federal, comprendían por Acuerdo Presidencial del 23 de junio de 1971, una superficie de 14,500 hectáreas; actualmente sin embargo, se considera solamente una superficie aproximada a las 10,000 ha. El ex-lago de Texcoco se localiza en la porción más baja y casi central de la cuenca del Valle de México, lo cual imprime ciertas características especiales a la zona, la cual ha tenido, a través del tiempo, cambios progresivos de acumulación de sales en el suelo y el agua (SRH 1971).

La falta de una cubierta vegetal que protegiera los suelos de la erosión eólica, había sido la causa de que el vaso del ex-lago de Texcoco se constituyera como la principal fuente de las tolvaneras que afectaban a la ciudad de México (INIF 1978); para mitigar este efecto, en dicha zona se han realizado diversas obras que van desde las tendientes a mejorar los suelos (Ureña 1975), hasta la introducción de especies arbóreas (González 1982) y la pastización de extensas superficies de terreno (Llerena y Tarín 1978; Mota 1979) con pasto salado (*Distichlis spicata* (L.) Green); al momento, la superficie sin cobertura vegetal comprende menos de 1,000 ha (Mercado 1996, comunicación personal).

Sin embargo, los suelos del ex-lago presentan, por su parte, características únicas en el mundo y solamente algunas especies vegetales capaces de resistir altas concentraciones de sales (especies halófitas) son las que pueden soportar estas condiciones (Prada 1975). No obstante esta aseveración, algunos trabajos iniciales en el ex-lago incluyeron el establecimiento de plantaciones forestales con especies halófitas y no halófitas, mediante la preparación del sitio por varios métodos: rellenos, construcción de bordos, aplicación de mejoradores de suelos y construcción de subdrenaje, entre otros (Sosa 1975).

Actualmente estas plantaciones ocupan una superficie del orden de las 500 hectáreas, considerándose necesario conocer con precisión el estado en que se encuentran, a finde tomar las medidas y precauciones pertinentes con el propósito de mantenerlas en buenas condiciones. Así mismo, es necesario evaluar sus impactos ecnómicos y ecológicos para tener un marco de referencia para la continuación del programa.

La Cuenca Tributaria—Esta área está integrada por tres zonas que incluyen las cuencas de once ríos, totalizando una superficie de 144,180 hectáreas, en las que se han venido realizando trabajos de recuperación y conservación del suelo y agua desde 1973 (AGRIPEFOR 1992). a) la Zona Noreste comprende las cuencas de los ríos San Juan Teotihuacan, Papalotla, Xalapango y Coxcacoaco; b) la Zona Oriente está integrada por las cuencas de los ríos Texcoco, Chapingo, San Bernardino, Santa Mónica y Coatepec y; c) la Zona Sureste está conformada por las cuencas de los ríos San Francisco y la Compañía.

La Cuenca Tributaria del ex-lago de Texcoco, comprende así mismo, varios municipios del Estado de México, ubicados al oriente de la Zona Federal y del Valle de México; la mayor parte de cuya superficie está sometida a perturbaciones en diferentes grados, a veces muy severas. En esta zona, se ha realizado una gran cantidad trabajos para corregir dicha cuenca y disminuir la erosión por escorrentías superficiales que se depositan en el vaso del ex-lago.

Estos trabajos incluyen construcción de presas de mampostería y gabiones para corregir cauces, disminuir erosión y arrastre de sedimentos, así como para prevenir la creación de cárcavas. También se han utilizado subsoleo, construcción de terrazas y diferentes sistemas de plantación, con el propósito de restaurar los ecosistemas por medio del establecimiento de una cubierta arbórea.

La evaluación de todos los trabajos relacionados con la recuperación del suelo y de las plantaciones realizadas a la fecha, tanto en la Zona Federal como en la Cuenca Tributaria, constituye en estos dias una alta prioridad, con el propósito de realizar los ajustes necesarios a los aspectos operativos del Programa de Recuperación Ambiental del ex-lago de Texcoco. Dos actividades fundamentales en este sentido, son la reconstrucción del historial completo de las acciones realizadas y la integración de todo el acervo documental generado por muchos años de actividades, para que esté disponible y sirva de apoyo para la toma de decisiones y planificación de actividades por parte de la dependencia responsable. En este mismo contexto, es importante abrir nuevas Líneas de Investigación que contribuyan de alguna manera a reenfocar y ampliar el espectro de un Programa de Investigación y de Transferencia Tecnológica de corto, mediano y largo plazos, que apoyen los esfuerzos del Programa Operativo de la Comisión Nacional del Agua (CNA).

Entre las primeras Líneas de Investigación iniciadas por la Comisión del Lago de Texcoco desde su creación en 1980, se tienen la relacionada con la recuperación de suelos, la del efecto de la desecación del lago y la de aprovechamiento de los recursos que ahí se encuentran. Una Línea de Investigación adicional es la del establecimiento de una cubierta vegetal con especies halófitas (hierbas, pastos, arbustos y árboles), para evitar la erosión por el aire. En la Cuenca Tributaria al oriente del ex-lago, por otra parte, se han realizado obras de corrección de la cuenca, conservación de suelos y reforestación utilizando maquinaria pesada y distintos sistemas de plantación.

Es bien conocido que a través de varios años se ha realizado una gran cantidad de diagnósticos, evaluaciones estacionales parciales y experimentos, etc., con los que se ha generado una gran cantidad de información (publicaciones formales, Tesis, Tesinas, reportes internos, entre otros). Sin embargo, esta información se encuentra muy dispersa y consecuentemente no sistematizada; no existe una colección completa de toda la información generada, pero persisten en cambio, algunas personas de las que iniciaron los trabajos de recuperación de suelos, que recuerdan hechos y lugares que es necesario reconstruir y documentar apropiadamente. Lo anterior servirá como punto de partida para rediseñar estrategias o líneas generales de acción para lograr la recuperación ambiental del ex-lago de Texcoco.

Aspectos generales

Este proyecto está diseñado para desarrollar acciones de investigación, transferencia tecnológica y capacitación (Fig. 3) de manera consistente en tres horizontes de planeación: corto plazo (1997 y 1998), mediano plazo (1999-2001) y largo plazo (2002-2006); la duración total del proyecto es, por lo tanto, de 10 años. El proyecto incluye cinco Líneas de Investigación y contempla la realización de acciones en los todos los ecosistemas forestales presentes tanto en la Zona Federal (superficie aproximada de 10,000 hectáreas) como en la Cuenca Tributaria (superficie aproximada de 144,000 hectáreas) del ex-lago de Texcoco.

Las cinco Líneas de Investigación son las siguientes:

1). Evaluación, caracterización y manejo de la vegetación existente (natural y artificial).

2). Evaluación de trabajos de recuperación de suelos.

3). Ensayos con especies halófitas nativas y exóticas.

4). Integración de Bases de Datos Relacional (con ACCESS).

5). Integración de una Base de Datos Geográfica (con ARCINFO).

Para cumplir con las Metas y Ojetivos de este proyecto, es necesario realizar una gran cantidad de actividades que comprendan las cinco Líneas de Investigación enlistadas y los 10 años del horizonte de planeación de largo plazo. Dado que este artículo es reducido, no es posible ampliar mucho la información, razón por lo cual, a continuación sólo se presenta una descripción con un mínimo de detalle de las actividades que están desarrollando durante el horizonte de planeación de corto plazo, en cada una de las 12 Componentes que componen el proyecto.

1. Evaluación de trabajos de recuperación de suelos que usaron métodos físicos, químicos e hidrotécnicos en la Zona Federal.

Se realizan muestreos y análisis químicos de suelo-agua-planta, en áreas para las cuales se consideran los aspectos de: bordos, rellenos, canales, drenes, lavado y uso de mejoradores. Lo anterior, para fines de evaluar los trabajos de recuperación de suelos en los que se emplearon métodos físicos, químicos, hidrotécnicos y vegetativos. Adicionalmente a lo anterior, se establecen sitios para muestreo permanente y se ha diseñado una metodología de seguimiento.

2. Inventario de las plantaciones forestales realizadas en la Zona Federal.

La información incluye la ubicación precisa de los sitios de muestreo referenciada geográficamente. También se toman en cuenta las obras de infraestructura hidráulica y los métodos de preparación del terreno, la aplicación o no de riego, etc., con lo cual, se ha definido el diseño e intensidad de muestreo. Se obtienen los datos de campo de inventarios temporal y períodico para contar con la información dasométrica y sanitaria del estado actual y de evaluaciones

EL PROYECTO DEL INIFAP (CENID-COMEF)

ACCIONES REQUERIDAS

REALIZAR BUSQUEDAS EN DIVERSOS CENTROS DE DOCUMENTACION Y ENCUESTAS CON PERSONAL QUE HA PERMANECIDO POR MUCHO TIEMPO EN LAS AREAS DE ESTUDIO

RECONSTRUIR E INTEGRAR EN TODO LO POSIBLE EL ACERVO DOCUMENTAL HISTORICO QUE ESTE DISPONIBLE

EVALUAR LOS TRABAJOS DE RECUPERACION DE SUELOS Y DE ESTABLECIMIENTO DE COBERTURA VEGETAL A FIN DE PROPORCIONAR RECOMENDACIONES PRACTICAS PARA SU CONTINUACION

EVALUAR EL EFECTO DE LOS TRABAJOS REALIZADOS EN EL ABATIMIENTO DE LOS NIVELES DE IMPACTOS AMBIENTALES

GENERAR INFORMACION CONFIABLE PARA REALIZAR AJUSTES O MODIFICACIONES A LOS PROGRAMAS OPERATIVOS EN DIFERENTES HORIZONTES DE PLANEACION

PROPONER NUEVAS ACCIONES OPERATIVAS Y LINEAS DE INVESTIGACION PARA LA AMPLIACION DE PROGRAMAS DE RESTAURACION AMBIENTAL EN TODA LA REGION

Figura 3.—Acciones necesarias propuestas por el proyecto del CENID-COMEF para el Lago de Texcoco.

dasométricas subsecuentes de las plantaciones forestales realizadas hasta la fecha en esta área de estudio.

3. Evaluación de trabajos de recuperación de suelos con uso de plantaciones forestales en la Zona Federal.

Con apoyo en los resultados estadísticos de los datos correspondientes a los análisis químicos de suelo-agua-planta y del inventario de las plantaciones forestales, se caracteriza el desarrollo actual y se estima el desarrollo futuro de los parámetros principales de los individuos plantados.

4. Evaluación del impacto ecológico de las plantaciones forestales de la Zona Federal.

Mediante la correlación de la información recabada y generada por varias de las componentes, se procede a realizar análisis comparativos a fin de evaluar, en forma indirecta, algunos indicadores de impacto ambiental y los efectos que han tenido las plantaciones forestales en la mitigación de la problemática de esta área de estudio.

5. Recomendaciones prácticas para manejo de las plantaciones forestales de la Zona Federal.

Mediante la correlación de la información generada por el inventario forestal y la obtenida por el muestreo y análisis químicos de suelo-agua-planta, se realizan análisis comparativos para evaluar el impacto ambiental de las plantaciones y, a partir de éstos, se definirán prácticas de aplicación inmediata para su continuar su establecimiento y manejo futuro.

6. Levantamientos florísticos estacionales y estructura vegetal de poblaciones naturales en la Zona Federal.

Estos levantamientos de información se realizan en las épocas de lluvia y de estiaje del año, para detectar los cambios generados por la presencia de las plantaciones forestales, la pastización y los trabajos de recuperación de suelo por otros procedimientos. Las poblaciones se muestrean mediante Líneas Canfield, que se ubican con GPS. Luego se establecen sitios permanentes de muestreo para levantamientos futuros. De esta manera se espera proponer la reproducción, en forma masiva, de algunas especies promisorias que contribuyan a la restauración de la cobertura vegetal de los ecosistemas perturbados.

7. Propuestas de alternativas para el programa de cobertura vegetal en la Zona Federal.

Como alternativas para contribuir, en la medida de lo posible, a acelerar el proceso de recuperación de suelos, se procederá a la evaluación del potencial productivo de esta zona de estudio y a proponer las especies cuyos requerimientos ecológicos las coloquen como especies promisorias, es decir, con buenas posibilidades de adaptación a las condiciones ambientales de la propia área de estudio.

8. Detección de áreas de mayor infiltración de agua en la Cuenca Tributaria.

Mediante el uso de SIG (ARC/INFO), con apoyo en capas de información (tipo de suelos, uso actual del suelo, topografía, etc.) y en estudios geohidráulicos realizados con anterioridad por otras instituciones, además de datos actualizados de campo para verificar las condiciones actuales, se procede a la detección de algunos indicadores que determinan las características de las áreas que infiltran mayores cantidades de agua al subsuelo, aquellas que tienen menor capacidad de infilración y las que definitivamente no pueden, en la actualidad, captar el agua de lluvia y que por ende generan problemas mayores en el terreno. Esto es muy importante porque las de la primera categoría serán consideradas como prioritarias para realizar en ellas los trabajos necesarios tendientes a su restauración, ya que son las que contribuyen en mayor medida a la recarga de acuíferos.

9. Integración de una Base de Datos Relacional (con ACCESS) para la Zona Federal y la Cuenca Tributaria.

Toda la información producida por los inventarios, muestreos y recorridos de supervisión con los trabajos de este proyecto, tanto para la Zona Federal como para la Cuenca Tributaria, es integrada en esta base de datos. Dicha base de datos tiene como entidad común al sitio o localidad georeferenciada donde se toman los diferente tipos de datos. El acceso a toda esta información se logra a través de una interfase de usuario desarrollada igualmente en ACCESS.

10. Integración de una Base de Datos Geográfica (con ARC/INFO) para la Zona Federal y la Cuenca Tributaria.

Para esta componente, se recurre a toda fuente de información cartográfica disponible y recorridos de campo en la Zona Federal del ex-Lago de Texcoco, en relación a temas generales como: Geología, Fisografía, Edafología, Clima, Vegetación, Lagos Artificiales, Obras Hidráulicas y de Conservacion del Suelo; asi como todo tipo de estudios relacionados con los temas del presente trabajo; algunas de estos mismos temas serán utilizados para la Cuenca Tributaria. A esta información se añadirá la que se genere por este Proyecto.

11. Capacitación y transferencia de tecnología.

Los seis participantes del INIFAP-CENID*COMEF, tienen como actividad sumamente importante, la de proporcionar capacitación a todos los participantes de la CNA-Gerencia Lago de Texcoco, en todos los trabajos desarrollados en las distintas componentes. Se considera como tarea primordial, capacitar a todos ellos en la integración y manejo de las bases de datos relacional y geográfica, para que puedan continuar su manejo apropiado y obtener informes que los apoyen en la toma de decisiones de acuerdo con sus propias necesidades.

12. Publicación de resultados.

Los resultados obtenidos, se presentan y publican en los diferentes medios disponibles: revistas, boletines, trípticos, etc., etc. La intención es también la de aprovechar todos los eventos científicos nacionales e internacionales relacionados con los temas del Proyecto, para asistir a ellos y dar a conocer los resultados obtenidos, asi como para captar nuevas ideas y detectar nuevas tecnologías y conocimiento generado en otras partes del mundo con problemas similares.

Resultados preliminares

Aunque es muy prematuro hablar de resultados dado el poco tiempo que se ha trabajado, se pueden señalar algunos avances:

- Se realizaron prácticamente todos los recorridos para localización de áreas de muestreo en la Zona Federal: se tienen ubicados un total de 180 sitios para muestreo de suelos y plantas; de éstos se tiene un avance del 50 % del muestreo y de los análisis químicos de laboratorio; en los mismos 180 sitios se muestreó la vegetación espontánea en la época de lluvia, teniéndose un 40% de los ejemplares colectados ya identificados en el Herbario Nacional. S ubicaron 10 sitios para el muestreo de aguas, los cuales fueron muestreados en tiempo de lluvias de 1998; se están concluyendo los análisis de laboratorio.

- Para contar con la información dasométrica y sanitaria de su estado actual, se cuenta con el 60 % de los datos de campo del inventario temporal de las plantaciones forestales realizadas en esta área de estudio, estimándose de manera muy preliminar, una sobrevivencia general superior al 30 %. Las principales causas de muerte de los individuos detectadas, son heladas y sequía; los daños por plagas no son significativos.
- Dado que muchos de los sitios temporales donde se obtuvo información de campo en la Zona Federal (suelos-agua-planta, plantaciones, vegetación natural espontánea) están georeferenciados, se programa el establecimiento de sitios para inventario permanente integrado de todas las variables involucradas dentro de esta información; también se está diseñando una metodología de seguimiento contínuo.
- Se ha reunido bastante información cartográfica de la Zona Federal, la cual está siendo digitalizada para la evaluación del potencial productivo de esta área de estudio, a fin de compararla con los requerimientos ecológicos de especies con buenas posibilidades de adaptación a las condiciones ambientales de dicha área de estudio. También se ha iniciado la digitalización de algunas capas de información para la Cuenca Tributaria, enfocada a la detección de las áreas con mayor infiltración de agua de lluvia. Toda esta información está siendo integrada a una Base de Datos Relacional que incluye bases de datos cartográficos, tabulares y datos producidos por este proyecto.
- La Base de Datos Relacional ha pasado de las etapas de diseño a la captura de toda la información producida por los inventarios, muestreos y recorridos de supervisión con los trabajos de este proyecto, tanto para la Zona Federal como para la Cuenca Tributaria, teniendo como entidad común al sitio o localidad get eferenciada y cuyo acceso a toda la información se logra a través de una interfase de usuario desarrollada en ACCESS.
- Cuatro de los seis investigadores del INIFAP-CENID*COMEF, diseñaron y realizaron un Taller de Planeación Participativa con la presencia de 15 Técnicos de la CNA-Gerencia Lago de Texcoco, a fin de rescatar información importante que se considera primordial para respaldar la toma de decisiones con respecto a las necesidades de desarrollo futuro del proyecto. Los dos investigadores restantes preparan un curso de SIG (ARC/INFO) para los mismos técnicos.

Consideración final[4]

Las condiciones actuales de los ecosistemas forestales bajo estudio en este proyecto, tomaron mucho tiempo en desarrollarse; lograr la plena recuperación/restauración y consecuente protección, bajo los principios de un desarrollo sostenible, requerirá de soluciones y compromisos interinstitucionales y de los tres niveles de gobierno de muy largo plazo. El CENID-COMEF, dependendiente del INIFAP y la CNA-Gerencia del Lago de Texcoco, continuarán conjuntamente sus trabajos para recuperar, proteger y mantener los ecosistemas forestales de las áreas de estudio en condiciones de buena salud y productividad en el más amplio sentido.

Literatura Citada

AGRIPEFOR. 1992. Evaluación del Programa de Reforestación del Proyecto Lago de Texcoco: Zona Noreste. Instituto de Estudios, Investigaciones y Servicios Chapingo, S.C. Chapingo, México. 72 pp.

Cruikshank G., G. 1995. Proyecto Lago de Texcoco: rescate hidroecológico. Servicios de Artes Gráficas. México, D.F. 111 pp.

González V., C.E. 1982. Una alternativa de cobertura vegetal del ex-lago de Tezcoco. Ciencia Forestal 7(40):3-24. INIF. México.

INIF. 1978. Investigación y experimentación para el establecimiento de vegetación nativa e introducida en el área del vaso del ex-lago de Tezcoco. Reporte de Investigación. Dirección General de Investigación y Capacitación Forestal. México. 35 p.

Llerena V., F. y M. Tarín V. 1978. Establecimiento del pasto salado (Distichlis spicata L.) en suelos extremadamente salino-sódicos del ex-lago de Texcoco. Memoria del XI Congreso Nacional SMCS. México. pp. 1-16.

Mercado, G., F. 1996. Comunicación personal.

Mota U., C. 1979. Determinación del rango de teloerancia al ensalitarmiento por el pasto salado (Distichlis spicata (L.) Green), en suelos del ex-lago de Texcoco. Ciencia Forestal 4(22): 21-44. INIF, México.

Prada Rodríguez, J.N. 1975. Capacidad de adaptación de tres especies vegetales a diferentes condiciones de ensalitramiento en suelos del ex-lago de Texcoco. Tesis de M.en C. Colegio de Postgraduados. Chapingo, Méx. 87 p.

Sosa Cedillo, R. 1975. Investigaciones sobre la adptación de especies forestales arbóreas en el vaso del ex-lago de Texcoco. Bol. Div. No. 37. INIF. México. 30 p.

SRH. 1971. Estudio agrológico especial del ex-lago de Texcoco, Edo. de México. Serie de Estudios. México., D.F. 145 p.

Ureña Castellanos, C.F. 1975. Estudio preliminar para la utilización de diversos mejoradores y láminas de lavado para la recuperación de los suelos salino-sódicos en el ex-lago de Texcoco. Tesis Profesional. UACH, Chapingo, Méx. 85 p.

[4]El autor agradece la colaboración en el proyecto de: M.C. Diego Reygadas P., M.C. Francisco Moreno S., Dr. Reynaldo Valenzuela R., IBQ Juana Ma. Castro S. y Biól. Marcela Gutiérrez G. del CENID-COMEF, así como del Ing. Gerardo Cruickshank G. e Ing. Fernando Mercado G. de la CNA-Gerencia Lago de Texcoco.

Evaluación Participativa como Parte Integral del Muestreo de los Recursos Naturales[1]

Reynaldo Valenzuela Ruíz[2]

Resumen—La necesidad de diagnosticar y de planificar ha sido reconocida ampliamente por diferentes sectores sociales y económicos. Se han realizado muchos esfuerzos para capacitar a recursos humanos interesados en asumir la conducción de los pasos tan importantes como lo son el diagnóstico y la planificación y en esta forma mejorar la eficiencia en el diseño de proyectos de desarrollo de los recursos naturales y sociales.

Este documento contiene los resultados de la aplicación de una evaluación rural participativa, en la que se persigue un desarrollo integral sostenible de la comunidad denominada "El Oro" Municipio de Santo Domingo Nuxaa, en el estado de Oaxaca. Se ofrece una ligera reseña de antecedentes del lugar, algunos cuadros con datos de los recursos naturales, así como de los sistemas de producción practicados en el lugar, datos técnicos y productivos, así como los socio-económicos.

Se incorpora una lista de problemas y de sus posibles soluciones encontradas en forma asociada con los productores del lugar, los técnicos y los miembros interesados de la comunidad (comprende casi el 90 %).

También se realiza un análisis FODA (Fortalezas, Oportunidades, Debilidades y Amenazas).

Los resultados obtenidos dan evidencia de la bondad de la metodología empleada, dando énfasis en la participación sonante y decidida de los elementos motivo del estudio. (Población de la comunidad, productores y algunos agentes externos.)

Abstract—The diagnosis and planning process necessity has been recognized widely by different economic and social efforts. It has been done many attempts to train human resources interested in assuming the so important steps like the diagnosis and planning to improve the efficiency in project determination and design for the development of natural and social resources.

This paper contains the results from the application of a participatory rural appraisal and an integrated sampling process which look for an integral and sustainable development in a community called "El Oro", located in the Municipality of Santo Domingo Nuxaa, in the state of Oaxaca, México.

It starts with a short background about participatory rural appraisal and the same for the community, including some pictures of its natural resources data, coming from an applied forest sampling. The description of agricultural production systems were also analyzed as well as technical and socioeconomic data coming from the development of a cross section to the surface owned by the community.

It is also added the identification of some problems and their solutions found jointly with producers and technicians and interested community members (almost 90 %).

It is performed an analysis SOWT (Strengths, Opportunities, Weaknesses, and Threats).

Results give evidence about the kindness and feasibility of the applied methodology, stressing the sound and decisive participation of elements subject to the studio.

La realización de planes, programas y proyectos que en forma convencional realizan las instituciones gubernamentales y civiles, tienen como objetivo central el mejoramiento de la calidad de la vida de las comunidades en donde se realizan. Sin embargo estos planes, programas proyectos y actividades se empiezan a gestar desde los niveles mas altos y son pasados a través de niveles bajos para su directa aplicación o desarrollo. Situación que implica muchas veces el desconocimiento de qué hacer y de los términos de referencia en su ejecución, dando como resultado en su mayoría, el fracaso en el logro de objetivos y metas.

Mas delicado resulta aún el hecho de que los miembros de una comunidad motivo de un programa, proyecto o actividad de desarrollo, nunca son tomados en cuenta en lo que se respecta a sus gustos y preferencias, por lo que sus opiniones son mantenidas cautivas constituyéndose en un potencial muy grande pero que se pierde a través del tiempo y en muchos casos se convierte en resentimientos hacia el gobierno y sus agentes, impidiéndose con esto la ejecución libre, asociada y consensada de las actividades de desarrollo. En una situación de esta naturaleza, ni la teoría económica ni la micro y macro economía pueden prosperar y se suman los casos de deterioro y agotamiento de los recursos con consecuencias muchas veces irreversibles y/o con mucho gasto público para su recuperación.

La evaluación participativa "es un proceso de colaboración en la solución de problemas a través de la generación y uso del conocimiento. Es un proceso que se dirige hacia la acción correctiva, involucrando todos los niveles en un proceso de toma de decisión compartido".

Es un proceso ágil y efectivo y utiliza las herramientas de la planeación participativa, lo cual puede ayudar para:

- Articular aspectos técnicos y socioeconómicos en la definición de problemas y búsqueda de soluciones.
- Formular consensos dentro de las comunidades rurales en torno a las acciones específicas que respondan a los diversos intereses locales y que mejoren el manejo de los recursos naturales de la localidad.
- Fortalecer la capacidad de negociación de los grupos comunitarios, facultando propuestas de acción y de políticas que respondan a los intereses y necesidades locales.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Sistematizar la participación de organizaciones que interactuan con la comunidad para detener y revertir la disminución de la calidad de vida y productividad rural.

Sin embargo, es inminente que se presente en la mente de todos los actores las preguntas que de alguna forma se presentan dentro de lo que se constituye como el reloj de la evaluación:

1. ¿ Porqué necesitamos evaluar ?
2. ¿ Quién la desea y para qué decisiones ?
3. ¿ Cuáles son los asuntos clave o principales ?
4. ¿ Cuáles son las preguntas específicas que debemos de contestar ? ¿ Qué información buscamos y dónde ?
5. ¿ Cuál método usamos para recopilar información ?
6. ¿ Quién participa ¿ Cuándo recopilamos la información ?
7. ¿ Cómo analizamos la información para producir evidencia ?
8. ¿ Quién necesita que información y en que forma ¿ Quién interpreta la evidencia ?
9. ¿ Qué sucedió ? ¿ Cómo reportarlo ?
10. ¿ Porqué sucedió ?
11. ¿ Qué lecciones aprendimos ?
12. ¿ Qué haremos en forma diferente ?

Al darle respuesta a estas preguntas, los actores participantes se sienten con confianza y se involucran con mayor decisión.

Varias herramientas del método de la evaluación rural participativa fueron aplicados en la comunidad de "El Oro" perteneciente al Municipio de Santo Domingo Nuxaa, en el estado de Oaxaca, para trabajar un diagnóstico, con miras a su desarrollo sostenible.

Justificación del Estudio

En general, México está viviendo una situación de extrema pobreza en las áreas rurales y en particular las áreas forestales no escapan a esta situación, pues es aquí en donde los efectos se dejan sentir con mayor fuerza, en la medida en que los núcleos sociales, viviendo en estas áreas ejercen cada día su presión sobre el recurso natural base, a tal grado de cambiar el uso del suelo por alguna práctica que ellos consideran mas beneficiosa.

La Mixteca Alta Oaxaqueña es una imagen de esta situación, y la comunidad de El Oro viene siendo un ejemplo representativo, ya que se manifiestan en ella grandes problemas de erosión aveces profunda, disminución en cantidad y calidad de agua, la desaparición gradual y aveces acelerada de la cubierta vegetal natural (bosque de pino y encino), y en general una seria perturbación del ecosistema natural. Todo este panorama requiere como estrategia la de revertir el proceso de degradación ecológica, cuya base sería la ejecución del diagnóstico.

Objetivos

—Generar una base de información acerca de las principales características técnicas, sociales, económicas, ecológicas, políticas y culturales de la comunidad.

—Caracterizar el estado actual de los recursos naturales con los que cuenta la comunidad.

—Identificar en forma asociada un conjunto de acciones productivas, de conservación, de restauración, y de fomento de los recursos naturales; así como generar alternativas en los sistemas de producción de acuerdo con la capacidad del suelo.

Justificación de la Aplicación de la Evaluación Rural Participativa

1. Movilización de la comunidad. Esta técnica se ejecuta en las comunidades, bajo la responsabilidad de ella misma y con la participación activa de sus miembros. (Se tuvo un promedio de asistencia por sesión de 45 jefes de familia y de 17 mujeres).
2. El uso de herramientas visibles (diagramas, mapas, matrices)
3. Análisis participativo de la comunidad, incluyendo sus problemas y soluciones potenciales.
4. Generación de alternativas de desarrollo de base.
5. Fortalece la participación y colaboración entre la comunidad y las instituciones externas.
6. Permite la formulación de propuestas.
7. Permite la integración, al participar todos los grupos comunitarios incluyendo a las mujeres.
8. Rapidez y bajo costo.
9. Despierta a los técnicos.
10. La comunidad tiene control sobre la definición del proyecto.
11. Se basa en la información directa y de primera mano.
12. Permite un proceso de sistematización.

Con estos puntos se espera:

—Que la comunidad sufra un proceso de fortalecimiento al realizar el diagnóstico y el análisis de su realidad.

—Que surjan propuestas de acción.

—Que se fortalezcan las instituciones locales.

—La existencia de material de consulta procedente de los resultados.

Metodología

En esta fase se procedió a realizar visitas de campo individuales o de grupo estableciendo contacto directo con los miembros de la comunidad. La información primaria se obtuvo de informantes clave de la comunidad, como lo son maestros, líderes religiosos y gente de mayor edad. En general se utilizó:

—La observación directa a través de las visitas y reuniones informales.

—Entrevistas con informantes claves.

—Entrevistas medio estructuradas con jefes de familia.

—Talleres participativos.

—Levantamiento de un inventario forestal.

—Desarrollo de un transecto de 20 metros de ancho con una longitud de 2600 metros, tomándose como sección cruzada en las áreas agrícolas y pecuarias.

La información adicional fue obtenida en las Secretarías del Gobierno Estatal, así como en algunas agencias federales (SEMARNAP, SAGAR, INSOL).

Cabe señalar que los talleres participativos fueron la clave para el éxito del desarrollo del diagnóstico, en cuyo caso se emplearon las herramientas de:

—Autoevaluación (inducida o guiada).
—Jerarquización con puntuación.
—Diagramas, mapas.
—Historia de la comunidad.

En cada ejercicio que se asignaba, se establecía un límite de tiempo y se procedía a confrontar los resultados de los diferentes grupos participantes.

En lo que respecta al inventario forestal se diseñó un muestreo completamente al azar con sitios circulares de muestra de un décimo de hectárea, y con su respectiva compensación por motivos de la pendiente, cuando este lo requería. En cada sitio se tomó información de los aspectos ecológicos silvícolas así como dasométricos con las observaciones sobre el suelo, escurrimientos o manantiales, presencia o evidencia de presencia de la fauna silvestre, renuevos y su condición, practicas de aprovechamiento.

Siempre se contó con la opinión de los elementos de la comunidad que nos acompañaron y se les explicó para que servirían cada dato o registro y cuál sería el producto final que se obtendría con la información que se estaba obteniendo.

Resultados

En primer lugar es importante mencionar que al involucrarse los miembros de la comunidad en cada una de las etapas de desarrollo del diagnóstico, ellos se sentían mas apropiados del proceso y por lo tanto la información fluía sistemáticamente y con precisión.
Se obtuvieron resultados en los siguientes:

1. Entorno Físico

La comunidad "El Oro" se ubica en el Municipio de Santo Domingo Nuxaa en el Distrito de Nochixtlán en el estado de Oaxaca. Su extensión territorial es de 3,828 ha totales de las cuales un poco mas de 2,000 ha son de tipo forestal. Esta superficie forestal no está aparcelada, no así la agropecuaria. Los medios de comunicación son la telefonía rural y caminos de segundo orden (terracerías). No existen obras de drenaje, sin embargo cada casa cuenta con su letrina. Se cuenta con agua potable procedente de un manantial localizado en el bosque comercial. Cada casa tiene servicio de electricidad, en cantidad y calidad suficiente para las necesidades familiares.

2. Entorno Social

El régimen de tenencia de la tierra es de tipo comunal. Sin embargo, y por costumbre la tierra está dividida entre los comuneros y cada persona respeta las parcelas de los demás. Existe un núcleo poblacional en el que se ubican la mayoría de los servicios. Existe un total de 609 habitantes de los cuales 290 son del sexo masculino y 319 del sexo femenino.

Los niveles de alfabetización son elevados, entre 90% al 95%. Tasa de natalidad de 3.28 %; la tasa de mortalidad de 0.49 %. Existe un centro de salud.

No existe problema de alcoholismo pero hay incidencia de enfermedades gastrointestinales, de las vías respiratorias, sarampión, reumatismo, trastorno en las mujeres por el uso de anticonceptivos. Finalmente se cuenta con una escuela primaria con los seis niveles o grados.

3. Entorno Económico

Las principales actividades productivas de la comunidad son:

—producción agrícola (maíz, frijol, trigo, chícharo, algunos cultivos de temporal)
—producción pecuaria (ganado vacuno para tracción, ganado caprino para contingencias, avicultura para el autoconsumo).

Recolección y Análisis de Datos.
Se trabajaron seis tipos de datos básicos:

Datos Basicos	Diagramas, Matrices, Croquis
1. Generales	• Generalidades y organización social de la comunidad. • Relaciones institucionales.
2. Espacio	• Mapa de la comunidad.
3. Tiempo	• Historia de la comunidad. • Análisis de tendencias (Global y/o Temática)
4. Socio Economicos	• Fuentes de Trabajo, Ingresos y Egresos. • Ejemplos varios: Calendario de actividades, calendario de migración, matriz de comercialización. • Niveles de bienestar.
5. Tecnicos y Productivos	• Diagrama transversal de la comunidad. • Croquis de las parcelas. • Calendario agropecuario. • Matriz de preferencias
6. Problemas, Soluciones e Identificacion del Proyecto	• Listado y prioridades de los problemas. • Soluciones propuestas. • Análisis de viabilidad (Matriz de viabilidad y FODA). • Programación de actividades.

—producción forestal (madera en rollo, elaboración de tablas, polines, leña y carbón en parte para uso doméstico y en parte para comercialización).

La comunidad cuenta con una tienda rural CONASUPO con productos básicos mas medicamentos como antiestamínicos y analgésicos. También existen pequeñas tiendas de abarrotes en el seno de algunas familias.

La población económicamente activa es del 67 %. No hay migración permanente de la gente de la comunidad, solo algunos en forma temporal para buscar trabajo en la ciudad capital del estado o para la ciudad de México.

El ingreso resulta estar entre 50 – 100 pesos diarios cuando existe la posibilidad de un trabajo.

4. Aspectos Culturales

Los jóvenes que desean continuar con la educación secundaria, se trasladan a una comunidad vecina denominada "Ojo de Agua", en donde existe una tele secundaria. Para estudiar la Preparatoria, tienen que trasladarse a la ciudad de Oaxaca.

Mas del 90 % de la población practica la religión protestante bajo la denominación Presbiteriana, el resto menor al 10 % es Católica. Se cuenta con una cancha de balón cesto.

5. Aspectos Políticos

Los órganos de gobierno de la comunidad se encuentran representados ant l gobierno del estado por una Agencia Municipal, formada por un Agente, un Secretario y un Tesorero, con sus respectivos suplentes. Ante la Secretaría de la Reforma Agraria, existe un Comisariado de Bienes Comunales, que funge a nivel Municipal. También existe un Consejo de Vigilancia formado por un Presidente y dos Secretarios de Apoyo. No existen representaciones de Partidos Políticos.

6. Aspectos Ecológicos

El clima predominante en donde se encuentra enclavada la comunidad según la clasificación de Koepen y modificado por García es el Templado Subhúmedo C(W), con una precipitación menor a los 800 mm.

El período de las lluvias se inicia en Mayo y se establece adecuadamente en Junio. Los meses de Junio y Septiembre son los mas lluviosos, mientras que los meses de Julio y Agosto con menor intensidad. El total de tierras cultivables se clasifica en temporal, de riego y de humedad.

El período de heladas es entre Octubre a Marzo.

Los suelos presentan erosión moderada aunque algunas veces profunda, pero son muy homogéneos en sus características físicas y químicas. Por su estructura predominan los suelos arenosos con alto contenido de pedregosidad. La tendencia en la coloración andan alrededor del color rojizo, amarillo y pardo. Son pobres en nitrógeno y fósforo y con tendencia alcalina.

Se describieron también los sistemas de producción agrícola, pecuario, y forestal de la siguiente manera:

Tecnología Agrícola

En este aspecto se detectaron las asociaciones de maíz – frijol y con la práctica de descansar cada dos años la tierra; y haciendo rotación con otros cultivos como el trigo principalmente. Las labores culturales son en forma general el barbecho y la preparación del terreno, que normalmente se realiza con yunta de animales; la siembra, la mayoría de la veces en forma manual; fertilización y primera escarda, cajón o segunda escarda; la eliminación de malezas, el ataque de plagas y la cosecha. La producción está en los niveles de para maíz de 700 kg. y para el frijol de 200 kg.

Se hizo un análisis de mercado de los productos agropecuarios y forestales; se evaluó también la actitud de la comunidad ante el cambio.

Tecnología Pecuaria

Se identificaron cuatro sistemas de producción animal: cría de ovinos para carne y lana; cría de animales de trabajo (bovinos y equinos); y la cría de aves y cerdos en el solar. A continuación se especifican los costos de producción y los ingresos por concepto de la ganadería tradicional en la comunidad.

Concepto	Costos
Costos:	$
Alimentación 1	3,784.00
Mano de Obra 2	7,300.00
Costo Total	11,784.00
Ingresos:	
Venta de animales	2,000.00
Venta de lana	
Venta de estiércol	
Total de Ingresos	2,000.00
Utilidad de explotación	–9,084.00

[1]Rastrojo de maíz entero y grano que se produce en la Unidad de Producción Familiar ($3,200 de rastrojo, $292 maíz para las aves y $292 de maíz para cerdos).

[2]Mano de obra familiar en las etapas más críticas.

Sistema de Producción Forestal (Bosque Comercial). La composición del bosque natural de la comunidad consiste de un bosque mezclado de pino-encino y otras latifoliadas como el aile y el madroño. En el bosque comercial domina por su presencia el *Pinus pseudostrobus*, y en el no comercial el *Pinus pringlei*.

Estos bosques se localizan en terrenos de topografía muy accidentada, con una altitud promedio sobre el nivel de mar de 2,381 m. Las exposiciones más frecuentes son la norte y la noroeste. La pendiente promedio es de 33.2%.

Cuadro Resumen de las Caracteristicas del Area Forestal Comercial de la Comunidad del oro, sto. Domingo Nuxaa, Oaxaca

Superficie aproximada	900 ha
Números de sitios circulares de 0.1 ha	22
Superficie inventariada	2.2 ha
Intensidad de muestreo	0.24 %

Tipo de vegetación: Bosques de pino-encino, con las siguientes especies presentes:

Pinus pseudostrobus
Pinus leiophylla
Pinus teocote
Pinus montezumae
Pinus pringlei
4 especies del género *Quercus*
Otras latifoliadas: *Alnus, Arbutus* sp.

	Transecto1	Transecto2	Transecto3	%
Pendiente	28.6	41.2	30	33.2%
A.S.N.M.	2508	2250	2386	2381.3%
No.de Arboles Adultos totales	118	183	106	407

Existencias Volumétricas. (Empleando un coeficiente mórfico de 0.65 para pino, y de 0.90 para encino, esto último debido a las ramificaciones del género Quercus).

	Pino	Encino
Diámetro Nor. Prom. (cm)	48.36	33.20
Altura Prom. (m)	29.49	15.93
Vol. Árbol tipo (m3)	3.52	1.24
Vol. en m3/ha	327.4	104.26

Incremento en Volumen de Pino

El incremento diamétrico anual promedio es de 0.492

El incremento volumétrico del árbol tipo por cada cm de diámetro normal es de 0.105 m3.

El incremento anual en volumen del árbol tipo es de 0.052 m3.

Por lo tanto el incremento anual en volumen/ha para el pino es de 4.8 m3/ha.

Area Basal

El área basal promedio de pino-encino (utilizando el Relascopio de Bitterlich) fue de 24.4 m2 en promedio considerando solo los últimos 6 sitios.

Promedio de árboles/sitio 18.5
Arboles adultos/ha 185

Densidad por género

	Pino	Encino	Otras Latifoliadas
Totales	205	185	17
Por ha	93	84	7
%	50.36	45.45	4.20
D.N. (cm)	48.36	33.2	
Altura (m)	29.49	15.93	
Regeneración	829/ha	386/ha	

Estado Fitosanitario

Los primeros 16 sitios arrojaron los siguientes porcentajes en lo relativo a estado fitosanitario:

Bueno 67.0%
Regular 15.9%
Malo 7.9%
Despuntado 4.4%
Muertos en pie 4.8%

En los últimos 6 sitios se obtuvieron los siguientes datos:

Sanos 61.40%
Plantas parásitas 27.00%
Bifurcados en la base 6.25%
Ocoteados 3.27%
Despuntados 2.00%

Estudio de Mercado

En la investigación de mercado, mismo que fue aplicado para todos los productos que se obtienen dentro de la comunidad, (agrícola, pecuario , forestal) se obtuvo el siguiente resultado

Estudio de Mercado

- Prácticamente todos los comuneros producen los mismos bienes, bajo un proceso similar.
- En el proceso productivo participan todas los miembros de la familia, principalmente padre e hijos.
- L a comunidad tiene una apertura mercantil prácticamente nula, y la finalidad de cada tipo de los productos es la misma para cada productor.
  - —Productos Agrícolas: autoconsumo
  - —Productos Pecuarios: fuerza de tracción, previsión y autoconsumo
  - —Productos forestales: construcción y venta

Productos Agrícolas

a. Proceso productivo

- Barbecho del terreno con yunta. Esta actividad se puede realizar durante el período de Noviembre a Marzo del siguiente año.
- Bordeo del terreno con yunta (Cuando el terreno se encuentra en una ladera muy inclinada, solo se hace el barbecho). Esta actividad se puede realizar durante el período de Noviembre a Marzo del siguiente año.
- Siembra. La siembra se realiza durante los meses de Abril y Mayo, utilizando semilla del ciclo anterior, y de variedades criollas. En promedio, se utilizan 15 a 20 kg. de semilla por hectárea, cuyo único tratamiento consiste en ser guardada en su lugar fresco y seco.
- Deshierbe, se realiza pasados 25 a 30 días desde la siembra, siempre de manera manual.
- Fertilización, se realiza de manera simultánea con el deshierbe. Cabe señalar que esta actividad es la única

que representa un desembolso por parte de productos. Se utilizan cuatro bultos de sulfato de amonio mezclados con un bulto 18-46-00 por hectárea. En caso de no conseguir el 18-46-00, se utiliza únicamente el sulfato de amonio.

- Cosecha. La cosecha se realiza en los meses de Noviembre a Diciembre. En promedio se obtiene una tonelada de maíz o menos por hectárea.

b. Costos de Producción.

El único costo en que se incurre durante la producción del maíz de temporal, es la fertilización.

Hay dos formas de fertilizar el terreno; con abono orgánico o bien con fertilizantes químicos. En el primer caso, se pueden comprar bultos de estiércol en la Comunidad a un costo de 55 pesos por bulto, y se utilizan 5 bultos por hectárea, lo que da un costo de 275 pesos por hectárea, Una variante (menos efectiva) es meter a los animales de la yunta al terreno de labor, y que lo abonen directamente.

En el segundo caso, el costo del fertilizante está compuesto por el costo del insumo en el almacén, y por el costo de transporte del mismo a la Comunidad.

El fertilizante se compra en los valle (Oaxaca y Nochixtlán) a un precio de $50 a $55 por bulto de Sulfato de Amonio y de $135 por bulto de 18-46-00. El costo de transporte es de tres pesos por bulto.

De lo anterior, se desprende que el costo de fertilización por hectárea se integra como sigue:

Componente	Costo Unitario($)	Unidades	Costo Total($)
Sulfato de Amonio	55.00	4	220.00
18-46-00	135.00	1	135.00
Transporte	3.00	5	15.00
Total			370.00

c. Financiamiento

Para la producción de maíz, no se ha solicitado créditos a ninguna institución. El único medio para financiar la producción de maíz, es a través de elaborar y comercializar productos del bosque.

d.- Apoyos Externos a la Producción

No se otorgan subsidios a la producción. Sin embargo en forma de apoyo directo se reciben recursos de PROCAMPO; el problema es que son canalizados demasiado tarde como para destinarlos a la producción.

e.- Problemas de Producción

Los principales problemas que los comuneros enfrentan en la producción son:

f.- Destino de la Producción

- Grano. El grano que se obtiene, se dedica el autoconsumo (principalmente elaboración de tortilla), apartando tan solo unos 15 a 20 kilos para ser utilizados como semilla en el próximo ciclo. Solo cuando la familia es pequeña o recién formada, cabe la posibilidad de vender alguna parte, pero es muy raro encontrar este caso.
- Zacate. El zacate o rastrojo se almacena en cobertizos para proveer de alimento a los animales de la yunta.

Productos Pecuarios.

Destino de la Producción.

- Cuando las cabras alcanzan una edad de 2 años, pueden ser comercializadas. Sin embargo, esto no se hace a menos que se tenga alguna necesidad (enfermedad, urgencia de fertilizantes). En general, la producción no se destina al autoconsumo. La comercialización de las cabras se hace en la comunidad, a la que acude un mayorista proveniente de Noxhixtlán, quien adquiere el producto a $60 por cabeza, que son pagados de contado.

Productos Forestales

a.- Tablas, Tablones y Polines

Los principales productos que se extraen del bosque son tablas, tablones y polines, que se elaboran utilizando en forma manual la motosierra. El destino de los mismos es la construcción de viviendas para las productores; además la comercialización.

b.- Carbón

Hace algunos años, el carbón era una actividad primordial en la Comunidad, dada la existencia de un convenio para exportación del mismo a Alemania. Sin embargo, problemas de carácter organizativo derivaron en el fin del convenio, y ahora el carbón solo se elabora por pocas personas, y su destino es el mercado local.

La especie que se utiliza es el encino. Cinco árboles rinden 8 bolsas de 18 a 20 kilos cada una, cuyo destino es la comercialización a acopiadores que acuden a la Comunidad y pagan un precio de cinco pesos por bulto.

Propuesta Asociada de Desarrollo Sustentable Comunitario

La propuesta resultante del diagnostico condujo a proponer un modelo de Desarrollo Sostenible Comunitario (DSC) para la Comunidad bajo estudio. Esta propuesta implica la adopción de los siguientes principios generales:

1 Que cada uno de los miembros de la Comunidad El Oro se constituyan en el motor y gestores de su propio desarrollo.
2. Crear las condiciones sociales y de organización que permitan analizar una serie de proyectos productivos, de protección, fomento y restauración de sus recursos naturales coque resulten viables y pertinentes desde un punto de vista técnico, económico, social, político, cultural y ecológico.
3. Que cada uno de los miembros de la Comunidad del Oro se constituyan en verdaderos administradores de sus recursos naturales, entendiendo que estos constituyen el único medio que tienen a su alcance para superar los graves niveles de pobreza que padecen.
4. Que es mediante la suma de esfuerzos individuales, como se puede avanzar en el mejoramiento integral de las condiciones de vida de la Comunidad.
5. Que a la par de sus satisfactores materiales provenientes de sus recursos naturales aún existentes, es posible conciliar los principios de utilización de estos recursos con su conservación, de tal manera que se garantice su permanencia para la generaciones futuras.

Proyectos

1. Establecimiento de huertos familiares de hortalizas y verduras orgánicas que por un lado contribuyan al ahorro familiar, y por el otro utilicen mano de obra proveniente de mujeres y niños.
2. Establecimiento de arboles frutales intercalados con los cultivos agrícolas en terrenos con pendientes mayores de 20%, especialmente durazno, manzano y tejocote.
3. Establecimiento de cercos vivos con nopales y agaves que a la vez que delimitan las parcelas de cultivos agrícolas, evitan o disminuyen los riesgos de erosión del suelo.
4. Establecimiento de especies fijadoras de Nitrógeno como la Acacia, de manera intercalada con los cultivos agrícolas.
5. Establecimiento de un programa de recuperación de áreas erosionadas con cárcavas, que incluya la introducción de diques de troncos, ramas y piedras, suavizar los taludes y plantar arbustos e introducir pastos.
6. Establecimiento de un programa de transformación de productos pecuarios, que permita la elaboración de carnes no perecederas, así como el aprovechamiento integral de los productos secundarios, tales como víscera y pieles.
7. Establecimiento de un programa de validación tecnológica sobre suplementos alimenticios para el ganado en el último tercio de la gestación y en los dos primeros meses siguientes al parto.
8. Implementar alternativas tecnológicas de bajo costo y uso intensivo de mano de obra, para favorecer el incremento de nutrientes al suelo, tales como: aplicación de abono orgánicos, reforestación con especies de arboles nativos, construcción de represas y bordos.
9. Establecimiento de sistemas de captación y almacenamiento de agua de lluvia.
10. Implementar un programa de mejoramiento de la vivienda utilizando los materiales provenientes de su recurso forestal.
11. Promoción de un sistema de ahorro comunitario, mediante la implementación de cajas de ahorro y bancos comunitarios.
12. Establecimiento de un sistema de crédito que apoye la adquisición de maquinaria y equipo mediano, que permita aprovechar integralmente los arboles. Especialmente la adquisición de pequeñas sierras cintas para aprovechar trocería de cortas dimensiones y fabricar cajas de empaque. Esto puede hacerse a nivel de talleres familiares o comunitarios, incluyendo por supuesto el establecimiento de las carpinterías.
13. Establecimiento de una Empresa Cooperativa Comunitaria que produzca, acopie y comercialice el carbón buscando competitividad en el mercado nacional e internacional.
14. Establecimiento de una Empresa Cooperativa Comunitaria que se responsabilice del manejo forestal de las áreas comerciales forestales de la comunidad.
15. Establecimiento de por lo menos tres viveros no permanentes para producir las especies locales de pino y encino.
16. Implementar un programa de protección de manantiales y cauces primarios y secundarios, mediante el establecimiento de fajas protectoras.
17. Identificación de otros proyectos productivos tales como producción de miel, peces, y hongos comestibles.
18. Establecimiento de un programa agroinductrial, que permita el manejo post cosecha de frutas y de hortalizas, que evite las pérdidas y agregue valor mediante el envasado, la deshidratación y el procesamiento de conservas y de mermeladas.
19. Establecimiento de un programa de talleres de costura, nutrición y herbolaria en donde las mujeres de la comunidad sean las principales actoras.
20. Establecimiento de un programa de granjas familiares o comunitarias para la cría de animales domésticos principalmente, el pollo para complementar las economías precarias mediante la venta de excedentes.
21. Establecimiento de huertos familiares de hortalizas y verduras orgánicas para el autoconsumo.
22. Establecimiento de un programa de mejoramiento de los servicios sanitarios que incluya el reciclaje de los deshechos orgánicos humanos implementando aboneras secas que frenen la defecación al aire libre y genere abono orgánico.
23. Implementar un programa de mejoramiento de la calidad del agua.
24. Implementar un programa de capacitación agrícola, pecuario, forestal y de salud.
25. Establecimiento de un programa de creación de espacios de vinculación comunitaria y recreación infantil como un centro comunitario que permita el acercamiento, la interacción y la comunicación entre los miembros de la comunidad.
26. Establecimiento de un programa de actividades recreativas, artísticas, deportivas y cutlturales para la comunidad.

Bajo esta óptica se está consciente que el proceso que se propone iniciar en la comunidad de "El Oro", será uno tal que sea gradual, y que parte de una realidad y cuyo principio y fin es el hombre mismo en un reencuentro con su entorno físico, que él mismo debe de ser capaz de utilizar, proteger y restaurar.

Conclusiones

—Cualquier tipo de muestreo forestal o evaluación de los recursos forestales no podrá por si solo arrojar los resultados reales esperados por muy buena que sea la técnica empleada o por emplear.

—Es necesario incluir a los miembros de la comunidad bajo estudio o evaluación como parte integral de cualquier actividad.

—La evaluación participativa demuestra ser una magnífica herramienta en cualquier actividad de evaluación de recursos naturales.

—En el desarrollo de cualquier técnica de muestreo es necesario asomarse mas de cerca de las actividades restantes de la o las comunidades que quedan enclavadas dentro de las áreas motivo de la evaluación de recursos.

Bibliografía Consultada

1. Elizabeth Odour – Noah; et al. 1992. Implementing PARA: A Handbook to Facilitate Participatory Rural Appraisal. Program for International Development. Clark University.
2. Gonzalez Alfonso y Zazueta Aaron, 1993. El Proceso de Evaluación participativa: Una Propuesta Metodológica. Programa de Manejo Participativo de Recursos Naturales. El Instituto de Recursos Mundiales y A.C. Grupo de Estudios Ambientales. Primera Edición, WRI, GEA. A.C. Cuaderno # 1.
3. Selener Daniel; Eudora Nelly; Carbajal Jose. 1997. Guía Práctica para el Sondeo Rural Participativo. Instituto Internacional de Reconstrucción Rural. Quito, Ecuador.
4. Valenzuela Ruíz R.; Serrano Gálvez E. 1995. Diagnóstico para el Desarrollo Sostenible Comunitario de la Comunidad "El Oro", Municipio de Santo Domingo Nuxaa, Oaxaca. División de Ciencias Forestales, Universidad Autónoma Chapingo; Asociación Mexicana de Transformación Rural y Urbana (AMEXTRA).

Forest Cover and Natural Volatile Organic Compound Emissions in North America[1]

Christopher D. Geron[2]

Abstract—Forest inventory data is important in deriving emission estimates of biogenic volatile organic compound (BVOC) at hourly to annual temporal and tens of square meter to global spatial resolutions. We discuss methods used to adapt remotely sensed data and forest inventories to BVOC emission estimation. Databases employed include USDA Forest Service Forest Inventory and Analysis (FIA) and Canadian Ministry of Forests (British Columbia) data, which we use to estimate canopy coverage at species level resolution. The plot level data is also used to speciate 1.1 kilometer gridded remotely sensed classifications of vegetation cover, foliar mass, and leaf area. Developing ecosystem-level emission rates for vegetation categories in existing remotely sensed databases is also discussed. We compare resulting emission and canopy cover estimates from the different approaches at county levels. Due to assumptions made of the composition of the forest cover-types, emission estimates can vary by more than an order of magnitude for the different approaches. We discuss techniques to combine temporal and biophysical measures from remote sensing data with vegetation species information from the survey data. Potential improvements to forest inventories for these and similar applications relating to air pollution exposure are discussed.

Tropospheric or low level ozone (O_3) is a major constituent of smog and is responsible for billions of dollars in crop and forest loss and respiratory health effects each year. To aid in understanding and controlling this problem, the North American Research Strategy for Tropospheric Ozone (NARSTO) mandates that emission models and inventories of tropospheric ozone precursors including volatile organic compounds (VOC), the oxides of nitrogen (NO_X), and carbon monoxide (CO) be developed for Canada, Mexico, and the U.S.A. Sources include mobile (e.g. automobiles, aircraft), point (e.g. fossil fuel powered utility plants), area (agricultural or small dispersed industrial sources such as refinishing, refueling, and printing operations), and biogenic or natural sources. The largest source of VOC in North America is natural or biogenic in origin. In the U.S. biogenic VOC (BVOC) emissions exceed those from all other sources combined. Emissions from forests are estimated to account for at least 90% of these BVOC emissions, with crops and rangeland vegetation accounting for the balance (Lamb et al. 1993). Annual estimates of anthropogenic VOC for the U.S. are approximately 20 tg yr^{-1}, while corresponding estimates of BVOC are approximately 40 tg yr^{-1}. Furthermore, BVOC tend to be more reactive than most anthropogenic VOC and are therefore more important on a per molecule basis in O_3 production. Here I present a brief overview on the use of forest inventory and remote sensing classifications for use in estimating BVOC emissions in North America.

Methods

The landcover characteristics data used to estimate BVOC emissions in North America are constructed from several independent databases. Forest density in the United States (fraction of forest cover per 1.1 km grid cell) is taken from the database of Zhu and Evans (1994). Since it is based on optical measurements from satellite at two different (30 m and 1.1 km) scales, this dataset provides estimates of forest canopy fractions for areas usually not covered by other sources, such as small woodlots, riparian zones, forested urban regions, and the semi-arid western woodlands with less dense canopy cover. The percentage of tree species present within each grid cell is determined from the forest survey data described in Geron et al. (1994). Additional data for forests in the eleven westernmost conterminous United States and Alaska, including those for the National Forests and Parks, have also been compiled and added to this data. This information yields crown cover percentages by species level (compared to genus level coverage of Geron et al. 1994) to be consistent with species level emission data discussed later in this paper. Desert, rangeland, grassland, shrubland, and agricultural areas by crop type, are allocated to the remaining portions of the grid cells from the Agricultural Census and the North American Land Cover Classification (NALCC). Growing season peak foliar biomass densities are derived from the methods of Geron et al. (1994). However, for seasonal simulations, biomass density is adjusted by multiplying the peak density by the ratio of NDVI for the time and domain in question to NDVI for peak density. Similar procedures are used to construct vegetation cover databases from 1.1 km and Canadian forest inventory data, although at this point no corresponding remotely sensed forest density data exists for Canada. Therefore, total forest area is restricted to the forest area estimated from the Canadian forest inventory and the NALCC. Mexican land and vegetation cover is also described using the NALCC. Efforts are also underway to assess species composition for Mexican forests. Emission factors are formulated on a leaf biomass basis for individual tree species in mg-carbon g^{-1} (foliage dry weight) hr^{-1} and on an areal basis for mixed vegetation categories (e.g. western conifers) in mg-carbon m^{-2} (land surface area) hr^{-1}. In-depth detail on these approaches can be found in Geron et al. (1994), Guenther (1997), Guenther et al. (1994), Guenther et al. (1995), and Kinnee et al. (1997).

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Results and Discussion

In the U.S. forest inventory database, there are currently over 450,000 plots (see approximate locations in Fig. 1) and more than 4.5 million tree records. Although there are over 320 tree species in the FIA databases of the U.S., a large proportion of estimated BVOC emissions can be accounted for by relatively small number of species. This is illustrated in Table 1 where tree species of extensive range, abundance, and high emission factors dominate the relative BVOC emission potential, which is a function of these factors. In the eastern U.S., BVOC emissions are controlled by *Quercus, Populus, Pinus*, and *Picea* species, which account for an estimated 83% of hourly BVOC emissions under standard conditions of PAR = 1000 mmol m^{-2} s^{-1} (approximately half of full sunlight) and leaf temperature = 30°C. *Pinus, Picea, Pseudotsuga, Abies, Quercus,* and *Populus* species dominate BVOC emission potential (95%) in the Western U.S. (West of 102° Longitude). Less than 2 percent of the estimated forest canopy area is composed of species for which no current BVOC emission information exists. Areas with highest emissions are those with high components of conifers, (which are high monoterpene and methyl butenol emitters) Quercus (oaks), Picea (spruces) and Populus species (which are high isoprene emitters). Estimated geographical distribution of BVOC emissions in North America under standard conditions of PAR = 1000 mmol m^{-2} s^{-1} and leaf temperature = 30°C is illustrated in Figure 2. Due to current lack of forest inventory data for Mexican and most of Canadian forests in the landcover characteristics database, emission uncertainties in these areas are roughly an order of magnitude. Uncertainties in the U.S. are much lower (within ± 50% for isoprene ± 100% for other compounds), largely due to use of the detailed forest inventory.

Substituting the 1.1 km forest density data and the western U.S. forest inventory (used in the BEIS3 model) in place of the Biogenic Emissions Landuse Database (BELD) of Kinnee at al. (1997) used in BEIS2 (version 2 of the Biogenic Emission Inventory System) yields significant changes in many regions of the western United States. Forest genus classification in the BELD for the western U.S. was estimated by assigning fixed crown cover percentages to species listed in each cover type (Kinnee et al. 1997). In western Washington, Lamb et al. (In Prep.) found that this resulted

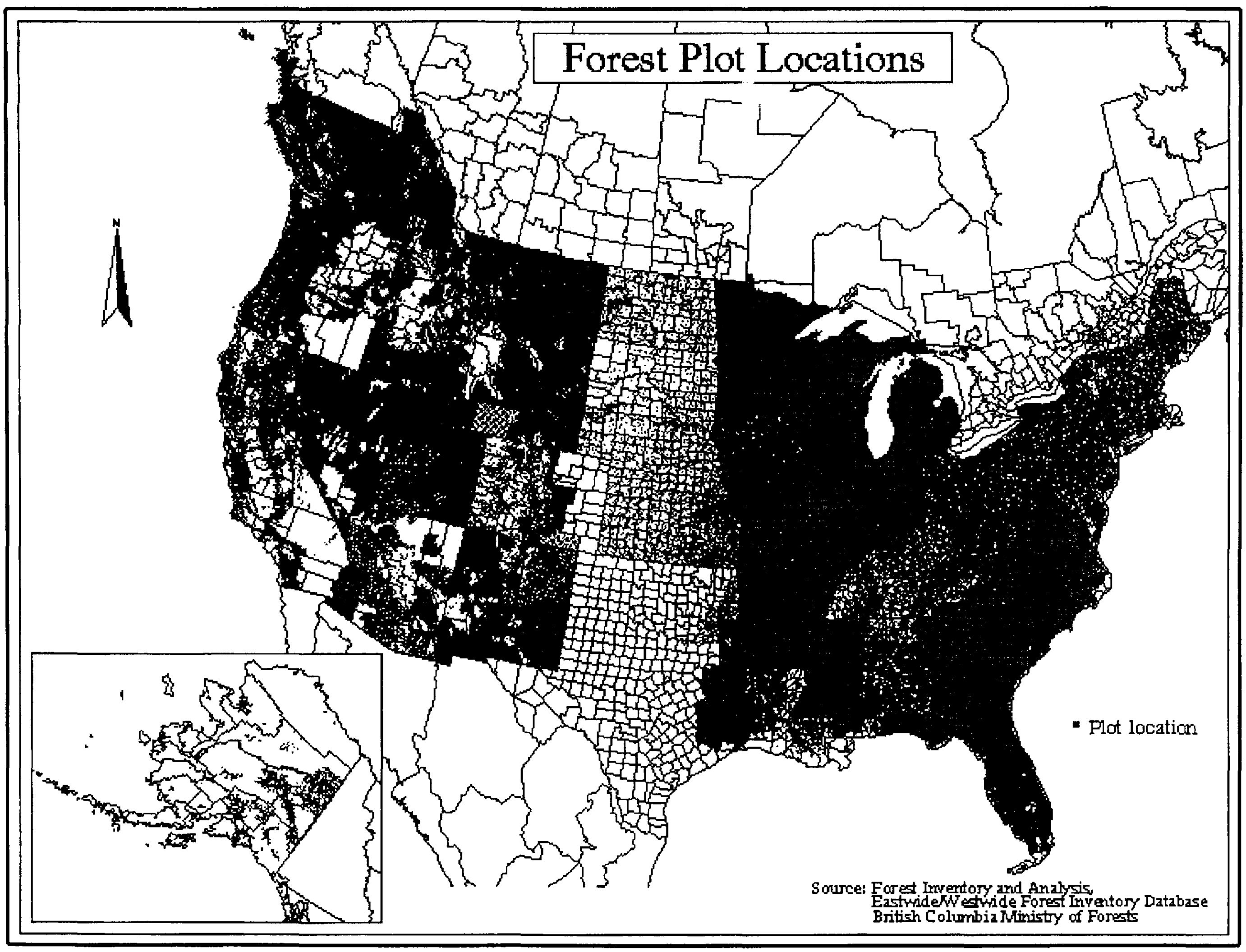

Figure 1.—Approximate locations of forest inventory survey plots compiled to date used to estimate BVOC emissions in North America.

Table 1.—Crown cover and emission potentials (under standard conditions) by forest tree genera and region within the U.S. Area is horizontal projected crown area in 10^6 hectares. %Crn is proportion of total crown area. REP is relative emission potential, which is equal to the product of the basal total BVOC emission rate, biomass density, crown area, and a canopy adjustment factor (to account for shading within the canopy) for each genus relative to the total REP for the region. Cum is cumulative REP for the region.

Eastern U.S.					Western U.S. (including Alaska)				
Genus	Area	%Crn	REP	Cum	Genus	Area	%Crn	REP	Cum
Quercus	32.1	0.248	0.499	0.499	Pinus	10.1	0.184	0.278	0.278
Populus	4.18	0.032	0.141	0.640	Picea	12.7	0.231	0.234	0.512
Pinus	20.4	0.158	0.094	0.733	Pseudotsuga	8.41	0.153	0.138	0.651
Picea	4.18	0.032	0.093	0.826	Abies	5.60	0.102	0.136	0.787
Liquidambar	3.78	0.029	0.059	0.886	Quercus	3.15	0.057	0.104	0.890
Abies	2.08	0.016	0.023	0.908	Populus	2.17	0.039	0.062	0.953
Acer	12.6	0.097	0.019	0.927	Tsuga	2.43	0.044	0.013	0.966
Nyssa	2.56	0.020	0.010	0.937	Juniperus	3.78	0.069	0.012	0.977
Thuja	1.31	0.010	0.009	0.946	Thuja	0.98	0.018	0.011	0.988
Carya	6.17	0.048	0.007	0.953	Alnus	1.32	0.024	0.003	0.991

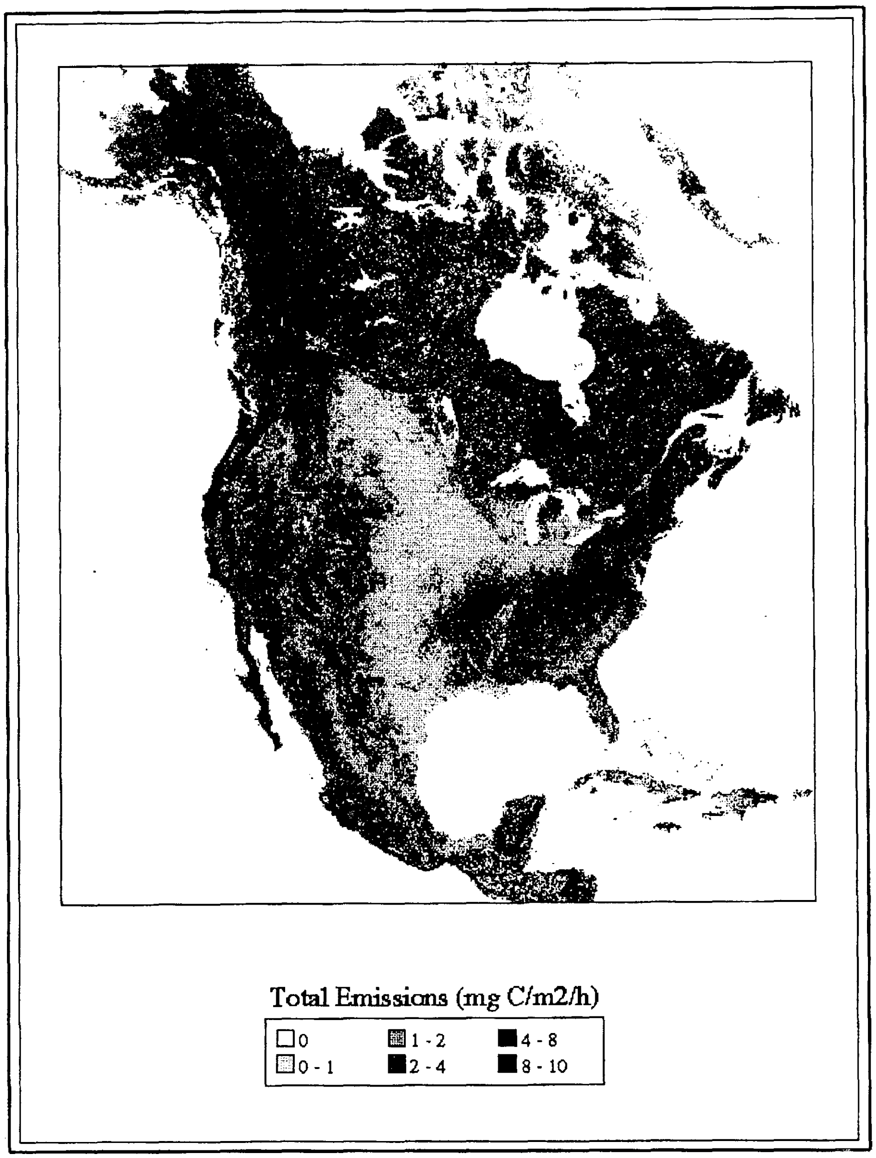

Figure 2.—Hourly estimated BVOC emissions from North American Landscape types under standard conditions of PAR=1000 mmol m^{-2} s^{-1} (approximately half of full sunlight) and leaf temperature= 30°C.

in isoprene emissions which were 5 to 10 times higher than measured mixed layer fluxes. The BEIS3 landcover data yielded isoprene emissions that were within a factor of two of the flux estimates, even though total canopy coverage for the state of Washington was only 8% less than that from BELD. Canopy coverage of high isoprene emitters in the BEIS3 (using the western U.S. forest inventory data) database was only 1-2% for the region on average. Conversely, BEIS3 isoprene estimates for other western regions may be considerably higher than that yielded by BELD. These include portions of California, Colorado, and Utah.

Forest density estimates in the agricultural midwestern states is also somewhat higher than that from the BELD, since the Zhu and Evans (1994) data yield estimates of tree cover on small woodlots, transportation and stream corridors, and other noncommercial forest lands. This may result in isoprene emissions being from 10 to 50% higher than BEIS2 emissions. Forest density, and therefore emissions, in the remainder of the eastern U.S. remains largely unchanged due to changes in the landuse databases, since the forest extent estimated from the Forest Density data is similar to that estimated from the forest inventory data compiled thus far.

Our current plot coverage of forest inventory data appears to be fairly thorough in terms of regional coverage of major forest types. However, coverage of commercially less valuable forest ecosystems can be sparse. For instance in the semi-arid forest scrubland of central Texas and Oklahoma, little forest survey data currently exists. This introduces considerable uncertainty (roughly an order of magnitude) in BVOC emission estimates for landscapes in this region. Vegetation coverage in desert-chapparral, riparian, and urban environments is also sometimes sparse or lacking. Using remotely sensed indices allows us to estimate greenness of vegetation coverage in these areas, but supporting plot level (ground based) measurements of species abundance and canopy characteristics would improve trace gas flux estimates from these systems considerably. This would also aid researchers in determining which vegetation species to examine for trace gas emissions.

Recommendations

Caution must be exercised when using generalized forest/landcover classes for estimating BVOC emissions. Since individual tree species within a forest ecotype can have drastically different BVOC emission factors (qualitatively and quantitatively), we recommend that forest inventory data be used to determine amount of crown cover by species within areas where these emissions may be important. However, current forest inventories often stress areas of commercial importance, and neglect areas where timber harvesting may not be economical or feasible. These areas are often very important for trace gas exchange, and include urban forests, wetland forests and riparian zones, and marginally productive (but extensive) semi-arid forests such as those in Central Oklahoma, Texas (see Fig. 1), much of Mexico and portions of Canada. Finally, most parameters relating to foliage amount must be estimated from attributes such as tree diameter, height, and commercial or wood volumetric indices of stocking. If measures of canopy closure from aerial photos (such as that included in the British Columbia inventory) or ground measurement of intercepted solar radiation could be associated with each forest inventory plot, then regional models and inventories of forest trace gas exchange would be greatly improved.

Acknowledgments

The authors wish to thank the USDA Forest Service FIA units for their assistance in obtaining and interpreting the Forest Inventory and Analysis Data. Richard Woods of the British Columbia Ministry of Forest Resources was especially helpful in compiling and interpreting the British Columbia Forest Inventory data. Cliff Stanley and Ellen Kinnee of DynTel Inc. was provided invaluable database management in this effort. Pat Meredith provided expert editorial support.

Literature Cited

Geron, C. D., A. B. Guenther, and T. E. Pierce, An improved model for estimating emissions of volatile organic compounds from forests in the eastern United States. J. Geophys. Res. 99, 12,773-12,791, 1994.

Guenther, A.B., C. N. Hewitt, D. Erickson, R. Fall, C. D. Geron, T. Graedel, P. Harley, L. Klinger, M. Lerdau, W. A. McKay, T. E. Pierce, B. Scholes, R. Steinbrecher, R. Tallamraju, J. Taylor, and P. R. Zimmerman, A global model of natural volatile organic compound emissions. J. Geophys. Res. 100:8873-8892, 1995.

Guenther, A.B., P.R. Zimmerman, and M. Wildermuth, Biogenic volatile organic compound emission rate estimates for U.S. woodland landscapes. Atmos. Environ. 28, 1197-1210, 1994.

Lamb, B., D. Gay, H. Westberg, and T. Pierce, A biogenic hydrocarbon emission inventory for the U.S. using a simple forest canopy model. Atmos. Environ. 27A: 1673-1690, 1993.

USEPA, National Air Pollutant Emission Trends, 1900-1994, Office of Air Quality Planning and Standards, EPA-454/R-95-011, Research Triangle Park, NC 27711, October, 1995.

Zhu, Z. and D.L. Evans, U.S. Forest types and predicted percent forest cover from AVHRR data. Photogram. Eng. and Rem. Sens. 60:525-531, 1994.

Some Methodological Approaches to Estimate and Monitor Carbon Mitigation in the Forestry Sector[1]

Ben H.J. de Jong[2]

Abstract—Forestry and agroforestry are promising land-use alternatives for reducing the increasing levels of global atmospheric carbon. To understand the role of forestry and agroforestry systems in the carbon cycle it is necessary to quantify both the net annual carbon fluxes and the total carbon content of the systems. The effect of a forestry project has to be compared with a "business as usual" baseline.

There exist various methodological approaches to estimate the impact on carbon fluxes of forestry and agroforestry. Known problems of baseline assumptions, carbon flux reporting, and monitoring and verification are exemplified with field collected data and recent experiences of the Scolel Té Pilot Project for Community Forestry and Carbon Sequestration in Chiapas, Mexico (Scolel Té 1998). The "Greenhouse Gas Bubble (GGB)" concept as an alternative instrument for carbon offset trading and reporting is discussed.

The third Conference of the Parties to the United Nations Framework Convention on Climate Change (UN-FCCC), held in December 1997 in Kyoto, Japan describe two market-based mechanisms that will allow countries to trade in greenhouse gas emission (GHG) reductions:

1. Between two Annex 1 countries (countries with binding emission limits), known as Joint Implementation (JI), and
2. Between an Annex 1 country and a non-Annex 1 country (countries with no binding emission limits, mainly developing countries), known as Clean Development Mechanism (CDM).

The existence of carbon offsets in low-cost countries and demand in obligated high-cost countries may create a market for the buying and selling of GHG offsets. Under a possible future carbon offset trading program, countries would be most likely to pay for such reductions in another country where the cost for reducing emissions is lower. Although forestry measures are not yet specifically included within the current articles relating to the CDM[3], it seems likely that provisions for forestry will be included at some stage, given the significance of developing country forests within the global carbon cycle. Several studies have indicated that the global potential for enhancing carbon (C) storage by forestry and agroforestry may be as much as 60-90 x 10^9 tons of C (tC, Dixon et al. 1991; Winjum et al. 1992; Dixon et al. 1993; Trexler and Haugen 1994; Brown et al. 1995). Forestry and land-use mitigation measures can serve other environmental, economic, and social interest simultaneously, and may offer some of the most cost-effective ways to climate change mitigation. GHG offset projects in the land use and forestry sector can particularly be attractive if they can be tied to local social and economic goals (Trexler 1993).

In Mexico, the forestry sector is a key element in any national greenhouse emissions mitigation plan. Currently, land use / land cover (LU/LC) change is the second source of C emissions to the atmosphere, accounting for an estimated 35% of total emissions. However, the forestry sector has the potential to convert Mexico from a net carbon source to a carbon sink, if proper actions are taken (Masera et al. 1997).

Using forests as a means of mitigating climate change could be achieved both by conserving existing stocks of C in forests that are currently threatened, and by creating new stocks in growing trees.

In forestry, as with other types of activities, the net effect of a project is the difference between the project scenario and a baseline, reference, or "business-as-usual" case (Fig. 1).

Calculating emission reductions associated with a project scenario present certain difficulties in land use because carbon fluxes from vegetation and soil are complex, bi-directional and continuous. A number of methodological and policy questions need to be addressed before forestry carbon offset trading can provide reliable, verifiable emission reductions (Tipper & De Jong 1998). This paper discusses some of the methodological approaches related to the quantification of carbon sequestration in forestry projects:

- Establishment of baseline assumptions
- Accounting procedures to quantify the effect of forestry projects on carbon budgets
- Monitoring and verification of project performance

The following sections illustrate the effect of the different approaches applied to address these problems. Where necessary, particular reference is made to the Scolel Té Pilot Project for Community Forestry and Carbon Sequestration in Chiapas, Mexico (Scolel Té 1998) and the results of an assessment of the cost of a large-scale forestry program for CO_2 sequestration (Tipper et al. 1998). The "Greenhouse Gas Bubble (GGB)" concept as an alternative instrument for carbon offset trading and reporting in the forestry sector is discussed.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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[3] There is some debate on the interpretation of the Kyoto protocol relating to forestry. One particular discussion is whether forests are specifically excluded from the CDM.

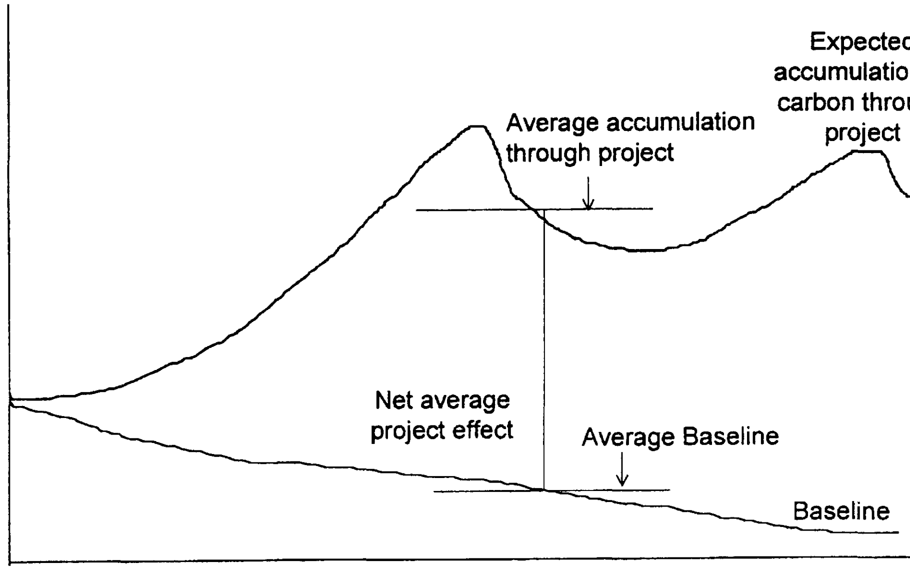


Figure 1.—Hypothetical effect of a C mitigation project, compared to a "business-as-usual" baseline.

Baseline Assumptions

The definition of a suitable baseline or reference case involves the elaboration of a hypothetical or counterfactual scenario. Differences in the order of a single percentage point in the assumed rate of loss of current carbon storage in the baseline assumption can halve or double the perceived net effect of a given intervention over the course of a 60 year time frame. As such, the interests at stake are considerable. Since both the buyer and the seller of a carbon offset have interest in a high net effect of a project, they may exaggerate the baseline assumption, unless some form of regulatory mechanism is used to counterbalance these interests.

The main problem to establish a baseline within the LU/LC sector relates to the prediction of future changes. This is particularly difficult, because the proximal causes and driving forces behind land-use decisions are diverse, interrelated, and often discontinuous. At regional levels, factors such as demographic changes and government policies often have significant effects. At specific locations, uncertainties about land ownership, social conflicts, the impact of development projects, crop failure and fires can cause unpredictable changes in land-use decisions among farmers (De Jong et al. 1998). Methods used are either extrapolations of past rates of change of carbon stocks into the future (trend-based models), or process-based models that attempt to simulate the demographic and economic processes driving land-use change (Brown et al. 1989; Faeth et al. 1994; Fearnside and Malheiros-Guimaraes 1996; De Jong et al. 1998). One problem with trend-based predictions is the influence of the geographic domain used in the assessment—if the domain is restricted to areas where deforestation has been rapid in the past, then the baseline loss of carbon will appear high. Where records show considerable variations in the rate of LU/LC change over time and/or space, it is not obvious which scenario will be most likely in the future (Box 1).

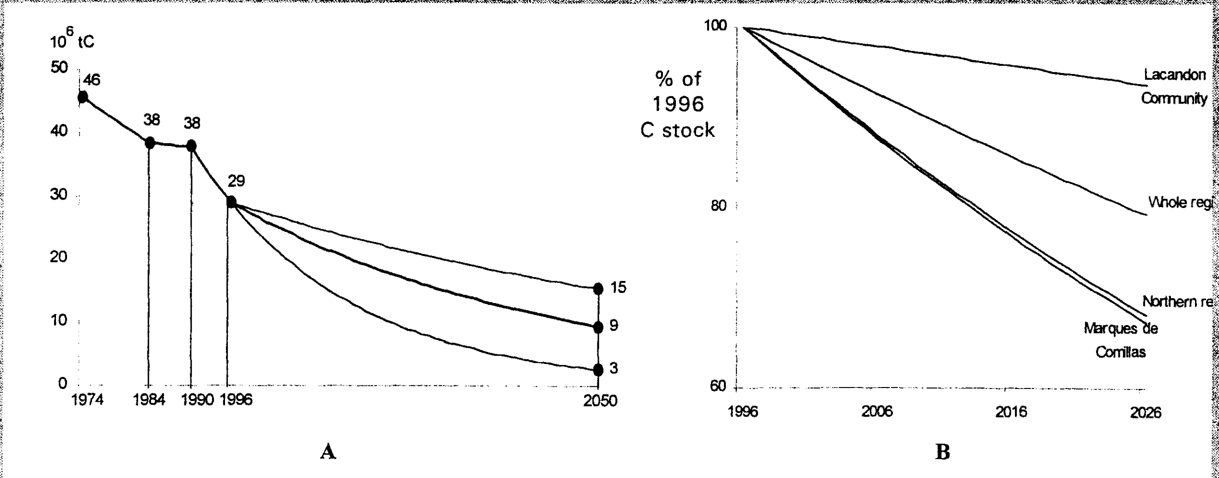
Another approach is to apply process-based models. Although these models may be capable of assessing the relative vulnerability of different categories of vegetation, they generally require large investments in data collection to make credible representations of land-use change processes. In densely populated areas where various factors influence local and regional land-use decisions, if will be difficult to define which factor is the main driving force behind the LU/LC change dynamics. Rudel and Roper (1997) tested various factors that are thought to contribute to deforestation in the tropics for 68 tropical countries. The factors they tested are, among others, population pressure, economic growth, and national land-use policies. Based on their results, they distinguish two types of deforestation processes:

1. a frontier model, characterized by the opening up of new areas, and
2. an immiserization model, characterized by a continuous fragmentation and deforestation in densely populated areas, dominated by resource-poor farmers.

Both processes occur simultaneously in Chiapas. In the densely populated Highlands of Chiapas, the immiserization process dominates, while the frontier model prevails in the nearby tropical lowland forests of the Selva Lacandona. Thus, land-use policies may have a positive effect in one region, but can create negative impacts in the other region. In fact, during the 70's the Mexican government promoted the frontier model in the Selva Lacandona region at least partly to reduce the immiserization process in densely populated areas. This makes the development of a general process-based land-use model complex and very sensitive to variations between regions. As such, it is most likely that reliable process-based models that explain land-use decision-making will first be developed on a regional scale.

On a project scale, baseline assumptions can also cause major problems in relation to credibility and probability. For example, forests not facing any threat cannot claim C offset (Trexler 1993). However, if forests do present threats, how to guarantee that the exploitative action that threatens the forest is not simply displaced to another area?

Box 1



Historical and predicted carbon storage, indicating variations in the rate of C loss over time (A) and space (B). Data are based on field collected C-densities, interpretation of satellite images and historical LU/LC maps.

Figure A is based on the interpretation of satellite images of 1974, 1984, 1990 (MSS), and 1996 (TM) of an area of approximately 300,000 ha in the highlands of Chiapas. For each major LU/LC class C-densities were measured in 39 field plots. To project possible C loss in the future, the C-density of the completely deforested LU/LC classes (agriculture, pasture and settlements) were assumed to have lost all the vulnerable C stock, thus their C density was set to 0. From the C densities of all other classes the average C density of the completely deforested LU/LC classes was subtracted to estimate the C pools that were prone to be lost through LU/LC change (So called vulnerable C). The C density of each LU/LC class was incorporated in the LU/LC statistics to calculate the decrease in C stock during the periods 1974-1984, 1984-1990, 1990-1996, and 1974-1996. The highest, lowest and average decrease in C-stock, expressed in % per year was used to predict future trends in vulnerable carbon storage. Depending on the rate of C storage depletion, in 2050 the expected C stock fluctuates between 3 and 15 x 10^6 tC.

Figure B is based on the comparison of LU/LC between an historical vegetation map (which was elaborated through interpretation of aerial photographs of the 1970s) and the interpretation of a 1996 TM satellite image. C densities of the major LU/LC classes were collected in 29 field plots. C densities and LU/LC statistics were then used to derive estimates of change in carbon stocks, as expressed in % per year, for the whole region and separately for the three sub-regions, using natural or political boundaries as the separation criteria. The Northern region and Marques de Comillas present the highest depletion in carbon stock, whereas the carbon stock in the Lacandon Community remains almost unchanged. The first two regions are subject to government induced settlement programs, whereas the Lacandon Community, which contains the Montes Azules Biosphere Reserve, is subject to government conservation efforts. Total C stock in The Nothern Region and Marques de Comillas would decrease with about 35% in the next 30 years, while the stock in the Lacandon Community would reduce with about 5% in the same period. C stock for the whole region would decrease with about 20%.

Carbon Fluxes in Managed Systems

Various carbon accounting procedures exist to explain the system C dynamics, relative to a baseline (Tipper and De Jong 1998). All accounting procedures are somehow based on flux models that try to estimate temporal changes in carbon pools and fluxes between pools (Box 2).

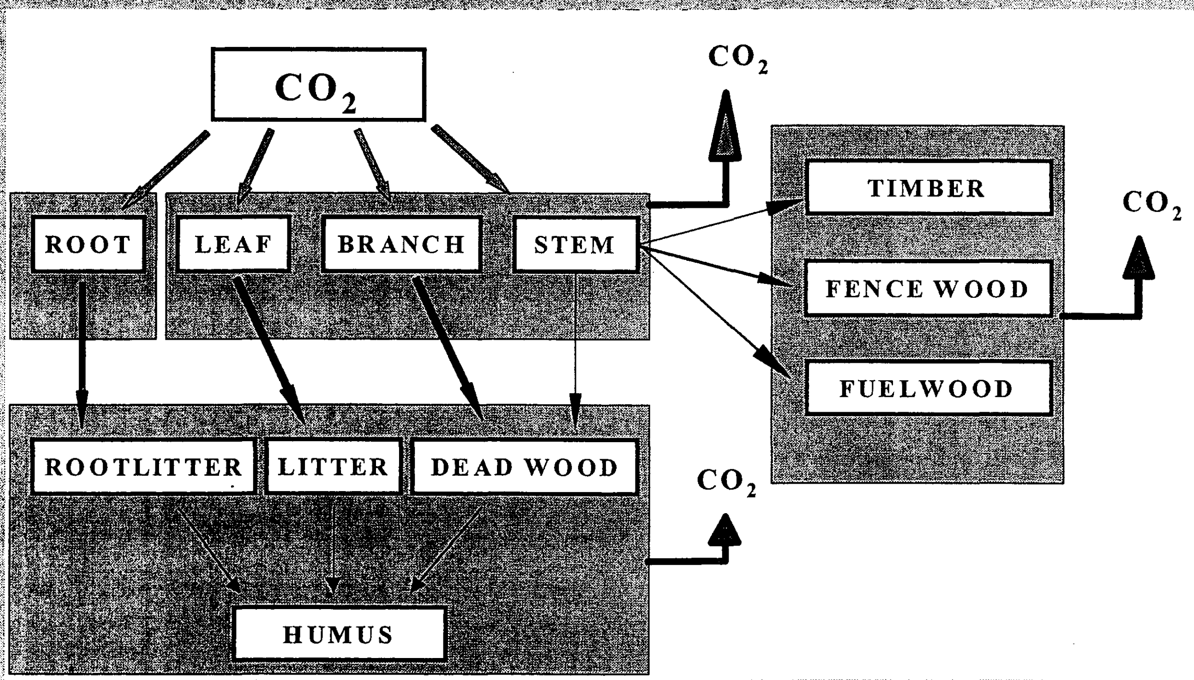
The results of the flux estimation can be reported as:

- Yearly fluxes between the vegetation and the atmosphere (expressed in tC/year) or the sum of the yearly fluxes at a given cut-off date (expressed in tC, Nabuurs and Mohren 1993, 1995; De Jong et al. 1995,1998).
- Long-term average increase in the carbon stock of a managed stand relative to a hypothetical baseline (expressed in tC, Nabuurs and Mohren 1995; De Jong et al. 1998).
- Cumulative carbon storage (expressed in tC.years, Tipper and De Jong 1998).

Yearly Fluxes

This method is conceptually the simplest way to provide carbon offsets to reduce emissions. In this procedure changes in pools and fluxes between pools are calculated and presented on a yearly basis. One of the main shortcomings of this approach is related to the fact that carbon fluxes in

Box 2



Schematic diagram of common C-flux models, applied in forestry.

The C flux models CO2FIX, developed by Nabuurs and Mohren (1993) and GORCAM, developed by Schlamadinger and Marland (1996) derive carbon accumulation and storage by a tree plantation over the course of a number of rotations, based on an "expected growth" curve. Adjustments can be made for product lifetime. Soil C fluxes generally are simulated by a litter, humus and deadwood decomposition fraction and a litter humification factor. Tree mortality, leaf, branch and root turnover rates, and harvesting can change the living biomass, while decomposition, humification and burning are factors that can affect dead biomass and product pools. In GORCAM, part of the medium and long lived products can be assigned to energy, when a fuel substitution factor is used (Schlamadinger and Marland, 1996).

forestry ecosystems are irregular and bi-directional. In the simplest case, a plantation system generally shows a slow uptake of carbon during the growing cycle and high emissions shortly after harvesting (Fig. 2). If the offset trading assign credits on the yearly flux basis, what to do with the negative flux (emission) after harvesting?

An economic assessment of the effect of a forestry project based on yearly fluxes requires the summation of the flows over a specific period of time, to derive a total expressed in tC. In the case of conservation of forest reserves, this is rather straightforward, as this alternative prevents a one-off release of carbon. However, when the management scheme includes periodic harvesting of (part of) the stand, the total C accumulated will depend largely on the relationship between rotation length and the time horizon set as the project limit. The buyer of the offset credits will prefer to set the time horizon just before harvesting, whereas the carbon offset will be at least partly lost when harvesting takes place.

Long-Term Average Increase

Many projects in the pilot phase of the UN-FCCC program of Activities Implemented Jointly are assessed on the basis of the long-term average increase in the carbon stocks relative to the baseline, expressed in tC (Fig. 2, Tipper and De Jong 1998). This approach assumes a long-term maintenance of the alternative system, calculates the yearly fluxes related to C dynamics and estimates the average effect of the system on a long time horizon (typically 100-150 years).

Some of the major shortcomings of this accounting system is that it is not compatible with national level emission reporting so that additional inventory work would be required to reconcile the reporting systems and that the performance of the system over such long time horizons will be difficult to estimate and that various insurance mechanisms have to be developed in case the system fails within the time horizon. This approach is attractive since up-front investment may be credited in expectation of future increases in terrestrial carbon stocks. In fact, this approach currently applies to the Scolel Té Pilot Project (Scolel Té 1998).

Cumulative Carbon Storage

The cumulative carbon storage approach is based on the expected lifetime of carbon emissions and radiative forcing of the CO_2 in the atmosphere (See Tipper and De Jong 1998 for the theoretical explanation of this approach). It assumes that most of the CO_2 emitted at the present will be absorbed within a time scale of about 100 years, and that the cumulative radiative forcing produced by the emission will be proportional to the area under the depletion curve, expressed in tC.years. Calculation of this area provides an estimate of the cumulative carbon storage that would be required to offset an emission of 1 tC at the present time (About 50 tC.years per tC emission). To apply the tC.years to tC conversion factor to forestry projects, a cut-off date needs to be defined that will limit the amount of credit that can be obtained from a given project activity. A cut-off date

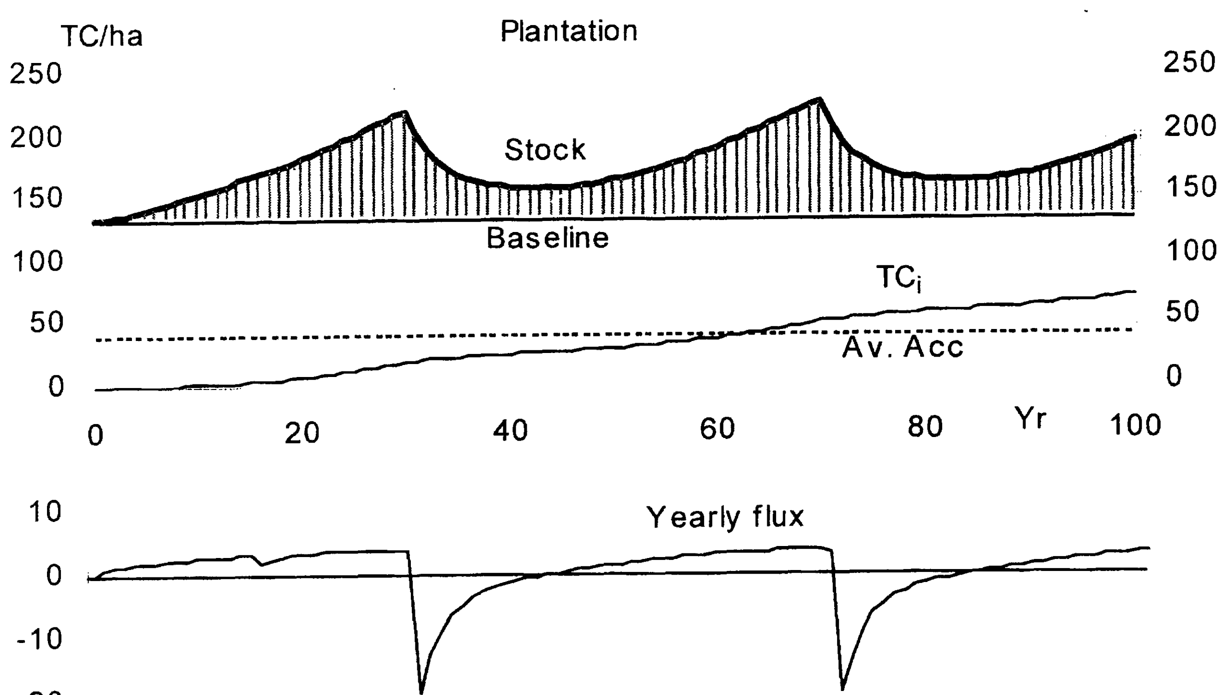


Figure 2.—Graphical representation of the various accounting procedures to explain the system C dynamics, relative to a baseline. Stock = accumulated carbon in the system; TC_i = emission offset in tC, using the cumulative carbon storage approach; Av. Acc = long-term average accumulation increase of C in the system, relative to the baseline; Yearly flux = net yearly C flux of the system.

in the order of 100 years has already been applied to various projects assessed on the average stock increase approach and seems also rational for the cumulative carbon storage approach. Even if the system is broken off before the cut-off date, it still contributes to the overall radiative forcing reduction, and the amount of tC emission offset obtained up till then can be calculated with the following formula:

$$\text{tC emission offset in year } i = \Sigma_i (C_{acc,i} - C_{base,i}) / \text{Conversion Factor}$$

Where $C_{acc,i}$ is the C accumulated in the alternative system and $C_{base,i}$ the C accumulated in the baseline, both in year i (Fig. 2). This approach is attractive as it resolves the accounting problems between emissions and uptake and there is no need to assume the conditions for indefinite sustainability of an equilibrium state of forest management (For a discussion on the advantages and disadvantages of this approach see Tipper and De Jong 1998). The approach is also in line with the global climate change concern: the greenhouse effect of certain gases in the atmosphere. This approach would require international agreement on the conversion factor. Once agreed upon, it needs to be reviewed periodically to take into account changes to the nature of the sinks due to climate change and land cover change, such as change in ecosystem productivity through climate change and CO_2 fertilization.

Monitoring and Verification

Notwithstanding the overwhelming literature available about potential biotic mitigation measures, there is still a large gap between accepting that C fluxes can in fact be modified to help mitigate climate change and accepting that this modification can take the form of individual projects that can be monitored and verified as part of a C emissions control system (Trexler 1993). By definition, monitoring activities of C mitigation projects typically measure all significant flows, whereas verification aims at evaluating the accuracy and reliability of the monitoring scheme. Monitoring programs are important for land-use projects to increase the reliability of data and to improve project performance. To ensure that forestry projects used for GHG mitigation are reliable and verifiable, guidelines are needed to provide structure and direction for project managers (Sathaye and Ravindranath 1997). These authors also point out that carbon pools in forest systems as well as forest products and energy should be evaluated for their significance (pool size) and vulnerability (rate and direction of change). Decisions about appropriate methodology and intensity depend on the relative importance of the individual pools (significance, speed and direction of change). Possible leakage issues must be addressed within a regional or national context (Leakage is the term used to describe the shifting of activities with GHG implications outside the boundaries of a project in space and/or time, Andrasko 1997). The Scolel Té project in Chiapas, Mexico gives an example of how monitoring and leakage can be addressed in a project in which many individual farmers participate (Andrasko 1997; De Jong et al. 1997). The project is designed to increase farmer income by implementing a set of alternative practices chosen by the farmers that also increase carbon stocks. Each farmer presents a "Plan Vivo" current land-use plan of his land, which is a starting point to monitor possible land-use changes in the future. Furthermore, the project is designed to also reduce potential leakage off-site, especially to the Selva Lacandona rainforest (De Jong et al. 1995, 1997).

Definition of the project boundary is important to facilitate decisions about questions such as if observed carbon fluxes relate to a certain project or not. The project boundary has to be set into a regional or national context to avoid what Andrasko (1997) calls "Edge Effect", that is the set of policy and technical issues emerging at the boundaries of monitoring domains. To avoid leakage or double accounting of carbon offsets it is essential to establish a linkage between individual carbon sequestration projects and regional or national flux reporting. Selecting the monitoring domain boundaries between project and regional and national accounting involves decision-making about the accuracy desired at both levels and financial resources available.

Assessment of offset reliability will ultimately require international agreements on a risk assessment methodology that can commonly be applied across projects and project types. Crucial to offset reliability is the timeline over which projects should be assessed and whether all projects should be subject to a common timeline analysis (Trexler 1993).

Greenhouse Gas Bubble (GGB)

Many scientists believe that the uncertainties in estimating the size of fluxes related to LU/LC changes can be reduced to acceptable levels if that is the desire of the international community (Noble 1998). Monitoring programs can be designed to provide credibility to forestry carbon offset projects. The effectiveness, cost and reliability of methods vary by type of project, scale, and the fluxes being monitored (Sathaye and Ravindranath 1997). One solution to cope with the monitoring domain problem is the development of what Andrasko (1997) calls "nested" monitoring systems. While developing countries, including Mexico, are not obliged to accept national binding emission limits, they could establish voluntarily GGBs covering specific regions and/or sectors (Tipper and De Jong 1998). To establish a GGB, the government sets an emission ceiling over a specific region and/or sector, such as a major forest area. Once the limit of a GGB is established, any extra emission reduction could then be credited. Such a system would allow to set up a reporting scheme that is mutually compatible and information flows between the monitoring entities could improve the accuracy of both systems. For example, up till now an average carbon density for each land cover class is used as the basis to estimate fluxes by comparing land-cover statistics. Project-level monitoring schemes could develop carbon density equations within each land cover class, based on satellite image interpretation. These equation can be adopted and incorporated in the periodic regional land cover change detection system, that has to be set up to comply with the GGB agreement. The U.S. Acid Rain Program uses the GGB concept to control SO_2 and NO_x emissions (Solomon 1994).

As with other management systems, the procedures of monitoring and verification of GGB and project performance should be constantly subject to improvement and refinement. The key to improvement is to reflect upon the main sources of error within the system. In the Scolel Té

Pilot Project, for example, the carbon densities and fluxes of the land management systems are currently based partly on direct biomass measurements, supplemented by the best available data in the literature. New data will be used to improve C-flux modelling, as these come available from project and GGB monitoring and verification. Figure 3 illustrates the potential information flows that can occur during the planning and implementation stages between GGB and project assessments. Project monitoring, as handled by the Scolel Té Pilot Project is also set up to improve farmers' compliance with monitoring schedules. This will be subject to gradual improvement through modification of the Plan Vivo methodology, training of farmers, and linkage of incentive payments to fulfillment of reporting requirements.

GGBs could be established in regions where:

- Already exist interest in carbon sequestration
- Poverty alleviation is critical and alternative options are lacking (e.g. immizeration areas)
- Biodiversity conservation is of national and/or international importance
- Data on LU/LC changes and related carbon fluxes are available
- Inward and outward fluxes or leakage are limited and measurable

Mexico, as a non-Annex 1 country, is very keen to explore the CDM potential, especially of the forestry sector. The government is currently setting up a Mexican Office for Greenhouse Gas Mitigation (MGGM). The National Institute of Ecology (INE), which is in charge of the Global Climate Convention, has already initiated studies that are required under the commitments of the Kyoto protocol and was the first country in Latin America to provide initial communication under the protocol. To comply with the increasing requirements of the UNFCCC and subsequent protocols, INE is currently improving its capacity to:

- Identify, adapt, and implement methodologies for GHG emissions assessment of the various sectors
- Calculate emission baselines to assess GHG mitigation initiatives
- identify promising forestry mitigation options, presenting their main technical and economic features

Table 1 presents a summary of activities and their requirements, necessary to set up and manage GHG offset programs. Some of these activities are already in progress, whereas others fit well within a GGB framework, such as nested GHG accounting frameworks, policy instruments to standardize accounting and presentation procedures, and data integration procedures. Data collected within a GGB framework can be used to improve the accuracy of national GHG emission reporting, and GGB can eventually be the starting point to establish future binding national emission limits.

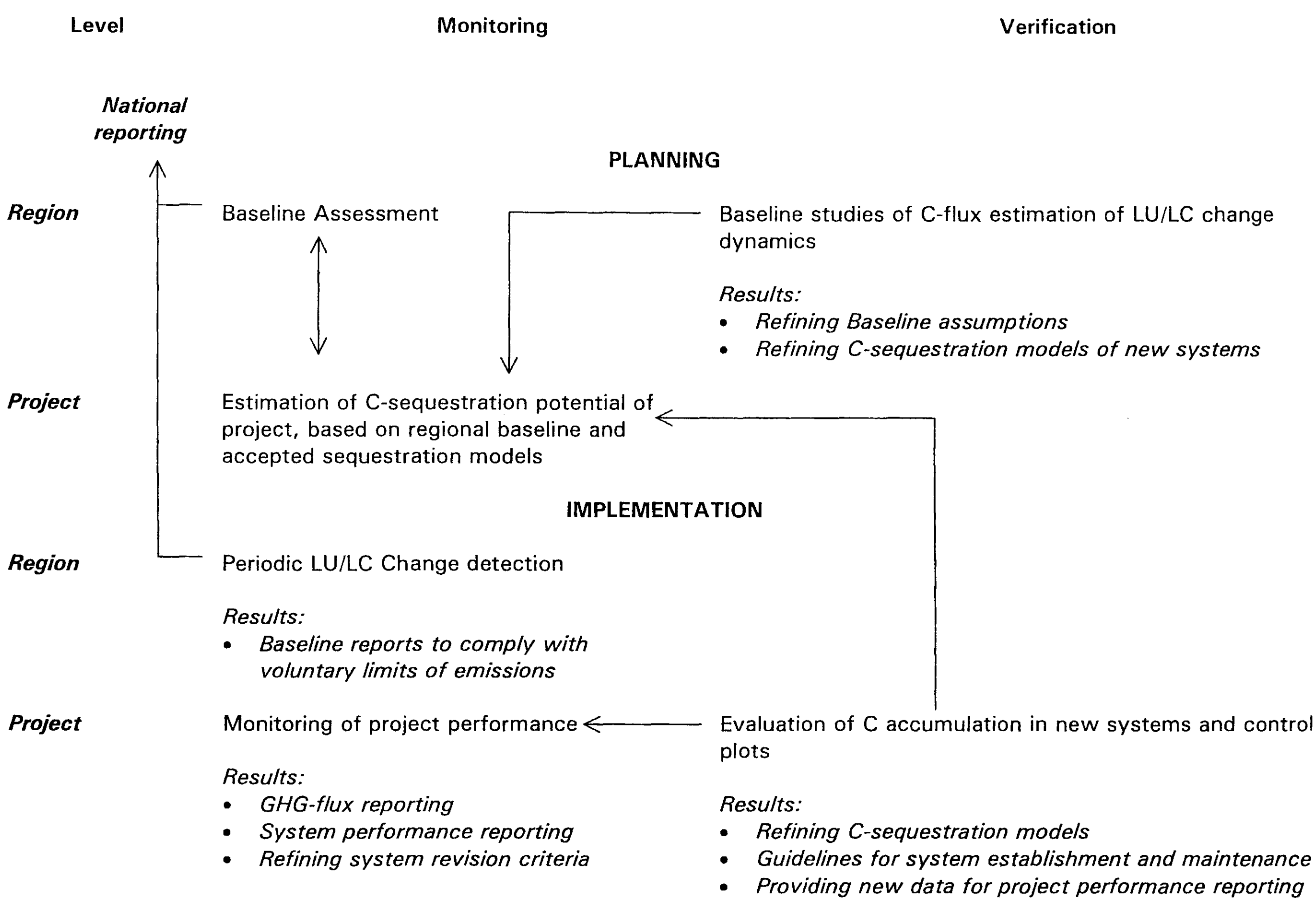


Figure 3.—Information flows between the reporting entities, within a Greenhouse Gas Bubble (GGB) framework.

Table 1.—Activities and their requirements, necessary to set up and implement a Greenhouse Gas Bubble. **bold**: activities and requirements in process; normal: proposed activities and instrument development; *italic*: aditional activities and requirements that have to be developed.

Level	Activities	Requirements
	Planning stage	
Greenhouse Gas Bubble (GGB)	• **Identification of critical areas (INE 1998)** • **Identification of project opportunities (INE 1998)** • **LU/LC change modelling with associated GHG flows (Tipper et al 1998)** • *Identification of government policies and short and medium term development programs* • *Identification and quantification of sources of leakage*	• Policy instruments to define baseline determination • *Agreement on default values of major parameters* • *Guidelines on format data reporting* • *LU/LC change detection protocols* • *Leakage tracking procedures* • Quantification procedures to measure GHG impact of policies • **Identification and acceptance of a minimum set of credible, well designed, verifiable forest mitigation activities (De Jong et al 1997)** • **Data on carbon densities and variation in LU/LC classes (De Jong et al 1999)**
Project	• Elaboration of proposals of farmer and community management plans • *Ex ante* estimation of GHG fluxes in management systems • Identification of possible project level sources of leakage	• Policy instruments to standardize accounting, modelling and data presentation procedures
Interactions between levels	• **Exchange of information to improve accuracy of data at both levels (De Jong et al 1997, Figure 3)**	• Standardization of data presentation • Data Integration procedures
	Implementation stage	
GGB	• Periodic LU/LC change assessments	
Project	• **Plot and system wise monitoring and verification of GHG fluxes in managed and control plots**	

References

Andrasko, K. 1997. Forest Management for Greenhouse Gas Benefits: Resolving Monitoring Issues Across Project and National Boundaries. Mitigation and Adaptation Strategies for Global Change 2(2-3): 117-132.

Brown, S. Cannell M.G.R, Kauppi, P., Heuveldop, J., Sathaye J., Singh, N. and Weyers, S., 1995 Establishment and management of forests for mitigation of greenhouse gas emissions. IPCC 1995 Assessment. Cambridge University Press.

Brown, S., Gillespie, A.J.R., and Lugo, A.E. 1989. Biomass estimation for Tropical Forests with Applications to Forest Inventory Data, Forest Science 35(4): 881-902.

De Jong, B.H.J., Montoya-Gómez, G., Nelson, K., Soto-Pinto, L., Taylor, J., and Tipper, R. 1995. Community forest management and carbon sequestration: A feasibility study from Chiapas, Mexico. Interciencia 20(6): 409-416.

De Jong, Ben H.J., Ochoa-Gaona, S., Soto-Pinto, L., Castillo-Santiago, M.A., Montoya-Gómez, G., Tipper, R., and March-Mifsut, I., 1998. Modelling Forestry and Agroforestry Opportunities for Carbon Mitigation at a Landscape Level. pp. 221-237. In: G.J. Nabuurs, T. Nuutinen, H. Bartelink and M. Korhonen (Eds.). Forest Scenario modelling for ecosystem management at landscape level, EFI Proceedings No 19.

De Jong, Ben H.J., Tipper, R., and Taylor, J. 1997. A Framework for Monitoring and Evaluation of Carbon Mitigation by Farm Forestry Projects: Example of a Demonstration Project in Chiapas, Mexico. Mitigation and Adaptation Strategies for Global Change 2(2-3): 231-246.

Dixon, R.K. 1997. The U.S. Initiative on Joint Implementation. Int. J. Environment and Pollution 8(1/2): 1-17.

Dixon, R.K., Andrasko, K.J., Sussman, F.G., Lavinson, M.A., Trexler, M.C., and Vinson, T.S. 1993 Forest Sector Carbon Offset Projects: Near-term Opportunities to Mitigate Greenhouse Gas Emissions. Water, Air and Soil Pollution 70: 561-577.

Dixon, R.K., Sathaye, J.A., Mayeres, S.P., Masera, O.R., Makarov, A.A., Toure, S., Makundi, W., and Wiel, S., 1996. Greenhouse Gas Mitigation Strategies: Preliminary Results from the U.S. Country Study Program. Ambio 25(1): 26-32.

Dixon, R.K., Schroeder, P.E. and Winjum, J.K. (Eds.). 1991 Assessment of Promising Forest Management Practices and Technologies for Enhancing the Conservation and Sequestration of Atmospheric Carbon and Their Costs at the Site Level. EPA/600/3-91/067, US-EPA, Washington DC.

Faeth, P., Cort, C. and Livernash, R., 1994. Evaluating the Carbon Sequestration Benefits of Forestry projects in Developing Countries. World Resources Institute.

Fearnside, F.M. and Malheiros-Guimaraes, W. 1996. Carbon uptake by secondary forests in Brazilian Amazonia. Forest Ecology and Management 80: 35-46.

INE, 1998. http://www.ine.gob.mx

Masera, O.R., Bellon, M.R., and Segura, G. 1995. Forest Management Options for Sequestering Carbon in Mexico. Biomass and Bioenergy 8(5): 357-367.

Masera, O.R., Ordoñez, M.J., and Dirzo, R. 1997. Carbon emissions from Mexican forests: Current situation and long-term scenarios. Climatic Change 35: 265-295.

Nabuurs, G.J. and Mohren, G.M.J. 1993. Carbon fixation through forestation activities: A study of the carbon sequestering potential of selected forest types, commissioned by the Foundation Face. Inst. for Forestry and Nature Research (IBN-DLO), Wageningen, The Netherlands, IBN Research Report 93/4. 204 pp.

Nabuurs, G.J. and Mohren, G.M.J. 1995. Modelling analysis of potential carbon sequestration in selected forest types. Canadian Journal of Forest Research 25: 1157-1172.
Noble, I., 1998. The Gross-net Issue. http://www.igbp.kva.se/grossnet.html. 6 pp.
Rudel, T. and Roper, J. 1997. The Paths to Rain Forest Destruction: Crossnational Patterns of Tropical deforestation, 1975-90. World development 25(1): 53-65.
Sathaye, J. and Ravindranath, N.H. 1997. Policies, Measures and the Monitoring Needs of Forest Sector Carbon Mitigation. Mitigation and Adaptation Strategies for Global Change 2(2-3): 101-115.
Schlamadinger, B. and Marland, G. 1996. The role of forest and bioenergy strategies in the global carbon cycle. Biomass and Bioenergy 10: 275-300.
Scolel Té, 1998. http://www.ed.ac.uk/~ebfr11; http://www.ecosur.mx
Solomon, B.D. 1994. U.S. SO_2 emission trading: lessons for a global carbon budget. pp. 1083-1086. In: Global Climate Change: science, policy and mitigation strategies. Proceedings of the Air and Waste Management Association International Specialty Conference, April 5-8, 1994. Phoenix Arizona.
Tipper, R. and De Jong, B.H.J. 1998. Quantification and regulation of carbon offsets from forestry: comparison of alternative methodologies, with special reference to Chiapas, Mexico. The Commonwealth Forestry Review (In Press).
Tipper, R., De Jong, B.H.J., Ochoa-Gaona, S., Soto-Pinto, M.L., Castillo-Santiago, M.A., Montoya-Gómez, G., and March-Mifsut. I. 1998. Assessment of the Cost of Large Scale Forestry for CO2 Sequestration: Evidence from Chiapas, Mexico. IEA Greenhouse Gas R&D Programme. 84 pp.
Trexler, M C and Haugen, C. 1994 Keeping it green: evaluating tropical forestry strategies to mitigate global warming. World Resources Institute, Washington DC, U.S.A.
Trexler, M.C. 1993. Manipulating biotic carbon sources and sinks for climate change mitigation: Can science keep up with practice? Water, Air, and Soil Pollution 70: 579-593.
Winjum, J. K., Dixon, R.K., and Schroeder, P. E. 1992 Estimating the global potential of forest and agroforest management practices to sequester carbon. Water, Air and Soil Pollution 64: 213-22.
Worldbank, 1997.

Information for Forest Sector Policy[1]

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Reidar Persson[3]

Abstract—Information for forest resources management, conservation and development at national/state level is often insufficient. At the same time existing forest resources information is poorly used. This is particularly but not exclusively true of developing countries. There are several reasons for this. Institutions for the formulation and implementation of forest sector policies are weak. Dialogue between producers and users of information is insufficient or absent. Information gathering is seen as a merely technical problem. For the reasons mentioned the mechanism to formulate the questions to be answered in the political process are often absent. The visible result that forest inventory specialists can often observe is that inventory findings are simply not used.

It is proposed that increased emphasis is needed on interaction between policy development and implementation on one side and information gathering on the other side. For this an analysis function is needed that organizes existing information from various sources, has knowledge of data sources and data quality and provides a capability to undertake ad hoc studies on request. This function should also serve as a link between data collection and data use. By assisting users (public and private policy/decision makers) with tailor-made information and studies on request it acquires knowledge about the problems and needs of the user community. By interacting with data collecting organizations it can feed back to those its knowledge about current and emerging information needs. It can thus help identifying gaps in data collection as well as research needs.

Analysis of consequences of political action or non-action is presented as example of a demanding use of forest sector information. Obstacles to relevant information gathering and smooth interaction are discussed. Among them the attitude of governments and of various stakeholders to consider information as a potentially dangerous instrument of power.

The Problem

Information for forest resources management, conservation and development at national/state level is often insufficient. At the same time existing forest resources information is poorly used. There are several reasons for this apparently paradox situation. Institutions for the formulation and implementation of forest sector policies are weak. Dialogue between producers and users of information is insufficient or absent. Information gathering is seen as a merely technical problem. For the reasons mentioned there are often no mechanisms to formulate the questions that need to be answered in the political process. The visible result that forest inventory specialists frequently observe is that inventory findings are simply not used.

This is in essence the problem that my co-author and I take up in this paper. We restrict the discussion to the national and state levels and we think of situations in developing countries. But much of what we say has validity for developed countries as well.

Our views are based on observations made during many years' national and international work in the field of forest inventory and forest policy. The message we want to convey is that we forest inventory people have to broaden our field of interest and get more involved in the process of forest policy making.

The need for a strong linkage between forest inventory on one side and forestry planning and policy making in a country on the other side has been discussed on several occasions (FAO 1994 and Janz 1993). A forest inventory without use or a forest policy without supporting data, serve little purpose. A close integration of the two activities is most desirable for the development of the forestry sector.

It is also important to highlight that the task of inventory experts is not to make policy or plans but to support planners and policy makers in making informed decisions. In an ideal world, inventories will be designed in anticipation of problems to be solved and not otherwise; and planners would make decisions using forest resources information.

What we say is nothing new. The Rio Conference and its follow-up processes have highlighted the shortcomings mentioned. AGENDA 21, in its CHAPTER 11, problem area D, has given the following diagnosis: "Assessment and systematic observations are essential components of long-term planning, for evaluating effects, quantitatively and qualitatively, and for rectifying inadequacies. This mechanism, however, is one of the often neglected aspects of forest resources, management, conservation and development. In many cases, even the basic information related to the area and type of forests, existing potential and volume of harvest is lacking. In many developing countries, there is a lack of structures and mechanisms to carry out these functions. There is an urgent need to rectify this situation for a better understanding of the role and importance of forests and to realistically plan for their effective conservation, management, regeneration, and sustainable development."

The UN-CSD Intergovernmental Panel on Forests (IPF) has formulated demands on National Forestry Programs

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and national systems for collection of data. In one of he relevant paragraphs we read:

81(b) (The Panel...) "encouraged all countries, where appropriate and step by step, to improve national forest resources assessments, forest statistics and the capacity to analyze and make proper use of forest resources information, and encouraged donor countries and international organizations to support these initiatives;"

We can note an emphasis on linking assessment with long-term planning and evaluating effects and on improving the capacity to analyze and make proper use of forest resources information. Ideally, gathering, organizing, disseminating, analyzing and using information should come in one logical chain in which each link is made to fit the others.

Why is Information Needed?

At national and state level the need for information is almost exclusively related to the formulation and implementation of forest sector policies and strategies and to monitoring their impacts. The political process involves a number of steps which all require information: Public debate, problem identification, formulating options for political action and analyzing the consequences of such action. Following these steps informed decision-making and, finally, implementation can take place. Stakeholders and the general public can only participate in the process, if reasonably correct and complete information exists and is readily available. A good information base is, therefore, a requirement of democracy.

In a good political process much attention is given to consensus building. Effective implementation of a political program can hardly be thought of without consensus among the stakeholders regarding the main program components. It is easiest to build such consensus stepwise: Consensus on basic facts regarding the forest resource and the utilization of forests; consensus on the nature of the major political problems; consensus on which options there are to solve the problems; consensus on the consequences of different political programs. All this requires information of increasing complexity.

The critical importance of information for a successful political process has been highlighted by one of the intersessional activities of the UN-CSD Intergovernmental Panel on Forests, namely the Intergovernmental Workshop on The Process of Consensus Building, held under a Swedish-Ugandan Initiative 1996 (Sida & Ministry of Nat. Res., Uganda 1996). The Synthesis Report from this workshop states: "There cannot be consensus unless the *competing claims* on land are understood and agreed upon by the interested parties. Understanding these claims expedites convergence of opinion and hence orientation towards common vision and goals. This implies that all the *basic facts* have to be known and presented in a transparent manner before decisions that are acceptable to all and can stand the test of time, can be made." The same report also notes "The process of consensus building...must always be based on good knowledge of the actual land uses and on the different options for future use of land."

What Information is Needed?

Information gathering should be demand driven. What is the demand, from where does it come and how do we know it?

At national and state levels it is the political process in a wide sense that generates most of the demand for information. A good way to approach the question 'what information is needed' is to examine what information we need to analyze consequences of political action. Such analysis is very demanding in terms of information. What satisfies the needs for analysis of consequences will satisfy many or most other needs with regard to formulating policies and strategies and to planning their implementation.

Analysis of Consequences

Analysis of consequences is a necessary part of the political process. It considers optional action programs that have been designed and answers the question what happens if a given program is implemented. Box 1 intends to illustrate what this means.

In conjunction with an analysis of the kind described here a number of questions will also arise related to stakeholders and their driving forces: Who are the stakeholders, how will in particular forest owners respond to various changes such as changes in wood prices, other prices, taxation, training, extension service, financial support, progress in agricultural techniques, changes in the market for agricultural products and roadnet? In a country with much private forest ownership, how will the response from the owners differ between young and old, big and small, those living where the forest is and those living far away and those having forestry as their dominating source of income and those living from other sources, mainly? How will local populations be affected by changes in the forest? How are decisions made in a village? Some of these questions are not usually considered to be the subject of forest administrations. They cut across sectors, and there we have one of the more serious problems with information gathering for forest sector policy.

The analysis of consequences as outlined here is complex and very demanding in terms of base data and techniques. It is in this context the most difficult questions to data collection will be formulated. Certainly information gathering for forestry planning is far more than forest inventory. We, the forest inventory community, can only cover our part of the whole. But we should be more aware of the linkages and more involved in dialogue vertically, with politicians and those who do things in the forest, and horizontally, with other sectors of society, including research.

Monitoring

An important activity is monitoring the result of new policies and strategies. Here we encounter the problem of measuring change. The object of interest may be area change, e.g. area of plantations, or change in activities, such as silvicultural or harvesting activities. In our example above the interest will be changes in key characteristics of young forests. In the long run changes in volume or biomass

Box 1.—Analysis of consequences

In the political process a problem is identified. Let us assume it is poor status of young forests. At a later stage in the process options for solutions will be designed, e.g. different programs to promote the establishing of better young forests. Programs may include information campaigns, legislation, research, as well as financial incentives. There is then a need to estimate the consequences of optional programs.

A simple example: Politicians design programs for improving the quality of young forests and wish to know the wood supply possibilities at different points in the future assuming implementation of the programs. The quality of regeneration measures can be influenced by forest policy tools such as extension services, implementation of legal regulations, as well as subsidies and taxation. Revamp those political tools and make assumptions as to their impact on various types of forest owners. Study previous experience in this field. Use forest research to find realistic relationships between type and quality of regeneration measures on one side and biological response to regeneration measures on the other side.

are of interest. Certainly some of the observations needed for such monitoring are not in the mainstream of forest inventory, but will require quite special techniques. The developing country environment will call for particularly creative approaches.

What is Wrong?

There is agreement that the political process requires a solid basis of information. Without this the seeking of political solutions is blind, and working for consensus has no meaning. In reality however, the following is often the case:

- public debate is ill-informed and therefore easily mislead;
- problem identification is not based on relevant facts or on studies based on such facts;
- the same is true for the specification of options for political action;
- analyses of consequences suffer from insufficient knowledge base or are not at all undertaken;
- information related to forest resources is kept in confidential government files and not used to promote informed public debate or informed cooperation across sectors of society;
- finally we cannot take for granted that knowledge-based policy formulation is what a given government wants. The agenda of the powerful can be quite something else.

National Forest Inventories are used to collect information about a country's forest resources. The information produced is strategic in nature, serving planning at country or state level. Thus the political process can be said to be a main client of National Forest Inventories. Insight into this process and its information needs should govern design and information content of the inventories. This, however, is seldom the case. We observe that a clear link to national forest policy is missing. The design and information content of such inventories are often influenced by ideas from pre-investment surveys, from traditional forest inventories in developed countries, from management plan inventories etc. The reason for undertaking a national forest inventory may be that a donor is willing to provide funds for it. In another case the background to undertaking a national forest inventory may be a forest policy problem such as deforestation. To fight the problem is a complex matter of many sectors of economy and involves changing living conditions and behaviors of many. There is a general notion that more information is needed to attack the problem. In this situation a forest inventory is asked for as a one shot operation and without formulating the questions that have to be answered in the political process. The inventory in such a case may give a welcome impression of activity and may be attractive to donors but has little chance to produce the results needed.

Yet another common problem is that forest inventory is done in one office and production and trade statistics in another, with insufficient interaction between them. The result is that we may have statistics about wood utilization, but don't know how much standing volume is needed to make up for it. There is no translation between the results of forest yield studies and utilization statistics. Those who have tried to compare the two know that the differences are significant.

Findings from some targeted studies can confirm the picture just given:

In conjunction with the global forest resources assessment 1990 FAO examined the status of forest inventories in tropical countries and summarized its findings in table 1.

Table 1.—State of forest inventory in the tropics in 1990

Number of countries with forest resources data at national level		
Total number of countries considered		90
Forest area information		
No assessment		3
One assessment	λbefore 1980	39
	λ1980-1990	27
More than one assessment		21
Information on		
Plantations		24
Volume & biomass		18
Harvesting & use		15

Adapted from FAO 1993

The FAO report (1993) presents the following comments on the table:

- There is considerable variation among regions with respect to completeness and quality of the information.
- There is considerable variation in the timeliness of the information. The data is about ten years old, on average.
- There are some countries which have carried out more than one assessment. These countries, however, have not used appropriate techniques, such as continuous forest inventory design, for change assessment.
- Only a few countries have reliable estimates of actual plantations, harvest and utilization, although such estimates are essential for national forestry planning and policy-making.
- No country has carried out a national forest inventory containing information that can be used to generate reliable estimates of the total woody biomass volume and its changes.

Table 1 refers to the status in 1990. Since that time forest inventory activity in developing countries as a whole has dropped further (communication from FAO).

Co-author Persson has analyzed the system for collecting forest information and its relation to important policy issues in some Asian countries. The following are highlights from the findings.

—**National Inventory**: Most countries analyzed do have some kind of National Forest Inventory. They are rarely continuous inventories. They are very often designed to fit a special technique.

—**Areas**: The area information is often based on remote sensing. Often visual interpretation of LANDSAT-TM is being used. With this technique it is difficult to identify areas smaller than 25 ha. Available information is often more than ten years old.

—**Area of plantations**: In most countries plantations are thought to become the main source of wood in the future. Ambitious plantation programs are often taking place. But hardly any country has good information about plantations. This is because plantations are often made in small lots and in the form of lines or belts. The standard remote sensing techniques normally used for inventory cannot identify such plantations. Virtually nothing is known about growth and yield of plantations. Although plantations are often the main thrust of the forest policy no monitoring systems are in place that can tell the success of plantation programs.

—**Changes**: In most countries deforestation and rapid changes in land use are considered to be important forestry problems. Nevertheless reliable information about the changes taking place is rare. To learn about the size and the character of changes requires continuous inventory. But most inventories so far have been unrelated one-shot undertakings.

—**Fuelwood production**: In most countries fuelwood is the dominating forest product. In spite of this hardly anything is known about fuelwood removals. The difference between the highest and the lowest guesstimate in a country can have the magnitude 4:1. Technically it is very difficult to collect information about fuelwood. What is consumed is biomass of which fuelwood is just a part. The use of biomass and its composition vary also over the year and between districts.

—**Production of industrial wood**: Very little is known about the production of industrial wood. The figures given are often planned production (Annual Allowable Cut). Actual production is often much higher.

—**Non-wood forest products**: Occasionally we notice scattered statistics about non-wood forest products reaching the market. However, non-wood forest products play a major role locally for the subsistence of many rural people. The where and what and how much of this and the relationships with other land uses are in most cases unknown. What is known is fragmentary and rarely helpful for policy-making.

—**Biological diversity**: This topic receives high attention in public debate. Nevertheless there is little systematic information about status and change in this field. Research is going on and perhaps practical methods will be developed. But will the methods be used? At present even good information about forest area is lacking in most countries although methods to estimate areas have been known for hundreds of years.

—**Monitoring**: Most countries have no systems for following up what the impact is of different political measures. We have already mentioned plantations. Their area, type, success rate, growth rate and intended and actual use are poorly known or unknown. Further examples are changes in quality of the forests, and reduction of illegal fellings.

—**Supply driven information**: The inventory method used often decides which information is collected. The method is chosen before the questions are formulated.

—**In summary**: There is a wide gap between information needed and information actually collected. Decisions about which information to collect seem often to be based on tradition. Needs assessments are rare. In most countries the lack of information and knowledge makes it difficult to formulate policies and strategies. It is rarely known to what degree policies and programs are being implemented.

What Can be Done?

Progress requires a commitment by the Government towards sustainable development of the forestry sector. The policy-making and the strategy development that emanate from such commitment will generate the questions that should be answered by national forest inventories and other providers of information.

An Analysis Function

Much of what has been said above about information needs and about shortcomings in meeting them points at the need for an analysis function. In the process of policymaking a function is needed that organizes existing information from various sources, has knowledge of data sources and data quality and provides a capability to undertake ad hoc studies on request. This function should also serve as a link between data collection and data use. By assisting users (policy/decision makers) with tailor-made information and studies on request it acquires knowledge about the problems and needs of the user community. By interacting with data collecting organizations it can feed them with its knowledge about current and emerging information needs. It can thus help identifying gaps in data collection as well as research needs. The unit could even anticipate policy issues or problems and discuss them with all stakeholders and provide timely support to the inventory unit in making meaningful survey designs and later in effective use of collected data. Main aims of an analysis unit can be summarized in the following points:

- Support to policy development
- Support to policy implementation and evaluation
- Contribution to the development of national knowledge systems

Box 2 shows typical tasks/activities of an analysis function

Institutional Set-up for an Aanalysis Function—The institutional set-up has importance for the possibilities of an analysis function to work well. In order to create a working unit for this purpose is usually possible to use existing organizational structures. What is needed may often be to concentrate scattered existing activities in one place. It seems recommendable to assign the tasks described to an identified group with sufficient critical mass to allow building up of institutional memory. It seems also advantageous to associate the unit with an institution that has some degree of autonomy. This may facilitate the interaction with a wider group including inventory unit, statistical office, policy makers, planners and other stakeholders involved in or likely to contribute to solving a problem under discussion.

What has been described here is not a theoretical construction. Sweden has practical experience of an analysis function since several decades. Experience tells us that long-term political commitment is needed to make such a function working well, that it takes decades to build up necessary know-how and that institutional memory is important.

An example of Policy Studies for a District of India—Singh (1998) has outlined Terms of Reference for what he calls an "Analysis and Evaluation Unit" for India. It should be stressed that there is no request from the Government of India behind this. The value of the outline is that an experienced person has made an attempt to describe the aims and activities of such a unit and the implications of establishing it in a developing country. Singh has worked for more than 20 years in FAO's forest resources assessment program and is now at Harvard's Center for International Development. In his paper he presents the following example of an analysis of consequences of political options for a civil district in India.

Building of scenarios at the national level in a large country like India is fraught with the danger of becoming too general. The situation differs from district to district (and village to village) in relation to fuelwood and fodder. It may be noted that in 1991 of the 413 districts, only 40 districts had a forest cover of more than 50 per cent, while 187 districts had forest cover less than 10%. This shows the need for a location specific approach.

Keeping the above facts in view, a model study was implemented in the Adilabad district of Andhra Pradesh State, which has still today 40% of the forest cover. The purpose was to derive some policy inferences from the study. Fortunately for Adilabad district, comprehensive forest inventory data for the years 1973 and 1995 is available. A set of four scenarios was studied using the available forest resources and socio-economic data and the FAO Area Production Model. Effort was made to make the assumptions as realistic as possible. The model uses simulation and represents a low-sophistication thinking aid for planning and for discussion with stakeholders.

Box 2.—Tasks of an Analysis Function

- Create and maintain an overview of forestry related information that may be scattered in many hands. Example: information on supply and demand of forest products and services
- Undertake ad hoc studies to support formulation and implementation of forest policy, in particular analyses of consequences of political action
- Based on user contacts identify information needs not covered
- Based on contacts with producers of information serve users with tailor-made information, including information from multiple sources
- Ensure comparability between information coming from different sources
- Compile and disseminate standard forest sector related information, e.g. in a statistical yearbook
- Take responsibility for international exchange of information

Main assumptions of the model are the following:

Scenario	Supply -side Assumptions	Demand -side Assumptions
00	No change	No change
04	- Improvement of wood production on agricultural land; and - Establishment of 100 000 ha of fuelwood plantations	No change
30	No change	- Reduction of population growth rate; and - Reduction of 2% per year of woody biomass demand per capita
34	- Improvement of wood production on agricultural land; and - Establishment of 100 000 ha of fuelwood plantations	- Reduction of population growth rate; and - Reduction of 2% per year of woody biomass demand per capita

The result of analysis using Area Production Model is presented in figure 1. As a basis for more detailed discussion the following conclusions could be drawn from the study: i) Even in a district like Adilabad with a forest cover of 40% today, a long-term program is essential to balance the supply with the demand. In the best case the time is about 25 years. ii) Both increasing production and controlling consumption are necessary. This suggests the need for intersectoral integration in the local development planning. iii) The program for forest plantations must be high yielding to achieve self-reliance in the shortest time. iv) The establishment and development of plantations must be secured with people participation. Control of grazing and illicit removals are a must. v) Adequate finance on a

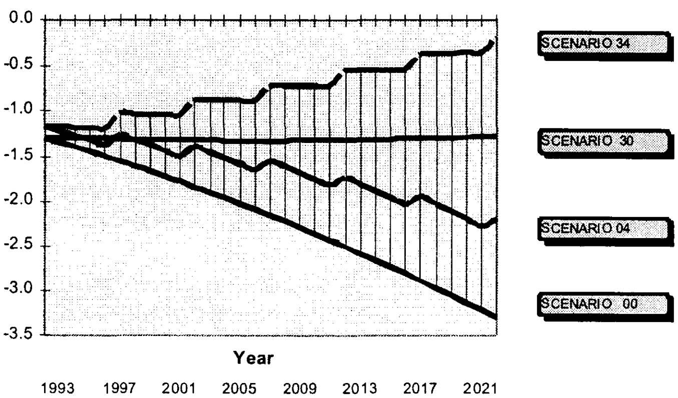

Figure 1.—Fuelwood deficit (million m^3)

continuing and long-term basis must be secured. This will call for an effective, creditworthy and efficient management environment.

In a next round of discussions one may introduce issues such as substitution of other fuels for wood, driving forces for tree plantation, ownership and tenureship. Users of the model will have to quantify the implications of such issues. Conclusion (iii), above, may lead to questioning the desirability of single-purpose fuelwood plantations. Who wants them, who protects them, which competing claims on land are there, and which alternatives can be thought of?

Monitoring

The need for change assessment has been pointed out, e.g. to monitor deforestation, land degradation and the success rates of plantations. In developing countries continuous forest inventory using permanent field plots has usually failed. Therefore remote sensing based approaches seem to be the only viable solution. The need to observe many, even non-traditional variables and the need for high resolution (plantations in small lots) pose a challenge in this connection. In some countries comparisons are being made between satellite data taken at intervals. FAO has refined and successfully applied this technique. It can furnish reliable time series of forest cover state and change estimates for any unit of area (FAO, 1996). However, there are many pitfalls. To really produce good information requires good organization (e.g. data from same season, same person to interpret all compared data sets from one locality in one operation).

Ongoing and Planned Activities

(1) In 1996 the Swedish International Development Cooperation Agency (Sida) has adopted a training program "Capacity building in developing forest sector policies and strategies and related organization and collection of data". One training course per year of 5-7 weeks' duration has been arranged, addressed to people in the interface between forest policy and related data collection. The experience from the program is good. Interest in developing countries is growing. The program has now even a follow-up component.

(2) Intersessional workshops in the framework of the UN-CSD Intergovernmental Panel (now Forum) on Forests: A Uganda-Sweden workshop on Consensus Building has been held in 1996 and a corresponding Vietnam-Sweden workshop on Knowledge-based Forestry is planned for 1999. The workshops have significance for the theme of this paper.

(3) FAO in its Global Forest Resources Assessment Program distinguishes four components, one of them being capacity building to "bolster countries ability to acquire their own assessments of forest resources and use these results in developing national policies and strategies". The need to link assessment with policy is clearly expressed (FAO 1997).

Conclusions

We can conclude by noting that there are still many shortcomings regarding the supply of relevant information to planning within the forest sector. Above all there is too little dialogue between inventory and policy making. But awareness is raising and there are now a number of promising activities and approaches that can improve the situation. We hope this exposure of ideas can help increasing the attention given to the problems addressed and stimulate further actors to contribute to their solution. Also we would very much welcome making some new contacts with people who work in the same direction and with whom we can join forces.

Literature Cited

FAO, 1993: Forest Resources Assessment 1990. Tropical countries. Forestry Paper No 112. 101 pages

FAO, 1994: A Review of FAO's Achievements in Forest Resources Assessment and a Strategy for Future Development. Based on an Auto-Review by K.D. Singh and K. Janz, Forestry Department. 39 pages

FAO, 1996: Forest Resources Assessment 1990 – Survey of tropical forest cover and study of change processes. Forestry Paper No 130. 152 pages

FAO, 1997: A Strategic Plan for Global Forest Resources Assessments. Forestry Department, 11 December 1997. 44 pages

Janz, K., 1993: World forest resources assessment 1990: an overview. Unasylva No 174, Vol. 44. 7 pages

Sida (Sweden) & Ministry of Natural Resources, Forest Department (Uganda), 1996: The Process of Consensus Building. The Swedish-Ugandan Initiative. Intergovernmental Workshop in Stockholm of Experts on Sustainable Forestry and Land Use, 14-18 October 1996. Vol. III: Synthesis Report. 44 pages

Singh, K.D., 1998: Establishment of an Analysis and Evaluation Unit (as a part of country capacity building in forest resources assessment). Manuscript, 5 pp.

Implementing Ecosystem Management Concepts at Multiple Organizational Levels[1]

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Abstract—The incorporation of ecological principles in: organizational management, strategic planning, and tactical options for field level analyses and decision-making is essential for implementing ecosystem management approaches. Ecosystem management evolved in response to changing knowledge and the expectations of society in addressing issues associated with sustainable environmental management. Simply put, ecosystem management represents the best set of natural resource management tools we have available. It is neither the beginning nor the end of any particular philosophy, discipline, or process. It does represent the current stage of evolution of the paradigm used by scientists and resource managers to view, understand and mange the interactions of humans and the environment they occupy. Ecosystem management requires that key concepts and principles be applied at several "levels" in order to fully develop and support the approach. Successful organizations and institutions, like successful organisms, must adapt, change, and respond to shifting conditions. Perhaps our greatest challenge is to be adaptive professionally, institutionally and operationally to ecosystem management principles.

The USDA Forest Service (simply referred to as the Forest Service hereafter) has developed and implemented an expanded ecologically based approach to understanding and managing resources and resource values and is clearly linked to other government efforts within the U.S. The agency refers to this approach as Ecosystem Management (Jensen and Bourgeron 1993; Kaufmann et al. 1994). The approach is not a completed and static process, locked in place and totally automated but rather is a work in progress. Over the last several years, it has been tested, adjusted and adapted across the National Forests and Grasslands and continues to evolve as an operational approach. It is the basis for all agency activities. Ecosystem management is clearly the most recent increment in the evolution of human understanding of the environment, and how we will as a society attempt to understand and manage our relationship with that environment.

The goal of ecosystem management, as stated by the Interagency Ecosystem Management Task Force (1995), is to restore and maintain the health, sustainability, and biological diversity of ecosystems while supporting sustainable economies and communities. The Forest Service continues to learn, test, modify and adapt as information and experience expand to meet this goal. The agency is refining a variety of ecosystem management activities that are the "tools" to implement the approach (Sexton 1998), and to determine guidelines and references for which tools are useful in what situations (Sexton et al. 1997). Implementing these tools and activities as a normal part of agency resource management activities is the focus of current Forest Service efforts in public resource management.

Experience strongly suggests that the incorporation of ecological principles in: organizational management, strategic planning and developing ecologically based information and options for tactical, field level analyses and decision-making results in improved, ecologically based natural resource management. Each area provides essential steps in the evolution of sustainable resource management. Ecosystem management requires that key concepts and principles be applied at several "levels" in order to fully develop and support the approach. This paper outlines the those levels and the major concepts and principles that apply at each level.

Whether an approach is called ecosystem management, sustainable development, place-based ecological assistance, sustainable forestry or any other term, resource management strategies must adopt and apply key ecological principles at several levels in order to describe and understand the options available for sustainable futures, both for humans and the environment. In an agency policy letter in June of 1992, then Chief of the Forest Service Dale F. Robertson (Robertson 1992) stated that "an ecological approach will be used to achieve the multiple-use management of the national forests and grasslands". His direction was that "we must blend the needs of people and environmental values in such a way that the national forests and grasslands represent diverse, healthy, productive, and sustainable ecosystems". This officially began the transition of the Forest Service to an ecosystem management approach for the management of the National Forest System. Further enforcing and refining the ecosystem management approach in 1996, former Chief Jack Ward Thomas (Thomas 1996) stated that, "ecosystem management is the integration of ecological, economic, and social factors in order to maintain and enhance the quality of the environment to meet future and current needs. It is a holistic approach to natural resource management" (See Figure 1 for a general framework for ecosystem management, from Sexton 1998).

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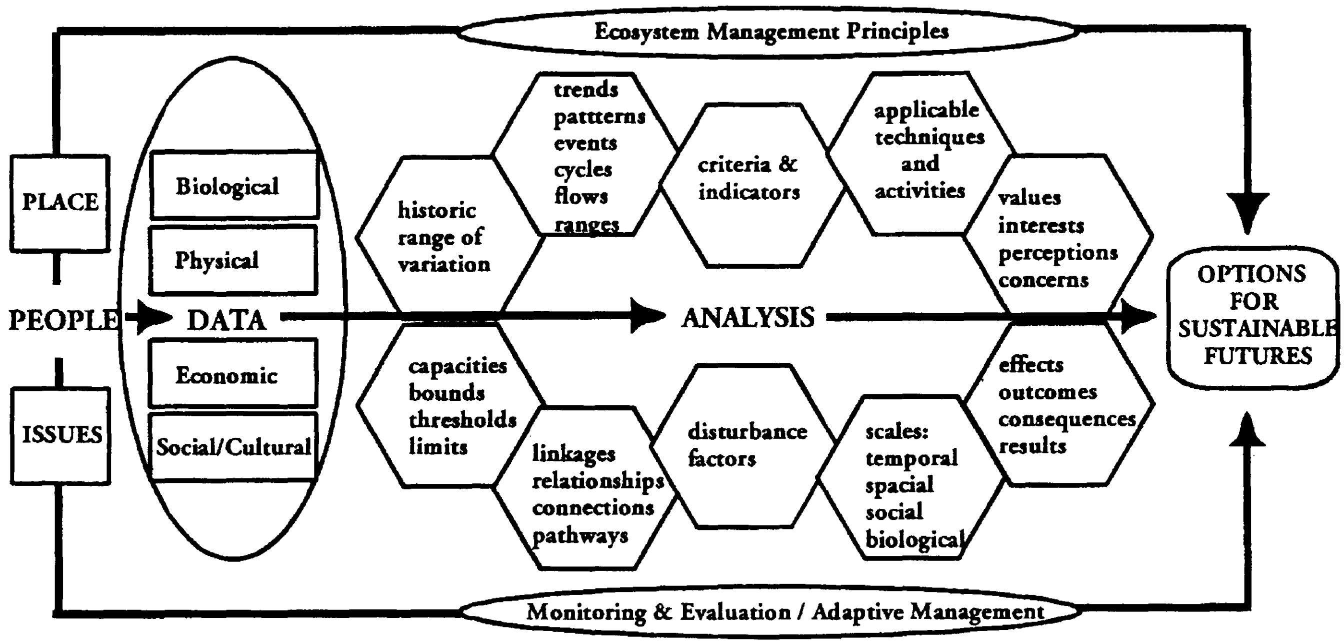

Figure 1.—General framework for ecosystem management.

Box 1. The Seven "Pillars" of Ecosystem Management (from Lackey 1998).

1. ***Values and Priorities***. Ecosystem management reflects a stage in the continuing evolution of social values and priorities; it is neither a beginning nor an end.
2. ***Boundaries***. Ecosystem management is place-based and the boundaries of the place of concern must be clearly and formally defined.
3. ***Health***. Ecosystem management should maintain ecosystems in the appropriate condition to achieve desired social benefits; the desired social benefits are defined by society, not by scientists.
4. ***Stability***. Ecosystem management can take advantage of the ability of ecosystems to respond to a variety of stressors, both natural and man-made, but there is a limit in the ability of all ecosystems to accommodate stressors and maintain a desired state.
5. ***Diversity***. Ecosystem management may or may not result in emphasis on biological diversity as a desired social benefit.
6. ***Sustainability***. The term sustainability, if used at all in ecosystem management, should be clearly defined—specifically, the time frame of concern, the benefits and costs of concern, and the relative priority of the benefits and costs.
7. ***Information***. Scientific information is important for effective ecosystem management, but is only one element in the process that is fundamentally public or private choice.

A number of authors have addressed principles related to ecosystem management. These have typically focused on a listing of principles (Christensen et al. 1996, Grumbine 1994, Lackey 1998), inherently suggesting that an ecosystem management approach and related concepts and principles are largely one-dimensional in this context (Box 1). In fact, experience has shown that principles and concepts are representative of and apply more appropriately to certain levels of abstraction about public values, institutional behaviors and norms, strategic focus and plans and tactical implementation through specific activities and tools. In developing an ecosystem management approach it is highly practical to focus on certain concepts and principles associated with particular levels of public, organizational and individual values, interests and actions. The concepts and principles underlying and framing ecosystem management progress from the very general and largely non-quantifiable public values to the specific and definitive resource management activities at the local level. There are four organizational levels at which ecosystem management concepts must be implemented in order to support the approach. These are: 1) national, 2) institutional, 3) strategic and 4) tactical. All must be in place to successfully support a long-term ecosystem management approach.

National Values and Goals

At the national level, with the current lack of consensus on priorities and values, and the associated limited common ground on resource management in general and public land management particularly, ecosystem management offers a framework for highlighting the range of disparate interests in the analysis and decision-making processes required of public land managers. While competing national views, values, perceptions and facts associated with the political, economic, social, and scientific arenas are debated and contested with little resolution or accord, the Forest Service and other land management agencies are required by law to address a wide range of issues, interests, facts and perceptions in the process of managing the public resource. An ecosystem management approach provides the most professionally credible approach to address the existing national challenges, recognizing that in many instances no practical, consensus solution in available.

Lackey (1998) has noted several general characteristics of national natural resource management and policy problems. These are:

> "(1) fundamental public and private values and priorities are in dispute, resulting in partially or wholly mutually exclusive decision alternatives;
> (2) there is substantial and intense political pressure to make rapid and significant changes in public policy in spite of disputes over values and priorities and the presence of mutually exclusive decision alternatives;
> (3) public and private stakes are high, with substantial costs and substantial risks of adverse effects (some also irreversible ecologically) to some groups regardless of which option is selected;
> (4) technical facts, ecological and sociological, are highly uncertain; and
> (5) ecosystem policy problems are meshed in a large framework assuring that policy decisions will have effects outside the scope of the problem."

While an ecosystem management approach is no panacea, it does provide a foundation for addressing resource issues at multiple scales. Ecosystem management at the national scale can be characterized as providing a framework for and supporting:

Making Better Decisions

Perhaps the overarching public goal in the context of the environment and managing natural resources is the need for "better" decisions, certainly about public lands and for many individuals, private holdings as well. It is a widely held belief by scientists and land managers that a more ecologically founded and holistically focused approach, such as ecosystem management, represents the evolution of the national natural resource management paradigm. However, the principle of adopting an ecological approach in order to make better environmental decisions begs that question of: better for who, in what ways, based on what priorities and over what time frame. Making a "better" decision, and ostensibly providing "more good" is a concept shared and supported by many, but with few specific agreements on details.

The current situation is one of extremely diverse public opinions and values, extensive litigation over the management of public lands and lack of political consensus on the specific role and direction for public resources. There continues to be wide spread debate and disagreement over values, priorities, desired conditions, necessary trade-offs, and associated risk and uncertainty. It appears unlikely that a substantially improved approach to understanding and managing resource will alleviate the contentiousness of the present environmental debate. However, there remains a general perception that "better" natural resource decisions are possible and necessary and should be pursued. Ecosystem management has emerged as the paradigm to support an improved natural resource decision-making process (Szaro and Sexton 1994, 1998 a&b).

Improved Resource Knowledge but Increasingly Competing Values

The primary factors that have created the need for a new paradigm for resource management have been summarized by Dr. John C. Gordon of Yale (Gordon 1994) as:

> "First, there are too many laws, or at least too many uncoordinated laws, and the general realization that in trying to implement the mix of direction, there just isn't enough to go around any more. Second, the accumulation of new knowledge rapidly outstripped the ability of the old paradigm to coordinate and explain it. Paradoxically, advances in knowledge highlighted the inadequacy of what we know. Third, a significant shift in public values occurred, such that there is greater interest in and desire for "sustained ecosystems" rather than for "sustained products" from the environment and especially from public lands."

Ecosystem management in the Forest Service has already demonstrated the capacity to provide a better understanding of the environment and to develop a range of sustainable resource management options in a wide variety of situations. That is, environmental performance under an ecosystem management approach has offered more clearly describable conditions, trade-offs, and management options for sustainable futures. This alone has met some expectations for "better" decisions. However, it is not yet clear whether better scientific and resource management information regarding choices about public resources has made the social, cultural and economic trade-offs even incrementally less contentious. While the principle of developing better resource decisions seems to be achieved under an ecosystem management approach, the likelihood of gaining public consensus related to desired conditions and associated trade-offs seems in doubt.

Developing Information to Address all Components

Depending upon the audience, "better" natural resource decisions can relate to parameters, values or constraints associated with: a) science (ecological information), b) economics (monetary information), c) resource management (practical experience information), and d) social and cultural interests (perception and value information). Ecosystem management, as the process underlying Forest Service natural resource management, attempts to bring all of this information into the analysis and decision-making process. As Lackey (1998) notes:

> "The debate over the proper management paradigm is often a debate over priorities and preferences. Values (and priorities) are important; they are the substance of, pejoratively, "politics" and, supportively, "democracy". Society, at least ours, finds it difficult to debate values; it is much easier to debate science as a surrogate of values and priorities."

It appears highly likely that current approaches and "facts" related to science, economics, and resource management, will continue to be the focus of debate and controversy surrounding public lands. Ecosystem management can provide a framework for this dialogue. The approach attempts to address all facets and interests in an integrated and holistic manner, including attention and discussion of a wide range of social and cultural issues that have and continue to be difficult to deal with in any quantitative, descriptive or definitive fashion. Whether the U.S. as a society is willing to use ecosystem management as a framework to support a meaningful and open debate on personal values and priorities related to public natural resources remains to be seen.

Institutional Concepts and Principles

In general, "better decisions" are represented at the next more detailed level of principles by certain concepts that symbolize what is perceived as "better" or provides for "more good" than the past situation. Inherent in any paradigm are certain concepts, values, goals, and assumptions. Strongly imbedded in the ecosystem management paradigm is the overarching goal for and value of sustaining ecosystems and the functions and services they support. Perhaps foremost among a common understanding regarding a range of ecosystem management approaches is the foundation principle of seeking options for sustainable futures. Ecosystem management at the institutional level is frequently characterized by the following concepts:

Sustainable Ecosystems

Ecosystem management related concepts and principles that bound governmental and institutional norms, set certain expectation for organizational focus, values and performance, and provide the institutional context of managing public resources. That is, the concepts and principles that guide organizational mission, priorities and activities set the stage for the focus and performance of that group. As previously noted, (Gordon 1994) the primary concept driving the evolution of ecosystem management is the general interest in sustainable ecosystems. Meaningful attention to sustainability requires the same definitional challenge associated with better decisions. That is sustainability only has meaning when described by what is sustained, over a given period of time, at some level.

This principle has been addressed in a variety of efforts at the global, national and institutional level. The Bruntland Commission's Report "Our Common Future" (WCED 1987), the development of international criteria and indicators for sustainable forests developed by the Montreal Process (Criteria and Indicators 1995), and the President's Council on Sustainable Development report, (Sustainable America 1996) have highlighted governmental efforts to address issues of environmental sustainability in the U.S. As an individual agency, the Forest Service has made clear policy statements on a priority focus on sustainable ecosystems (Robertson 1992, Thomas 1996) as an expected element of managing public natural resources through an ecosystem management approach in a national context. An institutional awareness of and focus on sustaining ecosystems, as an inherent element of mission is a critical component of developing and implementing an ecosystem management approach.

The Forest Service's policy on ecosystem management includes an objective to manage for "sustainable ecosystems", to retain their integrity in terms of composition, structure, function, and process. Implementing ecosystem management approaches will lead to "sustainable ecosystems", where the ecological system is the context for management, rather that just it's individual parts. The decision space associated with sustainable management options obviously varies with a particular place. In most cases, sustainable solutions occur across a range of alternative pathways that offer different, but still sustainable futures. Ecological approaches, and related goals for understanding and managing for sustainable futures, are all too frequently perceived as tightly constraining options. It is important to understand that the elements and tools of ecosystem management, or any ecological approach, are primarily intended to highlight options and support decision-making processes.

Sustainability is one of the most basic principles of the Forest Service approach to land management. The concept is certainly not new, but takes on particular dimensions within an ecosystem management context, particularly for aspects of biological diversity (Decker et al. 1991, Szaro and Johnston 1996). It has traditionally been used to address individual resource features or specific outputs. The Forest Service applies this principle to focus on sustaining healthy ecosystems. Using an analogy, the Forest Service is committed to sustaining the goose that lays the golden eggs. There seems to be broad understanding and consensus that managing for sustainable ecosystems is the essential foundation for ensuring sustainable environment services, products, and values, and the only means by which we can retain options for future generations.

Maintaining and Restoring Biological Diversity

By virtue of its size and geographic breadth, the National Forest System ranks as one of the country's most important reservoirs of biological diversity. The maintenance of biological diversity is an integral component of Forest Service ecosystem management plans because of its close linkage to sustainability (Christensen et al. 1996). Conserving biological diversity involves restoring, protecting, conserving, or enhancing the variety of life in an area so that the abundances and distributions of species and communities provide for continued existence and normal ecological functioning, including adaptation and extinction (Szaro 1995). This does not mean all things must occur in all areas, but that all things must be cared for at some appropriate geographic scale. While human interests may focus on a relatively small subset of the organisms or processes operating in an ecosystem, biological diversity will only be maintained successfully to the extent that land and water areas of appropriate scales are managed as ecoregional units (Christensen et al. 1996, Miller 1996).

Ecosystem planning for biological diversity must consider the dynamics of landscape scale patterns, both natural and managed, and their effects on hydrology, wildlife, and other resources as well as their impacts on human needs and expectations. For example, the planning process for a national forest needs to recognize the context in which that forest resides, such as what actions are being taken in surrounding areas. Planners and managers are increasingly aware that adequate decisions cannot be made solely at the site level (Szaro et al. 1996). The opportunities associated with a particular management unit are determined not only by the content of that unit, but also to a great extent by the landscape context in which it exists. This would include consideration of significant changes in surrounding, nonpublic land as potential reasons to revise forest plans (Szaro and Sexton 1998 a&b).

Quantifiable Indices

Any approach to resource management must include a range of metrics to provide for direction, goals and accountability. Establishing indices for a variety of outputs (things produced) and outcomes (situations that exist) resulting from or provided by an ecosystem management approach are a fundamental component of development and implementation.

Defining a "desired future condition" (DFC) is a concept basic to implementing ecosystem management. As the old saw goes, "if you don't know where you're going, any road will get you there". Any application of an ecosystem management approach requires attention to the development of some level of expression of what kind of environmental situation is sought or desired. DFC provides the general direction or vision towards which humans and their activities will attempt to guide environmental conditions. Obviously, DFC requires a complex and often problematic melding of science, resource management experience, economics and social values. In many instances, there simply is not a consensus or any common decision space on a set of desired future conditions. Engaging a broad range of interests in such a dialogue regarding national forests is a considerable challenge, given the diverse range of values and priorities. However, establishing this direction is essential. Without some view of the desired future, goals cannot be set, progress cannot be measured, and accountability cannot be determined.

In the context of the Forest Service, DFC can be extracted from the long and complex history of legislation regarding the National Forest System. Beginning in 1897 with the creation of Forest Reserves, and continuing through today, our socio-political system has addressed the national vision for the environment, natural resources and the National Forests through hundreds of laws, a range of executive orders and a century of annual budgets. Clearly this vision has been dynamic over time, and arguably represents the outcome of a democratic process. Nevertheless, at the institutional level, much about expectations for public lands is embodied in the complex framework of our current legal framework. While DFC must also be considerable at the strategic and tactical levels of resource management, the national expression of values, priorities and goals, sets the stage for the mission orientation and overarching framework for agency direction and activities. Engaging in a continuous dialogue with elected officials, interest groups, and a wide range of institutions, individuals and publics maintains a robust, albeit challenging view, of a national perspective on DFC.

Institutional attention to various forms of quantifiable indices specifically related to natural resources at the governmental level are reflected in the global and national metrics provided by the criteria and indicators resulting from the Montreal Process (Criteria and Indicators 1996). These 7 criteria and 67 indicators potentially provide a common means for measuring environmental conditions, trends, and addressing related sustainability issues both across and within countries.

The DFC in a national context provides the ability to develop a more detailed or local DFC for; large regions of the country, for large river basins, states, landscapes, watersheds, counties, or any of a large number of ways to recognize desired conditions for a particular place. A DFC then provides the platform to expand the broad vision for desired conditions to: an outline of general goals, associated specific objectives, related time lines, and predicted outputs and outcomes. Each of these lend themselves to the development and implementation of a variety of indices. These in turn provide the capability to determine the environmental direction resulting from management decisions, assess the type and rate of movement or progress, and address the effectiveness of selected activities to provide or produce particular outcomes and conditions.

Monitoring and Evaluation/Adaptive Management

Successfully implementing an ecosystem management approach requires significant institutional commitment to monitoring the results and effects of actions, evaluating activities in the context of environment goals and their effectiveness, and perhaps most importantly, continuously adjusting, adapting and improving management strategies and tactics based on science and management experience. An institutional level of support and priority for a comprehensive monitoring and evaluation program is an essential component of institutional priorities and activities for successfully implementing ecosystem management. Monitoring provides the mechanism to assure that ecosystem management activities are conducted: 1) as determined in analyses and plans (implementation monitoring), 2) that specific activities were implemented as designed and located, and resulted in the resource modifications desired (effectiveness monitoring), and 3) the combination of activities prescribed for a particular areas does in fact produce the desired outcomes and outputs projected (validation monitoring).

In each case, monitoring and evaluation can be conducted through a range of approaches, time frames, and investments. Monitoring can take place as research through application of the scientific method with results presented in a rigorous and statistical format. Monitoring can also be undertaken through structured empirical observation and documentation. The level of rigor and sophistication, the commitment of skills and funds, and the time frames involved should be developed in coordination with the type and complexity of issues, the level of risk and uncertainty associated with the resources and related decisions, and the amount and reliability of information associated with the analysis and planning process.

Perhaps most importantly, monitoring information, from whatever strategy or approach, should have a direct, conspicuous, and generally quantitative tie to the management decision process (Lessard 1998). While this seems intuitively obvious, the individuals, processes, and goals of those conducting monitoring have all too frequently been inharmonious with those individuals and organizations responsible for resource management. When monitoring is undertaken by groups, organizations or interests different from those responsible for the management process, with the objective of providing information useful to the management process, the direct tie from monitoring information to management change has been all to frequently lost. Data collectors invariably overestimate the significance and management applicability of their information, especially its use in other contexts. On the other hand resource managers have frequently operated under the assumption they were aware of and using the best available information for resource management, and adapting to new information, only to have it pointed out that they were in error. Monitoring for ecosystem management is fundamentally about reviewing, evaluating, and adjusting resource management information, analyses and decision-making and should be designed to determine whether management actions are moving the ecosystem toward desired conditions and trajectories, i.e., toward goals and expectations (Christensen et al. 1996). Constructing useful monitoring activities requires strong connections to the resource management and evaluation process.

Providing Public Resource Management in the Most Efficient Manner

First and foremost, an approach to managing public resources must provide for legal sufficiency. As laws expanded, became more complex and uncoordinated, required analysis and decision processes became far more demanding, time consuming and expensive. The ecosystem management approach has emerged as a response to the complexity and timeliness of required decision-making processes. This is an extremely complicated task under the existing legal framework especially since that framework is further refined by hundreds of federal court decisions each year. Most of the external direction for resource management tends to be process oriented. Therefore, the agency must maintain a system to recognize relevant process changes and adopt those in very short time frames. Ecosystem management provides a broad range of tools and activities that better meet the current range of laws than previous approaches. In a number of instances, courts have required some of these, like eco-region assessments, to address legal processes related to resource management decisions, e.g. threatened or endangered species. Ecosystem management, as an approach, better organizes activities and tools to move through existing requirements in the most timely and efficient manner possible.

Strategic Concepts and Principles

At the strategic level, concepts and principles take on two distinct facets: 1) environmental constructs that reflect how we think about the environment, and 2) management process constructs that reflect how we develop particular strategies to understand and manage ecosystems and resources given how we view the environment.

Environmental Constructs

In the first context, there are three concepts that underlie all management strategies. They represent a simple yet fundamental understanding of what we think we understand about the environment. These simple concepts set the stage for the subsequent development of more management process related constructs that attempt to address a range of situations, but with these concepts as a base. These basic concepts are:

- **Ecosystems are extremely complex**. Far more complex than we can understand in any degree of detail, even with just the information that currently exists. The typical experience is that there is not enough information to define the system with any degree of confidence, but there is far too much data for a single person to assimilate. In most cases we struggle simultaneously with a lack of knowledge and understanding, and with our capability to fully utilize the information that does exist.
- **Ecosystems are incredibly dynamic**. They have formed, disappeared, adapted, been dramatically altered by humans and natural events, and evolved to the state we presently observe, over long spans of time. The directions, patterns, extent, duration, and composition of physical, biological and human elements have followed an enormously involved and dynamic pathway to the present. What we see today are resources and landscapes that represent a snapshot in time. How do we manage for any desired set of sustainable conditions in systems that have developed under a regime of perpetual change? Implementing sustainable management strategies for highly dynamic systems requires rethinking old assumptions and old paradigms.
- **Ecosystems support many diverse, often competing demands from humans-but the bottom line is there just isn't enough to go around any more**. There seems to be wide spread understanding that there is not a sufficient resource base to provide for all of the interests, values, goods, services, and products that people want in the quantity and quality they want them. Any resource decision requires trade-offs and choosing a resource management "pathway". This is true even if the decision is to take no management action. In many cases this is perceived as some interests getting more of what they consider "good" and other interests getting less. Our current approach to analysis, modeling and projections, and decision-making appears to create and define winners and losers. We have to find a better way to understand and display information about ecological and human systems and develop a more comprehensive means for achieving consensus support for both short and long-term conditions that balance interests.

Management Process Constructs

In the second context, organizations implementing ecosystem management must develop and execute certain strategic activities to make the approach operational in field level situations. These strategies include organized processes, incentives and requirements to pursue and establish certain organizational or unit level attributes that support ecosystem management. These include:

- **System Oriented Strategies**. At the strategic level, considering natural resources based on a more holistic, system based approached is central to implementing ecosystem management. Collecting information, addressing problems, conducting analyses and working with a range of partners based on ecological boundaries establishes the practical context for understanding the environment and finding options for sustainable futures. This includes recognition of the complex nature of place, specifically linkages between the environmental, economic, and social/cultural aspects of the natural resource management arena. This concept also identifies the essential need to work across legal, political and administrative boundaries whenever possible to establish a comprehensive basis for understanding resources. The intent here is not to focus so much on the particular construct used to delineate an ecosystem but to recognize that there are many borders, boundaries, stratifications and categories that may prove useful in organizing information. Many of these are arbitrary and contrived for some particular purpose, and therefore better for some uses than others. Numerous approaches to identifying systems will probably be used in an ecosystem management approach. All will be imperfect. The goal in applying this strategic principle is to find organizing constructs that help all the involved stakeholders understand the area in question. Particularly the linkages between and among components of the environment, and the direct and indirect effects of any management strategy, including no overt human intervention. Keep in mind the objective is to find improved ways to look at the whole, as well as the individual parts.

- **Science-based Approaches**. Any ecosystem management approach must rely on the best available science. This is often mis-interpreted to mean seeking out individuals or groups engaged in research or focused on academic pursuits. This principle is intended to ensure that the best and most appropriate information is brought into the analysis process. Natural resource oriented scientists and researchers can bring useful information and insight into the process, but the science of resource management and related practical experience are equally important. Expertise, data and concepts should be sought and examined from the social, cultural, economic and environmental arenas. This absolutely includes using the most applicable science based approaches for dealing with human values, priorities and perceptions. Determining what is science based information and what is personal opinion or belief based information is often problematic. Locating the "best" science from any quarter is equally challenging. Do you attempt to define "main stream, well established and accepted" science or "cutting edge-still being debated" science. In seeking the best available science and information, all sources should be examined and objectively considered. Striking a balance between the practical nature of on-the-ground experience and learning, with experimentally derived information not yet validated at the scale and in the circumstances it might be applied is essential to the credibility of the ecosystem management process. Too often politically correct concepts and imprecise "buzz words" pass in general conversation for science. Keep in mind the objective is to find the most reliable, pertinent, and demonstrably up-to-date information possible that helps stakeholders understand the current situation, possible futures, and related trade-offs along any given management pathway.

- **Broad Collaboration and Stakeholder Involvement**. Ecosystem management is about people and places and their long-term interaction. Finding and involving the broadest possible range of agencies, organizations, communities, groups and individuals is essential for finding mutually agreeable solutions. Sharing information, values, goals, priorities and vision for the future, are the fabric that binds together and gives meaning and significance to the clutter of resource facts and numbers that frequently dominate debates about public resources. Forming and maintaining extensive coalitions of interests can be difficult, not so much due to conflicting interests or personalities, but frequently due to time spans and scale. Scale can create difficulties for stakeholders without clearly defined relationships. For example, if stakeholders have a "river basin" advisory group, what is the relationship to more local "watershed" advisory groups? What is the relationship among national groups, state groups, landscape groups and community groups? Are general interest organizations more relevant than very specific interest groups? How long can a stakeholder coalition be practically engaged in federal decision-making processes before interest, energy and available time are used up? Finding, organizing and maintaining a broad range of groups and interests is essential to a successful ecosystem management approach, but sheparding these partnerships through time, in particular governmental processes, and across broad geographic areas represents challenges to all parties.

- **Local Decision-making**. There is extensive experience showing that any particular model or construct is unlikely to be successfully extrapolated across a wide range of situations. The ability to make decisions, set processes, organize communications, and be intimately involved in data collection and analysis at the lowest possible level of federal organizations and with the area's people and communities, consistent with the issues and objectives for resource management is key to achieving common goals through ecosystem management. Local or place-based processes can be complicated where area or regional issues are used as surrogates for national policy debates, as trade-offs, or bargaining tools in broader issues. While complications do occur, a practical "rule of thumb" remains that having the most local level possible for the decision-making process and the development of partnerships has the best chance of success in finding mutually agreeable options.

Tactical Concepts and Principles

An ecosystem management approach has been variously described as a philosophy, a theory, a process, an outcome, and a constraint. For the Forest Service, ecosystem management is intended as a general approach to improve our understanding of resources, our ability to analyze various options and futures, and to support required decision-making processes. Ecosystem management is partly what we have found to have worked in the past. It is partly the inclusion of additional concepts and actions that expand the agency's ability to develop strategies based on ecological principles. Ecosystem management established an expanded "tool kit" for natural resource managers (Sexton 1998). It is clearly intended to enhance our ability to look at and understand the relationships of humans to ecosystems and their inherent processes and functions. In perhaps the most simplified view Ecosystem Management is "a lot more information, and a lot more complex information about larger areas".

There are a number of major activities, based on elements of an ecological approach, that characterize ecosystem management at the field level. These translate into actions and tools, that are the key to field level resource managers understanding and managing for sustainable futures.

Use Information Across Multiple Scales And Levels

Perhaps one of the most significant elements of the Forest Service's evolving ecosystem management approach is dealing with information and analyses at multiple scales (Sexton et al. 1998). Historically, characterization and analyses tended to focus intensely at individual projects and programs based on the area and scale they directly affected. The Forest Service is attempting to understand resources and landscapes at several scales simultaneously during assessment and analysis. Collecting and analyzing information at several scales provides a relational context at multiple levels and supports an improved understanding of linkages and relationships within and between scales. This supports a better understanding of connections between features, patterns and processes and helps characterize potential effects and outcomes.

We attempt to look at several different kinds of scale. **Biological** scale provides a means to assess information relating to lower or detailed levels, like genetic characteristics or species diversity up to broad or general scales like ecosystem, landscape, biome, or the biosphere. **Temporal** scales are used to understand systems, features and processes operating at several time periods, from spans of minutes, days, months or years up to millennia. **Geographic** scale is used to look at and understand the relationships of systems from a few square feet, to a particular drainage to a mountain range to a continent. **Human** scale or dimensions can be applied to help understand humans and how they form and use relationships and boundaries. Scales might use levels like individuals, households, neighborhoods, and communities. Another approach might use types of economies at local, regional, national or global levels. Many uses might also be found for information organized around city, county, state, and national stratifications. In most cases, a number of elements from each approach to scale will likely to used to characterize human-environmental interactions.

There are a wide range of means to organize information to support multi-scalar analytical needs of particular projects or programs. Basic principles/tools include:

- use a multi-scale approach for collecting and analyzing information;
- evaluate information at least one scale above and one scale below that being used to examine the project or program under consideration;
- use scale to address the pertinent features and related relationships in the biological, temporal, geographical and human dimensions;
- if necessary use several different approaches to scale in any one category;
- use scales (and related boundaries) appropriate for highly mobile species; and
- where appropriate use a coarse filter/fine filter analysis to identify and assess hierarchical relationships or rare features.

Determine Reference Conditions, Establish Current Status and Trends, and Cooperatively Agree on Desired Conditions

As an aid in expanding understanding of the past, present and possible future conditions of lands and resources, it is important to understand events and relationships over both long time spans and broad geographic areas. To help examine patterns, cycles, processes and other features, an extensive look at reference conditions helps to set the proper context. Basic principles/tools include:

- examine resource features, cycles, flows, patterns and events over both time and space;
- consider reference conditions, such as establishing historic range of variability, for resource elements and patterns, and human interactions;
- examine current status and trends in light of historical relationships; and
- work cooperatively with interested parties in defining desired conditions.

Assess the Role of Historic Disturbance Factors

Attempting to understand the role and process of disturbance in systems is another essential element of the Ecosystem Management tool kit. The most predictable aspect of natural resource systems is their extremely dynamic nature. One of the real "constants", in regard to the environment, is change. Ecosystems often do not behave in predictable patterns or directions. The type, amount, frequency and duration of disturbances create the unique patterns and elements that characterize landscapes and drive features of environmental processes. One of the key questions in an ecosystem management approach is how to manage dynamic landscapes with complicated disturbance histories and still provide for a reasonably predictable flow of values, uses, products and ecological functions.

Humans have historically tried to suppress the effects of natural disturbances, such as lightning-caused fires, floods, erosion, insects, disease and drought. These disturbances are often perceived to be in conflict with existing social and economic interests. As a result of well intended human interventions, biological diversity and ecosystem health have been affected—often to the detriment of the ecosystem. In a number of these cases the result has been unexpected negative effects on the economic, social, and cultural values the original interventions were intended to sustain.

The more we attempt to maintain an ecosystem in a static condition or state, the less likely we are to achieve what we anticipated over the long term. Because it is not a question of whether disturbance will happen, but what kind, where, and when, sustainable approaches for wild land management must incorporate the maintenance of historic disturbance regimes as an essential element of management actions. Resource professionals, the public, and governments need to understand and support the role of natural disturbance factors if ecosystems are going to be maintained over the long term. Basic principles/tools include:

- characterize the historic range of variation for disturbance factors;
- evaluate the effect of disturbance on the historic variability of landscape patterns, species dynamics, cycles and flows of energy and materials, and ecological processes;
- develop management activities that mimic and work within historic ranges and trends;
- characterize linkages and thresholds between disturbance, and related pattern, process and function across landscapes; and
- determine what features and elements of landscapes are rare and under what conditions.

Use Multiple Borders and Boundaries for Information

One of the major adjustments organizations have to make in implementing ecosystem management is learning to accept and use many different kinds of classifications, boundaries, categories, and strata for organizing information (Sexton and Szaro 1998). In the past, the typical approach was to examine a particular project by defining a single project area boundary and conducting analyses predominately within or near that single border.

An ecological approach requires the use of many systems and boundaries that may be well beyond the project area. It also may require the use of several different systems of ecological classification. For example, a single project may use several quite different systems to organize information about the terrestrial environment, another to address the aquatic environment, several more to examine the human dimension, and perhaps a system to understand the patterns of highly mobile, migratory species. Using multiple boundaries and systems, often at several scales, to help understand the ramifications of decisions introduces considerable complexity over historic approaches. Basic principles/tools include:

- develop ecological classifications that integrate current knowledge;
- use multiple classifications, categories and systems to best meet information needs; and
- clearly define the difference between a boundary defining the area to which decisions will apply and those that represent diverse needs for collecting and organizing information.

Recognize and Address Uncertainty and Risk

An ecosystem management approach that attempts to address sustainability of resources must explicitly deal with the elements of uncertainty and risk. The events of human history have repeatedly shown that the certainty of our knowledge has been consistently over estimated. The extremely dynamic and complex nature of ecosystems inherently suggests that uncertainty is likely to be the order of the day. In addition, humans have frequently misinterpreted or under estimated the form or magnitude of risk to resources and ecological systems, finding out after the fact that assumptions or projections were significantly flawed.

Resource management plans, assessments, and evaluations need to include improved descriptions of the type, amount, and intensity of risk and the degree and kind of uncertainty associated with programs or projects. As resource management professionals we need to find a practical way to evaluate and display to interested parties the level of uncertainty and risk associated with proposed management activities. This is not a simple task, but one that clearly needs our attention. Basic principles/tools include:

- use a holistic approach that evaluates ecosystems based on the sum of the parts, not on the individual pieces;
- build the uncertainty associated with any resource management situation into the models and projections used to develop and describe potential actions;
- document the assumptions and inherent error associated with data used to characterize resources and resource values;
- describe the risks related to resource management actions as clearly and honestly as possible when developing plans and making decisions; and
- establish monitoring and evaluation approaches that are commensurate with the uncertainty and risk associated with resource management activities.

Identify and Address Information Needs

Ecosystem management includes an increased interest in more and better information. Experience to date has shown that collecting, organizing, synthesizing and applying information is one of the major tasks of implementing an ecosystem management approach in field situations. Basic principles/tools include:

- seek out, synthesize and apply the best information available, including both the best science and management experience available;
- develop an information base about both the individual pieces and the sum of the parts. Examine and understand the relationship of features, patterns and single elements of the landscape to the processes, functions, cycles and flows that underlie the entire system;
- develop information relevant to the multiple scales used to understand project options;
- address the relationships, linkages, thresholds and limits of key cycles and flows, particularly carbon cycle, nutrient cycle, hydrologic cycle, biological diversity, population dynamics and succession, to the historic and present function of the system;
- when appropriate use a cooperative assessment approach to collecting and organizing information;
- develop partnerships to highlight and address common information needs, especially at the broader or larger scales where general information can be widely shared;
- cooperate to define information standards that will support common needs at the field level;
- use an automated approach to information management and modeling, like geographic information systems, so patterns, changes and effects can be easily modeled and displayed through time, over large areas and at multiple scales; and
- develop and use decision support systems that support characterization of human and environmental relationships over both time and space.

Emphasize Monitoring and Evaluation and Use an Adaptive Management Process

One of the most readily implementable elements of ecosystem management is putting an increased emphasis on applying monitoring and evaluation. Monitoring and evaluating the outcomes of management actions must be a commitment in order to make an ecosystem management approach work. This commitment must be built in as an integral component of planned management actions and supported by staffing and funding. Implementation of actions should be contingent on the fulfillment of the monitoring and evaluation plan.

An adaptive management philosophy and approach must be the organizational norm in order to fully implement an ecosystem management approach (Borman et al. 1999). The recognition of and commitment to dealing with management actions as experiments is necessary to support the growth, adjustment and evolution of sustainable management techniques. Basic principles/tools include:

- set reliable, practical criteria and indicators to measure and monitor; key features, patterns, cycles and flows, functions, processes and human dimensions effected by management actions;
- develop and monitor criteria and indicators for sustainability;
- make monitoring and evaluation essential components of projects and programs; and
- use an adaptive management process in organizational approaches to land and resource management activities.

Conclusion: Challenges in Managing for Sustainable Futures

Ecosystem management evolved because it is an approach that best meets the expectations of the current general national needs and interests of society in addressing issues associated with environmental management. This is not to suggest in any way that ecosystem management as a process will or can resolve the extremely diverse and often highly polarized views and values associated with the human-environmental interaction. Simply put, ecosystem management represents the best available set of natural resource management tools we have available. It is neither the beginning nor the end any particular philosophy, discipline, or process. It does represent the current stage of evolution of the general paradigm used by scientists and resource managers to view, understand and mange the interactions of humans and the environment they occupy.

Even with a robust ecosystem management approach in place, continuously evolving and improving, resource managers are faced with the challenge of managing and applying an extremely complex and demanding process. Which tools to apply at which scale, when is there enough information, are we adequately aware of what we do not know, what is the level of risk associated with a decision or assumption, are just a few among the list of questions that resource managers face when using ecosystem management. Even with an extensive set of very high quality tools, it still requires significant experience and skill to select the right tools at the right time, and then apply those tools properly in a particular situation. What do resource managers have to do to "get it right"? In "Environmental Policy in Transition, Making the Right Choices" (Sexton and Murdock 1996) it is suggested that any successful approach to addressing environmental decisions must have resource managers that are skilled at applying the available tools. Getting the process "right" can be summarized in the following general categories:

- **Get the issues and questions right**. Define the issues and specific questions in the simplest, clearest terms possible. Make sure the issues and questions are articulated in a manner that represents the interests and views of all involved parties, but also in a way that allows relevant quantitative information to be brought forward in the analysis and decision-making process.
- **Get the place and geographic extent right**. Define the areal extent necessary to fully address the issues and questions in a manner compatible with the decisions to be made. Resource issues and ecosystem management are inherently "place-based", therefore the size of area(s) involved in the process can make the process, and resolving issues, harder or easier. There are many ways to identify useful boundaries, and each ecosystem management process may use many boundaries for information

collection, analysis and assessment. Generally there is only one boundary representing the area to which specific decisions will ultimately apply.

- **Get the people and parties right**. Establish communications and working relationships with all stakeholders who are willing to participate. Go out of the way to keep parties who choose not to participate in the process informed. Resource issues and ecosystem management are inherently "people-based", therefore the people, organizations and interests involved in the process largely dictate how well issues and questions represent true concerns and the likely acceptability of and support for proposed options.
- **Get the facts right**. Describe clearly and fully what is known, what is not known, what is assumed, and what is suspected. Document to the degree possible the science available, the management experience that's applicable, the economic relationships past and projected, and the known public views, values and priorities. Putting the information related to all facets of ecosystem management down on paper and providing for broad review and input puts all the cards on the table, face up, and encourages all parties to maintain the most open and honest process possible.
- **Get the process right**. Ensure that legal requirements are met throughout the process where they apply. However, ensure that the process provides for the most open and participatory process possible. While certain specific steps and activities are essential to meet legal guidelines for decision-making, take advantage of the flexibility available to provide opportunities for groups, communities, businesses and individuals to become engaged in meaningful and positive ways. Make the process work well for everyone, avoid leaving stakeholders feeling like the legally required process precludes practical partnerships. Ensure that the right information is available to support the process, that is directly pertinent to the place, people and issues. Provide information that focuses on the issues and questions and avoid volumes of information that doesn't contribute to understanding the situation and making the decision.
- **Get the balance right**. Determine the appropriate level of quantification in addressing trade-offs, since resource management is fundamentally about choices, ensure those choices fairly and reliably are displayed for all parties. Seek a balance among competing interests, when no common decision space exists, be able to describe fully and simply why certain alternatives were selected. Focus on the importance of balancing competing factors, like facts and data versus personal values and priorities, short term versus long term conditions or interests, economics versus the environment, local interests versus regional interests versus national interests, risk as seen by scientists versus risk as seen by managers versus risk as seen by communities or interest groups. Balance individual decisions, categories of decisions (like mechanical activities versus physical and biological options), decisions with and across geographic areas of interest and issue areas of interest. Be prepared to clearly, succinctly and openly explain decisions and related rationale when ever possible.
- **Get the incentives right**. Create practical incentives that reward behaviors, processes, and situations that contribute to desire outcomes. Economic, social, cultural, and environmental incentives should reward environmental stewardship. Various forms of personal or group recognitions, awareness raising, and public notice and praise for positive forms of environmental support should be developed and applied. Penalties and disincentives should be developed for activities, behaviors and practices that do not support environmental sound conduct or participation. Incentives can be subtle or glaringly obvious. Find ways to positively reinforce environmentally appropriate actions and find disincentives to discourage environmentally inappropriate actions. Ensure that ecosystem management activities and related decisions provide the right kinds of incentives.
- **Get the rules and tools right**. Provide clear explanations of the processes, time frames, and decision points. Explain the various tools to be used in the process, the role they play in analysis and decision-making, and how they are intended to be used. Emphasize that tools and analyses are used to provide information for a more holistic understanding of the decision, but that individual models, analyses, and projects are each a part of the process and no specific bit of information is totally controlling the final decision. Be specific about what the true "rules" are, those activities, steps, authorities, processes, time frames, etc., that must be adhered to rigidly and unfailingly. Be specific about what the "tools" are, those actions, models, information, analyses that add information to overall approach but are part of the overall matrix of background information that surrounds and supports and guides the analysis and decision-making process. Don't surprise anyone with a rule when they are expecting a tool, and make sure people aren't using a tool but relying on it as a rule.
- **Get the priorities right**. Be clear and precise on what the priorities are, for the process, for any decision, for any activities along the way. If there are known or expected priorities for resources uses, allocations or trade-offs spell those at the beginning of the process. If there are priorities to address certain kinds of problems, or particular geographic areas in a larger landscape clearly describe what those are early on. Priorities should be openly and succinctly explained in the context of legal requirements, administrative direction, scientific understanding or management experience. If priorities are base on values, as opposed to "facts", those decisions and processes need to be documented for all participants and the beginning of the process.

Resource managers continue to address an extremely diverse community of interests. We all face demands for natural resources and related values that greatly exceed the capacity of those resources as we understand them today. For many organizations, we operate in a time of reduced staff and budgets. We must find ways to manage for healthy, productive, diverse, sustainable ecosystems that will provide resources to meet the needs of both present and future generations. This effort requires our cooperative energy, imagination, and resourcefulness. Successful organizations and institutions, like successful organisms, must adapt, change, and respond to current conditions. Perhaps our greatest challenge is to be adaptive professionally, institutionally and culturally to the ecosystem management principles and associated approach that seem to be the best hope for a sustainable natural resource base.

References

Borman, B.T., R.F. Tarrant, J.R. Martin, J. Gordon, F.H. Wagner, J. McIver, G. Wood, G. Reeves, J. Alegria, J. McIlwain, P.G. Cunningham, J. Verner, M.H. Brookes, N. Christensen, P. Friesema, K. Klein, J. Berg, J. Furnish, and J. Henshaw. 1999. Adaptive Management: Common Ground Where Managers, Scientists, and Citizens Can Accelerate Learning to Achieve Ecosystem Sustainability. *In:* The Ecological Stewardship Project: A Common Reference for Ecosystem Management. Sexton, W.T., R.C. Szaro, N. Johnson, and A. Malk, editors. Elsevier Press, Oxford, UK. 1500pp. (In press).

Decker, D.J., M.E. Krasny, G.R. Goff, C.R. Smith, and D.W. Gross (Editors). 1991. Challenges in the Conservation of Biological Resources—A Practitioner's Guide. Westview Press, Inc., Boulder, Colorado. 402pp.

Criteria and Indicators For The Conservation And Sustainable Management Of Temperate And Boreal Forests. 1995. The working group on criteria and indicators: Australia, Canada, Chile, China, Japan, Republic of Korea, Mexico, New Zealand, Russia, United States. Canadian Forest Service, Quebec, Canada. 27pp.

Christensen, N.L., A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin, J.A. MacMahon, R.F. Noss, D.J. Parsons, C.H. Peterson, M.G. Turner, and R.G. Woodmansee. 1996. The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecological Applications 6(3):665-691.

Gordon, J.C. 1994. The New Face of Forestry:Exploring A Discontinuity and the Need for A Vision. Gifford Pinchot Lecture Series. Grey Towers Press, Milford, Pennsylvania. 17pp.

Grumbine, R.E. 1994. What is Ecosystem Management. Conservation Biology 8(1):27-38.

Interagency Ecosystem Management Task Force. 1995. The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies. Volume I - Overview. June 1995, 55pp.; Volume II - Implementation Issue. November 1995, 137pp.; Volume III - Case Studies. June 1996, 221pp. Council on Environmental Quality, Washington, D.C.

Jensen, M.E. and P.S. Bourgeron (Editors). 1993. Eastside Forest Ecosystem Health Assessment, Volume II Ecosystem Management: Principles and Applications. USDA Forest Service. Pacific Northwest Research Station, Portland, OR. 397pp.

Kaufmann, M.R., Graham, R.T., Boyce, D.A. Jr., Moir, W.H., Perry, L., Reynolds R.T., Bassett, R.L., Mehlop, P., Edminster, C.B., Block, W.M., and P.S. Corm. 1994. An Ecological Basis for Ecosystem Management. Gen. Tech. Rep. RM-246. USDA For. Serv., Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 22pp.

Lackey, R.T. 1998a. Ecosystem Management:Paradigms and Prattle, People and Prizes. Renewable Natural Resources Foundation, Bethesda, Maryland. Renewable Resources Journal 16: 8-13.

Lackey, R.T. 1998b. The Seven Pillars of Ecosystem Management. Landscape and Urban Planning (Special Issue - Ecosystem Management) 40(1-3):21-30.

Lessard, G. 1998. An adaptive approach to planning and decision-making. Landscape and Urban Planning (Special Issue - Ecosystem Management) 40(1-3):81-88.

Miller, K.R. 1996. Conserving Biodiversity in Managed Landscapes. Pages 425 to 441 *in* R.C. Szaro and D.W. Johnston (Editors) Biodiversity in Managed Landscapes. Oxford University Press, New York. 778pp.

President's Council on Sustainable Development (PCSD). 1996. Sustainable America: A New Consensus for Prosperity, Opportunity, and A Healthy Environment for the Future. U.S. Government Printing Office, Washington, D.C. 186pp.

Roberston, D.F. 1992. Letter to Regional Foresters and Research Station Directors. File designation:1330-1. Subject: Ecosystem Management of the National Forests and Grasslands. 3pp. USDA Forest Service, Washington, D.C.

Sexton, K.W. and B.S. Murdock (Editors). 1996. Environmental Policy in Transition - Making the Right Choices. The Minnesota Series in Environmental Decision Making, Volume 1. Center for Environment and Health Policy, School of Public Health, University of Minnesota, Minneapolis, Minnesota. 109pp.

Sexton, W.T. 1998. Ecosystem Management: Expanding the Resource Management "Tool Kit". Landscape and Urban Planning (Special Issue - Ecosystem Management) 40(1-3):103-112.

Sexton, W.T., C.W. Dull, and R.C. Szaro. 1998. Implementing Ecosystem Management: A Framework for Remotely Sensed Information at Multiple Scales. Landscape and Urban Planning (Special Issue - Ecosystem Management) 40(1-3):173-184.

Sexton, W.T., N.C. Johnson, and R.C. Szaro. 1997. The Ecological Stewardship Project: A Public-Private Partnership To Develop A Common Reference For Ecosystem Management in the United States. Volume 2B; "Forests, biological diversity and the maintenance of the natural heritage", Proceedings of the XI World Forestry Congress, October 13-22, 1997, Antalya, Turkey: 75-82.

Sexton, W.T, and R.C. Szaro. 1998. Implementing Ecosystem Management:Using Multiple Boundaries for Organizing Information. Landscape and Urban Planning (Special Issue - Ecosystem Management) 40(1-3):167-172.

Szaro, R.C. 1995. Biodiversity Maintenance. Pages 423-433 *In* A. Bisio and S.G. Boots (eds.) Encyclopedia of Energy Technology and the Environment, First Edition. Wiley-Interscience, John Wiley & Sons, Inc., New York. 3024 pp.

Szaro, R.C. and D.W. Johnston (Editors). 1996. Biodiversity In Managed Landscapes - Theory and Practice. Oxford University Press, New York. 778pp.

Szaro, R.C., G.D. Lessard and W.T. Sexton. 1996. Ecosystem Management: an Approach for Conserving Biodiversity. Pages 369-384 *in* di Castri, F. and T. Younès (Editors), Biodiversity, Science, and Development: Towards a New Partnership. CAB International, Oxon, UK and International Union of Biological Sciences, Paris, France. 646pp.

Szaro, R.C., and W.T. Sexton. 1994. Biodiversity Conservation in the United States. Pages 369-384 *In* Breymeyer, A., R. Noble, S. Deets, N. Brand, K. Robbins, and S. Vandivere (Editors), Preservation of Natural Diversity in Transboundary Protected Areas: Research needs/management options, [National Academy of Sciences and Polish Academy of Sciences Workshop, May 16-24, 1994, Bieszczady and Tatry Biosphere Reserves, Poland.] National Academy Press, Washington, D.C. 279pp.

Szaro, R.C., and W.T. Sexton. 1998a. Ecosystem Management as an Approach for Sustaining Forests and Their Biodiversity. Proceeding of International Union of Forestry Research Organizations-Division 8/Environmental Forest Science Conference. Kyoto University, Kyoto, Japan. Kluwer Academic Publishers, Dordrecht, The Netherlands. (In press).

Szaro, R.C., and W.T. Sexton. 1998b. The Emergence of Ecosystem Management as a Tool for Meeting People's Needs and Sustaining Ecosystems. Landscape and Urban Planning (Special Issue - Ecosystem Management) 40(1-3):1-7.

Thomas, J.W. 1996. Forest Service Perspective on Ecosystem Management. Ecological Applications 6(3):703-705.

World Commission on Environment and Development (WCED). 1987. Our Common Future (The Bruntland Commission Report). Oxford University Press, Oxford, England. 383pp.

Propuesta para la Protección, la Restauración y el Manejo de la Región de Huayacocotla, Veracruz[1]

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Resumen—La propuesta de conservar y manejar áreas de importancia biogeográfica es considerada dentro de sus condicionantes ecológicas, sociales y técnicas, dado que la dirección de una zona con alta diversidad biológica debe ser ponderada en su doble carácter de regulador de actividades productivas y acervo biogenético. En la región de Huayacocotla, los diversos esfuerzos de investigación y administración hacen de esta área un "laboratorio natural" de repercusión sobre la calidad y diversidad del entorno natural de la Huasteca, del estado de Veracruz y del propio país; así mismo, trascender en la generación y validación de la ciencia y gestión de los recursos naturales. Asentamiento de Etnias, Propuesta de Area Natural Protegida y Región Prioritaria para la Conservación, se justifica su investigación ecológica por razón de la existencia de una Diversidad Biológica y de un proceso de degradación del medio de grave magnitud. La presente propuesta, parte de la integración de las bases biológicas generadas, cuyos registros están dispersos e incompletos, y faunísticos, que resultan inexistentes. Tal información resulta una contribución, indispensable, para la definición en la categoría de protección y el eficiente aprovechamiento de la integridad de los recursos naturales de la región de Huayacocotla.

El tema de estudio del presente trabajo es la Conservación, la Diversidad Biológica y Geográfica, así como los Recursos naturales de la Región de Huayacocotla, del Estado de Veracruz y del País. Las líneas de trabajo planteadas son 1) La Integración de las bases de información bioecológica de la región. 2) El Analizar la situación ambiental estatal y regional 2) La Propuesta para la definición del estado de protección. 3) El Esquematizar el manejo del medio. El desarrollo de la propuesta estará estructurado en un ensayo que determine que elementos son de considerar y cuales son prioritarios para la conservación y uso sostenible de un medio que cuenta con alta diversidad diológica y un grave conflictos social.

Objetivos

Exponer, en el marco del **Simposio Norteamericano**, la importancia de la organización y sistematización de las bases biológicas, tecnológicas y sociales para la formulación de estrategias para la protección, la conservación y el tratamiento del medio de una región de importancia forestal.

Antecedentes

Importancia y Problemática

Huayacocotla es considerada, por su extensión y producción, como la región forestal más importante del estado de Veracruz, posterior a una veda, decretada en 1952, se iniciaron, a partir de 1978, los aprovechamientos maderables intensivos. De hecho, en la actualidad la actividad forestal constituye el eje productivo determinante del uso de suelo y el tratamiento del medio de cerca de 16 mil hectareas de las 72 mil que comprende el municipio. Sin embargo, esto ha venido constituyendo, en términos reales, una limitación para la valoración y usufructo de los recursos naturales de la región. Existe un estado de ignorancia, omisión y desatención de la magnitud ecológica general y de elementos biológicos valiosos en particular, por parte de autoridades, técnicos y habitantes. Sin embargo, Huayacocotla convoca toda una serie de instituciones y organismos, tanto públicos como civiles, que han contribuido al desarrollo de la región abocándose a la investigación y gestión de los problemas sociales y ambientales. V. gr. La diversidad biológica, el potencial silvícola y la exploración de nuevos recursos objetos de conservación y uso que ha llamado la atención de centros de investigación de diversa índole.

El incrementa el aprovechamiento de los recursos naturales, a causa de las presiones demográficas, la transformación tecnológica, la cotización del potencial biogeográfico, la sobreexplotación tradicional, el cambio de uso de suelo y un proceso de crecimiento rural y pauperización social, urge la consideración integral. En esta región confluyen elementos biológicos y geográficos que la sitúan como prioritaria para su conservación, siendo necesaria tanto la investigación ecológica, como la crítica del aprovechamiento contemporáneo de los recursos, actividades que, por una dinámica de producción intensiva y de corto plazo, carecn de interés, dada su poca rentabilidad. Así también, en la sierra de Huayacocotla convergen de programas sociales y de estrategia política, motivados por un grave rezago económico, jurídico, asistencial y democrático; que sin embargo, en su trasfondo, involucra la participación en el usufructúo y conservación de los recursos naturales. De tal suerte que líneas de trabajo con mayores recursos no procuran el equilibrio, la autonomía y la sostenibilidad del medio, en contraposición con un mayor porcentaje de los recursos asignados que se concentran en la agricultura y ganadería, aun cuando un ochenta por ciento del área se considera de aptitud forestal.

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Aprovechamiento y Crisis Ambiental

La historia del aprovechamiento de los recursos bióticos ha devenido desde una explotación sin normatividad y considerando criterios inmediatos, hasta una necesidad de esclarecimiento en status y objetivos de protección y producción de técnicas silvícolas y de aprovechamiento de los recursos naturales específicamente regionales para el incremento de la calidad, la integridad y la eficiencia aproximándolos a los criterios de la sostenibilidad. Debido a esta situación generalizada de aprovechamientos irrestrictos y sin especificaciones, sobre todo de los bosques templado-frios, se tomó la decisión de vedar a Veracruz en 1952, pasando de una política de poca regulación, a otra de fuerte restricción. El resultado concreto de esta veda fue que de "bosques disminuidos de baja calidad y poco valor comercial", se pasó al clandestinaje, la sobremaduración y la pobreza rural. Ante esta situación uno de los primeros antecedentes donde se patentiza el interés por proteger hábitats y microhábitats de especies se encuentra en el "Proyecto para el establecimiento de una reserva ecológica en Huayacocotla" formulado a principios de la década de los ochentas. En esta propuesta se establece como objetivo general el fijar los lineamientos y las medidas para la protección de un área de bosque caducifolio y de bosque de pino-encino, recomendándose secuencias de investigación, principalmente de incursiones, pioneras y complementarias, florísticas y faunísticas.

En 1978 se levantó la larga veda forestal, al mismo tiempo que se impulsó en la zona un Programa de Desarrollo Forestal, iniciándose programas pilotos de aprovechamientos silvícolas, además, se promovió la formación de empresas campesinas con ayuda de organizaciones civiles. Al margen de las interpretaciones, el inicio de los aprovechamientos forestales coincidió, prácticamente, en tiempo y lugar, con la propuesta de la reserva ecológica; también ocurrió la paralización de la propuesta, casi desde su inicio, sobre todo en los trabajos de investigación específica, consulta y ajuste del proyecto de protección. Para 1982 se establecería la Brigada de Investigación Forestal Huayacocotla, representación del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), proponiéndose el establecimiento de investigación silvícola básica en apoyo a los productores forestales. Así mismo, instituciones como la Universidad Veracruzana, el propio Instituto de Recursos Bióticos (actualmente Instituto de Ecología A.C.), la Universidad Autónoma Chapingo, el Colegio de Postgraduados y la Universidad Nacional Autónoma de México, incrementaron su presencia y originaron los diversos trabajos de investigación.

Se requiere de incrementar el debate intelectual y la dirección de una población de capacidad autogestiva de sus patrimonios naturales, tanto como el acopio y la investigación de los elementos que apoyen la opinión y desarrollo de la comunidad local y la gestión de las políticas de manejo. Hechos como la ola de incendios que han afectado en los últimos años y de manera acelerada en el presente momento, así como el avanzado proceso de erosión y pertubación del medio natural, demandan el recuento y valoración de los recursos bióticos y geográficos. Instituciones de diversos caracteres y objetivos, han trabajado para convertir a los recursos naturales de la sierra de Huayacocotla en una fuente de bienestar social, varios han sido los proyectos, algunos exitosos y otros truncados, por lo cual es necesario analizar estas iniciativas considerando su aportación, su momento y su repercusión. Los organismos nacionales, en concordancia con las altas encomiendas mundiales de salvaguarda de los territorios naturales, se concentran sobre proyectos regionales, siendo las iniciativas de "grupos de trabajo", que han analizado una problemática concreta, la manera más factible de responder a las campañas de los gobiernos. El propio carácter social y cultural de los habitantes, de los campesinos y los indígenas, de los ejidatarios y los propietarios, ha sido un factor decisivo en el desarrollo y protección de la vida silvestre, el mantenimiento de la cubierta forestal y la preocupación por un uso sostenido del medio natural, esta también ha constituido la pauta de cooperación para conservar y recuperar la riqueza que engloba la biodiversidad de Huayacocotla.

Area Natural Protegida y Región Prioritaria de la Conservación

La degradación de los ecosistemas y la falta de bases organizadas y disponibles de la condición biológica son condiciones, que para Huayacocotla, deben ser ponderadas en su interés de protección y conservación. De sus cerca de 72 mil hectáreas, correspondiente al municipio, 3,600 están propuestas, para ser declaradas como áreas protegidas, con una categoría de manejo de Reserva especial (por la Ley del Equilibrio Ecológico, SEDUE-SEDESOL, 1988, actualmente Ley General del Equilibrio Ecológico y la Protección al Ambiente), y con registro de la Unión Internacional de la Conservación de la Naturaleza (UICN) de Indeterminada. En febrero de 1996, expertos de la Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), así como de otras diez y siete instituciones, definieron 155 "Regiones Prioritarias de México", a partir de su importancia biológica, y de su amenaza y oportunidad para la conservación. Registrada con el número 105 se encuentra Huayacocotla junto con otras ocho zonas del estado de Veracruz. La región constituye una importante reserva de diversidad biológica, ya sea por la concentración de tipos climáticos, áreas biogeográficas, ubicación de hábitats y microhábitats, así como de localidades específicas. Existen elementos ecológicos de relevante y excepcional importancia dentro de las especies florísticas y faunísticas, muchas de las cuales se encuentran en diferentes clasificaciones de vulnerabilidad y extinción, y con potencialidades de manejo sostenible. Especies, localidades y hábitats de un alto valor ecológico, con status y rentabilidad diversa, son objeto de la conservación o la degradación, el manejo o la explotación, esto a lo largo de una historia compleja.

Avances y Perspectivas

Se han identificado las fuentes de consulta, así también se ha llevado el acopio de la información requerida para partir y diseñar la metodología, puntos de muestreo, áreas de interés y objetivos de conservación. Existen proyectos de investigación silvícola, de aprovechamiento de recursos naturales y de desarrollo social de parte de instituciones y organizaciones. Algunos como el Proyecto de Desarrollo

Sostenido de la Huasteca Alta Veracruzana que promueven diversos parámetros de crecimiento y de evaluación del estado del medio. Los inventarios biológicos cuentan con diversos niveles de desarrollo e interés, en cuanto a la flora se han llevado incursiones, cuentándose con registros de validar e integrar. Por lo que se refiere a los listados de la fauna, sus escasas referencias carecen de actualidad y precisión, sin contarse con un catalogo regional específico, en este rubro se han promovido algunas iniciativas las cuales por falta de apoyo no se han podido concretar.

De las especies en vías de extinción no se ha llevado a cabo estudio alguno en su bionomía y ecología, a nivel regional, el cual indicase su status, guiase actividades como la prescripción de los aprovechamientos forestales, o bien, definiera más estrictamente los rubros de impacto ambiental. La labor primordial por el lado de la ordenación son los programas presentados por los servicios técnicos forestales y algunas manifestaciones de impacto ambiental. Se han efectuado estudios minuciosos en el caso de las áreas relictos de Pseudotsuga menziesii en los bosques de coníferas, donde se han encontrado especies forestales de importancia. La investigación han interesado por estos tipos de vegetación, menor atención han merecido los bosques mesófilo y caducifolio, que a causas de la dificultad de supervisión y la escasa capacidad técnica de manejo, se han visto afectados y disminuidos.

El conocimiento sobre la fauna silvestre con que se cuenta es producto de la información obtenida de los habitantes y de observaciones ocasionales de investigadores y servidores técnicos, asentadas en documentos como programas de manejo forestal. Uno de los primeros estudios fue efectuado, en el sur de la Sierra de Huayacocotla, por la Universidad de Kansas en 1948, concentrándose en mamíferos. Posteriormente, la "Propuesta de Reserva Ecológica en Huayacocotla» elaborado por investigadores del Instituto Nacional de Investigaciones sobre recursos Bióticos en el año de 1980 resume la información donde se infiere la existencia de una gran diversidad faunística en distintos órdenes.

Justificación

A través de diversos foros (V.gr. Taller de Identificación de Regiones Prioritarias para la Conservación de México) y en diversos estudios; se confirma la necesidad de profundizar en el conocimiento de esta región, en lo referente a problemas aparentes, y no evaluados, como la extracción inmoderada de madera, que generalmente se insertan como parte de conflicto del medio más importas y que incluye cambios drásticos de uso del suelo, deficiente infraestructura de extracción y transformación de productos forestales, carencia de un rigor técnico en los aprovechamiento, entre otros. Se señala la importancia de especificar el valor descriptivo de criterios como "la integridad ecológica funcional de la región, la diversidad de ecosistemas, sobre todo, de aquellos de transición (mesófilo) y tropicales (caducifolio y perenifiolo), endemismo, riqueza, especies útiles y potencialidad".

De igual manera se resalta el reconocimiento de los índices del impacto ambiental y conservación de los ecosistemas en aspectos como cambios en la densidad de población, la presión sobre especies clave, concentración de especies en riesgo, proporción del área bajo manejo, la valoración de los servicios ambientales, así como la presencia de grupos organizados, rubros que requieren de una precisión sobre la problemática y sus posibles protagonistas de solución. Tal es el caso de géneros y especies de flora y fauna con status, omisiones importantes en los registros y reporte de nuevas localidades, donde se infiere la existencia de una importante riqueza en diversos órdenes.

Diseño de la Investigación

Método General

La protección de una región implica significados epistemológicos y sociales de una aparente contradicción, como pueden ser la conservación y demandas sociales. Sin embargo, ambos aspectos justifican el reconocimiento ecológico, la identificación de sus principales y más valiosos elementos, sobretodo los endémicos, raros y en peligro a causa de la degradación de sus poblaciones y hábitats, lo que puede redundar, con base en una adecuada organización, en un desarrollo ambientalmente sustentable y socialmente equilibrado.

Para el estudio partiremos del panorama general del medio para comprender el propio estado de conservación de la diversidad biológica, cuyo conocimiento se obtendría a través de los inventarios florísticos y faunísticos, que apoyen tanto la valoración del acervo biogeográfico como el conocimiento de su potencial cultural como agente de desarrollo social y directriz política y cultural.

El área geográfica de estudio se circunscribirá al Municipio de Huayacocotla, donde se ven representados las áreas biofísicas e incluso culturales más representativos de la Huasteca Veracruzana.

Marco de Referencia

Marco Biogeográfico. La Región se ubica en el sistema montañoso de la Sierra Madre Oriental y estribaciones de la Cordillera Neovolcánica, al noroeste de Veracruz, con altitudes que varían de 950 hasta 2,700 m; así mismo, la región se incluye dentro de las cuencas de los ríos Tuxpan y Pánuco. El clima del tipo C(W2)B(i)n: templado subhúmedo con temperaturas medias del mes más frío entre 3 y 8oC, y los más calurosos, mayor a 16.5oC, con verano fresco y largo y niebla frecuente. La precipitación media anual es de 1,358 mm. En la vegetación prevalecen bosques de coníferas y latifoliadas (asociación pino-encino); bosque mesófilo de montaña, de transición; así como bosques subtropicales y tropicales, caducifolios y perennifolios. Debido a los aprovechamientos forestales y cambios de uso de suelo, una extensión considerable esta dominada por bosques de crecimiento primario y secundarios.

Marco Sociocultural. El Municipio de Huayacocotla, extiende su influencia por otros seis municipios, las cuales sufren de un estado de marginación económica, social que se expresa en hecho como una profunda crisis ambiental. Culturalmente, enmarcada por la Huasteca Veracruzana, en esta región moran poblaciones campesinas mestizas y grupos étnicos, organizados tanto en ejidos y pequeñas propiedades, como en tierras comunales y asentamientos seminómadas. El propio municipio de Huayacocotla, cuenta con una población indígena estimada de 8,635 habitantes que significa el 48% de la población total; En Ilamatlán, conviven cerca de 12,517 hablantes de lengua indígena, casi el 99% del total de la población; Zontecomatlán contribuye con 9,191 indígenas el 87% de la población; en Tlachichilco con un universo indígena estimado de 8,537 personas se puede hablar de un 83% con relación a los no indígenas; Texcatepec registran 7,328 habitantes con esta característica indígena es decir el 94% de los que viven en ese municipio; Chicontepec, 53,572 indígenas, 89%; Benito Juárez, 14,601 habitantes con cultura mesoamericana y 98% de representatividad, El mpio. de Ixhuatlán de Madero cuenta con 41,536 indígenas que seria el 89%. De la población indígena del estado de Veracruz calculada en 946,970 individuos, 155,917 habitantes, 16.5%, se sitúa en esta zona de la Huasteca veracruzana. Las lenguas predominantes son nahuatl, otomí y tepehua. De acuerdo a los índices de grado de marginación y categoría migratoria se establece de una "Expulsión" hasta una "Fuerte Expulsión" (INEGI, 1995).

Procedimientos Específicos

Se consideran tres etapas generales de seguimiento: Recopilación de antecedentes, Documentación y Evaluación Forestal, y Conformación de una Propuesta General de Manejo y Administración.

Recopilación de Antecedentes. La investigación se desarrollará a partir de la organización y sistematización de los bancos de datos, los archivos y la consulta de personal de diversas instituciones y dependencias, considerándose rubros como: Historia, sociología, economía, cultura, política, recursos naturales, silvicultura, diversidad biológica, protección y gestión ambiental. Las fuentes de información considerarán instituciones y dependencias como son El Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), El Instituto de Ecología A.C., La Universidad Veracruzana (UV), El Instituto Nacional Indigenista (INI), El Instituto Nacional de Estadística, Geografía e Informática (INEGI), La Universidad Nacional Autónoma de México (UNAM), La Universidad Autónoma Chapingo (UACh), El Colegio de Postgraduados (CP), La Secretaría de Agricultura, Ganadería y Desarrollo Rural (SAGAR), La Secretaria del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP), y los Gobiernos Estatal y Municipal

Documentación y Aplicación de Evaluación Forestal. Planteamiento y seguimiento de líneas de investigación y administración que actualmente se ejecutan y que contribuyen al manejo y conservación de los recursos naturales. Así mismo, se efectuará la cartografía y análisis de la dinámica de la cubierta vegetal por medio de fotointerpretación y sistemas de información geográfica.

Propuesta General de Manejo. Conformación de un proyecto de conservación, rehabilitación y adminsitración del medio, donde la información recabada y generada sea estructurada en un proyecto que genere fuentes de alternativas y factores de decisión.

Fuentes Consultadas

Anderson, W. H. 1980. Una guía sobre información de sensores remotos para biólogos especializados en vida silvestre. Manual de técnicas de gestión de vida silvestre. The Wildlife Society. EE.UU. pp. 305-320.

Brigada de Investigación Forestal Huayacocotla (BIF). 1988. Plan de investigación silvícola para la región de Huayacocotla, Ver. B.I.F. Huayacocotla/INIFAP. México 20 p.

Boege, E. y Rodríguez, H. 1992. Desarrollo y medio ambiente en Veracruz. Instituto de Ecología A.C. / Fundación Friedrich Ebert / Centro de Investigaciones y Estudios Superiores en Antropología Social. México. 303 p.

Burrough, P. A. 1986. Principles of geographical information sistems for land recources assessment. Clarendon Press. Oxford. Great Britain.

Cajuste, B. L. 1995. Vigilancia del avance de la desertificación y su control. En IV curso sobre desertificación y desarrollo sustentable en América latina y el Caribe. Colegio de postgraduados. México.

Cuevas G., R. 1994. Flora de la Estación Científica Las Joyas, Mpio. De Autlan, Jalisco, México. Tesis de Maestría en Ciencias. Colegio de Postgraduados / Centro de Botánica.

Davis, D.E. y Winstead, R. L. 1980. Estimaciones de tamaños de poblaciones de vida silvestre. Manual de técnicas de gestión de la vida silvestre. The Wildlife, EE.UU. pp. 233-258.

Day, G.I., et. al. 1980. Captura y marcación de animales silvestres. Manual de técnicas de gestión de vida silvestre. The Wildlife Society, EE.UU. pp. 63-94.

Downing, R. L. 1980. Estadísticas vitales de poblaciones animales. Manual de técnicas de gestión de vida silvestre. The Wildlife Society, EE.UU. pp. 259-281.

Flores, V. O. Y Gerez, F. P. 1994. Biodiversidad y conservación en México: vertebrados, vegetación y uso del suelo. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Universidad Nacional Autónoma de México (UNAM), México. 439 p.

Freese, F. 1969. Muestreo forestal elemental. Centro Regional de Ayuda Técnica, Agencia para el Desarrollo Internacional. México. 1969.

Gomez, B., M. G. 1977. Estudio dasonómico, Bosques de Huayacocotla, Ver. y Zacualtipan, Hgo., Secretaría de Agricultura y Recursos Hidráulicos, SARH, Subsecretaria Forestal. 341 p.

Kirkpatrick, R. L. 1980. Indices fisiológicos en la gestión de la vida silvestre. Manual de técnicas de gestión de vida silvestre. The Wildlife Society, EE.UU. pp. 105-118.

Lara, P. Y. Organización social y patrón de uso de suelo en Huayacocotla, Veracruz. En alternativas al manejo de laderas en Veracruz. Semarnap / Fundación Friedrich Ebert. México. pp. 151-166.

Lopez, E. 1998. Evolucionan Bases de Datos. Reforma. Suplemento Interfase 13/abril/1998.

Mallen, R. C. 1995. El tratamiento de la Fauna silvestre en los programas de manejo forestal en la región de Huayacocotla, Ver. Memoria del XIII Simposio Nacional sobre Fauna Silvestre. UNAM. México.

Marín, H. A. 1991. Bio - Dat. Un sistema de base de datos con opciones gráficas y estadísticas para las áreas biológicas y agronómicas. Tesis de maestría. Colepgio de Postgraduados. México.

Mexico. SARH. Subsecretaría Forestal y de Fauna Silvestre, 1994. Inventario Nacional Forestal Periódico, Estado de Veracruz.

Mexico. Secretaría de Desarrollo Social (SEDESOL). SARH. 1992. Calendarios cinegético, agosto - abril 1992 -1998. MOSBY, H.S. 1980. Observaciones y registros. Manual de técnicas de gestión de vida silvestre. The Wildlife Society. EE.UU. pp. 45-55.

Ramirez, R. F. y Palma, G. J. 1980. Proyecto para el establecimiento de una Reserva Ecológica en Huayacocotla, Veracruz, México. Instituto Nacional de Investigaciones sobre Recursos Bióticos. Veracruz. México.

Ripley, T.H. 1980. La planeación de la gestión de la vida silvestre, investigaciones y proyectos. Manual de técnicas de gestión de vida silvestre. The Wildlife Society. EE.UU. pp.1-7.

Reyes, A. J. A. 1992. Estudio florístico de la Sierra de Monte Grande, Municipio de Charcas, San Luis Potosí, México. Tesis de Maestría. Colegio de Postgraduados/Centro de Botánica. México.

Tipton, A.R. 1980. Modelos matemáticos en la gestión de la vida silvestre. Manual de técnicas de gestión de vida silvestre. pp. 223-232.

Wobeser, G.A., et. al. 1980. Colección y preservación del material biológico en campo. Manual de técnicas de gestión de vida silvestre. The Wildlife Society. EE.UU. pp. 563-577.

Subject III

The Evolving Complexity of Inventorying and Monitoring Forest Ecosystems

Complexity of Sampling Multiple Resources[1]

W.E. Frayer[2]

Abstract—Experience with many inventories for single and multiple resources has resulted in suggestions to be considered when sampling multiple resources. Discussion begins with the design of the sampling unit and continues for such items as sampling design, sampling over time and projections of future status. Specific recommendations are given for each area discussed.

Many inventories are originally designed to monitor status and trends of a single resource. There have been inventories for timber, wildlife, agricultural crops, wetlands and other resources. In almost every case, those relying on information from the inventories have concluded that other information is needed. Plant and animal responses are usually affected by their surroundings. Timber must be characterized by its environment in order to evaluate its availability for harvest. Wildlife inventories usually must combine habitat measures as well as population densities and trends. Before long, it appears that there are many multi resource inventories—that each single-resource inventory has now become an inventory of multiple resources. Then pressure is exerted or felt to combine these inventories in order to eliminate waste and overlap. There are good reasons for doing this as well as several reasons for being very cautious in doing so. Unless there is agreement among users that the information derived from a single multi resource inventory meets their needs, the inventory may create more problems than it solves. Putting many things together does not necessarily save money. Larger field crews may be needed, and measurement times may be greatly increased. What follows are some guidelines for a multi resource inventory based on my experience with several single-purpose inventories and some efforts to expand those inventories to multi resource inventories.

Sample Unit Size

I shall start the discussion with the sampling unit. I know it's desirable to define a sampling frame that consists of a list of all sampling units so that the usual approach of sample selection and use of finite population theory is easily applied. It's not that easy with multi resources—although it's been tried. Some have tried to collect more and more information on the same plot—a plot (sampling unit) that was originally designed for collection of data on one resource. I believe that sampling units must be flexible so that they can be optimized for collection of data on many resources. I believe a useful procedure is to treat a sampling unit as the list of data collected with reference to a point in space and time. Timber information might be collected, in part, by a point sample (probability proportional to basal area). Habitat data may be collected by delineating the boundaries of the habitat the point is located within. Wetland data could be a map of the wetland the point falls within, a description of the type of wetland, distances to other wetlands and any other features needed. Finite population corrections would not be used, because, in essence, there are an infinite number of points contained within the population. This could be considered analogous to sampling with replacement.

1. Recommendation: Use points as sampling units. Many configurations of areas around a point may contribute to variable values for the sampling unit (point).

Variation Within and Between Sampling Units

As suggested, a sampling unit might be a point with data associated with various resources collected around the point. At any rate, the sampling unit may be complex. Many inventories use a cluster of points/plots as a sampling unit. For some reason, these clusters are often located close together. This may give data gatherers the belief that they're representing a fairly homogeneous area with the data collected. For sampling precision, however, there are very good arguments for maximizing the variation within the clusters and minimizing variation between clusters. The precision of population estimates is strongly dependent on the variation between sampling units—this being a strong argument in favor of absorbing as much variation as possible within the units. It often takes considerable travel time to locate the sampling unit. Why, then, confine the area of the cluster on which measurements are made to an area as small as an acre or a hectare? Spreading the measurements out over a larger area will, on the average, introduce more variability into the cluster and less variability between clusters. In some cases, transects may prove highly useful.

2. Recommendation: Design sampling units such that variation is large within units and small between units.

Movement of Sampling Units

The concern here is similar to that of the previous discussion. Some inventory procedures have included the practice of moving sampling units (or portions of sampling units) so that they have minimal variability—as in moving all parts of a cluster into a single vegetative type. This not only is counterproductive to obtaining precise estimates—it can also be a real procedural problem in later inventories when the sampling unit may again straddle vegetative conditions that have changed since the previous inventory.

3. Recommendation: Do not move sampling units.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Allocation of Sampling Units

Many designs have been tried for sampling single resources and multiple resources. Sampling with partial replacement (SPR) is one of the more complex designs used in forestry (Ware and Cunia, 1962; Bickford et al., 1963). With most inventories there is an important component of monitoring change as well as assessing current status and perhaps forecasting future status under various assumptions. Any time that sampling units are chosen with unequal probability or a complex design like SPR is used, there is a danger that the personnel who try to replicate the procedure for the subsequent inventory will not follow the same, exact procedure used before. Another potential hazard is the change of things over time. What was originally an optimum design based on varying probabilities may be far from optimum unless the probabilities can be redefined—regardless of the design used. For example, stratified sampling can become quite laborious to handle if stratum boundaries keep changing. For these reasons, when possible, I believe it best to "keep it simple" and use proportional allocation when there is not a distinct, overriding disadvantage.

4. Recommendation: Use proportional allocation.

Sampling Designs

As indicated earlier, complex designs like SPR have been used in forest sampling. Multi stage designs up to four stages have been attempted (Schreuder et al. 1992b). A three-phase design using high-altitude photography for an unsupervised classification, low-altitude photography for a more derailed stratification and ground plots for measurement was shown to be advantageous when compared to double sampling for stratification with low-altitude photography and ground plots (Kent et al., 1979). Stratified sampling with either known or estimated stratum sizes has stood the test of time. The procedure when estimating stratum sizes generally uses some type of remotely sensed data (be it satellite imagery, or aerial photography). Known stratum sizes may be delineated by political boundaries (states, counties), physiographic provinces, or any land classification that proves useful. Multi resource inventories conducted by US Forest Service Experiment Stations all use a form of stratified sampling with estimated stratum weights. Wetland inventories conducted by the US Fish and Wildlife Service use stratified sampling with strata formed by cross sections of political boundaries and physiographic subdivisions.

5. Recommendation: Use designs/procedures that are as simple as possible.

Random vs. Systematic Samples

Sample points could be located systematically or at random. If located systematically, caution should be used to avoid the potential bias of that approach. For example, you wouldn't want to locate sampling units on a systematic grid if some of the data you want to collect are located on a grid as well. An example of the potential danger would be school lands or railroad holdings in the western United States, both of which were originally laid out in a systematic grid. Other examples of potential problems are roads, fence lines, canals and other features located in periodic fashion. If transects are used, there may be certain instances in which measurements might be more efficient if not equally spaced.

6. Recommendation: Use a systematic design, but with caution.

Sampling Over Time

Inventories of natural resources are usually carried out to monitor status and trends. Many designs were adopted because of their precision in estimating status (estimating current values of population parameters). Sampling unit design has often been dependent primarily on how well it could be used to collect data on current values. Point sampling for timber volume (which samples trees with probability proportional to basal area is such an example). If the trends are of much importance, it may make sense to use a sampling design that is optimum for estimating changes. The solution is fairly simple. Ware and Cunia (1962) showed that a complete remeasurement design is optimum for estimating change if the measurements on successive occasions are correlated. Thus, regardless of the exact design used, it is highly recommended that all sampling units be remeasured.

7. Recommendation: Remeasure all sampling units.

Changes in Strata Over Time

If stratification is useful—and it generally is as discussed earlier—there must be some acceptable procedure for handling the problem of changing stratum boundaries over time. If working with complete stratification and complete remeasurement of sampling units, the units can be characterized by the stratum at the first or second occasion. For additivity with results from the previous inventory, the original stratification can be used. Post stratification (using the strata as delineated at the second occasion) will provide better correlation with current status and would generally be more precise for estimates of trends as well as status. If the stratum sizes are estimated from a primary sample, the ground plots must be stratified in the same fashion and should truly represent a subsample of the primary sample. In this case also, there are different estimates available depending on the stratification used for the estimation. In this case, too, the most recent stratification is recommended.

8. Recommendation: Use the most recent stratification for all estimates.

Future Status

Information on change has assumed more importance in recent years. Presumably, there is reasonably good information on current status and attention has turned to change and how to manage it. Change estimates are often based on average annual change between inventories. Projections are another estimate of change and are becoming more common and of vital use in soliciting funding for affecting future status. Agricultural and forestry organizations have routinely dealt with projections. It has been common to project 10, 20, even 50 years into the future. Others have only recently attempted this. The latest status and trends study of U.S. Wetlands used a Markov process for estimation of future status and trends. Without some indication of future status, it was feared that there was little information on which to base federal policies and programs. Given that projections are useful, they should be made with caution. Monte Carlo studies and jackknife estimates have indicated that rates of change used in projection procedures must be very precise for the projections to have any validity at all even for only a few years into the future.

9. Recommendation: Projections should be made with caution.

In Summary

The recommendations made are based on the experiences of the author. Some individuals may have a different opinion on one or more of these. I believe they form a reasonable set of guidelines, especially for those with very little personal experience who find that they must design a multi resource inventory. When in that situation, an additional recommendation is in order:

10. Seek advice from those with experience!

The recommendations given in the paper are summarized here:

1. Recommendation: Use points to define sampling units. Many configurations of areas around a point may contribute to variable values for the sampling unit.

2. Recommendation: Design sampling units such that variation is large within units and small between units.

3. Recommendation: Do not move sampling units.

4. Recommendation: Use proportional allocation.

5. Recommendation: Use designs/procedures that are as simple as possible.

6. Recommendation: Use a systematic design, but with caution.

7. Recommendation: Remeasure all sampling units.

8. Recommendation: Use the most recent stratification for all estimates.

9. Recommendation: Projections should be made with caution.

10. Seek advice from those with experience!

Literature Cited

Bickford, C. A., C. E. Mayer, and K. D. Ware. 1963. An efficient sampling design for forest inventory: the Northeastern forest resurvey. J. For. 61:826-833.

Kent, B., D. Johnston, and W. E. Frayer. 1979. The applications of three-phase sampling for stratification to multi-resource inventories. In: Proceedings, Forest Resource Inventories. Colorado State University. pp. 993-1000.

Schreuder, H. T., V. J. LaBau, and J.W. Hazard. 1992b. The Alaska four-phase sampling design. Submitted to Photogramm. Eng. Rem.Sens.

Ware, K. D., and T. Cunia. 1962. Continuous forest inventory with partial replacement of samples. Forest Science Monograph No. 3.

Reducing Barriers to Assessing Sustainability in the U.S.[1]

Albert Abee[2]

Abstract—Long-term sustainability must be a driving force for managers of natural resources. Although sustainable development has gained worldwide prominence, key difficulties in making progress towards that goal have been: the inability of resource managers to adequately communicate across ownerships; to integrate environmental, economic and social issues; and to make consistent measures of progress toward assessing sustainability. Coupled with these challenges, even with a framework for measuring national criteria and indicators, is the difficulty of reconfiguring the operational programs of diverse land management entities to integrate such a framework. The Criteria and Indicators (C&I) of Sustainable Forest Management (SFM) internationally agreed to by the 12 countries of the *Montreal Process*, have provided a monitoring framework for assessing sustainable forest management nationally. The USDA Forest Service (FS) has adopted the C&I and is in the process of institutionalizing them within the agency. Key components of the FS strategy for institutionalizing the C&I include broad based support from a wide constituent base; support and advocacy of top management; an administrative team to facilitate plan implementation, and a specific action plan to implement Criteria and Indicators internally. This paper presents the context for the national measurement system and the need for and benefits of adopting the Montreal Process Criteria and Indicator framework for SFM. The FS approach to incorporating the C&I framework as a national tool to assess the outcomes of management activities is also presented.

Building a Bridge to the Next Century of Resource Management

Social health and public welfare are affected by and dependent upon natural resources and the management of the landscapes in which they occur. There is increased recognition nationally and internationally that long-term sustainability must be a driving force for managers of natural resources. The goal of sustainability is predicated on the notion that we cannot meet the needs of people without concurrently securing the health of the land and visa-versa. The United Nation's Bruntland Commission acknowledged this in 1989 and called for sustainable development to, "meet the needs of the present without compromising the ability of future generations to meet their own needs (1)."

Further impetus to act on the issue of sustainability stems from the signing of Agenda 21 from the 1992 UN Conference on Environment and Development (2). In this historic agreement the role of sustaining forests and communities was formally acknowledged by the community of nations. Based upon this commitment, The President's Council on Sustainable Development (PCSD) was established to provide advice on how to move the country towards a more sustainable future. To help harmonize national land use plans and activities, the Administration identified policy recommendations and actions to *help guide the next century of land management* (3, 4). Related to the U.S's ability to collaboratively manage for and measure indicators of sustainability, these policies have four *desired outcomes* (5).

Improved Understanding for Informed Decision Making

To better enable informed decision making, managers need to promote understanding of resources conditions, trends, and relationships through: science and technology; education & training; and by sharing information & data. *Science & Research* should focus research in highest priority areas and to develop standard environmental indicators, protocols, and performance measures. *Education & Training* should focus on providing training in public involvement techniques to: endorse and promote educational material that improves awareness of environmental and social benefits of sustainable development; to develop extension activities translating science into everyday language; and to bring science information to communities. *Information and Data* processes should bring stakeholders together to collaboratively develop common data standards, formats, collection methods, and to develop public data-sharing and delivery systems.

Improved Planning Strategies to Reconnect a Fragmented Landscape

Managers should work towards reconnecting a fragmented landscape by promoting planning strategies that are anchored in communities, regional in scope, and interagency in design. *Anchoring land use plans in communities* will foster opportunities to move away from a federally focused governmental decision-making structure towards a *collaborative design* that shares responsibility among levels of government. Similarly, agencies are encouraged to *take an interagency approach* to harmonize respective resource management/land use plans and to do landscape planning independent of jurisdictional lines.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Promote Shared Responsibility for the Accomplishment of Work

Managers should use incentives and partnerships to promote shared responsibility for data gathering, monitoring, and management. *Use Incentives* to increase cost effectiveness of existing regulatory systems by expanding the roles played by states, counties, and local communities, and to increase cost recovery and establish market based incentives for protection and good stewardship of lands. *Develop partnerships to* shift the focus from centralized environmental regulation organized around separate programs/agencies to protect land and water resources, to a comprehensive place-based approach where responsibility is shared with stakeholders. In such cases, the federal role is adjusted to monitoring and assuring agreed upon performance-based standards are achieved in the process of shared responsibility. To realize efficiencies and to expand the use of the ecosystem approach to land management, *share personnel and facilities* with both federal and nonfederal sectors.

Practice Adaptive Management in Response to New Information

Management needs to be responsive to new information and emerging needs. In practicing adaptive management, work with other government agencies to *improve services* and to establish a more "seamless" government. Managers should consider establishing *monitoring and evaluation systems* that assess progress from performance measures rooted in national standards. Policy and *guidance should be reviewed* to assess statutes and regulations to remove barriers to collaboration and the development of partnerships. During such reviews, managers should identify comparative advantages and strategic niches of public natural resources to local communities to assist them in sustainable development.

All of the policy recommendations forwarded by the President's Administration were designed to foster the ecosystem approach to management, which is the means towards the goal of sustainability across a multiple ownership landscape.

Qualities of a National Framework to Measure Sustainability

The concept of sustainable development has gained worldwide prominence. Difficulties in making progress towards the goal of sustainable development have been the inability to adequately communicate between neighboring land managers; to integrate environmental, economic and social issues; and to take comparable measures across a landscape comprised of multiple ownerships.

Traditional inventory and monitoring approaches that were resource-specific and individually driven, served us well for the last several decades. However; such piecemeal approaches no longer meet the operational needs of today and of future generations. As implied in the desired outcomes of the policy recommendations mentioned, we need a more integrated and comprehensive approach. Using the United States as an example, what qualities should a national measurement framework have?

National Measurement Frameworks Should Focus on Key "Vital Signs"

The policy and management framework of the United States is diverse. There exists *a set of federal environmental laws* (i.e., National Environment Protection Act, National Forest Management Act, Federal Land Planning Management Act, Sustained Yield and Multiple Use Acts, Clean Air & Water Acts, T&E Species, Reclamation Act, etc.), that apply to either federal and/or all lands including federal, state, private, and industrial. This body of federal laws is augmented by *an eclectic set of state laws* of our 50 states, and *multiple sets of county ordinances* reflecting differences within states. Added to these legal requirements are the *different missions, objectives, and regulatory frameworks* of a host of resource management organizations that manage land and carry out activities designed to meet human needs.

Multiple ownership patterns also add to the operational complexity. For example, of the 489 million acres of commercial forestland, 58% is managed by over six million land owners; 15% by forest industries; 17% by USFS; and 10% by other public agencies (6). Coupled to this complexity are *species distribution patterns and habitat needs* that are independent of ownership boundaries; the variable location and *nature of vital commodities*; and *customer demands* for more frequent updating of inventory data. *Thus, it is easy to understand why monitoring and inventory systems can quickly become an ever rising tide of funding and information needs.*

Similar to the medical profession's approach to monitoring the vital signs of the complex human body, a national assessment framework should reflect a "vital signs" approach designed to take the pulse of the living landscape.

National Measurement Frameworks Should Integrate Social, Economic, and Biological "Vital Signs" and Link to Key Indices of Sustainability

The complexity of the American way of meeting human needs has proven to be both a blessing and a curse. A curse in that, on an aggregated basis, land use activities often play as a cacophony of unrelated and conflicting activities rather than as a harmonic symphony. A blessing is that the national body of environmental law and legislation not only provides a national multiple use framework based on the principles of sustainability, but mandates the protection of land and water resources concurrent to meeting the social demands for raw materials and services.

The value of our nation's resource management organizations is not to be found in our management diversity, mission, or even our legal framework—however important, *but in the measurable outcomes that reflect our collective actions.* Healthy ecosystems and sustainable economies are goals shared by national, county, state, private, and industrial ownerships alike. In this respect Sustainable Development should be viewed as a three-prong stool: ecosystems must be healthy, economies must be sound, and communities must be strong in order to fully meet the needs and expectations of people (7, 8). National measurement frameworks should integrate a set of social, economic, and biological "vital signs" and link to key indices of sustainability.

National Measurement Frameworks Should Link Ownerships Across the Landscape

Although sustainability has become an explicitly stated and legislatively mandated goal of natural resource management agencies, in practice our collective approach has often fallen short of maintaining the health and sustainability of landscapes. A primary reason for this failure, is that to one degree or another, land managing agencies that share responsibility for managing land within a common landscape often worked in isolation; managed along administrative lines; and often managed for a single purpose. Specifically:

- There is *no integrated, unifying framework for working across the landscape with different owners* to help enable complimentary assessments and desired conditions.
- There is *no common language of integrated data standards and protocols* to provide for assessments and planning processes across the diverse landscape.

Concurrent to this piecemeal approach to planning and management, federal agencies had in place a federally focused governmental decision-making structure that was more input and comment based rather than fully collaborative in true partnership. Shared planning, decision making, and management responsibility across levels of government and with communities of interest was not widely practiced.

In hind sight, however well-intentioned, the historical approach to management of natural resources contributed to multiple environmental problems, as well as to the halt of orderly management. A case in point is the Pacific NW where concern over the habitat needs of the spotted owl resulted in litigation that totally shut down traditional timber harvest activities. The needs of the spotted owl required a regional approach and perspective to resolve habitat problems and public concern. To measure the pulse of the landscape through a set of vital signs, requires that a National measurement framework be inclusive of all major ownerships.

National Measurement Frameworks Should Promote Collaborative Stewardship

A good thing that has evolved from our experience is the emergence of ecosystem based approaches (9, 10, 11) and the notion of collaborative stewardship, where people work together to achieve common objectives. Currently federal, state and private agencies spend millions of dollars on measurements without the assurance that these measurements are additive or that they are providing the information to measure performance and progress in assuring long-term sustainability of America's forests. Lacking evidence and the ability to portray "health of the land," creates an atmosphere of concern and distrust increasing the polarization of groups interested in natural resources. It also makes the nation vulnerable to the tyranny of crisis management.

Collaborative stewardship focuses on partners working together and sharing information with the hope of establishing and recognizing common ground and linkages, that when acted upon, will yield on an aggregated basis, a more holistic and complimentary approach to natural resource management. The desired outcome is healthy ecosystems and sustainable economies while respecting each others unique roles, responsibilities, and land use objectives. National measurement frameworks should promote collaborative stewardship with shared responsibility.

The Montreal Process Criteria and Indicators for Sustainable Forest Management Provides a Unifying National Measurement Framework for Assessing Progress Toward Sustainability

The Criteria and Indicators (C&I) of Sustainable Forest Management (SFM) internationally agreed to by the 12 countries of the *Montreal Process*, is providing a unifying framework for measuring the "vital signs" and assessing sustainable forest management (12). Briefly, the United States worked with eleven other countries through the Montreal Process to produce a set of criteria for evaluating sustainable management of forests. The C&I are a relatively simple statement of seven key goals (criteria), with associated measurements (indicators), designed to promote an understanding of what constitutes sustainable management of temperate and boreal forests.

The seven criteria are: Conservation of Biological Diversity; Maintenance of Productive Capacity of Ecosystems; Maintenance of Ecosystem Health and Vitality; Conservation and Maintenance of Soil and Water Resources; Maintenance of Forest Contributions to Global Carbon Cycles; Maintenance and Enhancement of Long-term Multiple Socio-Economic Benefits to Meet the Needs of Societies; and Legal, Institutional, and Economic Framework for Forest Conservation and Sustainable Management. The Forest Service has adopted these C&I (13, 14) and will work with partners to include grassland as appropriate.

These criteria and indicators for sustainable forest and grassland management then provide *an integrated, unifying framework* for the development of *common data standards and protocols for working across the landscape*. This assessment framework will facilitate collaborative evaluation, planning, and decision efforts among governments, interest groups, and neighboring land managers to address common interests.

FS Action Strategy to Implement the National Measurement Framework to Assess Sustainability

Other leaders of federal agencies, the States, environmental and industry NGO's (15, 16, 17, 18) also recognize and support the need for measuring the status, trends, and conditions of our nation's forests and grasslands. Early in

1997, the National Association of State Foresters requested that the Forest Service play a leadership role in fostering SFM on all U.S. forests.

The Forest Service developed a detailed Action Plan (19) identifying specific steps and processes involved in institutionalizing the C&I into operational programs. The scope of the Action Plan, while featuring internal implementation, included processes and linkages to other external initiatives designed to implement C&I nationwide.

The Action Plan includes a range of activities that need to be accomplished concurrently and interactively with the other tasks, but it does not identify priority of the tasks and actions. The intent is to facilitate collaboration and ensure that critical steps are not overlooked or lag behind. The Action Plan identifies major tasks leading to institutionalization of the national-level Criteria and Indicators within the Forest Service. The Action Plan reflects a phased approach to implementation and identifies the first steps that must be taken (What); the accountable person(s) within the FS that will convene the action (Who); and the expected completion date (When).

Collaboration is the Heart of the Action Plan

A foundational value of the FS is that the FS does not have all the answers and cannot achieve the goal of sustainability alone. This section of the Action Plan is to continue communications with existing stakeholders group and further diversify and expand collaboration with other parties as appropriate. The task is to develop shared roles and responsibilities for taking and reporting measurements related to the national C&I framework.

- *Maintain and develop collaborative relationships and processes with stakeholders and partners involved in implementation of national criteria and indicators.* An example of the level of detail provided in the Action Plan is reflected in (a) below.

(a) What: Develop plan for "round table event" involving Chief, stakeholders, partners, and other agency policy level representatives, to encourage interagency and stakeholder involvement. Who: Sustainable Development Issue Team. When: Plan for event approved by 1/98.

Status as of Sept. 16, 1998: Completed 7/14/98. Participants pledged to work together to develop a Memorandum of Understanding (MOU) to define the respective roles responsibilities of cooperating agencies to populate the measurement framework.

- *Continue liaison with Montreal Process.* Maintain Forest Service involvement in international processes related to sustainable development. Ensure an open conduit to Technical Advisory Committee of the Montreal Process and other international activities as appropriate.
- *Maintain participation in administration sustainable development activities.* Maintain Forest Service involvement in White House, USDA Council on Sustainable Development, Interagency groups and initiatives related to sustainable development. Coordinate C&I framework with national data standardization activities of the Federal Geographic Data Committee.

Development of Indicators to Enable Full Field Implementation

This section of the Action Plan is to enable populating the C&I framework with data. The plan provides for technical refinement of criteria and the development of standard data sets and collection protocols to facilitate communication between partners.

- *Conduct a process to refine the set of 67 indicators.* With the involvement of stakeholders and partners evaluate the effectiveness of the indicators in assessing status and trends of Sustainable Forest Management at a national scale. This process includes identifying what information is available, who has it, data comparability, and gaps in information needs. It also provides for parallel processes designed to develop criteria for grassland.
- *Consistency in reporting.* Continue development of data definitions, inventory and monitoring protocols, and reporting procedures for indicators at a national scale to ensure consistency and compatibility across jurisdictions and ownerships. This process includes establishing new roles and responsibilities related to shared responsibility for collecting information nation wide. The outcome would be an interagency, nationwide platform from which information can be collected over time.

Strategic Direction through Incorporation of C&I into Strategic Planning Documents

This section of the Action Plan is to establish strategic direction, focus, and systems for accountability. The objective is to integrate the Montreal Process C&I framework into the Agency's strategic plans, annual reports and performance plans, and monitoring and inventory systems, including development of strategic guidance to advance principles of sustainability.

- *Integrate criteria into resource assessment documents.* Utilize national resource assessment as the Forest Service synthesis and reporting mechanism for the Montreal Process C&I at the national level, integrating the Criteria into the framework for the Resource Planning Act (RPA) Assessment.
- *Integrate Montreal Process C&I framework into the NFS information management structures.* Incorporate C&I into all resource planning, inventories, and monitoring systems, recognizing the relevance of scale in each process.
- *Integrate C&I into corporate data sets collected from national inventory grid systems.* Incorporate national scale measurement protocols for the Montreal Process indicators into national plot procedures and extend grids to cover all forestlands, taking into account the National Resources Inventory and other existing inventory capabilities.
- *Collect data and information on the status of the Nation's forests at the national level using the Montreal Process C&I.* Allow incorporation in each 5-year update of the national RPA assessment. Assess the relationship between currently collected information versus what is needed with C&I and identify possible cost savings that will help pay for C&I monitoring.

FS Progress in Implementing the National Assessment Framework

Democratic and collaborative processes are foundational to the American tradition. The FS has a rich history of developing partnerships with external communities, organizations, individuals, and who have an interest in the outcome of FS management activities.

The FS has established a formal collaborative relationship with other federal agencies, the NASF, professional societies, and a set of NGOs to work together to develop a Memorandum of Understanding (MOU) to define the responsibilities of cooperating agencies and partners committed to populate the national C&I framework for SFM. The partners agreed to: participate in scientific teams examining the C&I to establish a common list of national level, ecological, social and economic measures and protocols; to identify current sources of information; seek to establish a collaborative national inventory platform from which to gather data; and collect and report on indicators specific to agency missions; and to develop a *National Report on Sustainable Forest Management by 2003*.

The FS has restructured the national RPA Assessments dealing with forests to conform to the Montreal Criteria. Documents will address the question—What are the status and trends of U.S. forests in relation to the forest management indicators? The Agency is also in the process of restructuring national strategic objectives and outcome measures in the Government Performance Results Act strategic plan to reflect the Montreal Process C&I.

The FS is developing direction to link forest level planning goals and objectives to the national strategic goals and objectives. This will facilitate management unit level responsiveness to national SMF goals and establish accountability structures. We have also begun the incorporation of the C&I into national, regional, and local corporate inventory and monitoring measurement systems. (For example, at the national level, the FS National Inventory and Monitoring Program can provide data on 18 of the 28 biological indicators noted in Criteria 1-5. Work will continue to help answer more of the data needs).

The National Association of State Foresters has adopted the Montreal Process C&I as a goal and some states are in the process of conducting State assessments using the C&I.

Lessons Learned

It is important to build support within your own agency. A shared national vision internally builds momentum locally. Confusion can be avoided by gaining understanding of what the specific objectives are and how such add value to respective partners (20).

Building support and developing partnerships with external customers is also critical to success. The FS does not have all the answers and cannot solely accomplish SFM. Establishing collaborative processes through partnerships adds value to FS efforts as well as to partners.

It takes a lot of energy to change the operational traditions of an organization. To provide focus and momentum, establish an implementation team that represents the Agency and select players that are highly motivated and that believe in and want to be involved in the effort (21).

In order to assess forward progress a road map is necessary. Develop an Action Plan that identifies specific tasks for operational implementation; responsible individual; and time frame for completion.

Keep focus on agreeing to goals and objectives and build on consensus and common ground, rather than surfacing issues. Focusing on issues should be avoided in favor of working toward broad consensus on goals and objectives among local, regional, and national interests. When issues arise, they should be intercepted and dealt with at the appropriate scale. Work with willing partners respecting each other's unique roles, responsibilities, and land use objectives.

Generate Ownership at the Local Community Level through Responsible Empowerment. Responsible leadership often comes from unsuspecting places. Allow participants to assume lead responsibility for processes and tasks within defined decision space. As appropriate, the federal role should be adjusted to monitor and assure that agreed upon performance-based standards are achieved throughout the process of shared responsibility. Use a professional facilitator to run the sessions to avoid the perception of a "federally driven" process.

Use a Collaborative Decision-Making Process: Change the paradigm. Planning strategies should move from federally focused, governmental decision-making structures to collaborative designs that shares responsibility among citizens and government. Involve all interested parties early in the process. Be confident in enabling and encouraging shared responsibility for populating the national measurement framework with data. Do not impose constraints but define outcomes with quality assurance.

Challenges to Implementation of the Criteria and Indicators

While there is agreement that the "Montreal" Criteria are sufficiently broad and well enough defined to be a valuable framework for Sustainable Forest Management, considerable technical examination—as a parallel process, may be needed. While some indicators can be implemented fairly soon, many are far from actual application.

Complexity and "turf" issues can delay progress. Developing agreed upon protocols and data standards, or developing mechanisms to provide compatibility between common but dissimilar data sets requires flexibility and willingness to change.

We need to know more about issues of scale for the indicators and the appropriate protocols for different scales. For example, what is the relationship between national level reporting and sub-national/forest management unit level operations?

Parallel to cooperative program activities designed to populate the C&I measurement framework; coordination of the respective budgets of interagency partners is cumbersome.

Summary

American people love their land and together, everyday, are discovering new ways that public health and social welfare are linked to the health of the land. They expect the resource management community to sustain the nation's natural resources for future generations.

The nation continues to undergo significant changes that affect land managers. The values that we manage for, the scope of our work, and the partnerships involved have especially expanded. Many resource assessments have moved from piece-meal projects to regional assessments, enabling a more holistic understanding of ecosystem processes and social needs.

Legislation and regulation are important, but alone will not achieve sustainable ecosystems, communities, and economies. Collaborative planning efforts are proving to be the vehicle of choice for managers to reconnect the landscape; to foster community understanding and the development of shared goals; and is the primary integrator of the diversity of interests wherein the nation has its stability and strength.

National measurement frameworks should focus on key "vital signs" linked to sustainability; integrate social, economic, and biological indices; be inclusive of all ownerships across the landscape; and promote collaborative stewardship.

The adoption of the Montreal Process framework of C&I will go far in helping to establish a common language and operational framework for bringing the community of interests together to do collaborative national assessments of sustainable forest management.

Bibliography

1. World Commission on Environment and Development, 1987, Our Common Future, New York, Oxford University Press.
2. Agenda 21: Rio Declaration. Statement of Forest Principles. UN Conference on Environmental Development, 1992, Rio de Janeiro, Brazil.
3. President's Council on Sustainable Development: *Sustainable America: A New Consensus for Prosperity, Opportunity, and a Healthy Environment for the Future.* Washington DC: Feb 1996.
4. Interagency Ecosystem Management Task Force: *The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies, Volume 1-3.* Washington, DC: June 1995, Nov. 1995, October 1996.
5. Abee, A. 1996. Matrix That Harmonizes Recommendations and Action Items of the President's Council on Sustainable Development (*Sustainable America: A New Consensus for Prosperity, Opportunity, and a Healthy Environment for the Future.* Washington DC: Feb 1996) and the Interagency Ecosystem Management Task Force (*The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies, Volume 1-3.* Washington, DC: June 1995, Nov. 1995, October 1996). File designation:aabee/sustainability/whole.text. 16pp. USDI Bureau of Land Management, Washington D.C.
6. Powell, Douglas, J.L. Faulkner, D.R. Darr, Z. Zhu, and D.W. MacCleery. 1993. Forest Resources of the United States. In: Table 2, USDA Forest Service General Technical Report RM-234 (Revised). Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO, 80526.
7. Robertson, F. D. 1992. Letter to Regional Foresters and Research Station Directors. File designation:1003-1. Subject: Ecosystem Management of the National Forests and Grasslands. 3pp. USDA Forest Service, Washington DC.
8. Thomas, J.W. 1996. Forest Service Perspective on Ecosystem Management. Ecological Applications 6(3):703-705.
9. Sexton, W.T. 1998. Ecosystem Management: Expanding the Resource Management "Tool Kit". Landscape and Urban Planning (Special Issue—Ecosystem Management) 40 (1-3):103-112.
10. Jensen, M.E. and P.S. Bourgeron (Editors). 1993. Eastside Forest Ecosystem Health Assessment, Volume II Ecosystem Management: Principles and Applications. USDA Forest Service. Pacific Northwest Research Station, Portland, OR. 397pp.
11. Borman, B.T., R.F. Tarrant, J.R. Martin, J. Gordon, F.H. Wagner, J. McIver, G. Wood, G. Reeves, J. Alegria, J. McIlwain, P.G. Cunningham, J. Verner, M.H. Brooks, N. Christensen, P. Friesema, K. Klein, J. Berg, J. Furnish, and J. Henshaw. 1999. Adaptive Management: Common Ground Where Managers, Scientists, and Citizens Can Accelerate Learning to Achieve Ecosystem Sustainability. *In*: The Interagency Stewardship Workshop: Common Reference for Ecosystem Management. Sexton, W.T., R.C. Szaro, N. Johnson, and A. Malk, editors. Elsevier Press, Oxford. 1500pp. (in press).
12. Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. 1995. The working group on criteria and indicators: Australia, Canada, Chili, China, Japan, Republic of Korea, Mexico, New Zealand, United States. Canadian Forest Service, Quebec, Canada.
13. Dombeck, Michael, 1997. Letter to President, National Association of State Foresters. File code 3000, July 23, 1997, USDA Forest Service.
14. Dombeck, Michael, 1998. A Gradual Unfolding of a National Purpose: A Natural Resource Agenda For The 21 st Century, transcription of a speech given to U.S. Forest Service employees on March 2, 1998.
15. The Keystone Center. *The Keystone National Policy Dialog on Ecosystem Management.* Keystone, CO: Oct 1996.
16. GAO. Ecosystem Management: Additional Actions Needed to Adequately Test A Promising Approach. Washington, DC: US GAO/RCED-94111, 1994.
17. American Forest and Paper Association. *Ecosystem Management: "A New Approach to Federal Forest Management and Planning".* Washington, DC: American Forest Products Association, November 1993.
18. Bureau of Land Management. *Ecosystem Management in the BLM: From Concept to Commitment.* U.S. Government Printing, 1994.
19. Integration Of Criteria And Indicators Of Sustainable Forest Management In The USDA Forest Service. 1997. USDA Forest Service Sustainable Development Issue Team. Internal working document, USFS Washington DC.
20. Johnson, Kate, A. Abee, G. Alcock, D. Behler, B. Culhane, K. Holtje, D. Howlett, G. Martinez, and K. Picarelli. 1999. Management Perspectives on Regional Cooperation. *In*: The Interagency Stewardship Workshop: Common Reference for Ecosystem Management. Sexton, W.T., R.C. Szaro, N. Johnson, and A. Malk, editors. Elsevier Press, Oxford. 1500pp. (in press).
21. Yaffee, Steven L., Regional Cooperation: A Strategy for Achieving Ecological Stewardship. 1999. Management Perspectives on Regional Cooperation. *In*: The Interagency Stewardship Workshop: Common Reference for Ecosystem Management. Sexton, W.T., R.C. Szaro, N. Johnson, and A. Malk, editors. Elsevier Press, Oxford. 1500pp. (in press).

Mexican Experiences in Forest Monitoring Research[1]

Carlos Rodríguez Franco[2]

Abstract—Mexico started its National Permanent Forest Inventory in the 1970´s. There was a sustancial advance in field work in several states of the Mexican Republic, however, due to several reasons the project was abandoned and all the data were not processed.

Several Mexican Organizations related to the Mexican Forest Activity, also started their own permanent forest inventory, such as the Ex Unidad Industrial de Explotación Forestal with an influence area in the states of Mexico, Puebla and Morelos, the Ex Unidad Industrial de Explotación Forestal Michoacana de Occidente and the National Institute of Research in Forestry, Agriculture and Animal Husbandry of Mexico (INIFAP).

INIFAP since 1971 has established a permanent plot network in 10 mexican states covering all the forest ecosystems with 294 plots. Since that time all the measurements had been processed and analized for the states of Quintana Roo, Campeche, Chiapas, Chihuahua, Durango, Jalisco, Michoacan, Oaxaca, Puebla, and Veracruz.

The main problems faced during this time has been related to the lack of specialized technicians, the lack of methodologies for integrating all the data, and obtaining results and the scarcity of computational equipment for management and processing big amounts of records. Currently, all these problems have been resoluted.

The importance for INIFAP for undertaking this project at national level is to know in the short, medium and long term the behaivour and characteristcs of the different forest ecosystems, and determine their dynamics, and their capability of adaptation to several disturbances according to their growing conditions such as soils, topography and climate.

Finally, it is expected to have enough information for creating a data bank for obtaining growth prediction models for different characteristics of forest stands by ecosystems to be employed in planning forest management activities.

México, desde inicios de la década de 1970, comenzó sus trabajos de Inventario Forestal Continuo a nivel Nacional, habiendo tenido un avance sustancial en la toma de información en diversos estados de la República Mexicana; sin embargo, por diversas razones el proyecto fue abandonado y la información no fue procesada.

Diversas instituciones mexicanas relacionadas con la actividad forestal también iniciaron trabajos de inventario forestal continuo, como la Ex-Unidad Industrial de Explotación Forestal de San Rafael en su área de influencia (Estado de México, Puebla y Morelos), la Ex-Unidad Industrial de Explotación Forestal Michoacana de Occidente y el Instituto Nacional de Investigaciones Forestales y Agropecuarias, el cual estableció una red de 294 sitios permanentes en 10 estados del país, cubriendo todos los ecosistemas arbolados, estos trabajos iniciaron desde 1980, de la información obtenida desde ese entonces hay sitios que han sido procesados y analizados, dentro de los cuales se encuentran los de los estados de Quintana Roo, Campeche, Oaxaca, Puebla y Durango principalmente.

Los problemas que se enfrentaron para que no hubiese un avance en el procesamiento de la información proveniente de los sitios permanentes, se relacionan con la falta de personal especializado para definir los niveles de integración de la información; los resultados a obtener y la aplicación de los mismos, al manejo de los recursos forestales, así mismo no se contaba con la infraestructura suficiente de cómputo para el manejo y procesamiento de grandes volúmenes de información, problemas que actualmente han sido superados.

La importancia de poder llevar a cabo los trabajos de inventario forestal continuo, reside en el hecho de que al manejar información proveniente de una red de sitios permanentes de inventario forestal es posible conocer en el corto, mediano y largo plazos el comportamiento y características de los diferentes ecosistemas que integran el recurso arbolado de México, determinar la tendencia dinámica de dichos ecosistemas y conocer su respuesta a diferentes factores que influyen en su dinámica evolutiva, además de caracterizar la capacidad productiva en que prosperan de acuerdo con sus características edáficas, fisiográficas y climáticas.

Finalmente, se espera obtener la información suficiente para la creación de un banco de datos que permita la obtención de modelos de predicción del comportamiento de los diferentes tipos de rodales en lo que se refiere a crecimiento en diferentes dimensiones, y en su densidad, con lo cual se podrá realizar la planeación de las diferentes actividades silvícolas y asignación de tratamientos específicos para los rodales en cuestión en el corto, mediano y largo plazos, y además se podrán determinar los diferentes tipos de productos a obtener y se podrán definir las estrategias de abastecimiento y expansión de la industria forestal nacional.

La importancia de la participación de INIFAP en los trabajos de Inventario Forestal Continuo es el que sus investigadores tengan un panorama detallado de la problemática forestal existente en los ecosistemas forestales y el contar con diagnósticos que permitan un mejor enfoque y priorización de las actividades de investigación futuras, y sobretodo contar con una base de datos detallada en corto tiempo de recursos forestales, la cual tiene amplias posibilidades de aplicación en trabajos de investigación para el manejo de recursos forestales y para la planeación de actividades de protección, conservación y fomento de los mismos.

Antecedentes en Mexico

- En 1938 se crea la "Comisión de la Carta Forestal" para ubicación de los Bosques y Selvas a un nivel de 1 km cuadrado.

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- En 1950 se inició el Convenio México-FAO para realizar la cuantificación de los Recursos Naturales de México.
- En 1953 se concluye el Primer Inventario Forestal en gran escala, para la Meseta Tarasca, Michoacán.
- En 1955 se lleva a cabo el Inventario de la Ex-Unidad de Explotación Forestal Michoacana de Occidente a escala 1:20,000.
- En 1961 se inicia formalmente con apoyo de la FAO, el Inventario Nacional Forestal a través del Ex-Instituto Nacional de Investigaciones Forestales (Actualmente INIFAP):
- En 1965 se crea la Dirección General del Inventario Nacional Forestal con la meta de concluir el primer paso de Inventario en 20 años.
- En 1971 se inician las actividades del Inventario forestal continuo con el establecimiento de sitios permanentes en 9 estados, cubriendo una superficie de 4 millones de hectáreas.
- En 1971, INIFAP inicio la investigación en Monitoreo de Recursos Forestales con el establecimiento de una red de Sitios Permanentes en 10 estados del país.

Antecedentes de Investigacion en Mexico

- En 1950 se estableció el primer sitio permanente en México, "El Poleo", en Madera, Chihuahua, en una superficie de 8 hectáreas.
- En 1960 se estableció el sitio experimental "Las Nieves", en la Ex-Unidad Industrial de Explotación Forestal Michoacana de Occidente, en una superficie de 10 hectáreas.
- En 1966, Ex-Unidad Industrial de Explotación Forestal de San Miguel de Cruces, Durango, estableció el sitio "Cielito Azul", en una superficie de 36 hectáreas.
- En 1971 el INIFAP estableció el sitio "Plan de Marines", en San Juan Tetla, Puebla, en una superficie de 16 hectáreas.
- En 1980 el INIFAP establece una red de sitios permanentes en 10 estados cubriendo una superficie de 1,129 hectáreas., y desde 1980 se realizan remediciones periódicas cada 5 años.

Problemática Inicial Para el Monitoreo de Ecosistemas Forestales

- Amplia diversidad de ecosistemas forestales, con un gran número de especies, y condiciones de crecimiento.
- Carencia de personal altamente especializado, en las diversas disciplinas involucradas en Inventario y Monitoreo.
- Carencia de infraestructura, equipo especializado para toma y procesamiento de grandes cantidades de información.
- Falta de una metodología uniforme, con control de calidad, y sistemas de control y verificación de la información.
- Procesamiento incompleto de la información.
- Falta de metodologías para análisis dinámico de la información.
- Bases de datos no interoperables, no intercambiables y no congruentes.
- Actualmente toda la problemática señalada, ha sido superada.

Objetivos Generales

- Establecer una red de sitios permanentes a nivel nacional cubriendo de manera representativa, la diversidad de condiciones de crecimiento de todos los ecosistemas forestales del país, para su inventario y monitoreo.
- Generar una base de datos periódica de características de dimensiones y atributos de vegetación arbórea , arbustiva y herbácea, y de características del medio de crecimiento, incluyendo registro de factores de disturbio natural e inducido.
- Determinar las características cuantitativas y cualitativas de los ecosistemas forestales para diferentes condiciones de crecimiento.
- Documentar los cambios y tendencias de los recursos de los ecosistemas forestales y su biodiversidad.
- Determinar periódicamente los impactos y efectos de disturbio naturales e inducidos, en los ecosistemas forestales.

Objetivos Especificos

A Corto Plazo—Establecer sitios de muestreo en cualquier porción del espectro de tipo de ecosistema existente en el país que sirva a la experimentación, la operación e investigación, y que por su naturaleza numérica sea manejable en:

- Caracterización de ecosistemas forestales
- Fenología de especies forestales
- Técnicas de inventario forestal
- Desarrollo de modelos de crecimiento de árbol individual y de rodal completo
- Calidad de sitio
- Tablas de volumen
- Tablas de producción
- Guías de densidad
- Índices de competencia
- Establecimiento y desarrollo de regeneración natural
- Sistemas silvícolas
- Aplicación de cortas intermedias
- Efectos de disturbio sobre ecosistemas forestales
- Dinámica forestal.

* Analizar la información generada en los sitios para su estandarización.

A Mediano Plazo—
- Conocer el comportamiento de las especies en distintas etapas de desarrollo.
- Obtener el espectro de opciones que se presentan después de manejar los ecosistemas y evaluar su dinámica.
- Diseñar una metodología para desarrollar experimentos comparables sobre tratamientos a los ecosistemas, basados en modelos ya creados y sistemas silvícolas en proceso de validación.

- Evaluar los impactos de actividades de intervención en el ecosistema.

A Largo Plazo—

- Adecuar las nuevas metodologías de estudio del ecosistema y sistemas de manejo.
- Diseñar sistemas expertos para la toma de decisiones en el manejo de los ecosistemas.

Metodología

La metodología a continuación descrita, será definida de manera breve y concisa para la planeación de los trabajos de campo, y ésta irá afinándose a medida que se continúe con los trabajos en específico. La metodología será dividida en tres fases.

Planeación—En esta etapa se procederá a la recopilación de la información cartográfica del lugar de estudio, para lo cual se requiere de fotografías aéreas, de ortofotos y un mapa forestal; asimismo se requiere tomando como base el marco muestral efectuado para la realización del muestreo anterior, la distribución de los sitios levantados en el inventario forestal realizado a nivel de región, municipio, predio y rodal con la finalidad de determinar la diversidad de condiciones en las cuales se distribuyó la muestra con anterioridad, así como determinar los casos faltantes de muestra. Una vez realizado lo anterior, se procederá a la selección de la muestra de sitios permanentes del inventario forestal continuo tomándose los siguientes criterios:

- Se considera un diseño de muestreo completamente al azar.
- La población motivo de estudio será definida como aquella proveniente del conjunto de sitios levantados para el Estudio Dasonómico del Ejido.
- La intensidad de muestreo a realizar será de un 10% del número de sitios levantados con anterioridad.
- El sistema de selección de la muestra será sin remplazo.
- Para la elección de la muestra se dará un número progresivo a cada uno de los sitios levantados, de tal forma que con la definición de este marco muestral, será posible identificar y diferenciar a un sitio ubicado en una determinada región, municipio, predio y rodal. Una vez realizado lo anterior se procederá a la selección de la muestra de una manera completamente al azar, mediante la utilización de una tabla de números aleatorios.

Ejecución. Para la realización de los trabajos en esta fase se subdividirá en 3 actividades que son las siguientes:

A) Etapa pre-campo. En esta fase se llevará a cabo la identificación de la ubicación del sitio seleccionado, para determinar en que región, municipio, predio y rodal se encuentra establecido dicho sitio y proceder a su localización física en la siguiente fase.

B) Etapa de campo. En esta fase se procederá a la ubicación física del sitio en el terreno y se procederá a la toma de información siguiente:

- Delimitación del sitio, ubicación del centro del mismo (Georeferenciado)
- Datos del sitio. Número del sitio, características del sitio como altitud, exposición, pendiente, fecha de medición
- responsable del levantamiento.
- Número del árbol.
- Especie.
- Diámetro de tocón con corteza, medido con cinta diamétrica en cm.
- grosor de corteza para ambas mediciones en mm.
- Altura total en m, medido con clinómetro Suunto.
- Altura de fuste limpio en m, medido con clinómetro Suunto.
- Edad tomada a la altura del pecho, con taladro de Pressler.
- Amplitud de los últimos 10 anillos anuales de crecimiento.
- Número de anillos en los últimos 2.5 cm.
- Diámetro de copa en m, medido en dos direcciones Norte-Sur y Este-Oeste.
- Clase de copa tomada como dominante, codominante, intermedia o suprimida.
- Conformación del fuste tomada como fuste recto o bifurcado.
- Vigor del árbol, registrado como sano, enfermo o muerto.
- Señales de cicatrices por disturbios, causadas por incendios, ataque de insectos, o daños causados por obtención de resinas.
- Número de trozas comerciales.
- Volumen total por árbol, en m3 que será determinado a través de tablas de volúmenes específicas.
- Volumen de fuste libre de ramas en m3, determinado de las mismas tablas.
- Localización del árbol en el sitio por medio de un sistema de coordenadas X y Y y su numeración en orden progresivo, siguiendo el sentido de las manecillas de un reloj, para lo cual se requiere tomar la distancia del centro del sitio al árbol y su azimut correspondiente.
- Datos ecológicos-silvícolas considerados en el estudio Dasonómico.

C) Etapa Post-campo. Generación, validación y captura de la información obtenida en campo.

Análisis de la Información—La información obtenida será clasificada en primer lugar de acuerdo a la región, municipio, predio y tipo rodal de donde proviene con la finalidad de caracterizar al rodal en lo que se refiere al número de árboles que sustenta por unidad de superficie, diámetro normal promedio, altura promedio, área basal promedio, volumen promedio, edad promedio, incremento medio anual, incremento periódico, altura de fuste limpio promedio y número de trozas comerciales promedio. Para lo cual se obtendrá la estimación de los parámetros de tendencia central y medidas de dispersión para cada variable considerada en la toma de información realizada. El objetivo de este análisis será el caracterizar los diferentes tipos de estructuras arboladas en lo que se refiere a condiciones de crecimiento, composición botánica, parámetros de las variables medidas, y determinar en que rangos de condiciones prosperan de forma óptima tales estructuras. Así mismo, será posible determinar la composición y las interrelaciones existentes de cada uno de los estratos involucrados en cada tipo de estructura. Finalmente este análisis conducirá la determinación de las diferentes interacciones entre los diferentes componentes del ecosistema determinadas mediante matrices de correlación.

El segundo tipo de análisis de la información será referido a la estimación de los patrones de crecimiento de las especies, encontradas en un determinado tipo de estructura en lo que se refiere a su velocidad de crecimiento en altura, diámetro normal, área basal y volumen con lo cual se espera obtener los puntos óptimos de crecimiento en su espectro de vida, con lo que será posible determinar los turnos físico, económico, financiero y técnico para planear las actividades silvícolas por aplicar a cada tipo de estructura con la finalidad de optimizar la ocupación del espacio de crecimiento y lograr la máxima rentabilidad económica de valor esperado de uso del suelo por mantener arbolado en pie. Todo lo anterior será obtenido a través de modelos de regresión lineal múltiple o modelos de regresión no línea, según se logre el mejor ajuste de la información obtenida en cada caso.

El tercer tipo de análisis de la información será realizado para, determinar la eficiencia de uso del espacio de crecimiento; por parte de los árboles, prosperando en un determinado tipo de estructura para lo cual se desarrollarán mediante técnicas de regresión, diferentes índices de densidad con la finalidad de determinar el número óptimo de árboles en pie por unidad de superficie, para una etapa de desarrollo específica del rodal para lograr la máxima ocupación del espacio de crecimiento. Los índice de densidad a probar serán aquellos desarrollados por las técnicas del factor de competencia de copas, relación area-árbol, índice de densidad de Reinecke, y el índice de desarrollo por Seymour y Smith, tales índices permitirán la obtención de guías de densidad que fijarán la norma de ocupación del espacio de crecimiento en términos cualitativos como sobredensos, completamente poblados y subpoblados para cada rodal y términos cuantitativos dado que cada guía proporcionará información acerca del número de árboles por hectárea, el área basal por hectárea para ese numero de árboles con un diámetro promedio dado, lo que servirá de norma para la planeación de las actividades silvícolas para aplicar en cada caso y proyectar la estructura esperada en el tiempo.

Con la información proveniente de arbolado dominante de altura-edad se procederá a la obtención de una familia de curvas de índice de sitio ya sea del tipo anamórfico o polimórfico según se logre el mejor ajuste de la información a modelos de regresión lineal o no lineal, con la finalidad de determinar la capacidad productiva de cada rodal para sustentar el crecimiento de árboles, acorde a las características del medio en que prosperen dichos árboles. Dicha calidad de estación permitirá definir la intensidad de manejo a que deberán someterse dichos rodales.

Finalmente se procederá a la estimación del crecimiento de rodales mediante el uso de la técnica de un sistema de ecuaciones de producción, utilizando como variables predictoras las características de cada rodal en lo que se refiere a edad, índice de sitio, área basal por hectárea o número de árboles por hectárea utilizado en la utilización de volumen, este método tiene la ventaja de proporcionar excelentes estimaciones de la proyección del crecimiento esperado en el rodal a partir de un área basal inicial, es altamente aplicable a rodales incoetáneos, también de baja densidad y es utilizable para estimaciones de corto plazo, hasta que se logre obtener toda la información disponible para el desarrollo total de un tipo de rodal, con este análisis se logrará tener la planeación de las diferentes actividades silvícolas a aplicarse en cada caso específico, además de poder conocer el tipo de productos a obtener, se podrá proyectar el tipo de estructura y su crecimiento en el tiempo y se podrá conocer de antemano la factibilidad financiera de la aplicación de un determinado tipo de actividad silvícola en el rodal, con el cual se pueden planear un balance adecuado entre las actividades de abastecimiento en el momento actual y futuro de acuerdo a las necesidades de la industria a abastecer.

Logros Alcanzados

En el Cuadro siguiente se presentan de forma resumida, los avances alcanzados a la fecha.

Estado	Paraje	F. inicio	# Sitios	Especies	Estudios Generados	Tema
Chihuahua	5	1950-83	231	Pino 6 Encino 1	19	Ecología, Silvicultura, Biometría
Durango	1	1982	40	Pino 5, Pseudotsuga 1, Encino 1, Juniperus 1,	3	Silvicultura, Biometría
E. de Mexico	1	1981	18	Abies 1, Pino 1	2	Ecología
Jalisco	6	1980-85	219	Pino 7, Encino 1, Hojosas 1	6	Biometria, Silvicultura
Michoacan	1	1978-80	596	Pino 4	2	Biometría, Silvicultura
Oaxaca	6	1983-84	6	Pino 4	3	Biometria
Chiapas	13	1980	14	Pino 4, Hojosas 1, Cedro 1,	2	Ecología, Biometria
Veracruz	3	1985	3	Pino 2, Encino 1	3	Ecología, Biometria, Silvicultura
Campeche	1	1981	8	Tropicales 70	3	Ecología, Silvicultura, Biometria
Q. Roo	2	1981-86	10	Tropicales 10	2	Ecología, Silvicultura
Total	39		1145		45	

En los Cuadros a continuación, se presenta en detalle la relación de la Red Nacional de sitios permanentes del INIFAP, para el Inventario y Monitoreo de ecosistemas Forestales del INIFAP.

Lineas de Investigacion en Operación

En Ecologia—

- Caracterización de ecosistemas.
- Composición de especies.
- Fenología de especies forestales.
- Dinámica sucesional.
- Efecto de disturbios.
- Caracterización de plagas.
- Caracterización de enfermedades.
- Clasificación y análisis de suelos.
- Evaluación de producción de agua.
- Captura de carbono.

En Bimetria Forestal—

- Técnicas de inventario.
- Tablas de volúmenes.
- Modelaje de mortandad.
- Determinación de índices de sitio.
- Determinación de guías de densidad.
- Determinación de índices de competencia.
- Modelaje de crecimiento de árboles individuales.
- Modelaje de crecimiento de rodales.
- Modelos de simulación.

En Silvicultura—

- Establecimiento y desarrollo de regeneración.
- Determinación de estructuras.
- Efectividad de labores culturales.
- Diseño de cortas intermedias.
- Diseño de sistemas silvícolas.

LUGAR	PARAJE	FECHA DE ESTABLECIMIENTO	DIMENSIONES	CANTIDAD	NÚMERO DE CONTROL	FECHA DE REMEDICIÓN	TRABAJOS DE INVESTIGACIÓN	ESPECIES
Madera, Chih.	El Poleo	1980 (1950+)	100x100m	9	01,...,09	1990	1.- El Sitio Exp El Poleo y su Comportamiento; 2.- Treinta años del Sitio Permanente de Inv. Forestal El Poleo y su Comportamiento; 3.- Caracterización de un Bosque Virgen	*Pinus chihuahuana, P. durangensis, P. engelmannii, P. leiophylla y Quercus spp*
Madera, Chih.	El Largo	1981	100x100m	7	01,...,07	1986	1.- Transecto Ecológico del A.E.F. El Largo, 2.- Caracterización Dendrométrica de *Pinus arizonica* en el A.E.F. El Largo	*P. durangensis* *P. arizonica*
Madera, Chih.	Zona Norte de el ejido El Largo	1981	100x50	5	01,...,05	1986	Evaluación de aclareos establecidos por el Dr. Shubert	*P. engelmannii* *P. ayacahuite* *P. chihuahuana* *P. leiophylla*
Madera, Chih.	Zona Norte de el ejido El Largo	1981	100x100m	1	1	1986	Evaluación de aclareos establecidos por el Dr. Klepac	
[1]Madera, Chih.	Madera	1980 1981 1982 1983	100x100m 100x100m 100x100m 100x100m	5 3 3 2	01,...,05 06,...,08 09,...,11 12,...,13	1990 1986 1987 1988	1.-Caracterización dendroepidométrica de las etapas de desarrollo de las especies forestales del A.E.F. Madera; 2.- Análisis de diferentes etapas de desarrollo estructural en Bosques de *Pinus arizonica* del A.E.F. Madera; 3-Algunas consideraciones en la aplicación de aclareos en una masa joven de pino; 4-Aclareos en una masa joven de Pinus durangensis; 5.-Regeneración mediante árboles padres de *Pinus arizonica*; 6.- Dinámica del establecimiento de regeneración de *Pinus arizonica*	*P.durangensis* *P. ayacahuite* *P. arizonica* *Quercus spp*

[1] De los 13 SPIS, sólo quedan 3 en condiciones de remedir. Uno es testigo y dos están intervenidos por aclareos; el resto de los SPIS se perdieron por incendios.

LUGAR	PARAJE	FECHA DE ESTABLECIMIENTO	DIMENSIONES	CANTIDAD	NÚMERO DE CONTROL	FECHA DE REMEDICIÓN	TRABAJOS DE INVESTIGACIÓN	ESPECIES
[2]Madera, Chih.	Madera	1986	0.1 ha.	125	01,...,125	1991	1.- Determinación de calidades de estación para *Pinus arizonica* y *Pinus durangensis* en el Area Experimental Madera 2.- Suelo Calidad Estación en el Area Experimental Madera. 3.- Tablas de Densidad para *Pinus arizonica*	
San Juanito-Creel, Mpio. de Bocoyna	La Laja	1980 1981	100x100m 100x100m	2 5	01,...,07	1990 1986	1.- Comportamiento estructural del bosque de Pinus arizonica en el A.E.F. La Laja; 2.- La Laja San Juanito Creel	
Bocoyna, Chih	Bosque Modelo	1994-97	50x50m	64	01,...,64	1996 (solo inicial)	1.- Diseño, objetivos, localización y metodología del establecimiento, dentro del proyecto #904 de INIFAP	
San Miguel de Cruces Municipio de San Dimas , Durango	Cielito Azul	1982 (1966)	100x100m 100x100m	36	01,...,36	1986	Cortas Intermedias Cortas de Regeneración	
UIEF San Rafael	San Miguel Contla	1981	100x100m	4		1986		
UIEF San Rafael		1981	100x100m	2		1986		
CIFO								
Sierra de Tapalpa Jal.	Piedra Gorda	1980	100x100m	1	01	1990	Cortas de Liberación	
Sierra de Tapalpa Jal.	El Desmonte	1981	100x100m	1	02	1991	Cortas Intermedias	

[2] De los 125 Sitios de Inventario Forestal Contínuo sólo quedan 70 sitios, ya que el resto se perdió por incendios.

LUGAR	PARAJE	FECHA DE ESTABLECIMIENTO	DIMENSIONES	CANTIDAD	NÚMERO DE CONTROL	FECHA DE REMEDICIÓN	TRABAJOS DE INVESTIGACIÓN	ESPECIES
Sierra de Tapalpa Jal.	El Desmonte	1981	100x100m	1	03	1991	Cortas de Regeneracion	
Sierra de Tapalpa Jal.	La ermita	1981	100x100m	12	04,...,15	1991	Cortas Intermedias	*P. michoacana* *P. oocarpa* *P leiophylla*
Sierra de Tapalpa Jal.	El Carrizal	1985	1000m2	202			Plan de Manejo Demostrativo	*P. michoacana* *P. oocarpa* *P leiophylla* *P. pseudostrobus* *Quercus spp* *Arbutus sp*
Sierra de Tapalpa Jal.	Resumidero	1985	50x50m	1	16	1990	Cortas Intermedias	*P. michoacana*
Sierra de Tapalpa Jal.	Madroño	1985	50x50m	1	17	1990	Análisis Dendroepidométrico	*P. michoacana* *P. oocarpa*
Uruapan Mich.	Barranca de Cupatitzio	1978-80 1978	50x50m 100x100m	583 13	1,...,583 1,...,13	1988-90 1988	Análisis Dendroepidométrico	*P. lawsonii* *P. douglasiana* *P. michoacana* *P. leiophylla*

LUGAR	PARAJE	FECHA DE ESTABLECIMIENTO	DIMENSIONES	CANTIDAD	NÚMERO DE CONTROL	FECHA DE REMEDICIÓN	TRABAJOS DE INVESTIGACIÓN	ESPECIES
San Miguel Aloapan, Oax.	La Cuesta	1984	50x50m	1	3	1989	Crecimiento e Incremento de Pinus rudis en Aloapan de Ixtlán, Oaxaca	*Pinus rudis*
San Miguel Aloapan, Oax.	El Llano	1983	50x50m	1	4	1988	Crecimiento e Incremento de Pinus rudis en Aloapan de Ixtlán, Oaxaca	*Pinus rudis*
Tlaxiaco, Oax.	Cueva de Traidoras	1983	50X50M	1	1	1988		P. *pseudostrobus* var. oaxacana
Tlaxiaco, Oax.	Tres Cruces	1984	50x50m	1	2	1989		P. *pseudostrobus* var. oaxacana
Tlaxiaco, Oax.	Encino de Guitarra	1984	50x50m	1	3	1989		*P. tenuifolia* *P. pringlei*
Tlaxiaco, Oax.	Cueva de los Lobos	1984	50x50m	1	4	1989		
San Cristóbal De Las Casas Chiapas	Chili	1980	50x50m	1	1	1990	Diagnóstico de la Situación Silvícola del Estado de Chiapas	*P. pseudostrobus var. oaxacana* *P. oocarpa var. oaxacana*
San Cristóbal De Las Casas Chiapas	Chivero	1980	50x50m	1	2	1990		*P. oocarpa var oaxacana* *P. pseudostrobus* *Quercus spp*
San Cristóbal De Las Casas Chis	Grutas	1980	50x50m	1	3	1986	Estudio del crecimiento de *Pinus montezumae* de Los Altos de Chiapas	*P. montezumae*

LUGAR	PARAJE	FECHA DE ESTABLECIMIENTO	DIMENSIONES	CANTIDAD	NÚMERO DE CONTROL	FECHA DE REMEDICIÓN	TRABAJOS DE INVESTIGACIÓN	ESPECIES
San Cristóbal De Las Casas Chiapas	Área Semillera	1980	50x50m	1	4	1990		*P. montezumae*
Altamirano, Chis.	Altamirano	1980	50x50m	1	5	1990		*P. oocarpa*
Oxchuc, Chis	Ref. Oxchuc	1980	50x50m	1	6	1990		*P. pseudostrobus* *Quercus spp*
San Cristóbal De Las Casas Chiapas	Plantn. San Cristóbal	1980	50x50m	1	7	1990		*P. montezumae*
Teopisca, Chis,	Dolores Teopisca	1980	50x50m	1	8	1990		*P. pseudostrobus* *P. oocarpa ochotomai* *Cupressus spp* *Quercus spp*
San Cristóbal De Las Casas Chiapas	CIFPAS San Cristóbal	1980	50x50m	1	9	1990		*P. pseudostrobus*
San Cristóbal De Las Casas Chiapas	Mitzitán, San Cristóbal	1980	50x50m	1	10	190		*P. oocarpa* *P. montezumae* *P. pseudostrobus*
San Cristóbal De Las Casas Chis	Rancho Nuevo	1983	50x50m	4	11,...,14	1988		*P. montezumae*

LUGAR	PARAJE	FECHA DE ESTABLECI MIENTO	DIMENSIONES	CANTIDAD	NÚMERO DE CONTROL	FECHA DE REMEDICIÓN	TRABAJOS DE INVESTIGACIÓN	ESPECIES
Huayacocotla, Ver.	Fábrica Escondida, Ej. Canaleja de Otates	1985	100x10Um	1	1	1990	Trabajos dendroepidométricos	*P patula Quercus sp.*
Huayacocotla, Ver.	Mina de las Tuzas, Ej. Canaleja de Otates	1985	100x100m	1	2	1990	Trabajos dendroepidométricos	*P patula P. teocote Quercus sp.*
Huayacocotla, Ver.	Cerro del Huezamento, Ejido Tlalchil Quillo	1985	100x100m	1	3	1990	Trabajos dendroepidométricos	*P patula P. teocote Quercus sp.*
Escárcega, Camp.	C.E.F. Ing. Eduardo Sangri Serrano	1981	1,2 45x50m 3,4 50x50m	4	1,...,4	Cada año	Dinámica sucesional y epidométrica	*Varias especies arbóreas tropicales*

LUGAR	PARAJE	FECHA DE ESTABLECI MIENTO	DIMENSIONES	CANTIDAD	NÚMERO DE CONTROL	FECHA DE REMEDICIÓN	TRABAJOS DE INVESTIGACIÓN	ESPECIES
Escárcega, Camp.	C.E.F. Ing. ESS	1981	50x50m	3	5,6,7,	Cada año	Dinámica sucesional y epidométrica	*Varias especies arbóreas tropicales*
Escárcega, Camp.	C.E.F. Ing. ESS	1981	100x100m	1	8	Cada año	Dinámica sucesional y epidométrica	*Varias especies arbóreas tropicales*
San Felipe Bacalar, Q. Roo	C.E.F. San Fpe. Bacalar	1981	100x100m	1	1	1986	Establecimiento de especies forestales y dinámica sucesional	*65 spp arbóreas*
San Felipe Bacalar, Q. Roo	C.E.F. San Fpe. Bacalar	1981	100x100m	1	2	1986	Trabajos dendroepidométricos	*65 spp arbóreas*
San Felipe Bacalar, Q. Roo	H. Hazil, Q. Roo	1985-1986	50x50m	8	3,...10	Cortas intermedias y de regeneración		*51 spp arbóreas*

Conclusiones

Derivado del análisis de la información proporcionada en el presente documento, se pueden derivar las conclusiones siguientes:

- Se deben incluir en Inventario y Monitoreo, para el manejo de recursos naturales, aspectos no solo ecológicos, sino sociales y económicos, considerando el contexto global.
- Se deben de identificar problemas actuales y potenciales que no tienen límites geográficos y políticos.
- Se debe determinar como las actividades de manejo afectan los ecosistemas y reducir al mínimo su impacto.
- Se debe asegurar que el Inventario y el Monitoreo de ecosistemas, sea la base de manejo sostenible.

Bibliografia

ACOSTA M.,M. 1991. Modelo de crecimiento para **Pinus montezumae** Lamb. en el C.E.F. San Juan Tetla, Puebla. Tesis Maestría. U.A.Ch-División de Ciencias Forestales. 88p.

CARRILLO E., G. 1989. Apuntes del curso de inventarios forestales. Serie de apoyo académico No. 35. UACh- División de Ciencias Forestales. Chapingo, México. 206 p.

CHACON S., J. M. 1993. Comportamiento de la repoblación natural de *Pinus arizonica*, bajo diferentes grados de cobertura de dosel de arboles padres. Tesis de Maestría en Ciencias. Colegio de Postgraduados. Programa Forestal Montecillo, México. 65 p.

GOMEZ D. A. 1993. Análisis de la composición y estructura de una selva baja subperennifolia. UACH. División de Ciencias Forestales. Chapingo, México. 149 p.

MANZANILLA B., H. 1993. Los sitios permanentes de investigación silvícola un sistema integrado para iniciarse en el cultivo de los ecosistemas forestales. Boletín Técnico No. 116. Segunda edición. SARH. INIFAP. México. 101 p.

PEREZ B., J. L. 1988. Estimación de la producción de conos de *Pinus montezumae* Lamb., en el CEF San Juan Tetla, Puebla. Tesis profesional. UACH-División de Ciencias Forestales. Chapingo, México. 52 p.

PEREZ G., M. C. 1988. Caracterización de la estructura de rodales de Pinus oaxacana Mirov., en la Región "Altos de Chiapas", México. Tesis profesional. UACH-División de Ciencias Forestales. Chapingo, México. 64 p.

QUIÑONES CH., A. 1995. Evaluación de la calidad de sitio y del efecto de la densidad en bosques del estado de Durango. Tesis de Maestría en Ciencias Forestales. UACH División de Ciencias Forestales. 129 p.

RODRIGUEZ-FRANCO, C. Doctor of Forestry qualifying examination. May 6, 1986. Yale University. School of Forestry and Environmental Studies. Conn. 31 p.

TORRES R., J.M.; C. RODRIGUEZ F.; O. MAGAÑA T.; H. AGUIRRE D.; A.M. FIERROS G. Simulación de la producción y rendimiento de *Pinus rudis* en Aloapan, Oaxaca. Memorias de la Cuarta Reunión Científica Forestal y Agropecuaria. INIFAP-Centro de Investigaciones Forestales y Agropecuarias de Oaxaca. Xoxocotlan, Oax. pp 74-81.

VALLES G.. A. G. 1994. Evaluación de indices de competencia para predecir el crecimiento de arboles individuales de *Pinus cooperi* en San Miguel de Cruces, Dgo. Tesis de maetria en Ciencias. Colegio de Postgraduados, Programa Forestal. Montecillo, México. 98 p.

VALLES G., A.G; A. QUIÑONES S. 1997. Desarrollo de una tabla de densidad para *Pinus cooperi*, en el Sitio Experimental "Cielito Azul". Folleto científico No. 3. Fundación Produce Durango, A.C.-SAGAR, INIFAP. 23 p.

Plot Designs for Ecological Monitoring of Forest and Range[1]

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Paul H. Geissler[3]

Abstract—Given the need of governments today for extensive data on natural resources for use in national planning, the U.S. Forest Service has changed its policy from periodic inventory of the timber resources of the U.S.A. to annual inventories of its much broader ecological resources. Consequently, the design of the sample units used in assessment must be reconsidered. We propose a change, to be implemented gradually over time, from the standard circular primary unit to a long rectangular one. The advantages are: more useful data can be provided for both management and monitoring purposes; special interest surveys can be accommodated better; assessment is cost efficient because remote sensing can be used more extensively and, consequently, access to private land and effect of trampling are minimized. Because of the large number of variables to be measured for large-scale and management purposes, the fact that several are best measured on photos, and the fact that several variables require more than one visit in a season, the need for averaging one plot per day and additivity of estimates should be revisited.

It is well known that different sampling units (plots) are optimal for different sets of variables. For example, variable radius plot (VRP) designs have been used for a long time in Forest Inventory and Analysis (FIA) of the U.S. Forest Service (USFS) because timber volume was the primary interest. For that objective, probabilistically selecting more large trees relative to small trees was clearly more efficient. Similarly, if interest is in the number of trees with equal interest in each tree, fixed-area plot designs are optimal, because each tree has an equal probability of selection.

In large-scale surveys such as FIA where a large number of variables are measured, a compromise is needed. Although different designs are optimal for different variables, it is more efficient to assess them all on the same plots, rather than conduct separate surveys, because it allows the association between combinations of variables to be assessed. Circular plots are favored internationally because for a given area, the length of the boundary is minimal relative to plot area and because variable radius plot (VRP) sampling requires a sweep around the center point for efficient sampling.

The increased extensive need for information for management and planning and the dramatic improvements in remote sensing and geographic positioning systems suggest that a change in plot design may be desirable. In the U.S.A. there is increased interest in measuring a broad range of ecological and health variables, in assessing the association between them, and in modeling forest and range processes. Accomplishing this is more feasible now with the highly accurate lasers and geographic positioning systems (GPS units) which have become available for land surveys. Combining this new instrumentation with improved plot design and remote sensing, especially low altitude photography and videography, allows for quicker, more reliable measurement and better yet cheaper information. At the same time, ground access and trampling of the sample plot are minimized.

There is a need for closer coordination between mapping and sampling, including the ability to provide map-type data using techniques such as small-area estimation (Moeur and Stage (1995). It is also critical to maintain continuity with current inventory and monitoring efforts and to preserve comparisons with previous surveys. There also are needs for specialized surveys, coordinated with other major surveys, and a need to use data from these surveys for local forest management. Clearly, a compromise among the designs that are optimal for assessing the different variables and objectives is clearly needed.

Review of Literature

According to the SPAM (1997) report, Ernest Haeckel coined the term "ecology" in 1866 to define the study of the multifaceted struggle for existence as presented in "The Origin of Species" by Charles Darwin according to Kingsland (1991). Allaby (1994) defined ecology as the study of the interrelationships among organisms, and between them and all living and non-living aspects of the environment. It is clear then that effective monitoring for ecological purposes requires measurement of attributes associated with these interrelationships at the same or essentially the same locations. As this has rarely been done in the past, it is pertinent to begin by describing plot-sampling methods used in various disciplines.

Schreuder (1978) showed that a combination of sampling methods applied at a given point in a forest provides highly efficient and unbiased estimates of number of trees (N), using a fixed area plot centered at the point and of total basal area (G) using VRP sampling. The sum of tree diameters can also be estimated without bias but inefficiently using a VRP sample on the fixed area plot with the above estimates of N and G. This approach was based on one suggested by Fender

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and Brock (1963) who proposed estimating future G by counting trees after displacing an angle gauge by an amount that depended on an estimate of expected increment.

Burnham et al. (1980) noted that quadrats are often used to sample ant colonies, termite colonies, animals living in the soil, some species of insects, birds and small animals; but Seber (1986) considers transects to be easier to locate and more effective than quadrats, which tend to be affected more by animals moving at the boundary. However, he acknowledges that in dense shrub and rough terrain transects make it difficult for the observer to observe birds at the same time as walking quietly.

Burnham et al. (1980) contend that strip transects are often not appropriate for sampling mobile animals such as birds but line transects or variable-width transects may be. Strip transects are used extensively in counting animal pellets. They are also used in preference to quadrats when sampling from the air because of ease of location and more reliable covariate values are available for use in computing adjustments with ground sampling values in ratio and regression estimation (Seber 1982, 1986, 1992).

Schreuder and McClure (1991) suggested modifying FIA sampling procedure to improve detection of change in a forest and identify possible causes. If additional sample plots were established and paired with all or a subset of the existing plots, then potential cause-effect relationships could be identified with the latter and hypotheses formulated while the former could be used to test these hypotheses.

To generate descriptive statistics, detect change in these statistics over time and analyze data to identify potential cause-effect relationships, Schreuder and Czaplewski (1993) proposed a multi-level sampling frame consisting of wall-to-wall digital satellite map generated every 1-4 years to monitor such variables as forest fragmentation and habitat corridors, strips or large cluster of plots on aerial photography and/or videography to monitor disturbance and change in the aerial extent of variables such as forest cover and land use, clusters of ten 0.1 ha plots measured on the aerial photography or videography every 1-4 years for some variables such as tree mortality and field measurements on the ground every 4-16 years for variables such as ecological health and wood volume.

Olsen and Schreuder (1997) state that data from FIA and NRI (the Natural Resources Inventory conducted by the Natural Resources Conservation Service of the USDA) can be used to identify potential cause-effect relationships, useful cause-effect hypotheses to be tested, and supplementary data sets to be collected to more clearly establish potential relationships. Additional key information such as soil quality should be collected to improve the chances of identifying possible cause-effect hypotheses. Clearly these objectives call for various sampling efforts to obtain the desired information. Goebel et al. (1998) showed that multidisciplinary information can and should be collected with a common plot design even though it was realized that the FIA plot design used (in combination with transects) was not necessarily the best plot.

Schreuder et al. (1997) discuss the possibility of combining mapped and statistical information in a more comprehensive package supplementing the USFS Region 6 vegetation inventory and monitoring system (Max et al. 1996). It is clear that additional information must be collected in follow-up surveys by keying in on relevant information obtained in that system. Near-continuous information is needed on weather and possibly pollution variables to develop meaningful models to understand relationships and processes in the ecoregions and to assess the impact of management practices on them. However, instrumentation capable of providing this is not yet readily available.

Both FIA and NRI are going to annualized inventories, where a subset of existing plots will be measured in each state each year, probably 20% in the case of FIA. Both will be collecting much more ecologically based information than in the past. Although we focus on plot design for forestry purposes, i.e. National Forest Systems (NFS) or FIA needs, this proposal should be useful for NRI purposes too since FIA and NRI should be integrated and ultimately merged into one national resource inventory.

Methods

Although it is clear that the 1-ha circular FIA plot subsampled by 4 1/60 ha circular subplots has wide acceptance now, it is also true that this configuration has its origin in timber sampling. It is therefore likely that other plots shapes and sizes will replace it at some time, because of changes in objectives and technology. However, transitioning from the existing plot to a new one over time is important so we do not lose the ability to estimate change in critical parameters (mortality, growth, etc.). Hence we use as our starting point the FIA plot. The suite of variables to be measured by natural resource agencies has not yet been defined for range and forest health and soil quality variables. Consequently, we will focus on a set of variables fitting the 5 categories described earlier, treat those as the sole complete set of attributes to be measured, and indicate how we expect these variables to be measured. The fact that more than one visit in a season is required for animal populations offers opportunities for additional measurements of forest health variables such as change in the chemical content of foliage.

Proposed parameters of interest (measurable and useful):

1. Forestry
   a. Trees: Number of trees, tree basal area, length, diameter, and frequency of down woody material, tree mortality and regeneration, number of diseased and insect-infested trees, removals by species.
   b. Understory: number, mortality, height, % seedlings, % saplings, % mature shrubs by species.
   c. Forbes, grasses: number of species, aerial extent.
2. Soil
   a. Depth of organic matter, depth of A horizon, soil series, soil quality (SQ), pH
   b. Other characteristics: erosion rate, slope and aspect.
3. Animals, relative abundance of
   a. Birds
   b. Small ground vertebrates (mammals, reptiles, and amphibians)
   c. Ground insects
4. Water
   quality, depth, and extent.

Given the numerous attributes to be measured, cost constraints, and the fact that some variables can be obtained accurately from photos and others not, and different plot configurations are efficient for different variables, it is likely that some ensconced ideas in FIA should be dropped. Specifically, the idea of additive estimates (acreage at time 2 does not have to add to acreage at time 1 + change in acreage over the time period) and 1-day plots on average may have to change. With the tremendous improvement in both remote sensing and geographic positioning systems, it is highly probable that, in future, areas will be estimated much more reliably than they are now. Similarly, when assessing biodiversity and other ecological conditions, it is clear that much more time will have to be spent on each primary sampling unit (psu) to collect all the needed information.

Proposed Approach

Either the current FIA plot with the annular circular subplots or the current Region 6 Current Vegetation System (CVS) plot (Max et al. 1996) can provide useful information for both large-scale and management objectives. Both are currently used and transitioning to the new plot needs to allow for both.

As indicated earlier, aerial photography should play more of a role in inventorying and monitoring. Besides being used for direct measurement of some of the variables directly, it can also be used for testing purposes to determine how remote sensing can be used for more difficult to measure variables.

The proposed plot design is shown in Fig. 1 with further elaboration in Fig. 2. Briefly, we plan transitioning from the current circular plot to a plot for which the information can be better tied to remote sensing information. It is useful to think of the psu as a population in its own right for management purposes. For example plots are often classified into condition classes of interest such as biodiversity classes, timber productivity classes, erosion-control classes, etc. to assess where treatment needs to be applied when. A low-altitude or video picture of each plot is taken annually to serve as a permanent record over time.

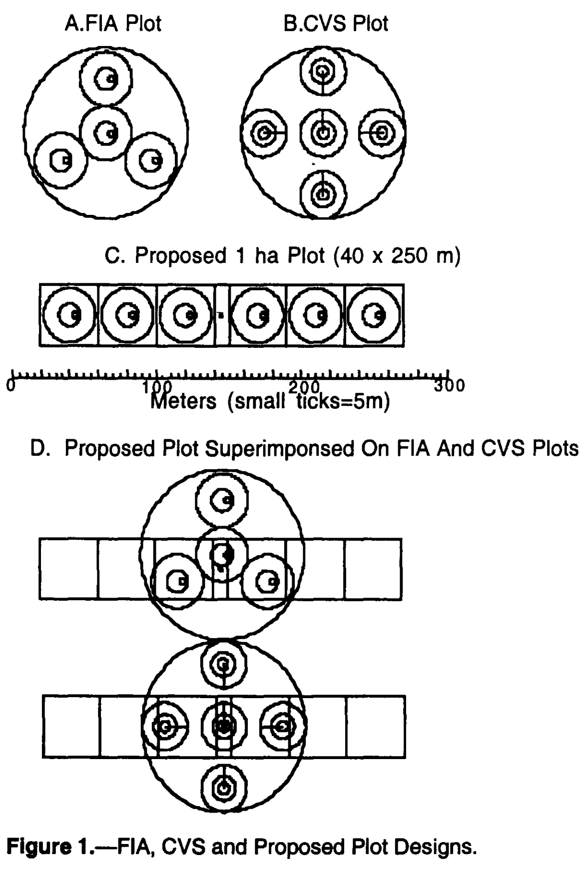

Figure 1.—FIA, CVS and Proposed Plot Designs.

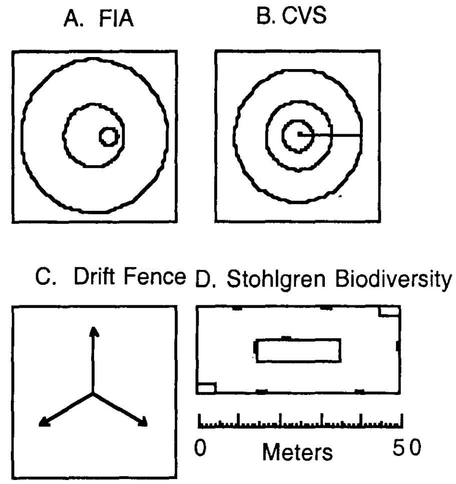

Figure 2.—Subplot Designs.

The current FIA and CVS plots are compact. Although they can be established in the field faster than long rectangular plots, they are less efficient for estimation. Because of spatial correlations, adjacent compact subplots tend to be similar. Measuring them duplicates much of the work already done and yields relatively little new information. Long subplots also spread out the observation area reducing the effect of spatial correlation. To increase the precision of the estimates for large areas, one seeks to make the plot estimates as similar as possible. To do this, one includes as much as the variability as possible within the plot, thus increasing efficiency. However, long plots have a large perimeter which increases the number of decisions required on 'boundary' trees- are they 'in' or 'out'? Long plots are advantageous for remote sensing, especially low-level aerial photography and videography. Numerous variables, e.g. mortality of trees, can be measured with high degree of reliability on remote sensing imagery. However, sampling subplots on the ground is desirable at this time to verify the remote sensed measurements and adjust them by regression estimation if necessary.

There is an increased emphasis on biodiversity such as identity of species present and species richness. Particularly in regards to maintaining rare native species and detecting exotic species while they still can be eradicated if necessary. Rare species are a major component of biodiversity but traditional forest inventories have ignored them. For example, Stohlgren et al. (1998) reported that almost half of the prairie plant species had less than one percent foliar cover. To observe rare species, it is important to search as large and diverse an area as possible. Maximizing the heterogeneity within a plot is also desirable for this reason.

Figure 2 includes a proposed biodiversity plot of Stohlgren et al. (1995, 1998) for comparison with the FIA and CVS plots. Important features of Stohlgren's approach include a relatively long rectangular plot with subplots, observations with four different sized subplots to observe biodiversity at different scales. Percent cover and vegetation height is only measured on the smallest subplots, but the presence of species is recorded for all subplots.

We recommend the long rectangular 1-ha plot (250 m x 40 m) for future inventory (Fig. 1c). This is an easy plot to photograph from the air, encompasses 3 out of the respectively 4 or 5 subplots of the FIA and CVS plots and with proper laser instrumentation should be easy to establish on the ground. It is divided into 6 40 x 40 m subplots which can be measured or subsampled for various variables as indicated in Fig. 2. A center 10 x 40 m subplot is primarily used for plot establishment purposes. Down the middle of the long plot we also have a 250 m long transect which is divided into 6 40-m segments that can be measured or subsets of which can be measured for the variables indicated in Fig. 2. The transects should be a vital part of the plot design, which they are not with the current FIA plot.

As a first step in increasing the efficiency of the plots, we consider maintaining the same subplot design, and arranging the subplots in 40 x 250 m plots. This design accommodates the current plot designs best for change detection while spacing out the subplots to be used after transitioning to increase efficiency. This approach presumes that boundary issues are more important for measurements made on the smaller subplots and that matching ground and air measurement are more important for the plot and larger subplots. Longer and narrower plots (25 x 400 m or 20 x 500 m) may be even more desirable in the future but do not allow for transitioning as well as 40 x 250 m plots since fewer of the CVS or FIA subplots can be accommodated.

Table 1 summarizes some of the attributes of the current FIA and CVS plot designs, the plot design we propose and longer narrower plots for the sake of interest).

In transitioning, the three CVS or FIA subplots contained within the 40 x 250 m primary sampling units serve a useful role in change estimation as the plot design changes. If estimates of change based on them and measurement of all or part of the new psu are insufficiently reliable for the FIA standards set, the other subplots in the original CVS or FIA plots would have to be remeasured too.

After transitioning to the proposed psu, we then have a set of 40 x 250 m rectangular plots for which low-altitude photography or videography coverage should be acquired annually as a permanent record over time. On the ground, the 250 m long center axis of these plots are permanently established and marked in an unobtrusive way and serve as starting points to subsample the psu in various ways for various attributes. The 10 x 40 m center area is used only for benchmarking purposes and to protect against excessive trampling as now often occurs since the center is the focal point of all current sampling efforts in both FIA and CVS.

For large-scale government planning estimation and analyses purposes, all 6 subplots are subsampled at a low intensity. Research is needed on how best to do this. The primary interests being how to meet national and regional objectives set for precision of the estimates and how to attain sufficient precision at the plot level to enable reliable equations to be established in conjunction with remote sensing information for predicting the parameters associated with covariates that can be measured on the photography. Because of the large number of variables to be collected, different sets of variables may have to be measured on different subplots to avoid excessive trampling and disturbance on the subplots. Although some variables can be measured more accurately and completely on aerial photography, these should also be sampled on the ground to document their accuracy or precision.

All 6 subplots are subsampled at a high intensity on federal lands. Research is also needed here, the primary interests being to establish meaningful interactions between the variables of interest and to determine the need

Table 1.—Some geometric characteristics of plot designs discussed.

Plot/Subplot	FIA	CVS	40 x 250 m	25 x 400 m	20 x 500 m	Stohlgren
Plot						
Area	1.000 ha	1.000 ha	1.000 ha	1.000 ha	1.000 ha	
Radius/Dimensions	56.42 m	56.42 m	40 x 250 m	25 x 400 m	20 x 500 m	
Perimeter	354 m	354 m	580 m	850 m	1040 m	
Large Subplot						
Area	0.101 ha	0.076 ha	0.100 ha	0.100 ha	0.100 ha	0.100 ha
Radius/Dimensions	17.95 m	15.58 m	25 x 40 m	20 x 50 m	25 x 40 m	20 x 50 m
Perimeter	113 m	98 m	130 m	130 m	140 m	140 m
Medium Subplot						
Area	0.017 ha	0.020 ha	0.020 ha	0.020 ha	0.020 ha	0.010 ha
Radius/Dimensions	7.32 m	8.02 m	10 x 20 m	10 x 20 m	10 x 20 m	5 x 20 m
Perimeter	46 m	50 m	60 m	60 m	60 m	50 m
Small Subplot						
Area	0.001 ha	0.004 ha	0.020 ha	0.020 ha	0.001 ha	0.001 ha
Radius/Dimensions	2.07 m	3.60 m	10 x 20 m	2 x 5 m	10 x 20 m	2 x 5 m
Perimeter	13 m	23 m	60 m	60 m	20 m	20 m
Micro Subplot						
Area						0.0001 ha
Radius/Dimensions						0.5 x 2 m
Perimeter						5 m

for and assess the effect of management practices on the resource.

For cause-effect purposes, a subset of the psu's is measured either completely or sampled at a high intensity. Special monitoring devices could be established on these psu's such as automatic weather and pollution monitoring stations, non-destructive chemical analysis machinery, etc.

Special surveys can be accommodated in this scheme too. A representative subset of the psu's would be selected for the "client." The variables of interest can then be remeasured at the government planning or management intensity level, or on a representative subset of the subplots.

Before we make more specific recommendations, the following gives a general overview of our thinking relative to advantages of different subplot sizes and shapes (Schreuder et al. 1993: 293-296).

- Long rectangular plots are advantageous for low altitude photography measurements and plant biodiversity estimates.
- A rectangular plot is easier to fly and interpret and a 1 ha plot is a convenient size to fly and photointerpret.
- To assess plant biodiversity (species richness and identification of species), ideally we want to cover as many habitat conditions as possible and as large an area as possible to find rarer species. Boundary issues are relatively less important because one only has to check to see if the occasional species not found in the subplots is in or out of the plot. This suggests that a long narrow plot or transect is desirable.
- Circular subplots are advantageous for VRP sampling where boundary issues are important as in regeneration subplots.
- Transects are advantageous for traversing a large area to measure scatter or rare objects such as down woody debris.

Animals are more difficult to observe than plants. Birds are frequently counted because they are active during the day and are easily observed. However, birds cover large areas and their populations may reflect conditions outside the plot. Many birds migrate, and so their populations will also reflect conditions on the wintering areas. Counts of birds are also influenced by the time of day and the weather. Dawn and dusk are the best times to count birds, but observers often are unable to do this because of the danger in accessing the sample sites at these times. If bird counts are used, the point count method (Ralph et al. 1995) is recommended. Recording the distance to observed birds allows an adjustment for visibility differences (Buckland et al. 1993). As the points should be at least 250 m apart to avoid counting the same birds, counts should be made at the ends of the 40 x 250 m plot. Additional points can be located 250 m out in each direction so the 4 points form a line, separating the points as much as possible. One solution is to install automatic recorders for a few weeks to record bird calls and those of some amphibians, insects and possibly bats (Peterson and Dorcas 1994). Highly skilled people are required to identify bird calls. Recording their calls allows birds to be identified without requiring an expert to visit the plot. We recommend that one recorder be located at the center point. It should be installed after the vegetation measurements are made and left in place for about 3 weeks.

Small mammals, reptiles, and amphibians have smaller home ranges and do not migrate. Thus their populations more closely reflect conditions on the plot, although they are more difficult to observe. However, drift fences can be used to direct animals moving through an area to a spot where they can be observed (Corn 1994). Pitfall traps are commonly used, but it is impractical to check them daily. An automated camera can be left in place for a few weeks to record animals. We suggest two drift fences in the end 40 x 40 m subplots where drift fences are typically 5 m to 15 m long, 50 cm wide and buried 20 cm in the soil. Because of the cost of the camera, a single drift fence in a central subplot may be used. We suggest a drift fence with three 15-m spokes, with a back turn at each end to turn animals back towards the center, and an automated camera in the middle (Fig. 2c). They should be installed after the vegetation measurements are made and left in place for about 3 weeks.

Pitfall traps can also be used to observe ground insects. The traps are 600 ml (one pint) plastic containers buried flush with the ground with ethylene glycol in the bottom to preserve insects falling in. They also can be left on the plot for a few weeks. The insect populations reflect conditions on the plot. A great variety of species at different trophic levels can be captured easily and well-established protocols exist for doing this. Specimens are taken back to the laboratory for identification. Although species identification is difficult, it is feasible if only selected taxa are identified. We recommend 4 pitfall traps in each of the 40 x 40 m subplots. Again, they should be installed after the vegetation measurements are completed and left in place for about 3 weeks.

To indicate the implementation opportunities we give examples below of how to collect the necessary information for the variables enumerated on above. The actual subsampling schemes to be used should be investigated to determine what the optimum might be relative to efficiency, accuracy of estimation, correlations with the aerial photo plot information, etc.:

We have six 40 x 40 m subplots subsampled as follows for the attributes:

1. For government planning information:
   a. Use circular subplots- say a 0.017 ha subplot (1/24 acre) in each of the subplots for number of trees, basal area, number of insect and disease infected trees, removals, and mortality.
   b. Use two 40-m transects in each of the subplots for length, diameter, and frequency of down woody material and for number of species of forbes and grasses. These might, for example, be located at the 10- and 30-m points along the center axis in each of the subplots. These can also be used for measuring erosion rates and slopes.
2. For management purposes- use one or two of the corresponding CVS or annular FIA subplots for each of the 6 subplots. Similarly use 4 or more transects in each of the 6 subplots for the down woody material. These transects can also be used to measure erosion rates and slopes.
3. For tree regeneration, understory vegetation, counts of forbes and shrubs, depth of the organic matter layer and A horizon and pH we recommend use of a larger number, smaller subplots in each of the 40 x 40 m

subplots. For example we might sample five 0.001 ha subplots (2.07 m radius) per 40 x 40 m subplot for government planning purposes and ten for management purposes.

4. Obtain soil quality and soil series measurements from a series of respectively 5 and 10 cores for government planning and management purposes in each of the six 40 x 40 m subplots. How to best do that in a non- or essentially non-destructive manner will soon be decided upon.
5. Animal relative abundance is measured by traps and recorders left on the plot for 3 weeks:
   a. Small mammals, reptiles, and amphibians are sampled by a 3-spoked 15 m drift fence with an automatic camera in one of the central 40 x 40 m subplots.
   b. Ground insects are sampled by 4 pitfall traps in each of the 40 x 40 m subplots.
   c. Calling birds, bats and insects are sampled by an automatic audio recorder located at the central point.

Traditionally, only a single visit is made to a psu. However, it is very difficult to obtain repeatable animal observations with one visit, because counts are influenced by weather, time of day, and other factors. Leaving recording equipment in the field for a few weeks would sample animals at all times, day and night, and under varying weather conditions, making the observations much more repeatable. An important advantage of automatic recorders is that nocturnal and shy animals can be observed. Similarly, additional useful information such as change in chemical content of foliage could be measured if more than one visit per season was acceptable in either FIA or similar natural resources surveys.

Literature Cited

Allaby, M. 1994. The Concise Oxford Dictionary of Ecology. Oxford University Press, New York. 415 pp.

Buckland, S.T., Anderson, D.R. Burnham, K.P. and Laake, J.L. 1993. Distance sampling: Estimating abundance of biological populations. Chapman and Hall, New York.

Burnham, K.P., Anderson, D.R. and Laake, J.L. 1980. Estimation of density for line transect sampling of biological populations. Wildlife Monographs No. 72.

Corn, P. S. 1994. Straight-line drift fences and pitfall traps. In Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. p.109-117 Smithsonian Institution Press, Washington.

Fender, D.E. and Brock, G.A. 1963. Point center extension: a technique for measuring current economic growth and yield of merchantable forest stands. J. For. 61:109-114.

Goebel, J.J., Schreuder, H.T., House, C.C., Geissler, P.H., Olsen, A.R. and Williams, W.R. 1998. Integrating Surveys of Terrestrial Natural Resources: The Oregon Demonstration Project. USDA FS, Inventory and Monitoring Inst. Rep. No. 2. 20 p.

Kingsland, S.E. 1991. Defining ecology as a science. In: L.A. Real and J.H. Brown, eds. Foundations of Ecology, p. 49-59. Univ. of Chicago Press, Chicago, Ill.

Max, T.A., Schreuder, H.T., Hazard, J.W., Teply, J. and Alegria, J. 1996. The Region 6 Vegetation and Monitoring System. USDA FS PNW Res Paper PNW-RP-493. 22 p.

Moeur, M and Stage, A.R. 1995. Most similar neighbor: an improved sampling inference procedure for natural resource planning. Forest Science 41:337-359.

Olsen, A.R. and Schreuder, H.T. 1997. Perspectives on large-scale resource surveys when cause-effect is a potential issue. Env. and Ecol. Stat. 4:167-180.

Peterson, C. R. and Dorcas, M.E. 1994. Automated data acquisition. In Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians, p. 47-57 Smithsonian Institution Press, Washington.

Ralph, C.J., Droege, S., and Sauer, J.R. 1995. Managing and monitoring birds using point counts: standards and application. Pages 161-168 *in* C.J. Ralph, S. Droege, and J.R. Sauer, eds. Monitoring Bird Populations by Point counts, USDA Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-149.

Schreuder, H.T. 1978. Count sampling in forestry. For. Sci. 24: 267-272.

Schreuder, H.T. and Czaplewski, R.L. 1993. Long-term strategy for the statistical design of a forest health monitoring system. Env. Monitoring and Assessment: 27:81-94.

Schreuder, H.T., T.G. Gregoire, and Wood, G.B. 1993. Sampling methods for multiresource forest inventory. Wiley, New York.

Schreuder, H.T. and McClure, J.P. 1991. Modifying forest survey procedure to establish cause-effect, should it be done? Proc 10th IUFRO World Forestry Congress, Paris, France. Revue Forestiere Francaise. Hors Series No.4. Sect D. p.67-78.

Schreuder, H.T., Czaplewski, R.L. and Bailey, R.G. 1997. Combining mapped and statistical data in forest inventory and monitoring. Env Monitoring and Assessment (in press).

Seber, G.A.F. 1982. The Estimation of Animal Abundance and Related Parameters. Griffin, London, 2nd ed.

Seber, G.A.F. 1986. A review of estimating animal abundance. Biometrics 42:267-292.

Seber, G.A. F. 1992. A review of estimating animal abundance. II. Int. Stat. Rev. 60:129-166.

SPAM. 1997. Sierra Nevada National Forests Land Management Planning Monitoring Strategy Development. Vol. I. Progress Report Fiscal Year 1997. Prepared by Sierran Provinces Assessment and Monitoring Team (SPAM). USDA FS PSW Region and Station. 92 p. Unpublished.

Stohlgren, T.J., Bull, K.A. and Otsuki, Y. 1998. Comparison of rangeland vegetation sampling techniques in the central grasslands. J. Range Management 51:164-172.

Stohlgren, T.J., Falkner, M.B. and Schell, L.D. 1995. A modified-Whittaker nested vegetation sampling method. Vegetatio 117: 113-124.

El Inventario Forestal de México: Evolución y Perspectivas[1]

Miguel Caballero Deloya[2]

Resumen—En el año de 1961, con el apoyo de la FAO, México inició la gran tarea de cuantificar sus recursos forestales. El apoyo de esta organización internacional concluyó en 1965. A partir de esa fecha, la responsabilidad de llevar a cabo el inventario nacional forestal, fue retomada en su totalidad, por el Gobierno Federal. Para este propósito se creó una Dependencia Federal dedicada exclusivamente a esta tarea. Los objetivos y la estructura de dicha Dependencia, los sistemas de trabajo y los recursos destinados a este propósito sufrieron cambios sustantivos a lo largo de los diferentes periodos presidenciales. Sin embargo, la ejecución del inventario, por muchos años, estuvo centralizado en una sola unidad administrativa. El primer inventario nacional forestal concluyó en el año de 1985. Después de este esfuerzo inicial, se careció de un mecanismo efectivo que permitiese actualizar periódicamente los resultados de la evaluación original. No fue sino hasta la década de los años noventas, cuando se implementó un nuevo esfuerzo por cuantificar el recurso forestal del país. En el año de 1992, se inició el proyecto denominado "Inventario Nacional Forestal Periódico", cuyos resultados se dieron a conocer en 1994. A diferencia del primer inventario, que se llevó a cabo a través de una Unidad Federal Centralizada, con recursos casi en su totalidad del Gobierno Federal, el nuevo inventario se basó en la participación y aportación de recursos de los Gobiernos Estatales, así como el apoyo de diversas organizaciones e instituciones nacionales e internacionales. En el presente, la Dependencia encargada de actualizar las estadísticas y la cartografía de los recursos forestales de la nación, es la Secretaría del Medio Ambiente, a través de la Subsecretaría de Recursos Naturales. La presente ponencia resume los aspectos y hechos históricos mas relevantes en la estratégica tarea de la República Mexicana por cuantificar y mantener información actualizada de la magnitud y el estado que guardan sus recursos forestales.

Antecedentes

Con el apoyo de la FAO, en el año de 1962 la República Mexicana se dio a la titánica tarea de cuantificar su recurso forestal nacional. El auxilio de la FAO fue definitivo. Esta organización aportó una parte importante de vehículos para el transporte de materiales y de personal, además de equipo e instrumentos de medición especializados. Además hizo posible la disponibilidad de asesores que se encargaron de capacitar a los primeros técnicos mexicanos que se entregaron a esta importante tarea. Los esfuerzos iniciales del inventario nacional forestal se dieron en instalaciones del Instituto Nacional de Investigaciones Forestales (INIF), en Coyoacán, sur del Distrito Federal. Para la implementación del proyecto, se contrató un entusiasta grupo de Ingenieros Forestales Mexicanos, una buena parte del cual, se sometió a una apropiada capacitación en México y en el extranjero. La colaboración de la FAO concluyó en el año de 1965. A partir de esa fecha, el Gobierno Mexicano retomó totalmente el proyecto. De ese año al presente el inventario nacional forestal ha sido motivo de numerosos cambios y ajustes. La presente ponencia pretende resumir las experiencias y los resultados de este importante esfuerzo nacional, a lo largo de 37 años de trabajo ininterrumpido.

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Proyecto Notablemente Influido por Circunstancias Politicas

Un detallado análisis de los cambios, ajustes y transformaciones que ha experimentado el inventario nacional forestal de México, durante sus años de existencia, revela que cada administración pública dejó un sello particular en la unidad o dependencia encargada de esta tarea, así como en los procedimientos de trabajo. Si bien el Estado ha sido siempre responsable de esta tarea, su nivel de ingerencia se ha ido reduciendo a través de los años. Los causantes de que los criterios y metodologías hayan cambiado a lo largo del tiempo, se pueden resumir en:

(I) Las crisis económicas nacionales del México contemporáneo.
(II) Los ajustes y cambios progresivos en las estrategias Gubernamentales.
(III) La evolución tecnológica y sus implicaciones en los sistemas de inventario y monitoreo de los recursos naturales.

Evolucion Historica

¿ Que Ocurrió a lo Largo de 37 Años?

Partiendo de la premisa de que cada administración pública tuvo un fuerte impacto en el inventario nacional forestal de México, se procede a presentar una breve discusión de algunos rasgos relevantes a lo largo de cada uno de los 7 sexenios que han incidido en el mismo.

Administracion Publica, Periodo 1958-1964

Presidencia del Lic. Adolfo López Mateos

Como ya se destacó, en el año de 1962 despegó el inventario nacional forestal con el soporte de la FAO. Con este propósito, se creó el Departamento de Fotogrametría e Inventarios en el entonces, Instituto Nacional de Investigaciones Forestales.

Profesionales forestales Mexicanos fueron enviados a capacitarse a Europa y a Estados Unidos. Por otro lado, expertos internacionales llegaron a México para asesorar y orientar el despegue de las operaciones. Tales fueron los casos de: F.C. Hummel; Louis Huguet; Aarne Nyssönen y Gustav Syren, etc.

Un aspecto muy importante de esta etapa, es que en la misma se establecieron las bases técnicas y administrativas del proyecto. Dentro de la actividad agropecuaria y forestal de México, por vez primera se emplearon algunas herramientas nuevas en un plano enteramente operativo y a amplia escala. Ese fue el caso del cómputo electrónico, de algunas técnicas estadísticas como el muestreo, de la Fotogrametría y la Fotointerpretación, etc.

En estos años, se trabajaron los inventarios forestales de los estados norteños de Chihuahua, Sonora y Durango.

Administracion Publica. Periodo 1964-1970

Presidencia del Lic. Gustavo Diaz Ordaz

A la conclusión de la colaboración de la FAO, Durante esta Administración Pública, la República Mexicana absorbió enteramente la responsabilidad de la implementación del proyecto.

Para ese propósito, el proyecto del Inventario Nacional Forestal fue separado de su hospedero original, el Instituto Nacional de Investigaciones Forestales, creándose la Dirección General del Inventario Nacional Forestal, Dependencia perteneciente a la Subsecretaría Forestal y de la Fauna.

La opinión frecuente de quienes vivieron directamente este cambio, es que se perdió gran parte de la agilidad administrativa y financiera que se tuvo en la etapa inicial, empezando así un proceso de naturaleza burocrática. Sin embargo, el Gobierno continuó absorbiendo enteramente, todo el gasto que ocasionado por la continuación del proyecto.

En estos años, se concluyeron los inventarios de Baja California, Nayarit, Parte de Quintana Roo (Chunjujub-Carrillo Puerto), Jalisco, Sinaloa y la vegetación forestal de Aguscalientes.

Administracion Publica. Periodo 1970-1976

Presidencia del Lic. Luís Echeverría Alvarez

Este sexenio implicó un cambio muy importante en el proyecto, ya que la nueva administración de la Dirección General del Inventario Nacional Forestal dio un nuevo giro a los trabajos, habiéndose perdido el enfoque básico y original hacia la cuantificación fundamental del recurso forestal.

El trabajo de la Dependencia se fragmentó en 4 grandes programas: (a) Inventario Forestal Continuo; (b) Catastro Forestal y División Predial; (c) Banco de Información Forestal y (d) Inventario Forestal Periódico.

Se concluyó el inventario forestal de la mayoría de las Entidades faltantes, como fueron: Colima, Zacatecas, Guerrero, México y D.F.; Tlaxcala, Morelos, Chiapas, Guanajuato, Hidalgo y Morelos.

Fue evidente, a partir de estos años, que la temática del inventario nacional forestal, a diferencia de años pasados, fue perdiendo vigencia e interés.

Administracion Publica. Periodo 1976-1982

Presidencia del Lic. José López Portillo

A partir de esta Administración Pública, la Dependencia directamente responsable del Inventario Nacional Forestal perdió un gran bastión. Perdió el nivel de Dirección General que había conseguido a partir de 1965. A partir de esta fecha hasta el presente, dicha Dependencia, jamás volvería a recuperar ese nivel administrativo.

Como consecuencia de lo anterior, y de la consecuente reducción presupuestal de la Dependencia, la mayor parte de los técnicos que aún quedaban laborando en el proyecto tuvieron que abandonarlo e iniciarse en otro tipo de actividades. Los activos y equipos del inventario forestal en su mayoría fueron canalizados a otros proyectos.

De los cuatro programas que se habían creado en la administración pasada, solo quedó uno, el programa sustantivo del Inventario Forestal Nacional, pero minimizado y en condiciones muy precarias.

Finalmente, cabe destacar que en este periodo se inicia una época de crisis económicas, de cambios y profunda inestabilidad en la Administración Pública que habría de tener subsecuentemente, impactos sustantivos adicionales en el proyecto. Quizá el mas importante es que a partir de este sexenio, la unidad encargada del inventario nacional forestal dejó de ser la Dependencia que hacía y absorbía todo el trabajo del inventario (cartografía; trabajos de campo; procesamiento estadístico de los datos, análisis de los resultados y elaboración de las memorias). A partir de estos años, la organización responsable del inventario dejó pués de ser el "hacedor" del trabajo, para convertirse en un coordinador, promotor, integrador e instancia normativa de los futuros inventarios.

Administracion Publica. Periodo 1982-1988

Presidencia del Lic. Miguel de la Madrid H

En este sexenio, México sufrió el impacto de una de sus peores crisis económicas de su historia contemporánea.

Por lo anterior, desapareció la Subsecretaría Forestal. La administración de los recursos forestales quedó a nivel de Dirección General (Normatividad Forestal). El Inventario Nacional Forestal quedó adscrito a ésta como una Dirección de Area.

Sin embargo lo mas sobresaliente de esta etapa es que en el año de 1985 concluyó el primer inventario nacional forestal de México. Terminó así, un ciclo que duró 24 años.

Administracion Publica. Periodo 1988-1994

Presidencia del Lic. Carlos Salinas de Gortari

Un aspecto favorable de esta etapa es el restablecimiento de la Subsecretaría Forestal.

Desapareció la Dirección General de Normatividad Forestal, habiéndose creado en su lugar la Dirección General de Política Forestal. El Inventario Nacional Forestal quedó adscrito a ésta.

Otro aspecto importante de este sexenio, es el resurgimiento del inventario nacional forestal. Así en 1991, se lleva a cabo un Inventario Nacional Forestal de Gran Visión, que aunque limitado en su nivel de utilidad (careció de trabajos de campo), permitió por lo menos contar con una nueva apreciación de la magnitud del recursos forestal del país.

En el periodo 1992-1994, se llevó a cabo el segundo inventario forestal nacional. Este esfuerzo presentó la modalidad de haberse llevado gracias a la participación y aportación de los Gobiernos Estatales.

Administracion Publica. Periodo 1994-2000

Presidencia del Lic. Ernesto Zedillo. La Etapa Actual

En el presente sexenio, vuelve a desaparecer la Subsecretaría Forestal. La Administración del recurso forestal es absorbida por la nueva Subsecretaría de Recursos Naturales de la Secretaría del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP).

Dentro de la Subsecretaría indicada, se creó la Dirección General Forestal, en la cual quedó inserta la "Unidad del Inventario Nacional de Recursos Naturales" (INRN). Entre otras, ésta presenta dos modalidades: (a) Por un lado, amplía su cobertura de inventario a los recursos naturales renovables- y no solo lo forestal, y (b) Se inicia el inventario nacional de suelos de México.

El Balance ¿Qué Conclusiones se Pueden Derivar de este Esfuerzo Historico?

Análisis del Primer Inventario Nacional Forestal

Es evidente que el primer inventario nacional forestal se dio con gran entusiasmo pero sin planificación de todo el proceso.

Por otro lado, los frecuentes relevos y ajustes políticos en las diversas dependencias de la Administración Pública directamente relacionadas con la tarea del inventario forestal, incidieron en continuos e imprevistos cambios, de objetivos, metas y de dirección. El cambio de organización "operativa" a "normativa", de parte de la Dependencia responsable del proyecto, no fue resultado de una estrategia, sino mas bien, de presiones y necesidades económicas, generadas por diversas crisis financieras que afrontó el Gobierno Federal y el país en lo general.

Lo anterior explica el hecho de que el ciclo del primer inventario nacional forestal haya durado 24 años. Las implicaciones de un ciclo de cuantificación tan largo en un país con una gran dinámica de transformación de sus recursos naturales es que los resultados no son válidamente integrables sin el ajuste correspondiente por el efecto del tiempo. Dicho ajuste, hasta donde el autor pudo averiguar, nunca se llevó a cabo.

Análisis del Segundo Inventario Nacional Forestal

En contraste con lo que ocurrió en el primer inventario nacional, en el segundo el ciclo duró solamente tres años.

La opinión de algunos expertos en este tema, consensa los hechos siguientes:

(I) Los trabajos se llevaron a cabo con excesiva premura.

(II) Se careció de una supervisión apropiada que constatara la calidad de los trabajos, particularmente en relación a la toma de datos de campo.

(III) Los resultados no fueron validados.

(IV) El nivel de los resultados no es enteramente compatible y apropiado con las necesidades de información que demandan las Entidades Federativas, principales usuarios potenciales de los mismos.

(V) Las metodologías empleadas y consecuentemente los resultados, no son compatibles con los del primer inventario. Por lo anterior, la comparación de cifras entre ambas evaluaciones no hace válida la cuantificación de cambios o tendencias.

La Situación Actual

Los nuevos funcionarios responsables y directamente involucrados con la tarea de cuantificar los recursos naturales de México patentizan una gran conciencia sobre la importancia de estas tareas. Sin embargo se encuentran con un panorama muy por atrás del que existía en el país en la primera mitad de la década de los años 70s. Concretamente, se dispone de un grupo muy limitado de profesionales, la mayoría de los cuales están lejos de tener el mayor nivel académico y la capacitación, sobre todo con relación a las técnicas mas modernas que existen sobre el tema. El equipo y la infraestructura física disponibles, tampoco son las mas apropiadas, si bien se dispone de una aceptable infraestructura en materia de procesamiento de datos y de trabajo cartográfico.

Sin embargo, ante esa perspectiva poco optimista, se presenta una demanda de información que rebasa con mucho, la de los años pasados, tanto desde la perspectiva cuantitativa -magnificada por una mayor población,- como cualitativa,- notablemente ampliada por nuevas demandas motivadas por las recientes preocupaciones de carácter ambiental y relativas a los recursos naturales renovables.

Sin embargo, no todo el panorama tiene un arista negativo. Existen también aspectos favorables, como son, por un lado, el hecho de que el avance científico y tecnológico ha puesto a disposición nuevas herrramientas y materiales que permiten acceso a tipos de información y a niveles de costos que superan con mucho los existentes en décadas pasadas. Es justo reconocer que en el presente se dispone de diferentes alternativas altamente eficientes en materia de imágenes de satélite y de fotografías aéreas, como resultado de recientes avances tecnológicos. De la misma manera, se cuenta con el auxilio de modernos sistemas de información geográfica y de procesamiento electrónico de datos. De la misma manera, han proliferado organizaciones que captan y procesan cartografía, materiales y datos en el campo de los recursos naturales. En el caso de México, se cuenta con los apoyos de prestigiadas instituciones como el INEGI, la Comisión Nacional del Agua, la UNAM, el IMTA, etc. para citar solamente algunos ejemplos. Es evidente que estos avances y apoyos ahora existentes, pueden brindar un sólido auxilio a los nuevos y futuros esfuerzos nacionales por cuantificar y monitorear los recursos naturales.

Las Perspectivas

Considerando las demandas presentes de la Sociedad actual, México debe superar el contexto de los inventarios forestales para cubrir, en sus nuevas cuantificaciones, el ámbito global de los recursos naturales renovables. En otras palabras, se deben cuantificar: (a) Vegetación; (b)Suelo; (c) Agua; (d) Fauna Silvestre; (e) Información Ambiental, etc. Es evidente que solo en la medida que exista en toda la sociedad, un pleno reconocimiento de lo anterior, y en consecuencia se tomen las decisiones apropiadas, el país estará en condiciones de implementar planes y programas realistas en torno a la conservación y el uso mas apropiado de sus recursos naturales.

El nuevo sistema de cuantificación de recursos naturales, debe tener todos los elementos y condiciones para aportar información e implementar un sistema de monitoreo de carácter estratégico de los recursos naturales, que entre otras piezas de información, aporte periódicamente, un conocimiento actualizado de : (a) Tasas de deforestación a nivel regional y estatal; (b) Impactos de cambios de uso del suelo sobre: la vegetación; los suelos; las poblaciones de fauna silvestre, etc.; (c) Abatimiento de la Biodiversidad; (d) Impacto de los incendios forestales y de meteoros naturales (ciclones, huracanes, sismos, etc.); (e) Avances del proceso de desertización en la geografía nacional; (f) Destrucción y pérdidas del suelo productivo en los contextos nacional, regional, estatal y local, etc.

Todo parece indicar que la unidad responsable del inventario nacional de los recursos naturales, jamás volverá a ser la “ejecutora directa” de los trabajos de cuantificación. En estas condiciones, dicha unidad deberá recibir todo el apoyo, por parte de las autoridades correspondientes, para que se constituya en una eficiente organización normativa, planificadora, concertadora, coordinadora y evaluadora del proyecto nacional. Su éxito dependerá en mucho de su capacidad para motivar la participación de los Gobiernos Estatales, de las empresas privadas, de las ONGs y universidades, centros especializados, organizaciones internacionales, etc.

Se considera que para ser eficiente, la Unidad del Inventario de Recursos Naturales, deberá:

(I) Implantar un sistema de capacitación dinámico y continuo a sus técnicos, respecto a las tecnologías mas modernas, eficientes y económicas de inventarios de recursos naturales.

(II) Incursionar intensivamente en las nuevas herramientas cartográficas, computacionales y estadísticas de mayor aplicación a los inventarios en la actualidad.

(III) Adquirir equipo e instrumental “de vanguardia” en la materia.

La Unidad del Inventario deberá diseñar una metodología estable y permanente que permita correlacionar válidamente,los resultados de los inventarios futuros y reducir al mínimo los errores de muestreo. Para reducir los costos al mínimo resultará muy conveniente recurrir a herramientas y metodologías de gabinete, que optimicen la información de campo.

Para que los Gobiernos Estatales estén deseosos y dispuestos a colaborar financieramente en la implementación de los inventarios, deberán tener la seguridad de que el nivel y precisión de las estadísticas, así como la escala cartográfica, es apropiada a sus requerimientos y necesidades. En este sentido, los responsables de la Unidad del Inventario, tendrán necesidad de llevar a cabo una labor sustantiva y dinámica en materia de gestión y concertación, particularmente con los Gobiernos Estatales. También será importante que se acerquen y mantengan comunicación estrecha con las organizaciones, tanto nacionales como internacionales, ligadas a este quehacer.

Los términos en que la Unidad trabajará en el futuro, enfatizan la importancia de la cooperación. A lo interno, resultará estratégico colaborar estrechamente con: INEGI, UNAM, IMTA, CNA, SAGAR, CP, UACH y Gobiernos Estatales. A lo externo, resultará muy útil buscar el apoyo sistemático de la FAO y de otras organizaciones intenacionales. En este sentido, México deberá aprovechar la sólida y productiva asociación que mantiene desde hace décadas, con Canadá y Estados Unidos, a través de la Comisión Forestal para América del Norte (COFAN), para apoyarse en la experiencia y los conocimientos de las instituciones y el personal altamente especializado de estos países.

México es un país, que no obstante su pasado, aún cuenta con un importante acervo de recursos naturales renovables. Estos recursos adquieren una importancia estratégica para el presente y el futuro de la Sociedad Mexicana. Por ello es necesario destacar que cualquier plan que se haga basado en el aprovechamiento sostenible de dichos recursos, requiere de su conocimiento preciso, actual y futuro. Para ello resulta indispensable disponer de un sistema de inventario confiable, eficiente y económico. El futuro de las generaciones Mexicanas y de los recursos naturales de que dispongan a partir del nuevo milenio, dependerá en alto grado, de la comprensión y de las decisiones que la sociedad y las autoridades de la nación, adopten sobre esta inevitable realidad.

International Long-Term Ecological Research: a Role in Research, Inventorying and Monitoring Forest Ecosystem Resources[1]

James R. Gosz[2]

Abstract—Long-term data are crucial to our understanding of environmental change and management. Historically, these studies have been difficult to maintain because of the dominance of short term funding programs, a misconception that long-term studies are merely monitoring, and emphasis on short term experimentation or hypothesis testing of specific interactions or processes. The literature also demonstrates a dominance of single, small-scale studies and a focus on a few species. The concept integrates comprehensive understanding of ecosystem processes, model development and the use of regional monitoring and survey data to develop regional understanding of natural resource conditions. The LTER concept is shown as contributing to multiple scale studies and complex assemblages of species. The need for collaborations among the numerous scientists and high-quality programs that are involved in understanding the various areas of our globe is a strong argument for the development of a worldwide network of LTER sites and programs. The main objectives of the ILTER are to:

- Promote and enhance understanding of long term ecological phenomena across national and regional boundaries;
- Facilitate interaction among participating scientists across sites and disciplines;
- Promote comparability of observations and experiments, the integration of research and monitoring, and encourage data exchange;
- Enhance training and education;
- Contribute to the scientific basis for ecosystem management and improve predictive modeling at larger spatial and temporal scales.

LTER sites in the countries of the ILTER Network can provide unparalleled opportunities for cross-site and comparative research efforts on many of the world's ecosystems. It is anticipated that each country's program will be part of a global network of scientists and of scientific information that will advance our understanding of not only local and regional, but also global, issues and provide solutions to environmental problems at these scales. These global LTER sites function as "research platforms" that lead to interdisciplinary research, extrapolation to larger areas or regions, provide the scientific basis for management and policy decisions that incorporate social and economic issues. The expected development of a Mexican LTER Network will allow the collaboration between Mexico, U.S. and Canada in a North American Regional LTER Network.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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A primary role for the ecological sciences is to develop an understanding of the environment that is required for managing our natural resource base in a sustainable manner. Regardless of whether we are testing theory, evaluating new techniques, evaluating management effects, or any of a number of other research endeavors, the ultimate value of such research is to increase our ability to understand the environment. Developing such insights over both time and space scales are important contributions of the many fields of ecology in combination with other disciplines in the biophysical, social and economic sciences. Modern ecological science recognizes that the environment is:

- Complex—many interacting factors are involved in ecological processes;
- Dynamic—factors vary over time in complex ways;
- Spatially variable—heterogeneous and exhibits different patterns at different scales;
- Biologically diverse—complex assemblages of thousands of interacting species;
- Physical-Chemical-Biological-Social-Economic controlled. Interdisciplinary efforts are needed to understand ecological patterns and processes.

This recognition then identifies the serious challenges we have in our research needs. For management of natural resources, the above list indicates that we need to develop our understanding of the environment based on multiple control factors, long term studies, multiple spatial scales, many species interacting in complex ways and interdisciplinary interactions. Since we recognize what is needed to understand the complexity of the environment and manage its natural resources, are we doing it? Are other nations doing it? One way of approaching these questions is to ask why so many countries are now developing Long Term Ecological Research programs and networks. Figure 1 shows the 15 countries that have recognized national programs in Long Term Ecological Research, as well as those near to having such national recognition and those in the initial stages of the process as of October, 1998. This development has occurred in only the last 4 years following an international conference at the end of 1993. The list is dynamic as countries complete the development of their programs and additional countries become interested. Updated versions of the map will be viewable at (http://www.ilternet.edu). Certainly, many or most of these countries have research, inventorying and monitoring programs, so why has there been such interest in the development of an additional research program geared to Long Term Ecological Research? The same question can be asked of the U.S., does our current knowledge base allow the understanding needed to manage our natural resources in a sustainable way.

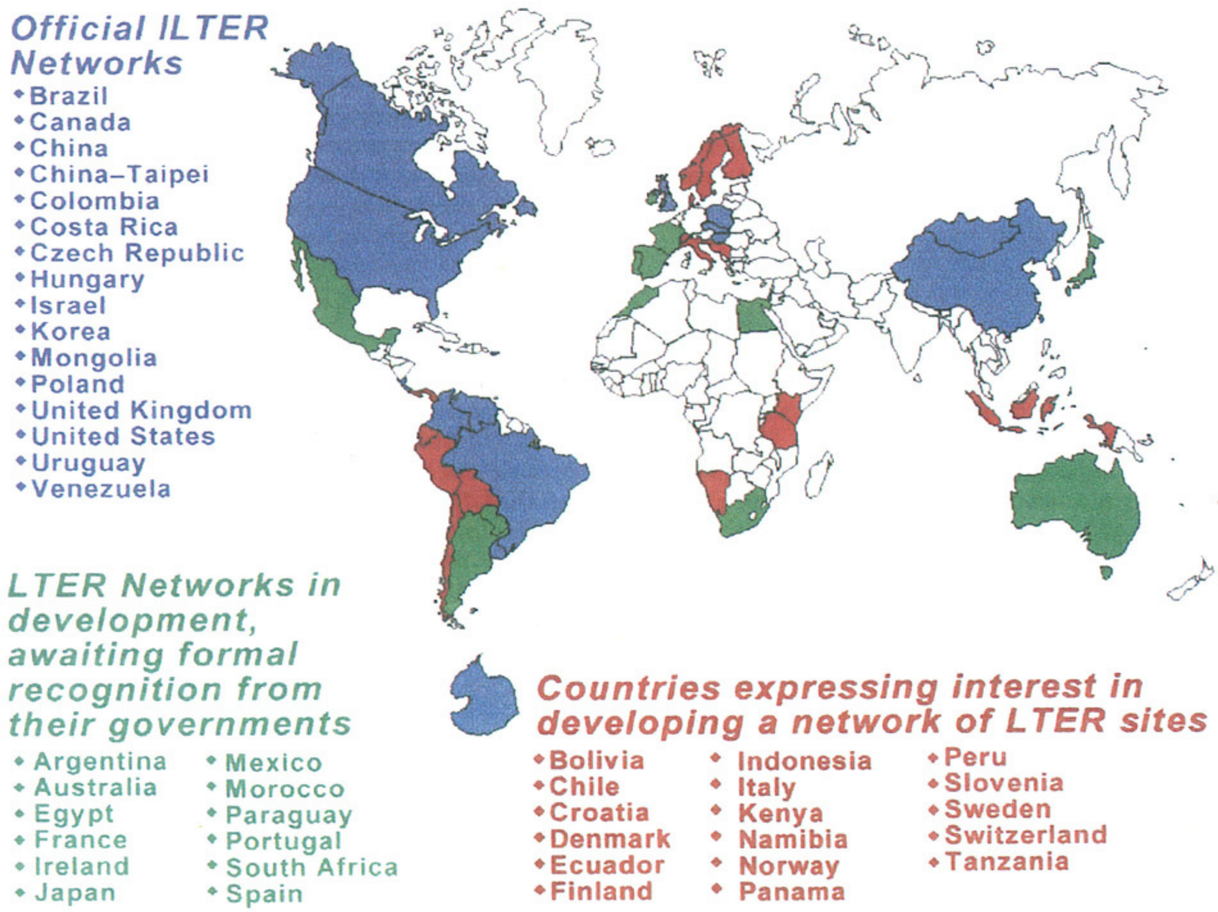

Figure 1

An analysis of the ecological literature in the U.S. provides some idea of how well we are doing in the development of information to meet these needs. Many studies (e.g., chapters and references in Likens 1989) demonstrate that short-term studies can provide misleading results. The environment is very dynamic and varies significantly over time. A study during 1 or 2 years captures only a "snapshot" of the variability and runs the risk of drawing incorrect conclusions about the behavior of ecological systems (Wiens 1997). Although the results of 1-2 years of research may be accurate for that period, extending the interpretation of those results to longer periods is misleading as other periods may have very different results and interpretations. The book by Cody and Smallwood (1996) has many chapters that demonstrate time after time how short-term conclusions may be abridged or overturned by a longer perspective. In spite of that knowledge, the literature continues to publish extensively about these snapshots in time. Tilman (1989) analyzed 623 experimental and 180 field studies and reported that over 75% were 1-2 year studies. Analyses of a recent journal of Ecology issue show little change from Tilman's analysis. Of 25 studies in the volume 7 (1998), No. 6 issue of Ecology, 84% were based on 1-2 years of data. This indicates that our literature (i.e., knowledge base) *is biased toward short-term results* and it is difficult to synthesize this knowledge to understand the natural dynamics in the environment. In another analysis of the ecological literature, Weatherhead (1986) found that of 332 plant, invertebrate and vertebrate studies from desert, temperate and tropical habitats, the mean duration was 1-2 years, and further that only about 10% captured "unusual" events such as droughts, wet episodes, insect infestations. We know that these infrequent events are critical in our understanding of forcing functions on the environment and many ecological processes react in a very different way after the "event" than before (Burke, et al. 1991, 1997). Thus, much of our ecological literature fails to document and analyze many of the significant influences on ecological functions. The Volume 7, No. 6 issue of Ecology had no studies that captured an unusual event.

Why has there been such emphasis on short-term research in the U.S.? Many reasons, ranging from the pressure on many scientists to publish frequently (using 1-2 years data) to a dominance of short term research awards, pressure to get results fast, and changing issues in funding agencies. Thus, traditional science is biased in certain ways as a result of the systems we have for doing and rewarding science, and as a result, our knowledge base is biased. This seems to be true for many countries suggesting a general human/society influence on the way the environment is studied and research is performed.

Analyses of the ecological literature identify other biases relative to the understanding needed for natural resource management. Wiens (unpubl data), Valone and Brown (1996), Kareiva (1994) identify that the spatial scales of study are biased toward single scales that often are done at 1 m^2. We are aware of the scale dependency of our studies meaning that the scale at which we study the environment "determines" the result that we get. It is similar to studying a process for 1-2 years in that, when we study determines the result just as the scale we use "determines" the result (Levin 1992). *The results of the ecological literature in the U.S. are biased to results based on single and small spatial scales!* This is especially relevant for landscape management programs that need broad scale and multiple scale analyses. The literature is difficult to use for syntheses of information on how processes vary with scale. The Volume 7, No. 6 issue of Ecology showed that all studies but two used a single scale and 50% used the scale of 1 m^2.

Kareiva (1994) and Valone and Brown (1996) also demonstrated that the ecological literature *is biased toward studies of only 1 or 2 species at a time*. Although we know that many thousands of species are involved in ecological processes, it is very difficult to use the current literature to understand how species complexity influences processes important in natural resource management.

Finally, the literature is biased toward single discipline results. We have many discipline-specific journals, discipline-specific departments in academic institutions, discipline-specific societies, all of which promote a literature that does not demonstrate the interdisciplinary understanding needed for understanding our environment. Most of our government agencies or ministries have focused missions that further impose a narrow focus. These biases may be the most serious and the most difficult to overcome! While the data from the studies discussed previously are judged by the scientific review process as scientifically valid, they limit the synthesis required to meet the challenge of understanding a complex, dynamic, diverse and heterogeneous environment. **We desperately need to develop efforts that can complement the more numerous activities that generate the above biases.**

Long Term Ecological Research; a Model for Integrated Research

Following the International Biological Program (IBP) of the 1970's, the ecological community in the U.S. developed discussions with the National Science Foundation to hold a number of workshops on the value of long term research that could continue the type of science developed during IBP. That resulted in the formation of the Long Term Ecological Research (LTER) program in the U.S. in 1980. The rationale was to develop long term measurements and experiments that would fill what was identified as a deficiency of results at the temporal scales of decades to centuries. From the original designation of 6 sites, the program has grown to a network of 21 sites stretching from Alaska to the Antarctic and from habitats as diverse as tropical forests, lakes, deserts, alpine tundra, row agriculture and urban environments. Additional sites are expected to be added to the network. That program has demonstrated convincingly of the value of long-term research, but more importantly, that other types of studies occur that address deficiencies in the research of spatial scales, complex factor control, diverse species assemblages and interdisciplinary interactions. For example, as ecological processes are studied for multiple decades, infrequent events are captured that demonstrate their importance as well as lead naturally to questions and the study of the broader scales associated with these infrequent events (e.g., regional drought, Burke et al. 1997). The research at broader scales plus the ability of the comprehensive efforts at long term research sites to utilize multiple platforms from ground-based measurements to satellite imagery allows such cross-scale research. In the U.S. LTER program there has been a natural tendency for multiple scales of research to develop associated with the long-term data sets and studies of many variables. Thus, as a result of performing long term studies that relate to decade temporal scales, the LTER program demonstrates a complementary ability to develop multiple scale studies from local to regional environments. There are other presentations at this conference that will demonstrate the contributions of LTER programs located in forested regions. Here I want to demonstrate the natural progression of scientific questions across spatial scales for a short grass steppe in Colorado. This example demonstrates how the questions evolve following the development of long term data sets and the observations of phenomena that are related to larger spatial scales. The following figures can be viewed at (http://sgs.cnr.colostate.edu/sgshome.htl) along with literature for this research site.

The Shortgrass Steppe Long Term Ecological Research Project has been conducting regional analysis since 1988. The overall goal in this research has been to understand the current pattern of ecosystem structure and function in the central grasslands of the U.S., and to assess the sensitivity of the region to changes in climate and landuse. The initial analyses, conducted in the late 1980's, focused on the analysis of regional point data, and assessed the relationships between climatic and soil variables and aboveground net primary productivity (Sala et al. 1988) and soil carbon (Burke et al. 1989). After analyzing results that included extreme events (e.g., drought) representative of broader scales, the question became "what area does our site adequately represent?" To what area can we logically extrapolate the results from our site-level investigations (Burke et al. 1990). Using a number of regional databases (Fig. 2), the results suggest that the climate, soils, and landuse of the Shortgrass Steppe LTER site represent approximately 23% of the total shortgrass steppe area. Outside of this region the models that were developed were inaccurate. That led to new efforts to understand why the models were wrong and to reparamaterize the models to work through the central grassland region.

More recently, they developed a large spatial database, organized in a geographic information system, of climatic variables (precipitation and temperature), soils data, plant species distributions, and landuse. The three sets of questions for this expanded research program were:

1. What are the regional, spatial controls over plant species distributions, and how will these distributions change under global climate change?; and

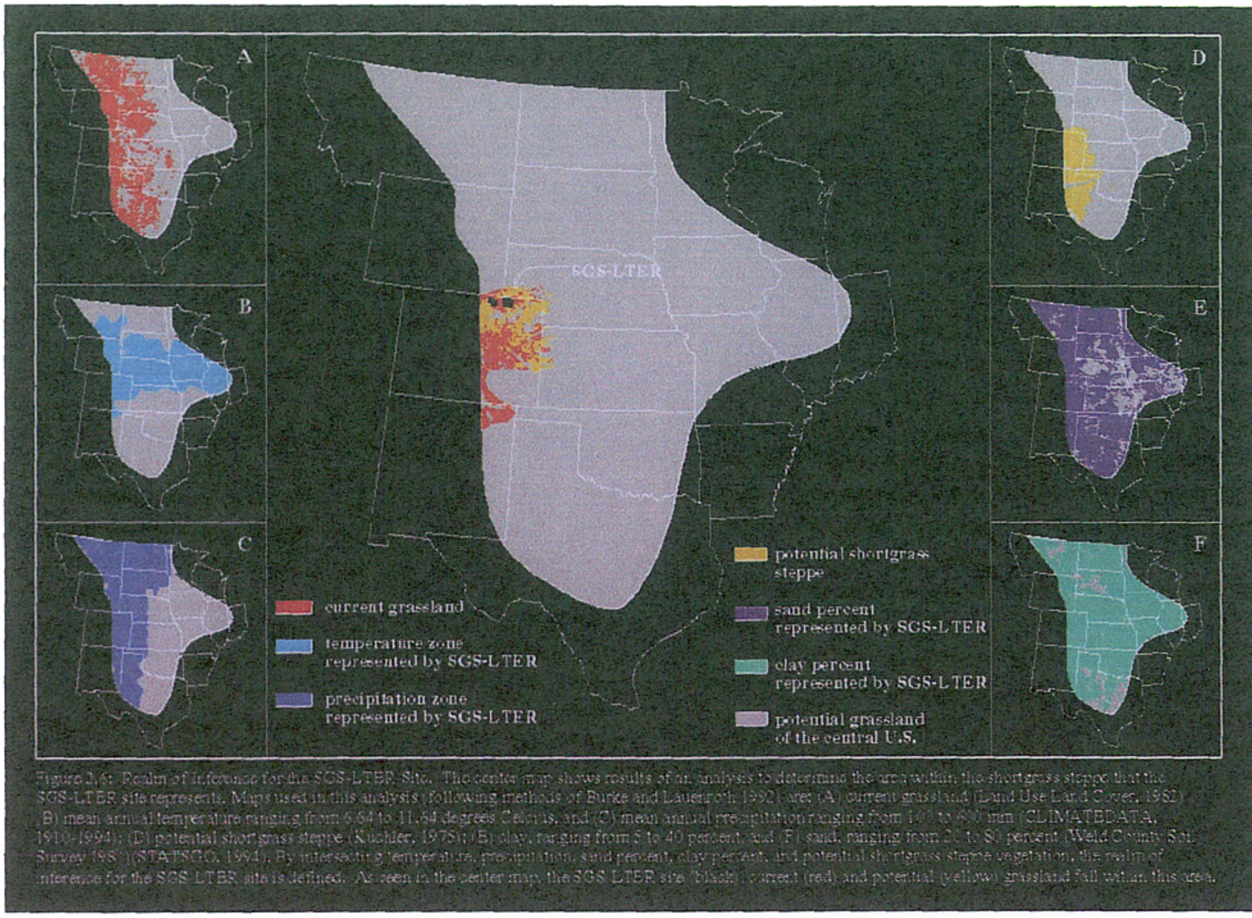

Figure 2

2. What are the regional, spatial controls over landuse management, how will these distributions change under global change, and

3. What are the regional impacts of landuse management on regional climate, and on ecosystem structure and function throughout the region?

Two general techniques were used in this research (Burke et al. 1991). The first was pattern analysis, in which multivariate analysis was conducted on the data to establish important relationships among variables. The second was simulation analysis, in which the spatial database was linked to simulation models to extrapolate across the region and into the future (Coleman et al. 1994). Examples of results from these new studies at the regional scale are the estimate of carbon loss in the region from 1900 to 1995 (fig. 3) and average grain yields (fig. 4) for the region.

These results demonstrate another very important aspect of these research-intensive sites. The combination of comprehensive understanding of the ecosystem processes and model development plus regional monitoring and survey information allowed the development of regional simulation models. The research or surveys or monitoring by themselves is insufficient. The combination develops unique capabilities to work at regional scales.

What is the relationship between long-term research and our understanding of biodiversity or the complex assemblages of species in an environment? Here too, long term studies have been influential. There are two typical results from long-term research sites that show their value. First, because populations of some species vary through time from abundant to many being rare or undetectable, a single survey may or may not record all of the species as present. Long-term studies more often detect higher numbers of species by because they see these variations over time. For example, at the Sevilleta LTER site in New Mexico, U.S., (http://sevilleta.unm.edu) vascular plant species richness can vary 3-fold between wet and dry years. For the Northern Temperate Lakes LTER in Wisconsin, U.S., (limnology.wisc.edu/"http://limnosun.limnology.wisc.edu/) zooplankton species richness for a 12-year period was twice the richness for any single year during the period. The second result is based on the value of the long-term research site for research in general. These sites allow a continuity of research efforts because of the protection of the site and generate data of various types that are useful for many studies. This makes the site more and more valuable for other studies and the experience has been that other disciplines are attracted to the site to work on their specific taxonomic groups. This results in a general increase in the

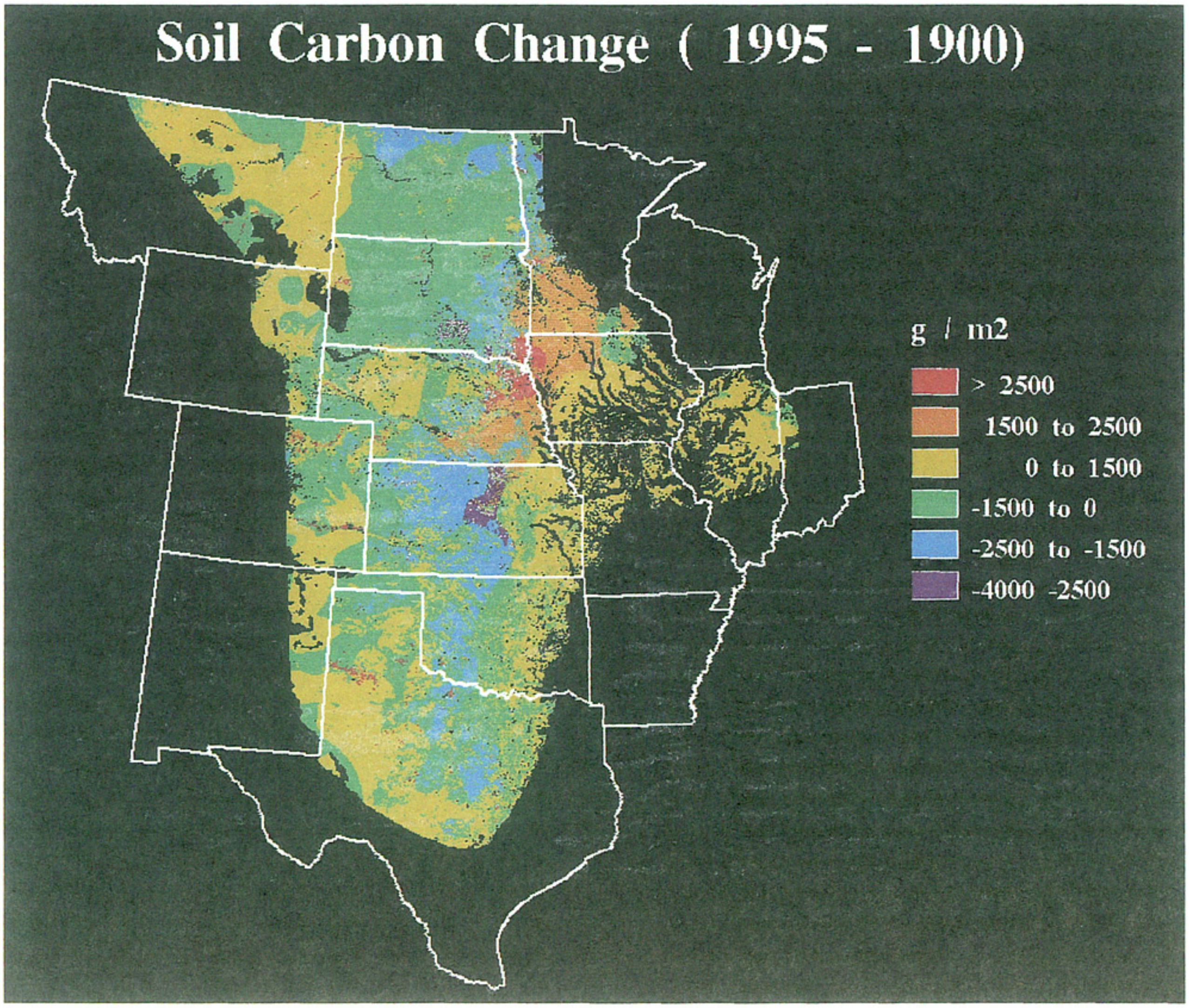

Figure 3

species studied on the site and an increase in the identification of species present. Species richness increases directly as a result of research efforts looking for more species! The studies of these species being performed on the same site and over similar periods of time allow increased understanding of how the complexity of species assemblages is related to the functional properties of the ecosystem.

The same features that attract many people working on different taxonomic groups also is attractive to people from different disciplines. In addition to the core areas in the U.S. LTER program that require the integration of different disciplines (e.g., population biology, nutrient dynamics, hydrology, climate), the sites become valuable for collaborative studies in areas such as hydrogeology, atmospheric physics/chemistry, genetics, microbial ecology, systematics, landscape ecology, social/economic sciences as well as development of theory, new techniques and land management approaches. *Long term research sites result in intensive studies by many individuals and disciplines working on common areas at similar times that facilitates the integration of information!* In addition, the data developed for these studies are managed effectively and archived for the use of other scientists, now and in the future. Data management is an important function in the success of LTER. These sites function like research platforms that concentrate the work of many scientists and disciplines to accomplish studies, integration, and syntheses in ways that are difficult for the more typical research efforts. They complement traditional research in ways that reduce the biases present in the ecological literature.

The development of intensive and comprehensive research efforts at individual sites provides additional value when cross-site comparisons and experiments are performed.

> "The power of the network approach of the LTER program rests in the ability to compare similar processes (e.g., primary production or decomposition of organic matter) under different ecological conditions. As a result, LTER scientists should be able to understand how fundamental ecological processes operate at different rates and in different ways under different environmental conditions" (Risser et al. 1993).

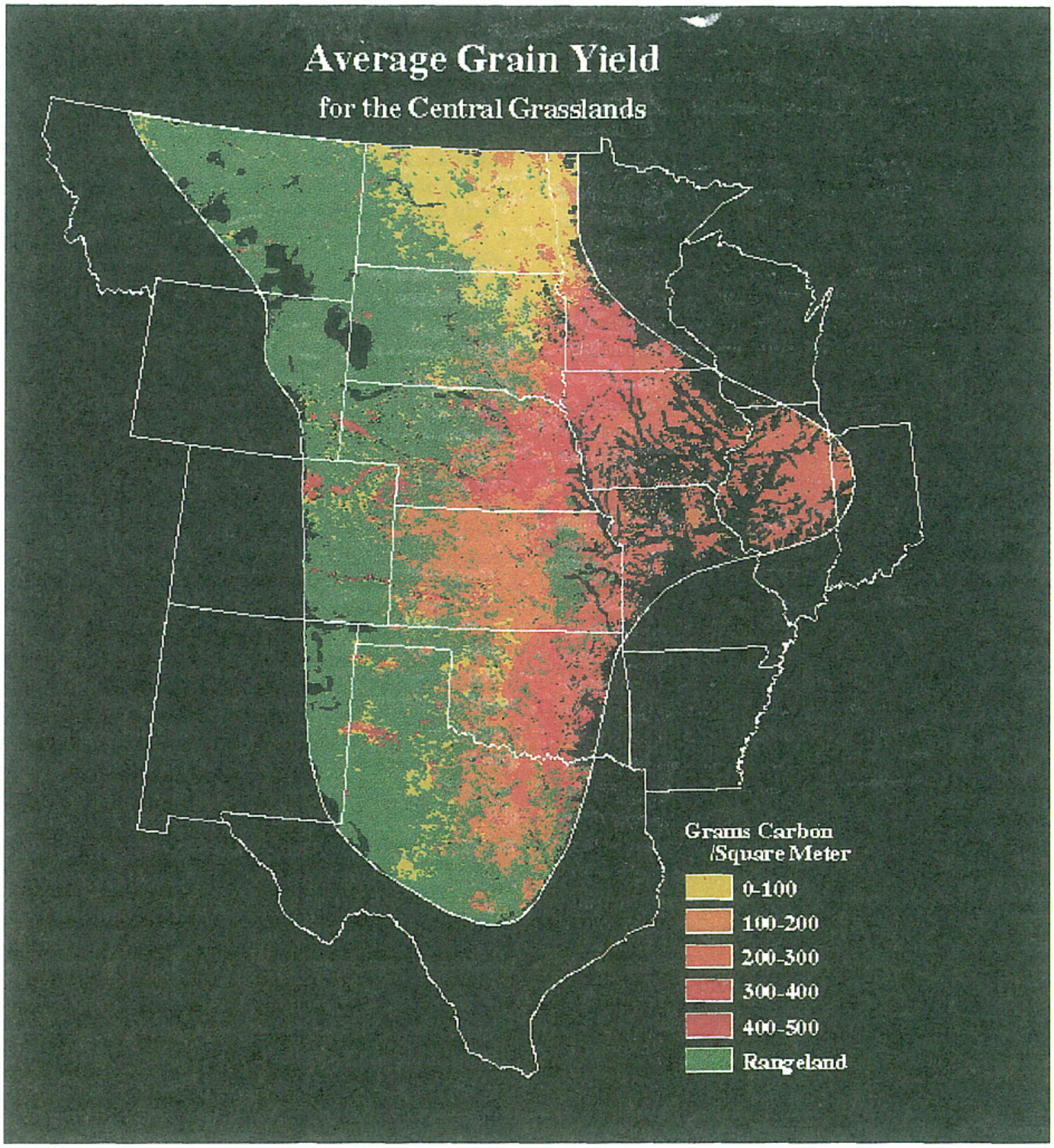

Figure 4

ILTER: Extending the Model Internationally

The need for collaborations among the numerous scientists and high-quality programs that are involved in understanding the various areas of our globe is an even stronger argument for the development of a worldwide network of LTER sites and programs. As a result of an international meeting in 1993 to focus exclusively on networking of long-term ecological research, an International LTER (ILTER) Network was formed with a mission to facilitate international cooperation among scientists engaged in long-term ecological research. Thirty-nine scientists and administrators representing 16 countries participated and developed the initial recommendations for the network. The International LTER needs were identified as:

1. Communication & Information Access for LTER Researchers Worldwide
   - Determine the general connectivity status of LTER sites and scientists by country or region
   - After completing a connectivity assessment, organize a clearinghouse system to facilitate technology and skills transfer between sites

- Create an information server on the global Internet to provide worldwide access to information and data relevant to international long-term ecological research
- Establish an international LTER (ILTER) server access mechanism (or mechanisms) for researchers in regions presently without access to the international Internet

2. Developing a Global Directory of LTER Research Sites
   - Develop minimum site capabilities or standards for inclusion in an ILTER directory
   - Identify existing and potential LTER sites worldwide
   - Create both electronic and hard-copy versions of an ILTER directory to be updated regularly
   - Form a directory working group to help define tasks and secure funding for the creation of an ILTER directory
3. Developing LTER Programs Worldwide
   - Encourage the pairing of mature and developing sites which share similar ecological settings and encourage cooperation between pairs of established sites within or between countries
   - Produce an inventory of sources of financial support for ILTER activities and infrastructure at participating sites
4. Scaling, Sampling and Standardization: Some Design Issues. The following questions should be addressed by LTER sites:
   - Will phenomena, which occur over long time scales, be adequately sampled over appropriate spatial scales?
   - What is the spatial and temporal range over which site data can be legitimately extrapolated, and what method(s) will be used?
   - How much effort will be required for synthesis and intersite comparison, and has flexibility for subsequent adjustment of observations been incorporated into the design?
   - Have the selected measurements been adequately tested, and have the required precision and frequency of observations been specified?
   - Does the range of variables selected adequately reflect the full range of driving, state and response variables for the system under investigation?
5. Education, Public Relations and Relationships with Decisionmakers
   - ILTER sites should be used as sources of information for formal higher education and interdisciplinary curricula development
   - ILTER sites should be used as sources of information for elementary and secondary school curricula development
   - ILTER sites and networks should provide clear and accurate information on LTER research to the general public and decisionmakers

The ILTER Network Committee has continued and broadened its activities through annual meetings. Following the initial conference in the United States in 1993, meetings have been held in the U.K. (1994), Hungary (1995), Panama/Costa Rica (1996), Taiwan (1997) and Italy (1998).

The committee has established the following mission statements, based primarily on the 1993 conference:

1. Promote and enhance the understanding of long-term ecological phenomena across national and regional boundaries;
2. Promote comparative analysis and synthesis across sites;
3. Facilitate interaction among participating scientists across disciplines and sites;
4. Promote comparability of observations and experiments, integration of research and monitoring, and encourage data exchange;
5. Enhance training and education in comparative long-term ecological research and its relevant technologies;
6. Contribute to the scientific basis for ecosystem management;
7. Facilitate international collaboration among comprehensive, site-based, long-term, ecological research programs; and
8. Facilitate development of such programs in regions where they currently do not exist.

Each country must assess its own needs and resources if it wishes to involve itself in an ILTER program. Each will have a unique set of opportunities and limitations that are best evaluated by the scientists and policy makers of that country. The typical procedure for a country is for the scientists of that country, along with the funding agencies, to decide whether to endorse the premise that ecology and environmental management are significantly benefited by studies in long-term and broad spatial scales. A plan is then developed that establishes the context and mission for such studies, sites and programs identified that will contribute to this mission, and support is obtained from within that country or international organizations for implementation and continued maintenance. It is anticipated that each country's program will be part of a global network of scientists and of scientific information that will advance our understanding of not only local and regional, but also global issues and provide solutions to environmental problems at these scales (Gosz 1996).

A more recent development among a number of countries is the formation of Regional LTER Networks. Neighboring countries often have similar issues and have demonstrated increased opportunities for collaboration and increased support to other countries in the region that are attempting to develop their own LTER Network. The East Asian-Pacific Regional LTER Network and the Latin American Regional LTER Network have been formed and are holding their own annual meetings in addition to the ILTER annual meetings. A Central Europe Regional LTER Network is being planned at this time and this conference will play an important role in the development of a North American Regional LTER Network.

Development of a North American Regional LTER Network

Collaboration among Canada's Environmental Monitoring and Assessment Network (EMAN, http://www.cciw.ca/eman/), the U.S. LTER Network (http://www.lternet.edu), and a planned Mexican LTER Network (MEXLTER, http://www.ilternet.edu/sites/mexico/) offers excellent possibilities for integrating the LTER research model for North America. The following description of the Mexican LTER Network is a statement found at their web site listed above.

Mexico's participation in the International Long Term Ecological Research Network is important for several reasons. As a result of Mexico's geographic situation and topographic complexity, it supports high levels of species and ecosystem diversity, representing a major fraction of the earth's biota. It is imperative that the country understands and protects this heritage because the combination of extensive rural poverty, low technical support and high population growth has led to a rapid land-use transformation in the country. Scientific understanding of the effects of land-use changes on natural ecosystems is necessary for developing practices toward sustainable management and conservation. Additionally, Mexico is affected by ecological processes that operate at continental scales, such as the El Niño–Southern Oscillation, which occur infrequently and can only be understood through collaborative long-term and large-scale efforts. Finally, the proximity of Mexico to a well-established network of long-term studies creates the opportunity for scientific cooperation and development of human resources.

The fundamental philosophy of the MEXLTER will be to address ecological research at large temporal and spatial scales in a fashion that has not been generally practiced in Mexico. Through the network structure, sites will have similar projects and share standardized data. The MEXLTER program is designed to encompass terrestrial and aquatic ecosystems, including managed ones. National-level studies should allow comparisons within and across biomes. At an international level, it should facilitate comparisons within and across biomes in different geographical areas. Therefore, the network should have representation of the major biomes within the country, making it desirable to procure replicated sites within biomes.

The objectives of the MEXLTER are as follows:

1. Establishing a network of sites to allow Mexican scientists to address ecological issues in an interdisciplinary way on broad spatial and temporal scales. A corollary is to understand the role of biological diversity in ecosystem processes and in the provision of services to the biosphere, including humans.

2. Creating a legacy of well-designed and documented experiments and observations for future generations.

At present the scientific community in Mexico is in the process of formally establishing the MEXLTER, working on an agreement with the National Council of Science and Technology to obtain funding for beginning the Network Office and the initial network of sites.

Seven core subjects will define the basic theoretical framework for the research conducted at the LTER sites. These subject areas address the most relevant functional and structural features of ecosystems, and the most pressing environmental issues for human welfare. Within each topic area, there will be a background and a hierarchy of three levels of detail, which will set the priorities for data acquisition. The core areas are:

- Patterns and control of ecosystem primary productivity
- Patterns and control of water, carbon and nutrient dynamics in ecosystems
- The role of biodiversity in the structure and functioning of the ecosystem
- Patterns and frequency of ecosystem disturbance
- Effect of climate change on the structure and functioning of ecosystems
- Interactions at the interface level between managed and natural ecosystems
- Defining criteria for ecosystem management and conservation

One of the reasons for establishing a network of research sites is to encourage the development of large-scale and comparative studies. The establishment of such studies will require frequent communication among potential collaborators in order to define possible joint studies. In order to facilitate such communication, the network will organize meetings of all the scientists involved in the long-term research at the participating sites. Meetings will be held every other year during the development of the project and will be designed to maximize interchange of ideas during the formative phase of each research project. Additional goals of the meetings will include the introduction of participating scientists to the concepts of long-term research networks and the importance of key aspects such as data management and the use of remotely sensed data.

Collaboration of the MEXLTER with regional networks will be made through regular regional conferences. Presently, the MEXLTER is actively involved with both the North American and Latin American regional networks. Collaboration with the global network will be made via the Internet and specific meetings.

Interactions with GTOS

LTER sites in the countries of the ILTER Network now can provide unparalleled opportunities for cross-site and comparative research efforts on many of the world's ecosystems at levels from genes to landscapes. These global LTER sites function as "research platforms" that lead to interdisciplinary research, extrapolation to larger areas or regions, provide the scientific basis for management and policy decisions that incorporate social and economic issues, and attract scientists from other sites and networks, expanding the effective "network" of sites. The ILTER Network is now well positioned to interact with other international activities such as the International Geosphere Biosphere Program (IGBP) and the Global Terrestrial Observing System (GTOS).

Other international networks are being developed and many have complementary objectives. It will be important to develop collaboration with these networks to maximize the value and efficiency of international research efforts. The Global Terrestrial Observing System (GTOS) was created to provide policy makers, resource managers and researchers with access to the data needed to detect, quantify, locate, understand and warn of changes (especially reduction) in the capacity of terrestrial ecosystems to support sustainable development. The GTOS focus is on five key development issues of global or regional concern;

- changes in land quality
- availability of freshwater resources
- loss of biodiversity
- pollution and toxicity
- climate change

ILTER and GTOS have an ongoing collaboration and ILTER sites will be used in various GTOS demonstration projects and supply data sets for international use.

ILTER/GTOS Benefits

We anticipate that international collaboration of programs like GTOS and ILTER will have a number of benefits:

1. Designation as a 'participating network'. In many cases, this will strengthen the justification for continuing measurements at the site(s). It will also provide a natural focus for coordinated, multidisciplinary measurements and programs.

2. Enhanced collaboration. By being included in a global network the opportunities for coordinated observations and scientific collaboration will be much improved. Individual networks will learn from the experiences of other networks for science, operation and data management.

3. Contribution to global environmental conventions: climate, biodiversity, desertification, and endangered species among others. The participating networks will make an important contribution to meeting the political and scientific objectives of these conventions and the responsibility taken on by their respective countries.

4. Enhancement of the network's impact. In most cases, the effectiveness of a network's operation will be enhanced if the collected data are used by others. Also, a network's program will benefit by having a structured access to data from other similar networks.

5. Facilitating access to comparative data from a wider range of sties to improve the interpretation of a particular site's data.

6. Visibility, both nationally and internationally, through participating in the networks and in various initiatives.

7. Opportunities for additional funding and benefits. Although the networks will be largely self-financed, it is expected that supplemental funding will be sought for special initiatives, for pilot projects, to fill gaps in observations, and for other reasons. The leverage provided by GTOS and ILTER will be very helpful in making the case for new funds.

Literature Cited

Burke, I.C., C. Yonkers, W.J. Parton, C.V. Cole, K. Flach, and D.S. Schimel. 1989. Texture, climate, and cultivation effects on organic matter in Grassland Soils. Soil Science Society of America Journal. 53(3): 800-805.

Burke, I.C., D.S. Schimel, W.J. Parton, C.M. Yonker, L.A. Joyce, and W.K. Lauenroth. 1990. Regional modeling of grassland biogeochemistry using GIS. Landscape Ecology: 45-54.

Burke, I.C., T.G.F. Kittel, W.K. Lauenroth, P. Snook, C.M. Yonker and W.J. Parton. 1991. Regional analysis of the central Great Plains, sensitivity to climate variability. BioScience 41: 685-692.

Burke, I.C., W.K. Lauenroth, and W.J. Parton. 1997. Regional and temporal variation in net primary production and nitrogen mineralization in grasslands. Ecology 78: 1330-1340.

Coleman, M.B., T.L. Bearly, I.C. Burke,and W.K. Lauenroth 1994. Linking ecological simulation models to geographic information systems: an automated solution pp. 397-412. In Michener, W. and J. Brunt (eds). Environmental Information Management and Analysis: Ecosystem to Global Scales. Taylor and Francis, London.

Cody, M.L. and J.A. Smallwood. (eds.). 1967. Long-term Studies of Vertebrate Communities. Academic Press.

Gosz, J.R. 1996. International long-term ecological research: priorities and opportunities. Trends in Ecology and Evolution. 11: 444.

Kareiva, P. 1994. Higher order interactions as a foil to reductionist ecology. Ecology. 75: 1527-1528.

Levin, S. A. (1992). The problem of pattern and scale in ecology. Ecology. 73: 1943-1967.

Likens, G.E. (ed.). 1989. Long-term Studies in Ecology. Springer-Verlag, New York.

Risser P.G., J. Lubchenco, N.L. Christensen, P.J. Dillon, L.D. Gomez, D.J. Jacob, P.L. Johnson, P. Matson, N.A. Moran, and T. Rosswall. 1993. Ten-Year Review of the National Science Foundation Long-Term Ecological Research (LTER) Program.

Sala, O.E., W.J. Parton, L.A. Joyce, and W.K. Lauenroth. 1988. Primary production of the central grassland region of the United States: Spatial pattern and major controls. Ecology. 69: 40-45.

Tilman, D. 1989. Ecological experimentation: strengths and conceptual problems. pp. 136-157. In. Likens, G.E. (ed). Long-Term Studies in Ecology. Springer-Verlag, New York.

Valone, T.J. and J.H. Brown. 1996. Desert rodents; Long-term responses to natural changes and experimental manipulations. pp. 555-583. In: Cody, M.L. and J.A. Smallwood (eds). Long-Term Studies of Vertebrate Communities. Academic Press.

Weatherhead, P.J. 1986. How unusual are unusual events? American Naturalist. 128: 150-154.

Wiens, J. 1997. Lengthy ecological studies. Trends in Ecology and Evolution. 12: 499.

USGS-NPS Vegetation Mapping Program[1]

Thomas Owens[2]

Abstract—The USGS Center for Biological Informatics is cooperating with the National Park Service to classify and map vegetation communities on 235 Park units. The USGS-NPS Vegetation Mapping Program's approach is to develop scientifically valid basic vegetation classification and spatial vegetation which can be used as building blocks for management planning, inventory, monitoring and research by local, regional, and national managers and scientists. The Program is noteworthy for its approach to vegetation mapping which includes developing: 1) a national vegetation classification system, 2) standardized inventory and mapping protocols, 3) accuracy assessment, and 4) scientific peer review. The Program uses extensive field work and aerial photography to perform classification and mapping work. Products include digital databases, comprised of classifications and descriptions of vegetation communities, spatial vegetation data, and metadata, which are important for detailed Park management as well as regional and national assessments of biodiversity. The Program has attracted the interest of other federal and state agencies, including the Fish and Wildlife Service, the Bureau of Reclamation, the Forest Service, and the EPA. These agencies are interested in incorporating the Program's protocols and standards into their own vegetation inventory and monitoring projects. For more information visit the website at http://www.biology.usgs.gov/npsveg.

Basic data are fundamental to the management of natural resources. Natural resource inventories allow managers and scientists to account for resources under their management and study, including the presence, class, distribution, and normal variation of plants and animals, and such important abiotic components as water, soils, landforms, and climate. It is necessary to compile the basic building blocks of information on these resources in order for the information to be combined in different ways to answer different questions. The USGS-NPS (U.S. Geological Survey, National Park Service) Vegetation Mapping Program is a vegetation inventory program that provides basic vegetation community information to National Park managers and scientists. The USGS Biological Resources Division's Center for Biological Informatics administers the Program and provides scientific and technical oversight for the National Park Service.

Program Goals

The Program's goals are to create highly accurate, detailed vegetation spatial databases in an efficient manner for the park units and vicinities, and expand the National Vegetation Classification Standard (NVCS) to include all detailed classes at these units. The data must be spatially and thematically accurate, meet the professional standards of the scientific community and applicable standards of the Federal Geographic Data Committee FGDC), have a nationally consistent, hierarchical, useful, classification scheme, have a level of detail (spatial resolution and classification level) useful to park management. The Program serves local management needs of each park while providing comprehensive vegetation information at national and regional levels. The Program is founded on good science, which means all data are based on statistically sound field work and proven, up-to-date technology is used.

Program Standards and Protocols

The major standards for the Program are 1) the vegetation classification standard, 2) the accuracy standard, 3) the metadata standard, and 4) the spatial data transfer standard.

The classification system must be based on sound science, be repeatable across the landscape, be based on standard field and data analysis methods, be broadly accepted, be ecologically meaningful and classify existing biological associations, and be mappable from imagery. In addition, it must be hierarchically organized, appropriately scaled, flexible and open ended, well documented, and can be cross-walked with other frequently used systems. The system that meets all these requirements is the NVCS. It is organized in the following manner:

Physiognomy

Division/Order—dominant life form (example: Tree Dominant)
Class—spacing & height of dominant form (example: Woodland)
Subclass—morphological & phenological similarity (example: Evergreen Woodland)
Group—climate, latitude, growth form, leaf form (example: Temperate Evergreen Needle-leaved)
Formation—mappable units (example: Evergreen Needle-leaved Woodland with Rounded Crowns)

Floristics

Alliance (Cover Type)—dominant species (example: Douglas-fir Woodland)
Community (Association)—subdominant or associated species (example: Douglas-fir / Snowberry Woodland)

Uniformity in classification methodology over the entire park system is critical to achieve the overall inventory and

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monitoring goals of this initiative. All parks must be mapped at the same level of classification detail (i.e. plant association/cover type) and must be able to be re-aggregated to the FGDC vegetation classification scheme.

The accuracy standard requires that the minimum mapping unit is 0.5 hectares, that locational accuracy meets the National Map Accuracy Standards at 1:12,000 (a well-defined object is located within 10 meters of its actual location on the ground), and classification accuracy will greater than 80% for each vegetation class. To ensure that the classification accuracy requirement is met an accuracy assessment is performed at all park projects. Stratified random sampling with replacement is used for the accuracy assessment. Ground visits are used to independently verify the mapping classes; the field crews have no knowledge of the mapped classes to ensure no bias exists in the accuracy assessment.

The metadata standard requires that all datasets are documented with metadata meeting the FGDC metadata standard. The metadata compilation tool MetaMaker is used to achieve this standard.

All spatial data produced must be in the Spatial Data Transfer Standard (SDTS) format.

Basic protocols were generated early on the program. There are four documents which outline the protocols: 1) Developing and documenting a National Vegetation Classification Standard, 2) Establishing standards for field methods and mapping procedures, 3) Producing rigorous and consistent accuracy assessment procedures, and 4) Establishing standards for using existing vegetation data.

The protocols provide general guidance to each park project. The protocols are being tested in prototype studies, protocols will vary based on a matrix of variables related to size of area to be mapped (park & environs), existing data and knowledge, complexity of vegetation and access/logistics. All field samples, accuracy assessment samples and potential mapping approaches (i.e. softcopy) will be GPS-based. The GPS based approach is important because all field data becomes spatial data and relatable to other layers in a spatial analysis. The development of protocols is near its final stage, although there will always be new challenges and issues as the program maps new units in different parts of the country.

Specifically, the protocols for classification field methods include data and information discovery meetings at the start of each project and the "gradsect" (short for gradient transect) approach. The gradsect approach stratifies the park into bio-physical units using geological, soils, topographic, wetland, disturbance and other data to find "hot spots" of environmental diversity where sampling will be the most efficient. This enables sampling the greatest amount of vegetational diversity within the smallest area. It is an efficient way to gather data for testing classification, describing classes and developing photointerpretation signatures/keys.

The specific protocols for mapping are that photointerpretation will be used. New aerial photography of the appropriate type(s), scale(s), and season(s) will be acquired for all areas (if useful, recent aerial photography does not exist). Small parks will be mapped at scales larger than 1:24,000. Softcopy approaches to mapping will be used, if technically feasible and cost effective.

Program Methods

The major steps that are taken to complete each park are 1) data review, 2) data acquisition, 3) gradsect, 4) initial field reconnaissance, 5) field sampling, 6) classification characterization, 7) photointerpretation, mapping and automation, 8) accuracy assessment, and 9) final product review. There are many other intermediate steps required, and these steps are often iterative, but this is the basic process flow for each park project. The Program contracts with experts in vegetation mapping and vegetation ecology around the country to provide the best expertise for each project. The Nature Conservancy is a major national partner, and the individual state Natural Heritage Program ecologists are heavily involved in specific park projects.

National Parks tend to be centers of scientific research and monitoring and have long histories of data collection. Data review and analysis can be a major task because of the wealth of available data and information. It is important to carefully analyze existing datasets because they may provide efficiencies in the project. Datasets that usually exist and may be useful are aerial photography, field plots, historical vegetation maps and spatial data, reports and monographs.

The next step is to acquire baseline data. This includes taking aerial photography, acquiring ortho images (usually USGS digital ortho quarter quads), acquiring other spatial datasets such as elevation, soils, geology, and disturbance history to be used in the gradsect. The gradsect is run (perhaps several times with different combinations of variables) to model the major environment drivers in a park. The resulting spatial database is used to help allocate sample points for field sampling, and to inform the photointerpretation process.

The mappers and ecologists who perform the classification participate in the initial field reconnaissance. The purpose of this trip is to familiarize the mappers with the photo signatures of the major vegetation classes, provide more information to the ecologists on the local environment, and to allow a discussion between the mappers and ecologists on how the park will be classified and mapped. Once the initial reconnaissance is complete, the mappers will initiate photointerpretation and provide this information to the ecologists to help them plan their field sampling strategy.

The field sampling may take one or more field seasons, depending on the size of the park. Three to five plots are taken in each vegetation association to measure the variability for each class. If the association is well defined in an area, only one plot may be taken. However, it is more common to develop many new associations for an area based on the work in a park. The field sampling strategy will evolve as plots are taken and photointerpretation proceeds, because new associations may be discovered.

There are at least two versions of the classification system. A preliminary version is developed early in the project by analysis of regional TNC databases and advice from local experts. This preliminary version is used to start the photointerpretation process, and is modified during the course of the project. The field data are automated into a database and analyzed quantitatively using computer programs or qualitatively using methods described in the NVCS document to develop the final classification. The photointerpretation and classification process are heavily interdependent and new information gleaned from one process may modify the other process.

Once a preliminary classification system is in place photointerpretation may begin. It is done under a stereoscope to allow topographic information to assist the process of identifying vegetation associations. The photointerpreters may take several field trips to the park for ground truth data which may or may not coincide with the field work for the classification. When the photointerpretation is completed, the data are rectified and automated. This may be a heads-up digitizing process using the ortho image as a background, or it may be a manual transfer to a hard copy ortho image with subsequent scan digitizing. Whichever process used, the products must meet the Program accuracy requirements for classification and location accuracy.

When the spatial database of the vegetation communities is complete a stratified random sample strategy for accuracy assessment is designed. Each vegetation association, that is extensively represented in the park, has at least 30 plots located in it. Fewer plots may be taken if the association is rare. The plots are navigated to with the aid of GPS receivers. The field crews may take a plot of the orthoimage with polygons delineated on them for locational purposes, but do not know how the polygons are classified. The field crews take extensive information in each sample polygon. The point data from the accuracy assessment are then compared to the mapped data to ensure that the spatial data meets the classification accuracy requirement of 80%.

The final data products, including the spatial data, the classification data, the accuracy assessment data, and the reports and metadata are reviewed by Program and park staff to ensure that all standards are met. Then the data are delivered to the park and placed on the website.

Peer Review

Peer review is an important component of the program. Reviews by independent scientists and managers ensure that the program is effective at meeting the users' needs, while maintaining strong standards. A review of the program occurred in September 1996 by USGS and Park Service scientists and managers. A second review has been recently completed by the National Park Service and another review of the program is currently being conducted the USGS. The reviews findings and recommendations have placed on the Program's website at http://biology.usgs.gov/npsveg. Recommendations made by the 1996 review have been implemented. Recommendations by the Park Service review and the USGS will be implemented as appropriate.

Program Status

The Program has developed and published protocol documents that establish the basic methods (discussed above). The Program has initiated mapping and classification projects in twenty parks and has completed five of these (Tuzigoot National Monument, Devils Tower National Monument, Mount Rushmore National Monument, Jewel Cave National Monument, and Scotts Bluff National Monument). The program plans to initiate projects in five new parks this fiscal year.

Applications

The Program's data and information can be applied in numerous ways. Some examples include 1) invasive exotics inventory, such as leafy spurge at Theodore Roosevelt National Park, by combining the spatial data with the classification descriptions, 2) Threatened and Endangered plant species inventory by applying the spatial data with the community description data to model the possible distribution of these species, 3) Using the vegetation associations' distribution, along with the structure information the Program collects, and topographic data to model fire behavior, 4) Scotts Bluff National Monument used the species listings in the community description data to develop seed mixes to restore natural prairies in disturbed areas, 5) use the spatial and description data to model wildlife habitat, for example grizzly bears in Glacier National Park, and 6) Use the vegetation classification data and descriptions for regional, national, and global assessments of endangered vegetation communities.

Conclusions

The program has been in existence since 1994. The lessons learned from the experiences to date are: 1) providing all products is critical—not just mapping products. The classification data and information at as important as the mapping products to resource managers and scientists. The results from the Park Service review indicate that parks where work has been completed are using all the data for resource and management applications. The parks do not want a cut-back in the products produced for each park or the resolution of the products, because they feel that each product is valuable, the resolution is adequate for site-specific management purposes, and the process is cost-effective, 2) these products are the basic building blocks of vegetation information, which is in turn a basic building block for a management and information support database, along with other information building blocks as topography, soils, wildlife habitat, transportation, and humans factors. Once these data have been developed, it is relatively simple to combine these data with other datasets and expert systems to answer management and scientific questions. It is not easy to disaggregate information into its basic building blocks, and 3) providing sound, scientific, well documented baseline information is critical to developing a monitoring program. The experience has been that there are many interesting historical datasets that have been developed for national parks, but if good metadata are not available that document the data development process, the data are worthless.

Integrating Spatial Statistics With GIS and Remote Sensing in Designing Multiresource Inventories[1]

Robin M. Reich[2]
Vanessa A. Bravo[3]

Abstract—In order to design an integrated multiresource inventory and monitoring system that evaluates the status and trends of natural resources (forest, rangeland, agriculture, wildlife, hydrology, soils, etc.) baseline data for comparison is needed. These systems are generally complex and it may not be wise to select just one or two variables for monitoring purposes. Also, analyzing these variables independently of one another may lead to incorrect conclusion because of their inter-dependencies. One approach is to model the spatial relationship that exists between key variables. This information can then be used, for example, to identify forest habitat that are either conducive, or 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 spatial and geostatistical procedures such as kriging and cokriging. The use of spatially explicit models can be used to monitor the efficiency of certain components of proposed management plans, as well as provide a general prediction of how key indicator variables are changing in time and space. Such models also provide greater insight into changes in the landscape, both on the macro- and micro-scale, and more importantly, the consequential impact these changes have on selected species. Theoretical and technical aspects of this approach are briefly described in this paper.

Spatial Modeling

An important problem facing natural resource managers is the integration of several types of data when modeling the spatial dynamics of an individual population. There are two aspects to the problem: first, the integration of data from different sources at a fine enough resolution, and second, modeling the spatial dynamics of an individual population.

The first aspect, data integration, has been researched extensively during the last decade. The most widely accepted procedure of integrating spatial data is the use of geographic information systems (GIS). GIS allow for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic of, or critical to analysis (Arnoff 1991). GIS has been used for a variety of purposes, including the identification of suitable wildlife habitat, timber harvest schedules, modeling biodiversity and population dynamics (Lui et al. 1995). Integration of remotely sensed data and geographic information systems is becoming an extremely powerful tool for producing maps of ecosystem resources and has become vital to resource managers in making decisions and establishing policy (Arnoff 1991). The main obstacle in the development of a descriptive GIS model is the coarse-grained resolution of raster data.

Spatial Predictive Models

The ability to model the small scale variability in stand characteristics requires the generation of full-coverage maps depicting stand characteristics measured in the field. While remotely sensed data has been shown to provide reliable information for macro-scale ecological monitoring, it falls short in providing the precision required by more refined ecosystem resource models (Gown et al. 1994). Spatial statistics and geostatistics provide a means to developing spatial models that can be used to correlate remotely sensed imagery with field measurements. If a satellite image is geographically referenced to a base-map, one can overlay the location of field plots on the image to obtain pixel intensities associated with each of the field plots. Thus, for each sample plot we have field data describing stand characteristics and seven intensities representing the 7 TM bands (Fig. 1A) (Arnoff 1991). If the field data is spatially correlated with the intensity of the remotely sensed image it is possible to develop a model describing this spatial continuity (Cliff and Ord 1981). It is also possible to include geographical variables, such as elevation, slope, aspect, and precipitation thought to influence the large scale spatial variability of the environmental property and is available in the form of a complete coverage of the study area. The functional form of this model is defined as:

$$\Phi_0 = \sum_{i+j}^{p} \sum_{\le p}^{p} \beta_{ij} x_{10}^{i} x_{20}^{i} + \sum_{k}^{q} \gamma_k y_{k0} + \eta_0 \qquad (1)$$

where, β_{ij} are the regression coefficients associated with the trend surface component of the model, γ_k are the regression coefficients associated with the q auxiliary variables, y_{k0}, available as a coverage in the GIS data base, and η_0 is the error term which may or may not be spatially correlated with its neighbors (Kallas 1997; Metzger 1997).

Once a spatial, or temporal dependancy is established for a given variable, this information can be used to interpolate values for points not measured (Robertson 1987). In most sample surveys, supplemental information is collected in

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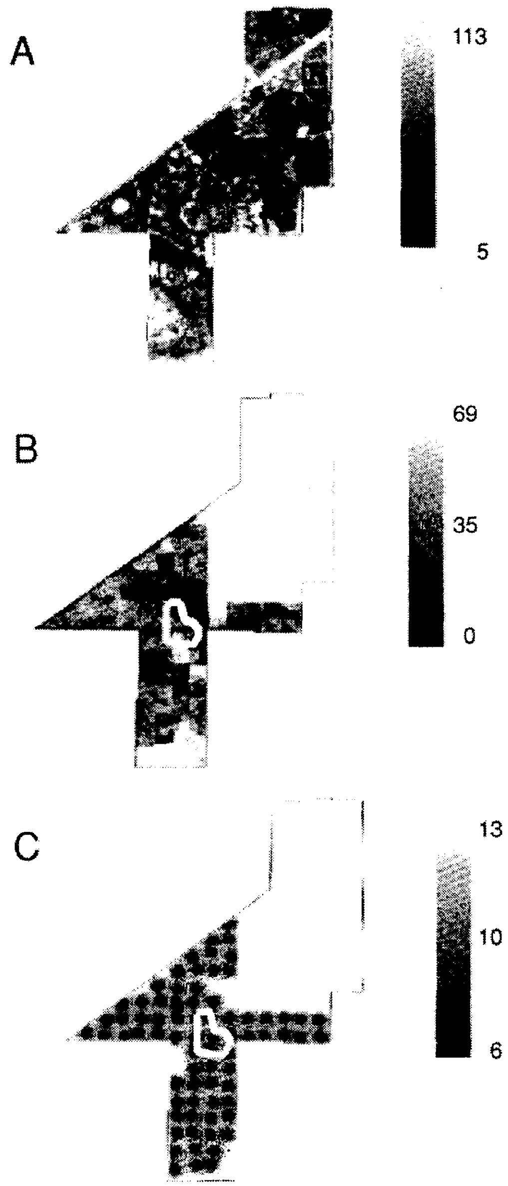

Figure 1.—Gray scale maps of an 890 ha experimental forest northeast of Gainesville, Florida depicting: (A) Digital numbers for band 5 of a Landsat imagery; (B) Estimated basal area (m^2/ha) at a 10 m resolution for a selected portion of the forest (R^2 = 0.77); (C) Standard error of prediction of basal area (m^2/ha) for a selected portion of the forest. The center of the black circles are the approximate locations of the sample plots used in developing the spatial model for basal area (Metzger 1997).

addition to the variable of interest (i.e., average stand diameter, percent crown cover, food availability, etc.). If these variables are spatially correlated with the variable of interest, this information can be used to improve estimates (Isaaks and Srivastava 1989). The use of auxiliary information in spatial prediction is referred to as cokriging. The usefulness of auxiliary information is enhanced by the fact that the variable of interest is generally under sampled (Isaaks and Srivastava 1989).

To account for this spatial autocorrelation in the residuals of the model developed to describe large scale spatial variability, we propose to model the small scale spatial variability (i.e. spatial noise) using the cokriging model:

$$\eta_0 = \sum_{r=1}^{n} w_r \eta_r + \sum_{t=1}^{m}\sum_{r=1}^{n} v_{tr} u_{tr} + \epsilon_0 \qquad (2)$$

subject to the linear constraints:

$$\sum_{r=1}^{n} w_r = 1, \qquad \sum_{t=1}^{m}\sum_{r=1}^{n} v_{tr} = 0 \qquad (3)$$

where, w_r are the kriging weights associated with the n-nearest residuals, v_{tr}, are the cokriging weights associated with the m auxiliary variables, u_{tr} that are spatially correlated to the residuals, and ϵ_0 is the error term which we will assume to be spatially independent and normally distributed with mean 0 and variance σ^2. One of the appealing features of cokriging is that the auxiliary information does not have be collected at the same data points as the variable of interest. This allows us to combine remote sensing and field data to provide a full coverage map with a higher resolution than would have been possible by using remote sensing and field data alone. In essence, remote sensing images provide information on large scale spatial variability, while field data provides information on small scale spatial variability.

Prior to fitting the cokriging model, the residuals of the model describing the large scale spatial variability are analyzed for anisotropy (spatial autocorrelation changes with direction). The residuals are also evaluated for the presence of spatial cross-correlation (Bonham et al. 1995; Czaplewski and Reich 1993; Reich et al. 1994) with the independent variables included in the large scale model, or variables for which only data associated with field plot locations is available. Complete coverage of the variables associated with the field data is not available in the GIS database. If no spatial cross-correlation is detected, the residuals can be modeled using ordinary kriging, otherwise the residuals are modeled using cokriging.

Spatial dependency of the residuals can be modeled using the Gaussian semi-variogram

$$\gamma(h;\theta)\begin{cases} 0 & h=0 \\ c_0 + c_1(1-\exp(-3\|h\|/a)) & h\neq 0 \end{cases} \qquad (4)$$

or some other appropriate model (spherical, exponential, linear, etc.), where $\theta = (c_0, c_1, a)$ is a vector of parameters subject to the constraints $c_0 \geq 0$, $c_1 \geq 0$, and $a \geq 0$. In modeling the cross-correlations between the residuals and independent variables, the constraints for the model are relaxed to allow the parameters c_0 and c_1 to take on negative values.

The parameters of the semi-variogram model are estimated by minimizing:

$$\sum_{j=1}^{k} n_j \{2\gamma^*(h(j)) - 2\gamma(h(j);\theta)\}^2 \qquad (5)$$

where $2\gamma^*(\,)$ is the sample variogram/cross-variogram obtained at k lags (h(1),..., h(k)), n_j is the number of observations contributing to the estimator at each lag, and $2\gamma(h;\theta)$ is the semi-variogram model with parameter $\theta = (c_0, c_1, a)$. Prior to fitting the variogram and cross-variogram model, the residuals and independent variables are rescaled by dividing the individual variables by their respective maximum values (Carr and McCallister 1985). The predicted surface of scaled residuals obtained using kriging/cokriging are then rescaled back to their original units by multiplying the surface by the maximum observed residual. The rescaled surface of the predicted residuals are then added to the predicted surface describing large scale spatial variability to create the final surface with the desired scale (Fig. 1B):

$$\Phi_0 = \sum_{i+j}^{p} \sum_{\leq p}^{p} \beta_{ij} x_{10}^i x_{20}^i + \sum_k^q \gamma_k y_{k0} + \sum_{r=1}^n w_r \eta_r + \sum_{t=1}^m \sum_{r=1}^n v_{tr} u_{tr} + \epsilon_0 \quad (6)$$

The kriging/cokriging surfaces can be cross-validated to assess the amount of variability in prediction error of the kriging/cokriging system. Cross-validation involves deleting one observation from the data set and predicting the deleted observation using the remaining observations in the data set. This process is repeated for all observations in the data set. Residuals are computed as the observed minus predicted values and analyzed using standard techniques employed in regression analysis to evaluate the underlying assumptions of the model.

Overall performance of the final model (large scale model + kriged/cokriged residuals) can be evaluated by computing an R^2 value similar to that used in regression analysis (Kallas 1997):

$$R^2 = 1 - \frac{\sum_{j=1}^{n} \{\eta(s_j) - \hat{\eta}(s_j)\}^2}{\sum_{j=1}^{n} \{\phi(s_j) - \bar{\phi}(s_j)\}^2} \quad (7)$$

In addition, response surfaces of predicted standard errors (Fig. 1C) for the final model can be computed using the following variance formula (Isaaks and Srivastava 1989):

$$\begin{aligned} Var(\epsilon_0) = & \sum_{i=1}^{n} \sum_{j=1}^{n} w_i w_j Cov(\eta_i \eta_j) + \sum_{i=1}^{m} \sum_{j=1}^{m} v_i v_j Cov(\mu_i \mu_j) \\ & + 2 \sum_{i=1}^{n} \sum_{j=1}^{m} w_i v_j Cov(\eta_i \mu_j) - 2 \sum_{i=1}^{m} w_i Cov(\eta_0 \eta_0) \\ & - 2 \sum_{j=1}^{m} v_j Cov(\mu_j \eta_0) + Cov(\eta_0 \eta_0) \end{aligned} \quad (8)$$

where $Cov(\eta_i\ \eta_j)$ is the autocovariance between the estimated environmental property at location i and j, $Cov(\mu_i\ \mu_j)$ is the autocovariance between the auxiliary variables at location i and j, and $Cov(\eta_i\ \mu_j)$ is the cross-covariance between the estimated environmental property and location i and the auxiliary variable at location j.

Spatial Integration

The ability to spatially model field data allows one to integrate the data over any specified geographical region (i.e. stand, management unit, watershed, region, etc.) to obtain a point estimate and associated standard error of prediction. This is accomplished by integrating the three dimension response surface representing the variable of interest over the area of interest and dividing by the area. Since the spatially modeled response surfaces can be represented as a grid in ARC/INFO, any specified region will contain a finite number (n) of grid cells of uniform size (i.e 10 m x 10 m). Our point estimate of a resource in some bounded region A, is obtained by summing the point estimates associated with each cell, Φ_i, and dividing by the number of cells in the bounded region:

$$\bar{\Phi} = \frac{1}{n} \sum_{i=1}^{n} \Phi_i, \quad \Phi_i \in A \quad (9)$$

The estimated variance is given by

$$\hat{V}(\bar{\Phi}) = \frac{1}{n^2} \sum_{i=1}^{n} \hat{V}(\varepsilon_i) + \frac{1}{n^2} \sum_{i \neq j}^{n} \sum^{n} \hat{\rho}_{ij}(h)\, \hat{V}(\varepsilon_i)^{1/2}\, \hat{V}(\varepsilon_j)^{1/2} \quad (10)$$

where $\hat{V}(\varepsilon_i)$ is the estimated variance associated with cell i (Eq. 9), and $\hat{\rho}_{ij}(h)$ is the spatial correlation between cells i and j, which are separated by distance h. The spatial correlation is estimated using the appropriate variogram function (Eq. 5) associated with the variable of interest. For example, if we apply Eq. 10 and 11 to the small polygon (24.64 ha) located in the center of Figures 1B and 1C we obtain a basal area estimate of 13.4 m^2/ha with a bound on the error of estimation of 3.7 m^2/ha at the 67% level of confidence.

Point Process Models

The second aspect, modeling the spatial dynamics of an individual population, is a more recent development, especially with the increase in computing power which makes it easier to perform intricate computations needed to explore complex spatial patterns. One class of spatial models that has received considerable attention in recent years is the Gibbsian interaction model, which is often referred to as Markov random fields (Ripley 1990; Cressie 1991). These models encompass conditional spatial autoregression and a wide class of models for interacting point patterns. The term Gibbsian interaction comes from statistical mechanics, where such models have been used for nearly a century to describe the behavior of gases (Ripley 1990; Cressie 1991). In most applications, interactions between events are assumed to be pairwise.

Examples of spatial stochastic models that take into consideration the interaction among events include work on sequential packing models of non-overlapping discs (Matern 1960; Bartlett 1974; Diggle et al. 1976), Poisson cluster models (Matern 1960; Diggle 1979), and Strauss-type and hard-core models (Strauss 1975; Kelly and Ripley 1976; Gates and Westcott 1980). While most of this work has been theoretical, the increase in computing power has contributed to progress in estimating the parameters of these models using theoretical approximations to the likelihood function or computer simulations. Approximate maximum pseudo-likelihood procedures provide reasonable parameter estimates and are somewhat easier than approximate maximum likelihood (Ripley 1990). Nonparametric estimations of pairwise-interaction point processes for similar problems have also been developed (Diggle et al. 1987).

In developing these models it is assumed that we have very specific information on the location of every individual within the population. This information may be obtained from intensive monitoring research sites aimed at studying very specific components of the environment. For example, one might be interested in studying the spatial relationship of the northern goshawk, or selected plants with their habitat. The plants and/or animals would be located in the field, georeferenced, and important variables thought to influence their presence measured. This information can then be used to model the spatial interaction of individual species (i.e. threatened and endangered plants and animals) with themselves, other species and their environment using procedures developed by Reich et al. (1997).

Suppose one has a mapped spatial pattern of points in a finite planner region. In the case of the northern goshawk, it is easy to identify potential habitat using environmental variables such as elevation, slope and aspect along with existing forest cover type maps. Even though suitable habitat may be identified this does not mean that the species will be present at that location. In habitats where the goshawk is present, a pattern where individuals are rather equally spaced from one another would be expected. Such a pattern is called "regular".

One way to model this spatial interaction is to consider a function of distances (r_{ij}) between individual sites of activity. In such instances, it is customary to assume that the equilibrium system is statistically characterized by a Gibbs distribution of total potential energy (Cressie 1991):

$$U_N(X) = \sum_{i<j}^{N} \Psi(r_{ij}) \tag{11}$$

where the points X can be regarded as being distributed according to a Gibbs canonical distribution:

$$f(x) = \exp[-U_N(X)]/Z(\Psi; N) \tag{12}$$

where Z(•) is a normalizing constant. For a single species population, a positive potential energy represents a repulsion between individuals while a negative potential energy represents an attraction between individuals (Fig. 2). This model can be expanded to include more than one species:

$$U_N(X) = \sum_{i<j}^{N_1} \Psi_1(r_{ij}) + \sum_{i<j}^{N_2} \Psi_2(r_{ij}) + \sum_{i}^{N_1} \sum_{j}^{N_2} \Psi_{12}(r_{ij}) \tag{13}$$

where $\Psi_1(r_{ij})$ and $\Psi_2(r_{ij})$ describe interaction between individuals of a given species and $\Psi_{12}(r_{ij})$ describes interactions between the two species. The approximate log likelihood of the pairwise potential (Eq. 4) is given by

$$\log L(\theta \mid X) = \sum \sum U_\theta(|X_n - X_m|) - \frac{1}{2} N(N-1) \log\left(1 - \frac{a(\theta)}{|V|}\right) \tag{14}$$

which is easily solved using nonlinear optimization procedures. To use this relationship one needs to be able to mathematically describe the interaction potentials of a spatial point pattern. Three parameterized potential functions proposed by Ogata and Tanemura (1981, 1985) can be evaluated to describe the interactions observed in the distribution of active and inactive nest sites:

$$\text{PF1: } \psi_\theta(r) = -\log[1 + (\alpha r - 1)e^{-\beta r^2}] \quad \theta=(\alpha,\beta), \alpha\geq 0, \beta>0 \tag{15}$$

$$\text{PF2: } \psi_\theta(r) = -\log[1 + (\alpha - 1)e^{-\beta r^2}] \quad \theta=(\alpha,\beta), \alpha\geq 0, \beta>0 \tag{16}$$

$$\text{PF3: } \psi_\theta(r) = \beta(\sigma/r)^{12} - \alpha(\sigma/r)^6 \quad \theta=(\alpha,\beta,\sigma), \beta>0 \tag{17}$$

The second cluster integral, a(θ) for the three potential function are given by:

$$\text{PF1: } a(\alpha,\beta) = (\pi/\beta)(1 - \alpha\sqrt{\pi/\beta}\,/2) \tag{18}$$

$$\text{PF2: } a(\alpha,\beta) = \pi(1-\alpha)/\beta \tag{19}$$

$$\text{PF3: } a(\alpha,\beta,\sigma) = -\frac{\pi}{6}\beta^{1/6}\sigma^2 \sum_{k=0}^{\infty} \frac{1}{k!}\Gamma\left(\frac{6k-2}{12}\right)\alpha^k \beta^{-k/2} \tag{20}$$

All three models are capable of modeling both repulsive and attractive forces.

The pairwise potential models PF1-3 are fit to point data using a nonlinear least squares procedure to maximize the log likelihood (Eq. 18). The Akaike Information Criteria (AIC) (Akaike 1977) is used to select the model which minimizes the value of AIC among the three possible models. A model with a smaller AIC is considered to be a better fit. In the case of point patterns with two categories (i.e. active vs. inactive nests), AIC is computed for each of the three

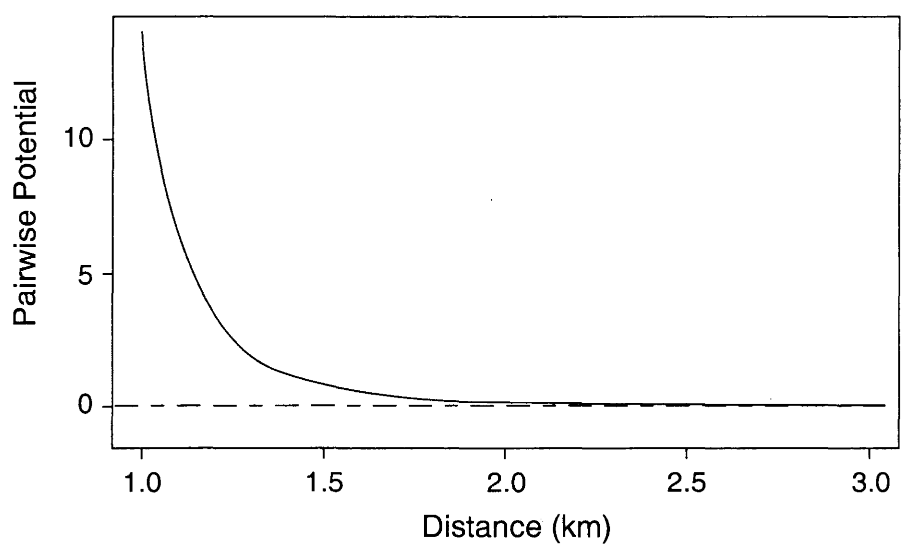

Figure 2.—Pairwise potential model (PF 3) describing the spatial interaction of northern goshawk territories on the Kaibab National Forest in northern Arizona. The northern goshawk is territorial with a minimum distance of 1 km between territories; territories are spatially independent at approximately 2.1 km (Reynolds and Joy 1995, personal communication).

components in Eq. 17 (AIC_{11}, AIC_{22}, AIC_{12}), and the best model for each component is selected independently. This is because the approximate log likelihood with respect to the parameters is equivalent to the independent maximization of the individual components (Ogata and Tanemura 1985).

As mentioned previously, just because an area is deemed suitable for the presence of a particular species does not mean that the species will be present. Within a given habitat, the spatial distribution of active sites are influenced by small scale spatial variability, such as differences in the abundance of a food supply, plant competition, distances to openings in the canopy, stocking levels, species compositions, etc. To include this small scale spatial variability in the model one can redefine the total potential energy as follows:

$$U_N(X) = \sum_{i}^{N}\phi_1(r_i) + \sum_{i}^{N}\phi_2(r_i) + \sum_{i<j}^{N_1}\psi_1(r_{ij}) + \sum_{i<j}^{N_2}\psi_2(r_{ij}) + \sum_{i}^{N_1}\sum_{j}^{N_2}\psi_{12}(r_{ij}) \quad (21)$$

where $\phi_1(r_i)$ and $\phi_2(r_i)$ are measures of small scale spatial interaction. This model would allow us to describe the territoriality of the northern goshawk and interaction with their immediate habitat. To model this component, the probability of habitat suitability can be defined at each of the grid points superimposed over the study area. This probability is computed as the ratio of estimated density of nests $\lambda(s)$, at spatial location s, to the maximum intensity observed in the study area. The potential energy associated with a given micro-habitat can be defined as

$$\phi(r) = -\log\left(\frac{\lambda(s)}{\max \lambda(s)}\right) = f(\mathit{stand\ characteristics}) \quad (22)$$

which can be regressed on individual stand characteristics available in the GIS database. Large positive values would indicate unsuitable habitats while small values would indicate suitable habitats (Reich et al. 1997).

Concluding Remarks

The application of such a model can be updated yearly with current information that can quantify progress of the species in question. Information can be very specific, such as, how the spatial location of the species is changing over time to more general questions relating to the effects of food supply availability, natural forest succession, and silviculture treatment. Information derived from the model could also be used to facilitate the efforts of field investigators studying the ecology of the selected species. This model, when combined with information on population dynamics, demographic information and linked to a forest successional model, could provide land managers with valuable insight in developing management plans to guide the recovery efforts of a species. Such a model could be used to address species viability and minimum area requirements.

This is a unique approach to modeling the spatial distribution of threatened and endangered species such as the northern goshawk with which their existence is related to past land management activities. The use of spatially explicit models can be used to monitor the efficiency of certain components of the recovery plan as well as to provide a general prediction of how the population is changing in time and space. In this pilot study, the modeling approach suggested above is worthwhile in developing an ecosystem maintenance and preservation program by providing greater insight into changes in the landscape, both on the macro- and micro-scale, and more importantly, to the consequential impact these changes have on selected species.

References

H. Akaike, " On entropy maximization principle," In *Applications of Statistics*, P. R. Krishnaiah (ed.), 27-41. Amsterdam, North-Holland, 1997.

S. Aronoff, "Geographic Information Systems: A Management Perspective," WDL Publications. Ottawa, Ontario.1991

M. S. Bartlett, "The statistical analysis of spatial patterns," *Advances Appl. Prob*., Vol. 6, pp. 336-358, 1974.

C. D. Bonham, R. M. Reich, and K. K. Leader, " Spatial cross-correlation of *Bouteloua gracilis* with site factors," *Grasslands Science*, Vol. 41, pp. 196-201, 1995.

J. R. Carr, and P. G. McCallister, " An application of cokriging for estimation of tripartite earthquake response spectra," *Math. Geology*, Vol. 17, pp. 527-545, 1985.

R. L. Czapleski, and R. M. Reich, *Expected value and variance of Moran's bivariate spatial autocorrelation statistic under permutation*, Research Paper RM-309. U.S. Department of Agriculture, Rocky Mountain Experimental Range Station., Fort Collins, CO, 1993.

A. Cliff, and J. K. Ord, *Spatial processes, models and applications*. Pion, Ltd. London., 1981.

N. Cressie, *Statistics for spatial data*. John Wiley & Sons, New York, 1991.

P. J. Diggle, J. Besag, and J. T. Gleavens, "Statistical analysis of spatial point patterns by means of distance methods," *Biometrics*, Vol. 32, pp. 659-667, 1976.

P. J. Diggle, " On parametric estimation and goodness-of-fit testing for spatial point patterns," *Biometrics*, Vol. 35, pp. 87-101, 1979.

P. J. Diggle, D. J. Gates, and A. Stibbard, "A nonparametric estimator for pair-wise interaction point processes," *Biometrics*, Vol. 74, pp. 763-770, 1987.

D. J. Gates, and W. Westcott, "Further bounds for the distribution of minimum interpolation distance on a sphere," *Biometrika*, Vol. 67, pp. 446-469, 1980.

S. N. Gown, R. H. Waring, D. G. Dye, and J. Yang, "Ecological remote sensing at OTTER: Satellite Macroscale Observation. *Ecological Application*.Vol. 4, pp. 322-343, 1994.

E. H. Isaaks, R. M. Srivastava, *An introduction to applied geostatistics*, Oxford University Press, New York., 1989.

M. Kallas, *Hazard rating of Armillaria root rot on the Black Hills National Forest*, M.S. Thesis, Department of Forest Sciences, Colorado State University, Fort Collins, CO 80523, pp., 1997.

F. P. Kelly, and B. D. Ripley, "A note on Strauss's model for clustering," *Biometrics*, Vol. 63, pp. 357-360, 1976.

J. Lui, J. B. Dunning, Jr., and H. R. Pulliam, "Potential effects of a forest management plan on Bachman's Sparrows (*Aimophila aestivalis*):Linking a Spatially Explicit Model with GIS," *Conservation Biology*, Vol. 9, pp. 62-75, 1995.

B. Matern, "Spatial variation," *Medelanden from Statens Skogsforsknings Institut.*, Vol. 49, No. 5, pp. 1-44, 1960.

K. Metzger, *Modeling small-scale spatial variability in stand structure using remote sensing and field data*. M.S. Thesis, Department of Forest Sciences, Colorado State University, Fort Collins, CO 80523, 1997.

Y. Ogata, and M. Tanemura, "Estimation of interactive potentials of spatial point patterns through the maximum likelihood procedure," *Ann. Instit. Statist. Math. Part B*, Vol. 33, pp. 315-338, 1981.

Y. Ogata, and M. Tanemura, "Estimation of interactive potentials of marked spatial point patterns through the maximum likelihood method," *Biometrics*, Vol. 41, pp. 421-433, 1985.

R. M. Reich, C. D. Bonham, and K. Metzger, "Modeling small-scale spatial interaction of shortgrass prairie species.," *Ecological Modeling*, Vol. 101, pp. 163-174, 1997.

R. M. Reich, R. L. Czaplewski, and W. A. Bechtold, "Spatial cross-correlation in growth of undisturbed natural shortleaf pine stands in northern Georgia," *J. Enivorn. and Ecol. Stat.*, Vol. 1, pp. 201-217, 1994.

R. Reynolds, and S. Joy, *Personal Communication*, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 218 West Prospect, Fort Collins, CO 80523, 1997.

B. D. Ripley, "Gibbsian interaction models," DA. Griffith (editor), *Spatial Statistics: Past, Present, and Future*, Institute of Mathematical Geography, Syracuse University, New York. p.3-25, 1990.

G. P. Robertson, "Geostatistics in ecology: Interpolating with known variance," *Ecology*, Vol. 63, pp. 744-748, 1987.

D.J. Strauss, "A model for clustering," *Biometrics*, Vol. 35, pp. 87-101, 1975.

Inventories of U.S. Wetlands[1]

W.E. Frayer[2]

Abstract—The U.S. Fish and Wildlife Service has a mandate to conduct periodic assessments of wetlands in the United States. The first national report was produced in 1983. The second national report was published in 1991. Several reports for states and regions have also been produced. A stochastic process was developed for projections of future wetland areas. The procedures of the inventories are discussed. Some results of the latest inventory are given in this paper.

An inventory is needed periodically for a wetland that is to be managed. An inventory of this type could be called a "management inventory" because it would provide information needed to manage the specific wetland. However, it would be impossible to have up-to-date inventories of all wetlands in an area as large as the United States.

If a wetlands inventory is to cover a large area—such as the United States—other tactics would be used. A well-designed, periodically updated inventory would not produce the information essential for management of specific wetlands; but, it can produce what is needed to determine if management of wetlands is in fact necessary. This kind of inventory has been given various descriptive titles; it is sometimes called a "policy inventory".

What kind of inventory is needed? Both are usually necessary. Unless a broad inventory is conducted and the resulting information points out specific needs, there is little chance of getting adequate support for a comprehensive series of management inventories. What can and has been done in the U.S. is to conduct a broad inventory of the nation's wetlands. This was conducted for the first time about 15 years ago for the 48 contiguous states by the U.S. Fish and Wildlife Service with the assistance of other agencies and contracts (Frayer, et al., 1983; Tiner, 1984). It consisted of studying approximately 3,500 sample units to determine changes between the mid-1950s and 1970s. The area sampled was less than 0.5 percent of the nation's area—something quite different from a 100 percent sample common for a management inventory. The results are fairly reliable and very useful.

A second inventory of the nation's wetlands was conducted several years ago (Frayer, 1991; Dahl and Johnson, 1991). The first inventory of Alaska's wetlands was also conducted (Hall et al., 1994). This paper presents the procedures used for these inventories and makes mention of a projection procedure that promises to be useful in forecasting future trends.

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Classification

In general terms, wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plants and animal communities living in the soil and on its surface. Technically, wetlands are lands transitional between terrestrial and aquatic systems where the water table usually at or near the surface or the land is covered by shallow water. Wetlands must have one ore more of the following three attributes: 1) at least periodically, the land supports predominantly hydrophytes; 2) the substrate is predominantly undrained hydric soil, and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at sometime during the growing season of each year. Common terms used to describe various wetlands include marshes, swamps, bogs, small ponds, sloughs, potholes, river overflows, mud flats, and wet meadows.

The classification and categories used are described by Cowardin, et al. (1979). Groupings of categories were made to accommodate 1) the special interests of the study and 2) the detail to which available aerial photography could be interpreted. The kinds of wetland for which estimates were produced include:

- Marine intertidal
- Estuarine intertidal nonvegetated
- Estuarine intertidal emergent
- Estuarine intertidal forested and scrub/shrub
- Palustrine unconsolidated shore
- Palustrine open water
- Other palustrine nonvegetated
- Palustrine emergent
- Palustrine forested
- Palustrine scrub/shrub

Within the classification structure that follows, wetlands and deepwater habitats are grouped according to systems. A system consists of environments of similar hydrological, geomorphological, chemical and biological factors. Each system is further divided following traditional ecological concepts. Although deepwater habitats were included in the study, they are not considered in this paper.

The *Marine System* extends from the outer edge of the continental shelf to the high water of spring tides or to the boundary of other systems as defined later. *Marine Intertidal* includes areas in which the substrate is exposed and flooded by tides, including the associated splash zone.

The *Estuarine System* consists of deepwater tidal habitats and adjacent tidal wetlands which are usually semi-enclosed by land, but have open, partially obstructed, or sporadic access to the open ocean and in which ocean water is at least occasionally diluted by fresh water runoff from the land. Offshore areas with typically estuarine plants and animals, such as mangroves and oysters, are also included. *Estuarine Intertidal* is the portion exposed and flooded by tides, including the associated splash zone. For the purpose of this study, Estuarine Intertidal wetlands are shown by the following groups: *Nonvegetated, Emergent,* and *Forested* and *Scrub / Shrub. Nonvegetated* contains no emergent vegetation but does include vegetation in the form of aquatic beds, while *Emergent* contains primarily those erect, rooted herbaceous plants typically found in wet environments. *Forested* is characterized by the presence of trees, and *Scrub / Shrub* includes areas dominated by shrubs and small or stunted trees.

The *Lacustrine System* includes some wetlands and deepwater habitats situated in topographic depressions or dammed river channels. Each area must exceed 20 acres or have depths in excess of two meters or have an active wave-formed or bedrock shoreline feature. The *Riverine System* includes wetlands and deepwater habitats contained within a channel. Lacustrine and Riverine wetlands were grouped with and included in Palustrine wetlands in this study.

The *Palustrine System* includes all nontidal wetlands not included within any of the other four systems. There are no deepwater habitats included. For this study, *Palustrine* wetlands are shown by the following groups: *Unconsolidated Shore, Open Water, Other Palustrine Nonvegetated, Emergent, Forested,* and *Scrub / Shrub. Unconsolidated Shore* includes wetlands generally having unstable substrates with less than 75 percent cover of stones, boulders, or bedrock and little or no vegetation. *Open Water* includes small inland open water bodies that are too small to be part of the *Lacustrine System. Other Palustrine Nonvegetated* includes other inland wetlands with little or no vegetation other than aquatic beds, and the remaining terms are defined as they were under the *Estuarine System.*

In addition to these, three more categories were used in the study. Two are *Urban* and *Agriculture;* and together with *Other Surface Area* (forests, rangeland, etc., not qualifying as wetland), they account for all other areas.

This is only a brief discussion of the classification used in the study. It is difficult to differentiate the categories further without introducing highly technical terms. For those interested in detailed, exact definitions, the descriptions presented by Cowardin, et al., (1979) are available.

Survey Procedure

The objectives of the latest national study were to develop statistical estimates of acreage for categories of wetlands for the lower 48 states during the 1970s, the 1980s, and changes for the period.

A stratified random sample was used with the basic strata being formed by state boundaries and the 35 physical subdivisions described by E.H. Hammond (1970). Additional strata specific to the study are special coastal strata encompassing most of the marine and estuarine categories used in the study and other strata encompassing the Great Lakes. This resulted in over 200 strata for the study.

Sample units had been allocated to strata in a previous study (Frayer et al., 1983) in proportion to the expected amount of wetland and deepwater habitat acreage as estimated by earlier work (including Shaw and Fredine, 1956). A total of 3629 sample units were used in the study.

Each sample unit is a four-square mile area, two miles on each side. The units had been plotted on U.S. Geological Survey topographic maps for the previous study. Also, 1:80,000 black and white aerial photography had been obtained for the 1970s. The 1980s aerial photography was then obtained, which was primarily 1:58,000 scale color infrared transparencies. The mean years of photography were 1974 and 1983, a nine-year period.

The 1980s photography was interpreted and annotated in accordance with the classification system described earlier and procedures developed by the U.S. Fish and Wildlife Service's National Wetlands Inventory Project. The results were compared to the 1970s photography, and any changes in classification were annotated. Both the recent classification and the classification for the 1970s were recorded for each change. If a change was human-induced, that was recorded also.

Results

Estimates for the 1970s, 1980s, and change during the period were produced for the kinds of wetlands described and are presented in Table 1. Some of the significant results are described below by category.

Marine Intertidal Wetlands

Changes in marine intertidal wetlands since the 1970s have been small, with estimated size in the 1980s being 104.3 thousand acres.

Estuarine Wetlands

Losses in estuarine wetlands occurred, with a primary loss of 70.9 thousand acres of estuarine intertidal emergent wetlands (coastal salt marshes) since the 1970s. States having the largest losses in estuarine wetlands since the 1970s are Louisiana with 49.7 thousand acres loss and Texas with 8.2 thousand acres loss. Most of the loss in Louisiana was to estuarine subtidal deepwater habitats (bay bottoms).

Palustrine Wetlands

The 1970s and 1980s estimates of palustrine wetlands are 100.3 and 97.8 million acres, respectively. The average annual net loss was 283.5 thousand acres.

Palustrine Nonvegetated Wetlands

Palustrine nonvegetated wetlands comprised 6.1 million acres in the 1980s. Gains since the 1970s have occurred in all four flyways and total 792.4 thousand acres. Almost all of this increase was in palustrine unconsolidated bottoms (primarily ponds), and most occurred on lands not currently classified as wetlands or deepwater habitats.

Palustrine Vegetated Wetlands

There was an estimated 91.6 million acres of palustrine vegetated wetlands in the 1980s compared to 95.0 million acres in the 1970s. The average annual net loss was 371.6

Table 1.—Area, in thousands of acres, by kind of wetland for the conterminous United States[1]

	1970s	1980s	Change
Marine	104.5	104.3	–0.2
Intertidal	(..)	(..)	(>50)
Estuarine	678.2	689.8	+11.6
Intertidal Nonvegetated	(..)	(..)	(>50)
Estuarine	4,144.9	4,074.0	–70.9
Intertidal Emergent	(...)	(...)	(..)
Estuarine Intertidal	709.0	708.9	–0.1
Forested & Scrub/Shrub	(..)	(..)	(>50)
Palustrine	368.9	387.3	+18.4
Unconsolidated Shore	(..)	(.)	(.)
Palustrine	4,781.4	5,535.2	+753.8
Open Water	(..)	(..)	(.)
Other Palustrine	198.6	218.8	+20.2
Nonvegetated	(..)	(..)	(.)
Palustrine	24,312.8	24,533.0	+220.2
Emergent	(...)	(...)	(>50)
Palustrine	55,151.2	51,747.8	–,403.4
Forested	(...)	(...)	(...)
Palustrine	15,505.6	15,344.5	–161.1
Scrub/Shrub	(...)	(...)	(>50)
All	105,955.1	103,343.6	–2,611.5
Wetlands	(...)	(...)	(..)

[1]Entries in parentheses are classes of standard error as a percentage of the estimated total.
... Standard error is less than 10% of estimate.
.. Standard error is greater than 10% and less than 25% of estimate.
. Standard error is greater than 25% and less than 50% of estimate.

thousand acres. This reduction is due primarily to losses of palustrine forested wetlands.

Palustrine Emergent Wetlands

There were several gains and losses of palustrine emergent wetlands. Gains were primarily from palustrine forested wetlands, and losses were primarily due to agriculture. States having gains include Louisiana, Arkansas, Mississippi, Alabama and Michigan in the Mississippi Flyway; and Georgia, South Carolina and Maine in the Atlantic Flyway. States having losses include California in the Pacific Flyway; North Dakota, South Dakota, Nebraska and Texas in the Central Flyway; Minnesota in the Mississippi Flyway; and Florida in the Atlantic Flyway.

Palustrine Forested Wetlands

There was a net loss of 3.4 million acres of palustrine forested wetlands since the 1970s. The 1980s estimates are 51.7 million acres of palustrine forested wetlands with an average annual net loss of 378.2 thousand acres. There were some large changes to other wetland categories, primarily palustrine emergent and palustrine scrub/shrub. However, more than two million acres were converted to non-wetlands in the period, with 1.0 million acres lost to agriculture.

The Mississippi and Atlantic flyways are dominant in the losses since the 1970s. Mississippi Flyway states with large losses include Louisiana (628.0 thousand acres loss), Arkansas (210.3 thousand acres), Mississippi (365.4 thousand acres), Alabama (97.4 thousand acres), Tennessee (40.6 thousand acres) and Michigan (57.9 thousand acres). Atlantic Flyway states with large losses include North Carolina (985.8 thousand acres loss), South Carolina (124.8 thousand acres), Georgia 454.6 thousand acres), Florida (184.1 thousand acres), Massachusetts (67.6 thousand acres), and Maine (8.9 thousand acres).

Palustrine Scrub/Shrub Wetlands

There were both losses and gains in palustrine scrub/shrub wetlands since the 1970s. Some significant losses were offset by gains of a different nature. The losses included conversion of over one-half million acres to non-wetlands. The gains came primarily from other palustrine vegetated categories.

States with large losses since the 1970s include Minnesota, in which 214.6 thousand acres were lost; and North Carolina, in which 205.3 thousand acres were lost. Gains were posted in Alabama, Louisiana, Georgia, Maryland, Pennsylvania and Massachusetts.

Conclusions

The results reported are based on a designed study of the wetlands of the lower 48 states. The results of this report document continued major net losses of wetlands and provide insights to where these losses took place. The design involved careful measurement of a sample of the nation's surface area. In general, results are meaningful only at the national level or for broad areas. Some of the results, however, have adequate reliability to be useful at flyway or state levels. Intensification of the samples for selected areas in future studies can provide useful results for those areas.

Some findings are very clear and involve large acreages. Large decreases in wetlands continued to occur in the lower Mississippi River states of Louisiana, Mississippi and Arkansas. Other sates with large losses in the Mississippi Flyway include Alabama, Tennessee, Minnesota and Michigan. Dominate losers in the Atlantic Flyway include North Carolina, South Carolina, Georgia, Florida and Massachusetts. Other states cited in this report as having significant wetland losses are California, North Dakota, South Dakota, Nebraska, Texas and Maine. Additional states having statistically significant wetland losses, since the 1970s are Illinois, Wisconsin, Missouri, Kentucky, New Hampshire, Vermont, Connecticut, New York, Pennsylvania, New Jersey, Maryland, Delaware and Virginia. In the palustrine forested category alone, an area approximately equivalent to the entire state of Connecticut was lost between 1974 and 1983.

Other changes are also clear, but involve lesser acreages. Importance of change is not necessarily reflected by area alone. Some of the smaller wetlands—particularly along the coastline of the United States—are extremely important habitats for plant and animal life.

Significant increases occurred in small open water areas. The important of these newly created habitats to fish and wildlife populations is yet to be fully determined.

This report does not document the significant reduction in quality of many wetlands. Some of the factors causing this reduction in quality are: canals and inlets that cause changes in water chemistry due to salt water intrusion, polluted runoff from adjacent uplands or polluted inflow from rivers and streams, urban encroachment, and dissection by transportation corridors.

Continual monitoring of surface area use and changes in use is needed to provide the basis for wise decisions. This report is the result of one such method of monitoring initiated by the U.S. Fish and Wildlife Service. The results in this report provide wetland information similar to the forest and range information required by the Forest and Rangeland Renewable Resources

Planning Act and to soils information required by the Soil and Water Resource Conservation Act. The results can be updated in the future on the schedule required by those Acts.

Although it would be preferable to remeasure the plots on a periodic basis, a shortage of funding may necessitate a different approach to obtaining new estimates. A procedure for projecting wetland areas was first developed and described by Frayer (1987) and later refined by Terrazas-Gonzalez (1997).

Literature Cited

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv. 103 pp.

Dahl, T. E., and C. E. Johnson. 1991. Status and trends of wetlands in the conterminous United States, mid-1970s to mid-1980s. U.S. Fish Wildl. Serv. 28 pp.

Frayer, W. E., T. J. Monahan, D. C. Bowden, and F. A. Graybill. 1983. Status and trends of wetlands and deepwater habitats in the conterminous United States, 1950s to 1970s. Colo. State Univ. 32 pp.

Frayer, W. E. 1987. In the absence of concern: wetland projections to the year 2000. In: Proceedings, Land and Resource Evaluation for National Planning in the Tropics. USDA Forest Serv. Pp 383-385.

Frayer, W. E. 1991. Status and trends of wetlands and deepwater habitats in the conterminous United States, 1970s to 1980s. Mich. Tech. Univ. 32 pp.

Hall, J. V., W. E. Frayer, and B. O. Wilen. 1994. Status of Alaska wetlands. U.S. Fish Wildl. Serv. 33 pp.

Hammond, E. H. 1970. Physical subdivisions of the United States. In: National Atlas of the United States. U.S. Geol. Surv. 417 pp.

Shaw, S. P., and C. G. Fredine. 1956. Wetlands of the United States. U.S. Fish Wildl. Serv., Circ. 39. 67 pp.

Tiner, R. W. Jr. 1984. Wetlands of the United States: current status and recent trends. U.S. Fish Wildl. Serv. 59 pp.

Terrazas-Gonzalez. 1997. Evaluation of projection methods to predict wetlands area sizes: the wetlands inventory of U.S.A. PhD dissertation. Colo. State Univ. 150 pp.

Expanding Applications, Data, and Models in a Forest Inventory of Northern Utah, USA[1]

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Abstract—Forest inventories, like those conducted by the USDA Forest Service, Forest Inventory and Analysis (FIA) Program in the Interior West, U.S.A., are under increased pressure to provide better information and reduce costs. Here, we describe our ongoing efforts in the Interior Western of the United States to expand traditional forest inventory strategies to accommodate a wider variety of user-defined products, auxiliary data inputs, and statistical models. To the traditional product line of estimates of population totals, we add spatial depictions of the forest resources as well as exploratory data analyses. To the existing forest inventory ground and photo plots we add spatially explicit digital data sets including elevation, aspect, slope, geology, precipitation, AVHRR- and TM-based vegetation cover types, as well as UTM coordinates. To the current model of double sampling for stratification we add generalized linear and additive models, classification and regression trees, and artificial neural networks. These expansions are illustrated through a synopsis of ongoing research studies in the northern Utah mountains.

Over 60 years ago, the United States recognized the need for information on the supply and condition of the Nation's timber resources and established a national forest inventory program under the McSweeney-McNary Act of 1928. That Act was expanded by the Forest and Rangeland Renewable Research Act of 1978 to include all forest resources. It is under this Act that the Forest Service Forest Inventory and Analysis Program (FIA) seeks to maintain a comprehensive inventory of the status, trends, use and health of the country's diverse forest ecosystems. Networks of remotely sensed and field plot locations have been established on nearly all forested lands throughout the Interior West by the Interior West Resources, Monitoring, and Evaluation (IWRIME) Program. Using a double sampling for stratification strategy, estimates of areal extent and structural attributes of these forested lands are reported at regional scales approximately every 10 years. More recently, emphasis has been placed on integrating forest inventory data with satellite-based information to improve precision of these estimates, as well as to produce maps of forest resources, explore ecological relationships, and monitor change through time. This recent emphasis is in response to demands by natural resource managers and scientists to know not only how much and what type of vegetation exists over an extensive area, but where it is located, and how it is changing through ecological processes, management activities, or catastrophic events.

Development of an approach to meet these multiple objectives is hindered by a number of challenges that can be visualized along three conceptual axes: data inputs, statistical models, and applications. Each of these axes poses unique challenges. Challenges arise when model inputs come from diverse data sources. For example, field data may be collected under a wide variety of sample designs having inconsistent sample plot shapes and sizes and unknown positional error. Available digital data may exist at vastly different scales than that collected on the ground, and may include unknown sources of error. Also, definitions of variables may vary among cooperating agencies. Statistical modelling challenges are also numerous and varied. Both response and predictor variables in forest structure models may be continuous or discrete. The relationship between response and predictors may be nonlinear or not easily described by a parametric relationship. Sample points may be spatially and temporally correlated, and often we need to model a multivariate response. In addition, inventory estimates of population totals must be unbiased. Finally, application challenges include needs for computational efficiency, developing methodology that is suitable to a production environment, and, perhaps most importantly, delivering products along with validation information that are relevant to specific user needs.

Our research efforts have been conducted in the Northern Utah Mountain Ecoregion (Omernik 1987) (Fig. 1). Field data in this ecoregion were collected from 1991-1994 by IWRIME. These 1 acre field plots were established on a 2.5 km offset grid for National Forest Lands and on a 5 km grid for other ownerships giving ~1500 plots for modelling in our study region. At each sample plot, forest variables such as site attributes, vegetation structure, and individual tree characteristics were measured. Details of the sample design, initial inventory estimates and analyses are reported in O'Brien (1996). The problem we face is how best to link this extant forest inventory data with a variety of satellite-based information to meet multiple inventory objectives in light of the challenges along each of the data input, model, and application axes. Here we describe our ongoing efforts in

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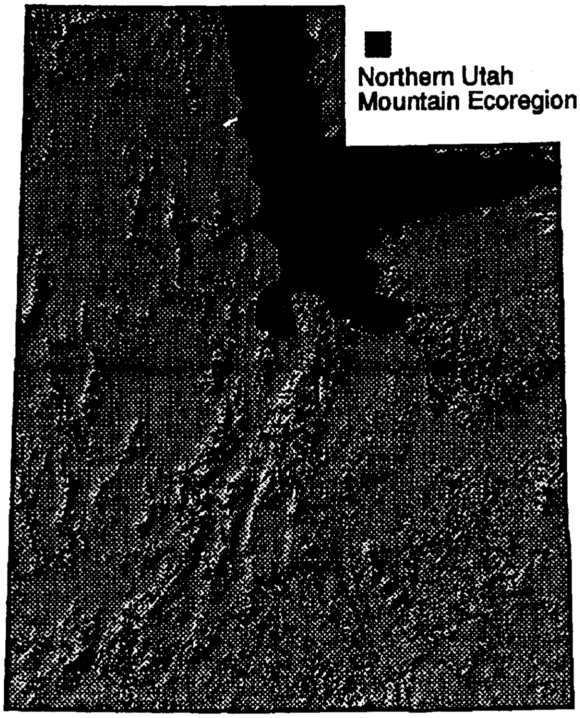

Figure 1.—Northern Utah Mountain Ecoregion study area for numerous research activities.

the northern Utah to expand traditional forest inventory strategies to accommodate a wider variety of user-defined products, auxiliary data inputs, and statistical models.

Conceptual Framework

Applications

One of our most difficult challenges may be to develop products that are relevant to specific user needs. While traditional estimates quantify the forest resources regionally, there are a wide variety of user groups in the U.S. and abroad that desire more diverse information from regional forest inventories. These information needs are more frequently driven by smaller spatial events than those addressed by regional analyses. Questions posed by these groups include: how much of a particular vegetation class or structure exists over a given area? How is that class and structure distributed in space? What ecological processes drive that distribution? And, how do we expect it to change?

For example, land managers often desire estimates of area by forest type within small areas like a ranger district, or perhaps estimates of timber volume within the digitized boundaries of a beetle kill area. While these small area estimates are essential to improve management, the most valuable management tool is a map depicting the spatial arrangement of forest attributes. Vegetation cover-type maps produced by programs like the USDI Gap Analysis program (see Homer and others 1997; Scott and others 1993) have been useful to some extent. However, most, if not all, of these maps lack any spatial depiction of vegetation structure reducing their utility for applications like the identification of suitable wildlife habitat (Edwards and others 1996). There is also a recent emphasis on increasing analytical capabilities by using extant inventory data to explore ecological relationships in forested systems. Such exploration might help address management needs like predicting stand growth response to management activities on less-studied resources like woodlands, or perhaps to reduce labor intensive sampling activities by modelling expensive field variables as functions of site characteristics. In addition, the question of how the resource is changing through time has become more pressing with recent Federal legislation requiring annual estimates of forest population totals.

Auxiliary Data Inputs

A wide variety of digital data sets are available in our study region. Data layers used in our studies include elevation, aspect, slope, geology, precipitation, geographic coordinates, as well as raw spectral values, indices, and vegetation cover-types based on satellite data from both the advanced very high resolution radiometer (AVHRR) and Thematic Mapper (TM) platforms. Elevation, aspect and slope were obtained from 90 m digital elevation models produced by the Defense Mapping Agency (DMA). Geology data were obtained from a digitized coverage of a 1:500,000 stable base mylar of the geology of Utah (Hintze 1980). Precipitation data came from a downscaling (Zimmermann, unpublished data) of coarse-scale Prism climate maps (Daly and others 1994). AVHRR-based data included the normalized difference vegetation index (NDVI), derived from the visible and near infrared spectral values (Loveland and others 1991) and a vegetation class from the 1993 Resources Planning Act forest type group map (Powell and others 1993) identifying 11 vegetation classes in the Northern Utah Mountain Ecoregion. Finally, TM-based data included red, near-infrared, and mid-infrared spectral values as well as a vegetation class based on the 1 ha cover-map produced by the Utah Gap Analysis Project (Edwards and others 1995, Homer and others 1997).

Statistical Models

Linking the diverse data inputs described above to meet diverse user needs poses interesting statistical challenges. Here we have a (possibly multivariate) response collected at n sample locations on an x-y grid. We have a large number of predictor variables whose functional relationship to the response may be highly nonlinear, with complex interactions amongst the predictor variables. We want to model the response as a function of the predictor variables for the purposes of predicting in space, estimating population totals and exploring ecological relationships (Fig. 2). In addition, the modeling has to be done in a "production" environment, i.e. repeatable by a variety of analysts frequently working on space-limited hardware with tight deadlines and small budgets. The question, then, is which of a myriad of statistical tools is most appropriate?

While a wide variety of approaches are available, we are currently considering five classes of models for meeting multiple forest inventory objectives. These include the

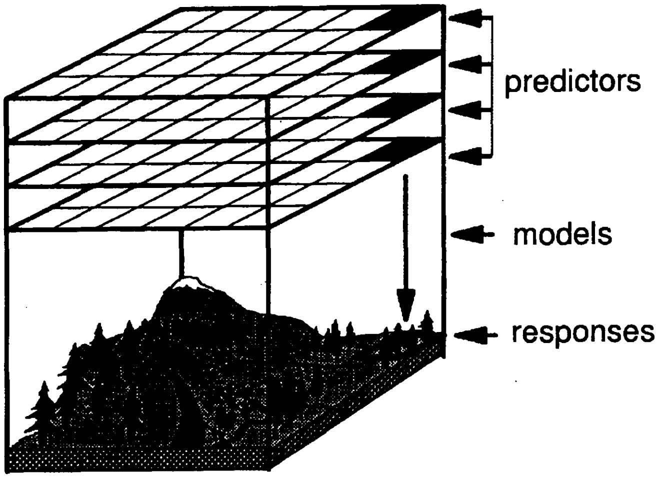

Figure 2.—Strategy for merging regional forest inventory data with satellite-based information for meeting multiple inventory objectives through a variety of statistical models.

classical linear model as well as a suite of 4 nonlinear regression methods. Linear models have been used extensively in forest inventory applications because they are fast to compute, easy to interpret, and require relatively few data points. In addition, they can be nested in a probability-based estimation strategy through stratified sampling or regression estimators (like those currently used in forest inventories) and can produce quite accurate predictions when the process generating the response is, in fact, linear. However, predictions are much less accurate when the relationship between the predictor and the response is highly nonlinear. Given this constraint, we are likely to be able to extract more information from the predictor variables through more flexible model structures capable of handling nonlinear relationships. Nonlinear methods considered include generalized linear and additive models (GLMs and GAMs) (McCullagh and Nelder 1989, Hastie and Tibshirani 1990), classification and regression trees (CART) (Morgan and Sonquist 1963, Breiman and others 1984), multivariate adaptive regression splines (MARS) (Friedman 1991), and artificial neural networks (ANN) (Ripley 1996). These nonlinear models were chosen because all are believed to be competitive for prediction when there are a small to moderate number of predictor variables (less than 10), as is the case for our forest inventory application. See DeVeaux and others, 1993, and DeVeaux, 1995, for discussions comparing these techniques.

Questions and Research Activities in Northern Utah

The following paragraphs summarize recent and ongoing research activities in the Northern Utah Mountain Ecoregion. Each individual study represents an expansion of traditional methods along one or more of the conceptual axes defining our research.

AVHRR vs. PI: How Much?

Traditionally, estimates of population totals have been constructed through through two-phase sampling procedures where phase one consists of aerial photo based information collected on an intensive sample grid, and phase two consists of a subset of that grid visited in the field. More recently, questions have been raised about the cost-efficiency of using satellite-based information for stratification in lieu of photo-interpretation. A study sponsored by the FIA Remote Sensing Band (USDA, In preparation), is underway to examine the relative precision of estimates of area by forest type and total volumes of major tree species in 6 ecologically different states within the U.S. under several stratification strategies. Traditional two-phase sampling estimates using photo-interpreted information in phase one are compared to estimates obtained when classified AVHRR and an AVHRR-based vegetation index are used for stratification and regression estimation, respectively. Preliminary results from the Northern Utah Mountain Ecoregion show that a tremendous reduction in cost can be realized through the use of classified AVHRR data over traditional photo-interpreted data for stratification with only minimal loss in precision.

GLMS and Digital Data: How Much and Where?

In Moisen and others (in review), we illustrate how generalized linear models can be used to construct approximately unbiased and efficient estimates of population totals while providing a mechanism for spatial prediction for mapping of forest structure. We model forest type and timber volume of five tree species groups as functions of a variety of predictor variables in the northern Utah mountains. Predictor variables include elevation, aspect, slope, and geographic coordinates, as well as vegetation cover-types based on satellite data from both the Advanced Very High Resolution Radiometer (AVHRR) and Thematic Mapper (TM) platforms. We examine the relative precision of estimates of area by forest type and mean cubic-foot volumes under six different models including the traditional double sampling for stratification strategy. Only very small gains in precision were realized through the use of expensive photo-interpreted or TM-based data for stratification, while models based on topography and spatial coordinates alone were competitive (Fig. 3a,b). We also compare the predictive capability of the models through various map accuracy measures. The models including the TM-based vegetation performed best overall, while topography and spatial coordinates alone provided substantial information at very low cost (Fig. 3c,d).

GAMS and Digital Data: Where and Why?

Frescino and others (in review) modelled forest composition and structural diversity in the Uinta Mountains, Utah, as functions of satellite spectral data and spatially explicit environmental variables through generalized additive models. Measures of vegetation composition and structural diversity were available from extant forest inventory data. Three types of satellite data included raw TM spectral data,

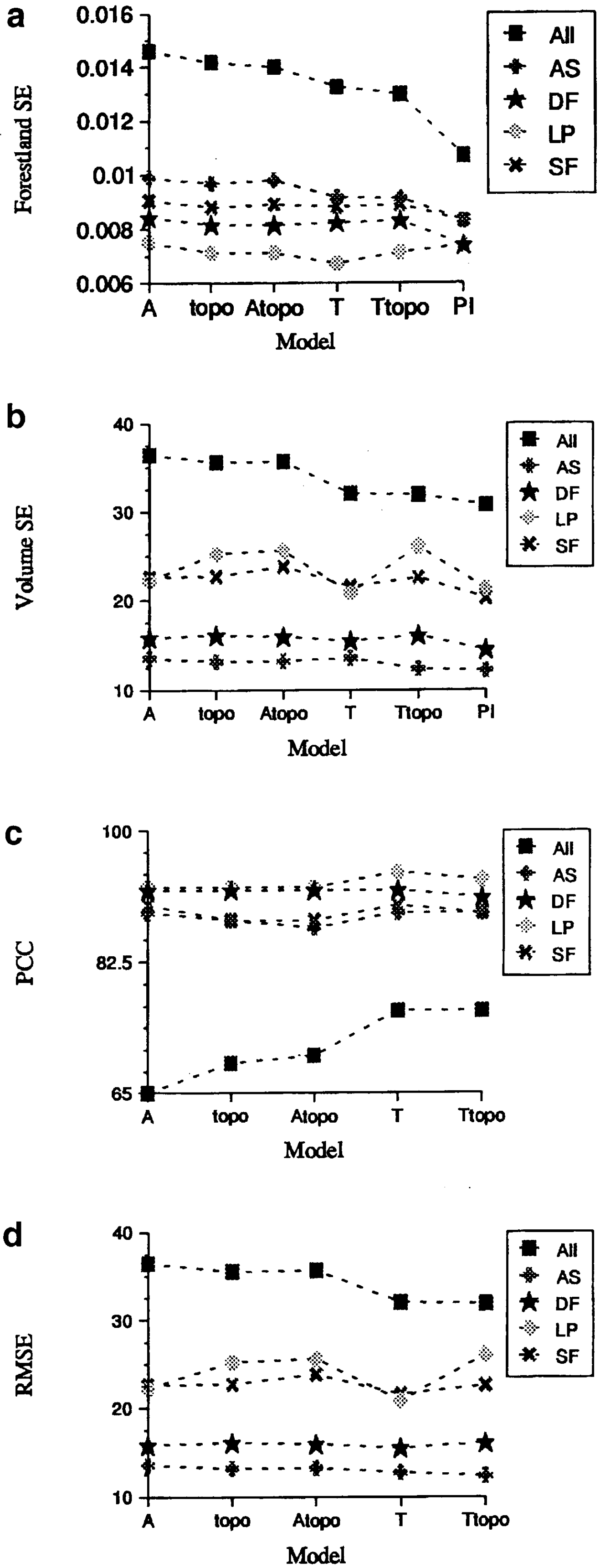

Figure 3.—Forest type and cubic-foot volume for 5 species groups were modelled as functions of several sets of predictor variables. Species groups included all timber species (All), Aspen (Asp), Douglas-fir (DF), lodgepole pine (LP), and spruce-fir (SF). Sets of predictor variables included classified AVHRR data (A), topographic variables and spatial position (topo), classified AVHRR along with topographic and spatial variables (Atopo), classified TM data (T), classified TM along with topographic and spatial variables (Ttopo), and photo-interpreted forest type collected on a 1 km grid (PI). Standard errors on estimates of area and volume by species group are illustrated in Figures 3 a and b respectively. Figures 3 c and d illustrate the accuracy of maps of forest type and tree volume per acre under each of 5 predictor sets. Accuracy of type maps was expressed as percent correctly classified (PCC) while maps of tree volume were expressed as the root mean squared error (RMSE). See Moisen and others (In review) for details.

a Gap Analysis classified TM, and a vegetation index based on AVHRR. Environmental predictor variables included maps of temperature, precipitation, elevation, aspect, slope, and geology. Spatially explicit predictions were generated for forest classification, presence of lodgepole pine, basal area of forest trees, percent cover of shrubs, and density of snags within a user-friendly display environment (Fig. 4). The maps were validated using an independent set of field data collected from the Evanston Ranger District within the Uinta Mountain Range. The models predicting the presence of forest and lodgepole pine were 88% and 80% accurate, respectively, within the Evanston Ranger District, and an average of 62% of the predictions of basal area, shrub cover, and snag density fell within an approximate 15% deviation from the field validation values. The addition of TM spectral data and the GAP Analysis TM-classified data were found to contribute significantly to the models' predictions, with some contribution from AVHRR data. The methods used in this study provide a systematic approach for delineating structural features within forest habitats, thus offering an efficient spatial tool for making management decisions.

Modern Regression Methods: How Much, Where, and Why?

There are numerous ways in which forest class and structure variables can be modeled as functions of remotely sensed variables, yet little work has been done to determine which statistical tools are best suited to the tasks given multiple objectives and logistical constraints. Moisen and others (1998) discuss ongoing work comparing the relative performance of linear models, GAMs, CARTs, MARS, and ANNs in meeting multiple forest inventory objectives (Fig. 5). Models have been built for a variety of forest class and structure variables using forest inventory and satellite-based information in the mountains of northern Utah, and extensive realistic simulations are under construction (Moisen, in preparation). The relative performance of each of the five classes of models mentioned above is being evaluated according to the following criteria: 1) accuracy of

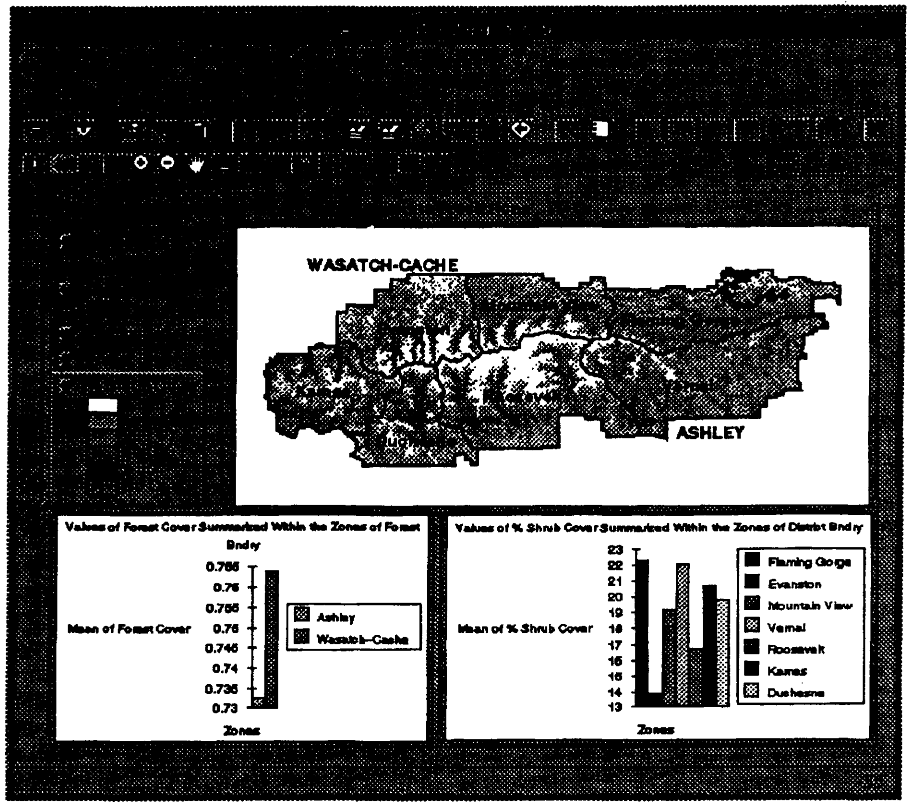

Figure 4.—Predictions and summary statistics over seven ranger districts in the Uinta Mountains. See Frescino and others (In review) for details.

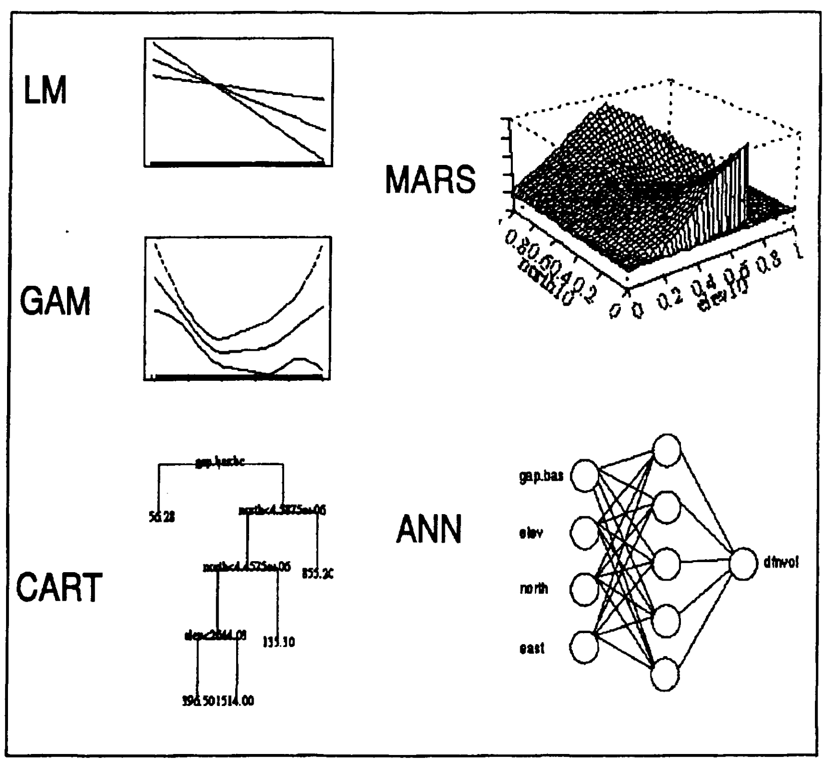

Figure 5.—Linear models (LM), generalized additive models (GAMs), classification and regression trees (CART), multivariate adaptive regression splines (MARS), and artificial neural networks (ANN) each offer unique opportunities and challenges if used as tools to meet multiple inventory objectives. See Moisen and others (1998) for details.

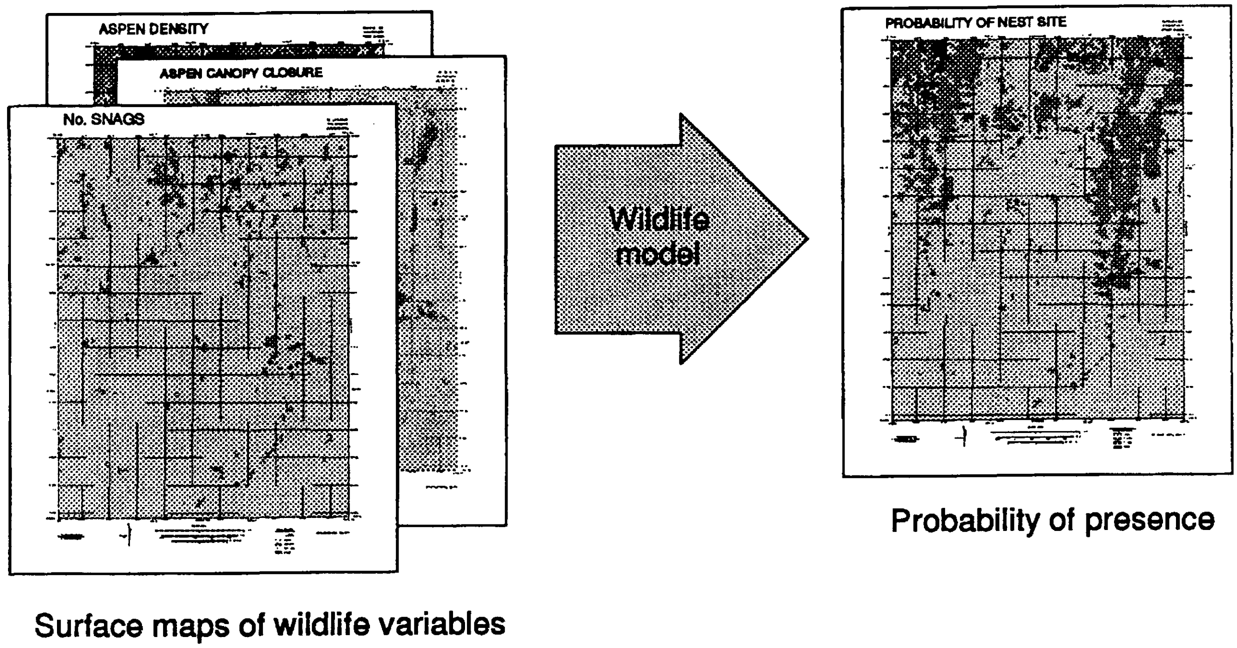

Figure 6.—Maps of forest attributes are needed for identification of suitable wildlife habitat.

spatial prediction; 2) efficiency in estimating population totals; 3) interpretability; 4) suitability to a production environment.

Wildlife Habitat: Where and Why?

Last, we are examining the ability to link the fine-scale resolution obtained from site-specific wildlife models, and fine-scale depictions of forest attributes, to large scale predictive models of wildlife. We first model the specific structural attributes of forest habitat following techniques described above. This process creates a statistical model relating a response (e.g., snag density, canopy cover, tree density) to a series of predictor variables (e.g., topographic variables, classified TM data, spatial position) From this process, a series of maps of forest attributes can be generated, each of which is a spatial representation of a predictor variable in a wildlife habitat model. To generate the probability of wildlife presence, each cell of each variable map is run through the predictive wildlife model and a probability of presence calculated (Fig. 6). Preliminary field tests of the predictive capabilities of this approach for cavity nesting birds in aspen forests indicate accuracies in the 60-85% range (Lawler and Edwards, Unpublished data). These results suggest that data, such as those collected by FIA, have applications to other aspects of forest management beyond simple estimation of population totals.

Summary

Here we have presented a conceptual framework for merging regional forest inventory data with satellite-based information for meeting multiple inventory objectives. We have described our ongoing efforts in the Interior West to expand traditional forest inventory strategies to accommodate a wider variety of auxiliary data inputs, statistical models, and user-defined products. Our goal is to continue research into the strengths and weaknesses of differing approaches, exploring how alternative data inputs, statistical models and applications as defined by users affect our ability to inventory and monitor forest attributes.

References

Breiman, L.; Friedman, J. H.; Olshen, R. A.; and Stone, C. J. 1984. Classification and Regression Trees. Monterey, CA: Wadsworth and Brooks/Cole.

Daly, C.; Nielson, R. P.; and Phillips, D. L. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33: 140-158.

DeVeaux, R. D. 1995. A guided tour of modern regression methods. In: 1995 Fall Technical Conference: Section on Physical and Engineering Sciences: Proceedings of conference; St. Louis, MO.

DeVeaux, R. D.; Psichogios, D. C.; and Ungar, L. H. 1993. A comparison of two nonparametric estimation schemes: MARS and Neural Networks. Computers in Chemical Engineering 8: 819-837.

Edwards, T. C., Jr.; Homer, C. G.; Bassett, S. D.; Falconer, A.; Ramsey, R. D.; and Wight, D. W. 1995. Utah Gap Analysis: an environmental information system. Technical Report 95-1, Utah Cooperative Fish and Wildlife Research Unit, Utah State University, Logan, Utah. 1138pp + 2 CD-ROMs.

Frescino, T. S.; Edwards, T. C., Jr.; and Moisen, G. G. [In review]. Modelling spatially explicit structural attributes using generalized additive models. Submitted to Ecological Applications.

Friedman, J. H. 1991. Multivariate addaptive regression splines. Annals of Statistics 19: 1-141.

Hastie, T.; and Tibshirani, R. J. 1990. Generalized Additive Models. New York: Chapman and Hall. 335 p.

Hintze, L. F. 1980. Geologic map index of Utah. Utah Geological and Mineralogical Survey, Salt Lake City, Utah.

Homer, C. H.; Ramsey, R. D.; Edwards, T. C., Jr.; and Falconer, A. 1997. Landscape cover-type modelling using a multi-scene

TM mosaic. Photogrammetric Engineering and Remote Sensing 63: 59-67.

Lawler, J. J. L. and Edwards, T. C., Jr. [Unpublished data.] Utah State University, Department of Fisheries and Wildlife, Logan, UT.

Loveland, T. R.; J. W. Merchant; D. O. Ohlen; and J. F. Brown. 1991. Development of a land-cover characteristics database for the conterminous U.S. Photogrammetric Engineering and Remote Sensing 57: 1453-1463.

McCullagh, P. and Nelder, J. A. 1989. Generalized Linear Models. New York: Chapman and Hall. 511 p.

Moisen, G. G.; Edwards, T. C., Jr.; and Van Hooser, D. 1997. Merging Regional Forest Inventory Data with Satellite-based Information Through Nonlinear Regression Methods. In: T. Ranchin and L. Wald, eds. Proceedings of the Second International Conference on the Fusion of Earth Data; Sophia Antipolis, France; January 1998. p. 123-128.

Moisen, G. G. and T. C. Edwards, Jr. [In review]. Use of generalized linear models and digital data in a forest inventory of Utah. Submitted to Journal of Agricultural, Biological and Environmental Statistics.

Moisen, G. G. [In preparation]. Modern regression methods for meeting multiple forest inventory objectives: a comparative study. Utah State University, Department of Mathematics and Statistics. Ph. D. dissertation in preparation,

Morgan, J. N. and Sonquist, J. A. 1963. Problems in the analysis of survey data and a proposal. Journal of the American Statistical Association 58: 415-434.

O'Brien, R. A. 1996. Forest resources of Northern Utah Ecoregion. Resour. Bull. INT-RB-87. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 34 pp.

Omernik, J. M. 1987. Map supplement: ecoregions of the conterminous United States. Annals of the Association of American Geographer. 77: 118-125 (map).

Powell, D. S.; Faulkner, J. L.; Darr, D. R.; Zhu, Z.; and MacCleery, D. W. 1993. Forest resources of the United States, 1992. General Technical Report RM-234. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest an Range Experiment Station. 132 p. + map.

Ripley, B. D. 1996. Pattern Recognition and Neural Networks. New York: Cambridge University Press. 403 pp.

Scott, J. M.; Davis, F.; Csuti, B.; Noss, R.; Butterfield, B.; Caicco, S.; Groves, C.; Edwards, T. C., Jr.; Ulliman, J.; Anderson, H.; Derchia, F.; and Wright, R. G. 1993. Gap Analysis: A geographic approach to protection of biological diversity. Wildl. Monogr. No. 123.

USDA. [In preparation]. Satellite-based stratification alternatives for forest inventory. Study sponsored by the FIA National Remote Sensing Band.

Zimmermann, N. [Unpublished data.] Utah State University, Department of Forestry, Logan, UT.

Permanent Control Sites for Monitoring Forest Resources in Protected Natural Areas in the State of Jalisco, Mexico[1]

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Abstract—One of the most important objectives of natural protected areas, is providing a relatively unaffected environment that can be observed in its natural state through time. International monitoring of natural resources has acquired great importance, as a result of the ever growing loss of such resources. Climate changes and above all the anthropogene effects on the forests have originated important reductions in biodiversity, as well as modifications in their normal development patterns.

The evaluation of reserves, requires the use of techniques and quantitative and qualitative ecological and silvicultural models that may allow defining adequate ways of handling. World wide, scientist try to find alternatives in order to unify approaches on monitoring and evaluation techniques for natural resources. The present work has the objective of showing the importance and meaning of the application of permanent control sites, with the propose of monitoring forest dynamics in two natural protected areas in the state of Jalisco, Mexico, They are the Sierra La Primavera and Volcan Nevado de Colima, they are considered as: "Forest protection and wildlife refuge zone" and "National Park" respectively. The first control groves in the experimental site "Forest-School" (Bosque-Escuela) of the University of Guadalajara were established in 1994. This sampling are part of the geographical forest information system of the area and are the first in their kind in the Sierra La Primavera and the National Park "Volcán-Nevado de Colima".

Resumen—Uno de los objetivos más importantes de las áreas naturales protegidas, es el de proporcionar un medio relativamente inalterado que se pueda observar en su estado natural a lo largo del tiempo. El monitoreo de los recursos naturales a nivel mundial ha adquirido gran importancia, debido a la pérdida cada vez mayor de estos. Los cambios del clima y principalmente los factores antropogénicos ejercidos sobre los bosques han venido originando mermas importantes en la biodiversidad, así como modificaciones en su patrón normal de desarrollo.

La evaluación de las áreas naturales requiere del uso de técnicas y de modelos cuantitativos y cualitativos, ecológicos - silvícolas que permitan definir tareas adecuadas de manejo. Por ello, a nivel mundial se busca generar alternativas para unificar criterios sobre las técnicas de monitoreo y evaluación de los recursos Naturales. El presente trabajo tiene como objetivo, mostrar la importancia y significado de la aplicación de los sitios de control permanentes con fines de monitoreo de la dinámica forestal en dos áreas naturales protegidas del Estado de Jalisco; México, tal es el caso de la Sierra La Primavera y el Volcán - Nevado de Colima, categorizadas como: "Zona de protección forestal y refugio de la fauna silvestre" y "Parque Nacional" respectivamente. En 1994 se establecieron los primeros sitios de control en el Campo Experimental Bosque Escuela de la Universidad de Guadalajara. Los sitios de muestreo forman parte del sistema de información geográfica forestal del Bosque-Escuela y son los primeros en su género en La Sierra La Primavera y en el parque nacional Volcán - Nevado de Colima.

Hasta la fecha, la tarea de los inventarios forestales se ha basado en el levantamiento del estado del bosque con fines de planeación del aprovechamiento. Pocas veces se toman consideraciones para la obtención de parámetros que permitan estimar la dinámica de la masa arbolada, como los incrementos anuales, los cuales son pieza fundamental para la planeación forestal e indicadores de cambios temporales de las condiciones ambientales en un rodal, los cuales también pueden estar sujetos a factores antropogénicos de gran presión como: el fuego, la erosión, el sobrepastoreo, la tala clandestina, la sobreexplotación y la contaminación de agua y aire. La estimación confiable de los aspectos ecosilvícolas y geomorfológicos de un ecosistema, información sociológica, riesgos y conflictos entorno a su medio natural en tiempo y espacio, permitirán una preparación y aplicación de acciones de manejo más eficientes, tendientes al desarrollo, protección y conservación de los recursos naturales. Para la estimación de cambios de estructura y composición de la vegetación, los sitios permanentes, permiten el control periódico del área de muestreo a través del tiempo y del espacio.

Según el Centro Mundial de Monitoreo para la Conservación, alrededor del 5% de la superficie terrestre

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Tabla 1.—Las áreas naturales protegidas de México.

Categoría	Número	%	Superfície (ha)	%
Reservas de la Biosfera	18	20.2	7,552,877	70.5
Reservas de la Biosfera especiales	13	15.5	491,336	4.6
Parques nacionales	44	49.4	688,103	6.4
Parques nacionales marinos	3	3.4	393,118	3.7
Monumentos Nacionales	3	3.4	13,023	0.1
Zonas de Protección de flora, fauna y agua	8	8.9	1,567,612	14.7
Total	89	100	10,706,069	100

mundial se encuentra bajo protección. En México el *Sistema Nacional de Areas Protegidas* (SINAP) define 89 áreas protegidas, las cuales cubren el 5% (10 millones de hectáreas) del territorio nacional (INE 1996). La tabla 1 muestra las categorías de las áreas protegidas en México.

En el Estado de Jalisco no existe un mecanismo establecido para poder evaluar la dinámica o los procesos de cambio de las áreas protegidas en particular, quizá debido a que no se cuenta con una red de monitoreo y evaluación; entendiéndose está como el procedimiento que vigila, mide y reporta en forma objetiva el grado de consecutividad de objetivos definidos. El monitoreo debe ser detallado y frecuente, pudiendo ser de manera: inicial, intermedia o continua, terminal, y/o posterminal. La evaluación de parámetros globales y específicos determinan e identifican problemas y limitaciones que dificulten el logro de metas planteadas para cada área en particular. Por lo anteriormente expuesto, en éste trabajo se presenta a manera de propuesta, establecer una red de sitios de control permanentes como una herramienta en el monitoreo y evaluación de las áreas protegidas del Estado de Jalisco. Se muestran dos ejemplos prácticos sobre la implantación de sitios de control, uno en el Campo Experimental Bosque - Escuela de la Universidad de Guadalajara, localizado en la Sierra La Primavera, y el otro en el Parque Nacional "Volcán-Nevado de Colima".

Diagnostico de Las Áreas Protegidas en el Estado de Jalisco

Actualmente se reconocen en el Estado de Jalisco 14 áreas protegidas y 17 propuestas. Las áreas establecidas cubren aproximadamente el 2.5% del territorio estatal y se encuentran decretadas bajo diferente categoría y manejo. El 64% de estas áreas se ubican en sistemas de montaña, el 34% restante corresponde a los sistemas costeros. Las áreas protegidas del Estado se localizan principalmente en la provincia fisiográfica del Eje Neovolcánico y la Sierra Madre del Sur (COESE 1993). Las áreas resguardan principalmente los ecosistemas de montaña, como los bosques de encino y pino, así como algunas porciones de vegetación tropical, como las selvas bajas y medianas; mientras que los ecosistemas costeros cubren en conjunto una longitud de aproximadamente 87 km. de playa.

En la tabla 2 se presenta un diagnostico de las áreas protegidas para el Estado de Jalisco de acuerdo a su sistema ecológico, categoría según la Secretaría del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP) y la Unión Internacional para la Conservación de la Naturaleza (UICN), responsable de su administración, extensión y fecha de decreto. La figura 1 presenta la localización de las áreas protegidas decretadas y en propuesta para el Estado de Jalisco.

Tabla 2.—Categorías y superficies de las áreas protegidas establecidas en el Estado de Jalisco, según el Gobierno del Estado de Jalisco (1993).

No.	Nombre	Categoría SEMARNAP*	Categoría IUCN *	Responsable	Area	Fecha de decreto
1	Volcán-Nevado	PN	II	SEMARNAP	10,153	05-sep-36
2	Sierra La Primavera	ZPF y RFS	IV	GOB/EDO/ UDG	30,500	06-mar-80
3	Sierra de Quila	ZPF y RFS	IV	SEMARNAP	15,192	04-ago-82
4	Sierra de Manantlán	RB	VI	SEMARNAP	139,577	23-mar-87
5	Cuixmala-Chamela	RB	VI	SEMARNAP	13,142	30-dic-93
6	Playa de Cuitzmala	ZR	IV	SEMARNAP	5.9 km/long.	29-oct-86
7	Playa de Mismaloya	ZR	IV	UDG/ SEMARNAP	69km/long	29-oct-86
8	Playa de Teopa	ZR	IV	SEMARNAP/ UDG	6km/long	28-jul-75
9	Playa El Tecuan	ZR	IV	SEMARNAP/ UDG	7 km/long	
10	Los Arcos	ZFF	II	MPIO. P. VALLARTA		
11	Parque Los Colomos	PU	IV	AYTO. ZAPOPAN	90	
12	Est. Biologica Chamela	EC	I	UNAM	1600	1971
13	Est. Cientifica Las Joyas	EC	I	UDG	1200	1985
14	Itzatan					

* ver anexo 1

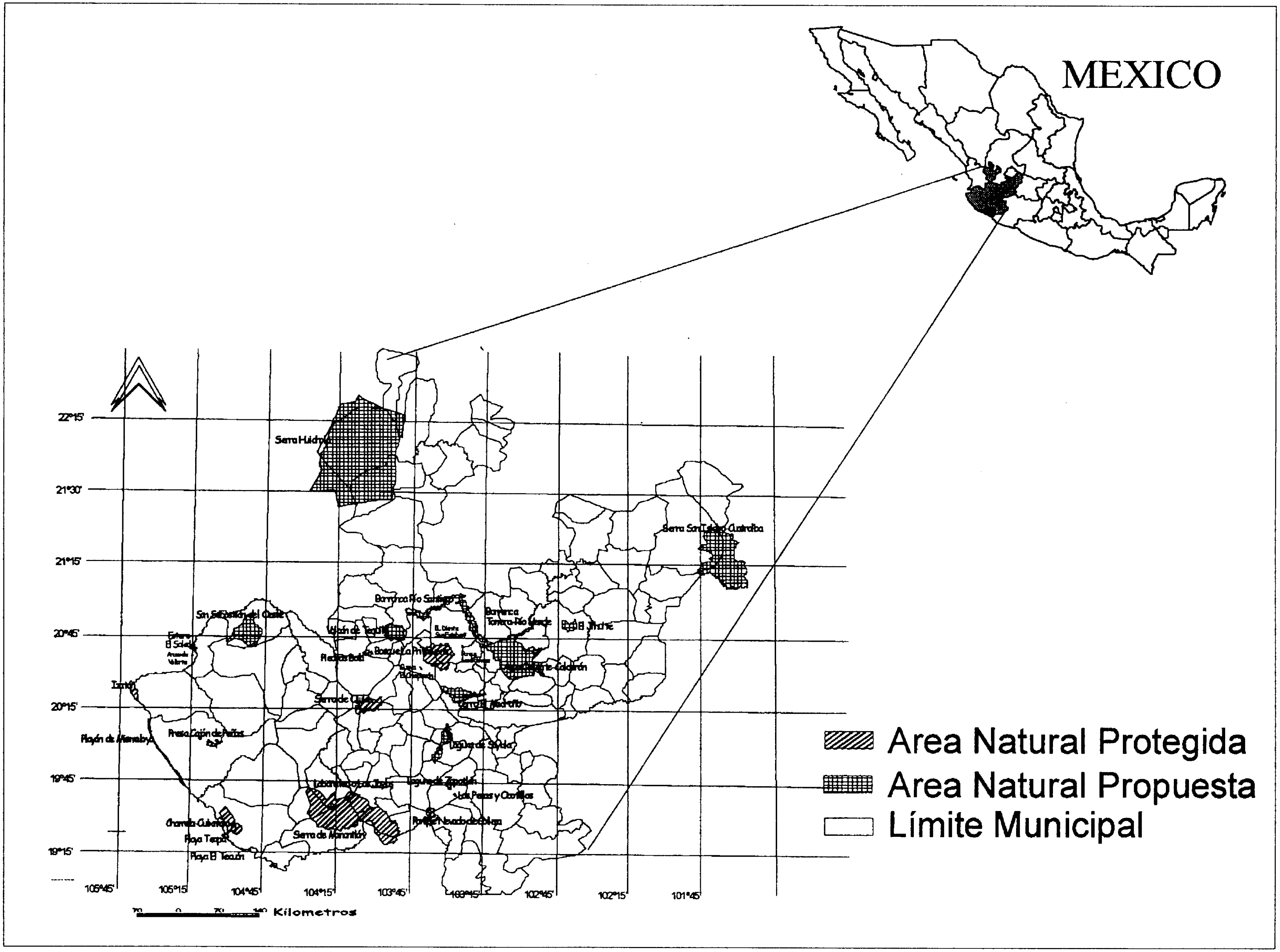


Figura 1.—Areas naturales protegidas y propuestas en el Estado de Jalisco.

Ubicación de Las Áreas de Estudio

Campo Experimental Bosque - Escuela en la Sierra La Primavera—El Campo Experimental Bosque - Escuela (CEBE) del Departamento de Madera, Celulosa y Papel de la Universidad de Guadalajara, se ubica en la parte suroeste de la Sierra, en la Provincia fisiográfica del Eje Neovolcánico (subprovincia Guadalajara) y comprende una superficie de 950 ha. Se localiza geográficamente, en las siguientes coordenadas; Latitud Norte 20° 34' 34" y 20° 36' 26" y Longitud Oeste 103° 37' 15" y 103° 40' 08".

Según la clasificación climática de Köppen, modificada por García (1973), reporta un clima A(C) (w_1) (w), que se interpreta como semicálido subhúmedo con lluvias en verano. La temperatura media anual es de 21°C, con una precipitación media anual de 960 mm (SARH 1986). Los suelos son en su mayoría del tipo regosol dístrico y luvisol albico (Damhs 1994). La vegetación dominante pertenece al bosque de encino pino, aunque también se encuentra vegetación del bosque subtropical caducifolio, vegetación secundaria, vegetación acuática y subacuática. La figura 2 muestra la ubicación del CEBE.

Parque Nacional Volcán - Nevado de Colima—El parque nacional "Volcán-Nevado de Colima" fue decretado en el año de 1936. Posteriormente en 1940, el decreto se modifica, teniendo como consecuencia la reducción de su superficie original. Actualmente se estima una superficie aproximada de 9600 ha (SARH 1993). El parque se encuentra ubicado dentro de la provincia fisiográfica del Eje Neovolcánico (Sub-provincia: Volcanes de Colima). El 83% de su superficie pertenece al Estado de Jalisco y el 17% restante al Estado de Colima. Los limites geográficos extremos son: 19° 28' 20" y 19° 36' 10" Latitud Norte y 103° 32' 27" y 103° 40' 00" Longitud Oeste (SEMARNAP 1996) (Figura 3.).

El rango de altura varían según el ultimo decreto, de 2200 hasta 3980 m en la parte sur y de 3350 hasta 4330 m en la parte norte del complejo volcánico. El período de lluvias es de mayo a octubre y el promedio de precipitación pluvial es de 1200 mm. Este edificio volcánico esta compuesto geológicamente de piedras magmaticas y estratos sedimentarios compuestos principalmente de piroxenos, hornablendas, andesitas y piedra pómez.

En la superficie del parque existen los siguientes tipos de suelo (clasificación de la FAO/UNESCO): Andosol humico, Andosol vitrico Cambisol eutrico y Regosol eutrico. Según la clasificación de clima de Köppen, modificada por García (1973), se presentan tres tipos de clima que varían en diferentes transectos altitudinales:

a) de 2000 a 2800 m C(w') (w) b (i') que significa clima templado subhúmedo con lluvias en verano, temperatura promedio anual de 12 a 18°C.

b) de 2800 a 4000 m predomina el clima C (w2) (w) b') (i') que se traduce en un clima semifrío con verano fresco y húmedo, lluvias en verano. La temperatura promedio anual es de 5 a 12°C.

c) de 4000 a 4330 m se presenta el clima E (T) H que significa un clima frío, con temperatura promedio anual de -2.5 a 5°C.

La comunidad arbórea presente en el complejo volcánico, varia en especies, densidad y distribución, encontrando mezclas de diferentes tipos de *Quercus spp.*, *Abies spp.* y *Pinus spp.*, entre otras hojosas. CIDASA (1989) clasificó la vegetación de ambos volcanes en cinco diferentes tipos, de acuerdo a la altura sobre el nivel del mar:

- 1000 hasta 2600 m : Bosque de pino y bosque mesófilo de montaña
- 1600 hasta 2100 m : Bosque de encino siempre verde
- 2500 hasta 3500 m : Bosque de oyamel (*Abies religiosa*)
- 3200 hasta 3800 m : Bosque de *Pinus hartwegii*, Paramo y Zacatonal

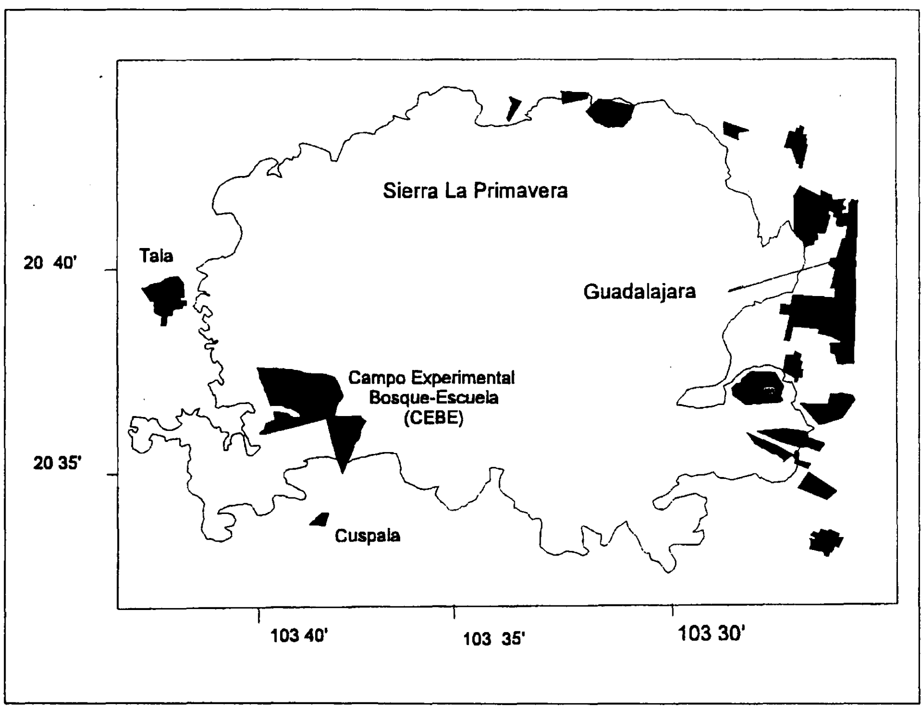


Figura 2.—Ubicación del Campo Experimental Bosque - Escuela.

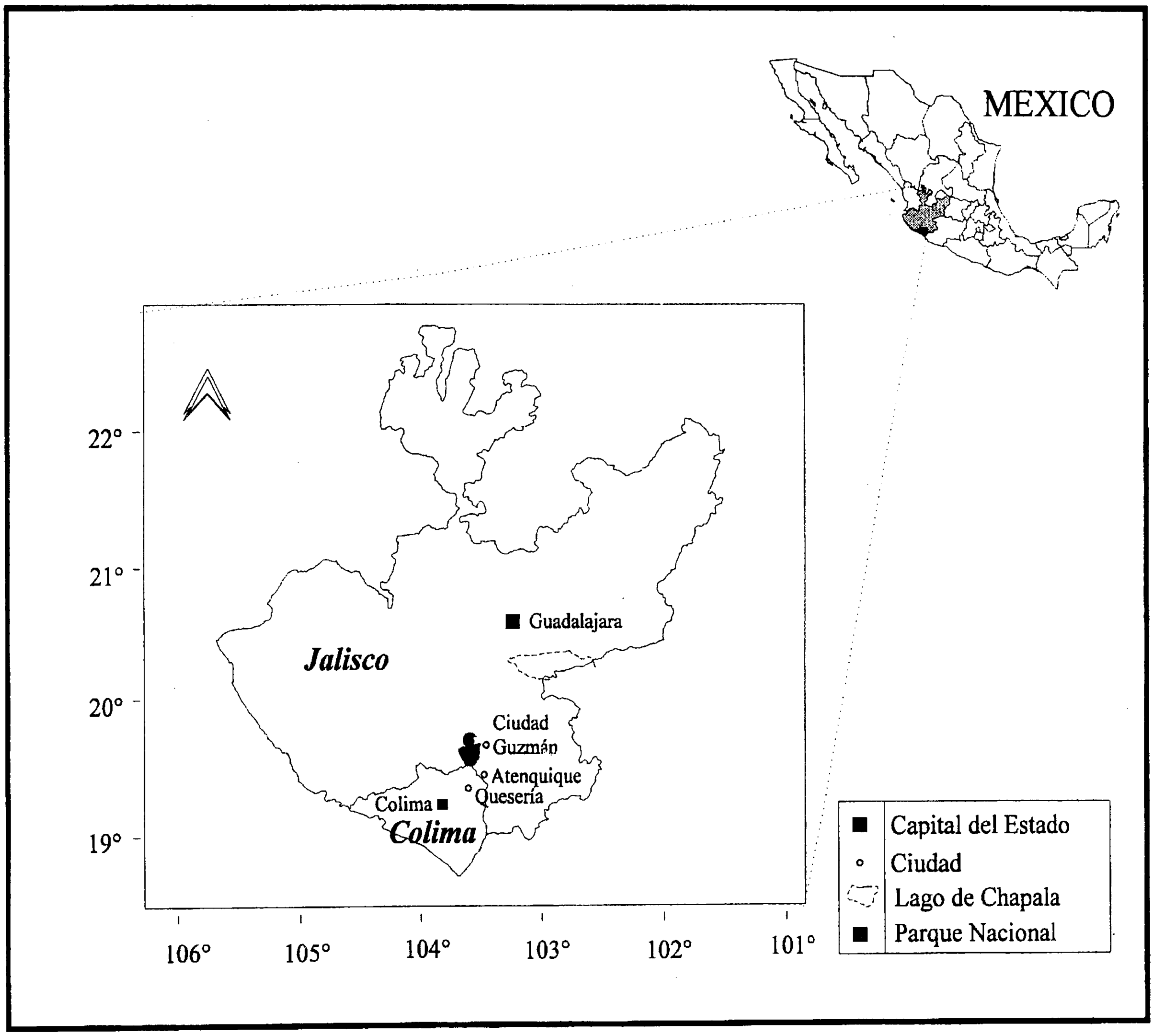


Figura 3.—Ubicación geográfica del parque nacional.

Metodología

La UICN (1993) determina que un programa de supervisión puede consistir en un número variable de tecnologías apropiadas para reunir información (por ejemplo, evaluaciones rápidas, encuestas extensivas o inventarios intensivos), pero debe incluirse un proceso básico de tres pasos:

a) reunir los datos biológicos y ambientales que permitan a los administradores predecir e identificar cambios,

b) definir, crear y poner a prueba modelos para comprender dichos cambios, y

c) crear una red global de supervisión que proporcione el modelo adecuado para detectar cambios de la biodiversidad.

De acuerdo a lo anterior, se considera que los sitios de control permanente reúnen los criterios que la UICN menciona. Los sitios de control son un método de inventario forestal desarrollado en Suiza en el año de 1965 (Schmid-Haas et. al. 1993). El principio de los sitios de muestreo es, que el centro del área de muestreo quede marcado de manera permanente, así como también cada uno de los árboles sea medido de manera individual, teniendo como referencia al punto central y su azimut respectivo, lo que permite con factibilidad proseguir su desarrollo (Schmid-Haas 1989). El área del sitio debe ser marcada de manera discreta, ser siempre los mismos y georeferenciar, de ser posible, su punto central.

En el caso de las áreas de estudio, la ubicación de los sitios de control se establecieron bajo los criterios antes mencionados, además se tomaron los siguientes parámetros, especies, diámetro a la altura del pecho (DAP), altura total, clasificación sociológica de los árboles, estado sanitario. Para el caso del CEBE se midieron árboles mayores o iguales a 10 cm de DAP, mientras que en el Parque Nacional, fue a partir de 7.5 cm. Para cada sitios del CEBE y el Parque Nacional, se realizaron ploters con ayuda del Programa TREES, realizado por Beisch (1996). El plot gráfico proporciona no solo la localización de los árboles dentro del circulo, sin la necesidad de medir nuevamente su azimut, sino también la localización del punto central del circulo de muestreo (Akça et. al. 1996). Con el objeto de monitorear la dinámica de los rodales, sé emplearon dos índices. El índice de diversidad de Shannon que es comúnmente utilizado para el análisis de ecosistemas alterados, el cual se calcula a partir del número de árboles por especie distribuidos regularmente en un rodal con la siguiente formula:

$H= \sum p_i \ln p_i$

Donde: H: índice de diversidad, p_i: posibilidad de conjunción de elementos, $\ln p_i$: logaritmo natural de p_i. Por lo tanto, a mayor valor del índice de Shannon mayor diversidad.

El índice importancia ecológica (IVI) de Curtis y Mcintosh (1951) (tomado de Lamprecht 1986), que se obtiene del producto de la suma de valores relativos de la abundancia, la dominancia y la frecuencia de una especie, su resultado es utilizado para determinar el peso ecológico de las especies, así como para analizar la distribución horizontal de las mismas. Cabe señalar, que este trabajo es el inicio de un proyecto de mayor magnitud que posteriormente se le integrara otros criterios o parámetros de importancia para el monitoreo. La información se integrará a un Sistema de Información Geográfica de las Areas Naturales Protegidas (SIGANAP) del Estado de Jalisco, que en la actualidad está desarrollando la Academia Forestal del Departamento de Madera, Celulosa y Papel y el Departamento de Producción Forestal de la Universidad de Guadalajara.

Establecimiento de sitios de control en el Campo Experimental Bosque - Escuela—Los sitios de control permanentes del CEBE se establecieron tomando como base 450 sitios del inventario forestal, que con fines de planeación se ubicaron durante el período 1990-1992. De acuerdo a un análisis estadístico de éstos, se determinó un tamaño de muestra significativa de 112 sitios. Los criterios que se tomaron para la ubicación de los sitios de control, consideran las 7 calidades de suelos presentes en el CEBE, así como también la accesibilidad. Hasta la fecha se han establecido 70, es decir, 10 sitios por cada calidad del suelo. Los sitios constan de tres compartimentos, 1000, 400 y 80 m_. La posición del punto central de los sitios, se realizó, en su mayoría por medio de fotointerpretación (fotografías aéreas de escala 1:10,000) y con un posicionador geográfico (GPS).

Establecimiento de Sitios en el Parque "Volcán - Nevado de Colima"—Debido a la abrupta topografía y la orientación norte-sur del complejo volcánico, se establecieron dos bloques de muestreo de aprox. 150 ha en los flancos este y oeste, los cuales fueron numerados de la siguiente manera, para la exposición Este: Bloques 1 (Nevado) y 2 (Volcán); para la exposición Oeste: Bloques 3 (Nevado) y 4 (Volcán). Dentro de cada bloque se estableció una red de 12 sitios de control permanente con distancias de 500 m. La localización del primer punto central de cada sitio para cada uno de los bloques, se ubicó al azar, después fueron calculadas las coordenadas de los siguientes punto centrales del resto de los sitios y se almacenaron en un aparato GPS navegador. Con la ayuda de la función de navegación del aparato y la señal satelital fueron ubicados los sitios. El tamaño del círculo de muestreo es de 0.05 ha y se encuentran distribuidos sistemáticamente dentro de cada bloque. Al igual que en el CEBE, se obtuvieron plots para cada sitio ubicado (figura 4).

Resultados

Camp Experimental Bosque - Escuela

Sitios de control—De los 70 sitios establecidos, se realizó una carta temática con la ubicación de estos (figura 5). Esta carta es parte del Sistema de Información Geográfica Forestal (SIGFO), que es la base de datos e información digital del plan de manejo sustentable forestal del CEBE. La experiencia de la aplicación de estos sitios de control, ayudará a integrar un plan piloto de monitoreo para el resto de las áreas protegidas del Estado.

Indicadores de la dinámica—Según el índice de importancia (IVI) para los individuos del compartimiento A (mayores a 10 cm de DAP), se observa que los pinos presentan una alta dominancia en las calidades de suelos secos, mientras que en los suelos semisecos a húmedo, los encinos registran el mayor valor. Este estrato arbóreo aun mantiene especies típicas de un bosque templado. Sin embargo, se observa que los pinos están siendo desplazados paulatinamente por los encinos. El índice de Shannon reportó su mayor valor de diversidad en la calidad de suelo media y húmeda y el menor valor en la calidad pobre y semihúmeda (Tabla 3). En las áreas con calidad de suelo media húmeda, que son las mejores del CEBE, reportan el valor más alto de diversidad, debido a que estas áreas fueron sobrepastoreadas, principalmente. Estos resultados serán utilizados como indicadores para la observación de cambios en la vegetación en posteriores remediciones.

Parque Nacional Volcan-Nevado de Colima

Sitios de control—En el Parque nacional se establecieron 40 sitios permanentes, distribuidos en 4 Bloques, los cuales se encuentran en las vertientes este y oeste de ambos volcanes en un rango entre 2595 y 3895 m (figura 6).

Indicadores de la dinámica—El IVI calculado para cada especie por bloque en diferente exposición muestra que *Pinus hartwegii* presenta un valor mayor en la vertiente Oeste, mientras que en la vertiente Este, *Abies religiosa,* tiene un mayor peso ecológico (Tabla 4). La figura 7 muestra la comparación de la dominancia relativa arbórea, donde la especie *Pinus hartwegii* tiene una amplia dominancia en la exposición Oeste, esta dominancia corrobora el IVI obtenido (300) para esta especie. En cuanto al índice de diversidad, se presenta un contraste significativo entre la vertiente Oeste del nevado y vertiente Este del volcán, donde los valores de diversidad oscilan entre 0 y 1.79

Conclusiones

Para el establecimiento de una red de monitoreo de las áreas protegidas se recomienda tomar la metodología de los sitios de control permanentes, ya que son una herramienta de gran ayuda para evaluar y dar seguimiento al estado de las masas arboladas a través del espacio y el tiempo. La aplicaciones de los índices de Shannon y de valor de importancia ecológica (IVI) en combinación con datos

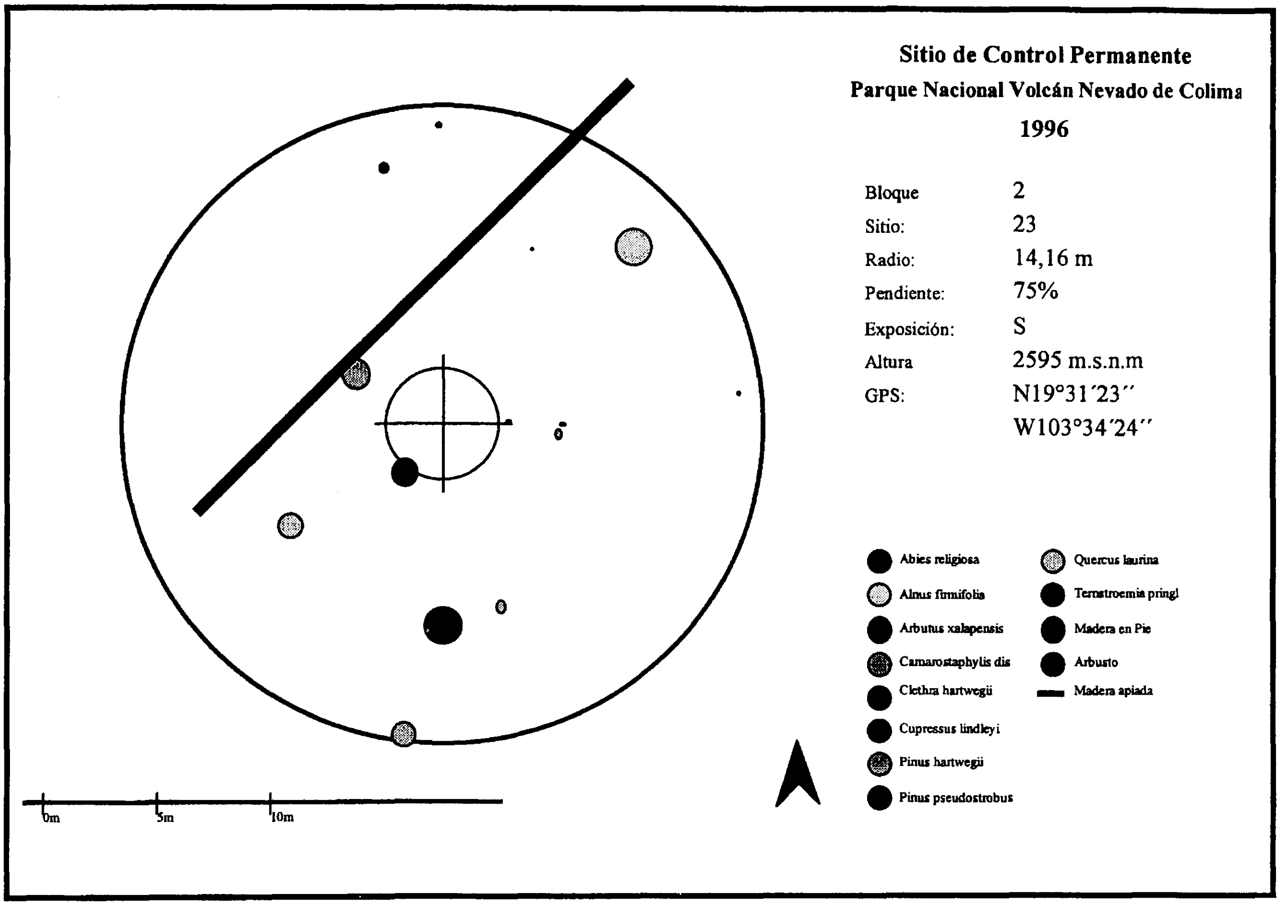


Figura 4.—Presentación gráfica de un plot.

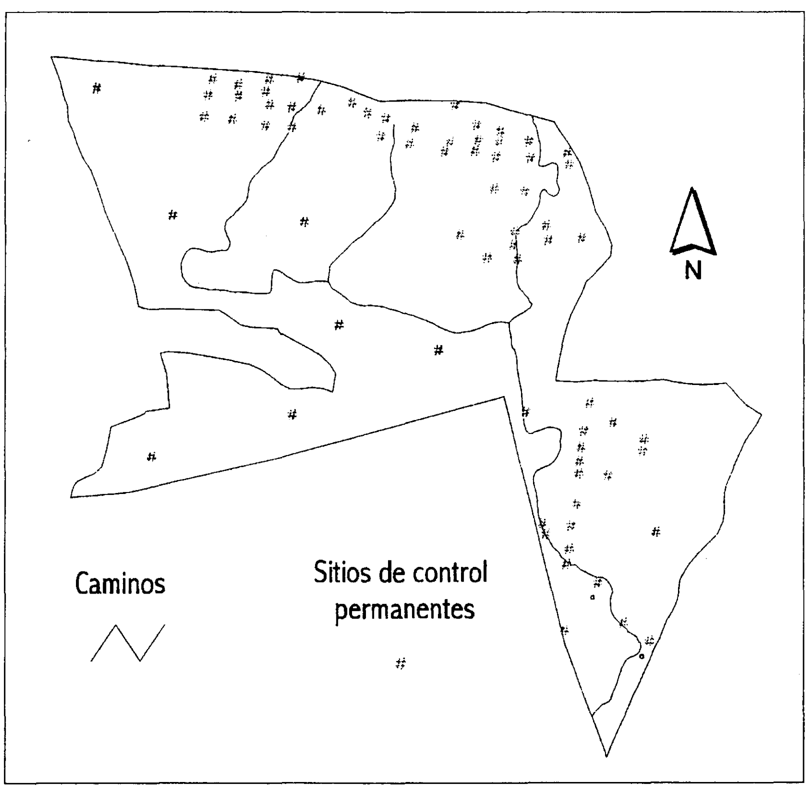


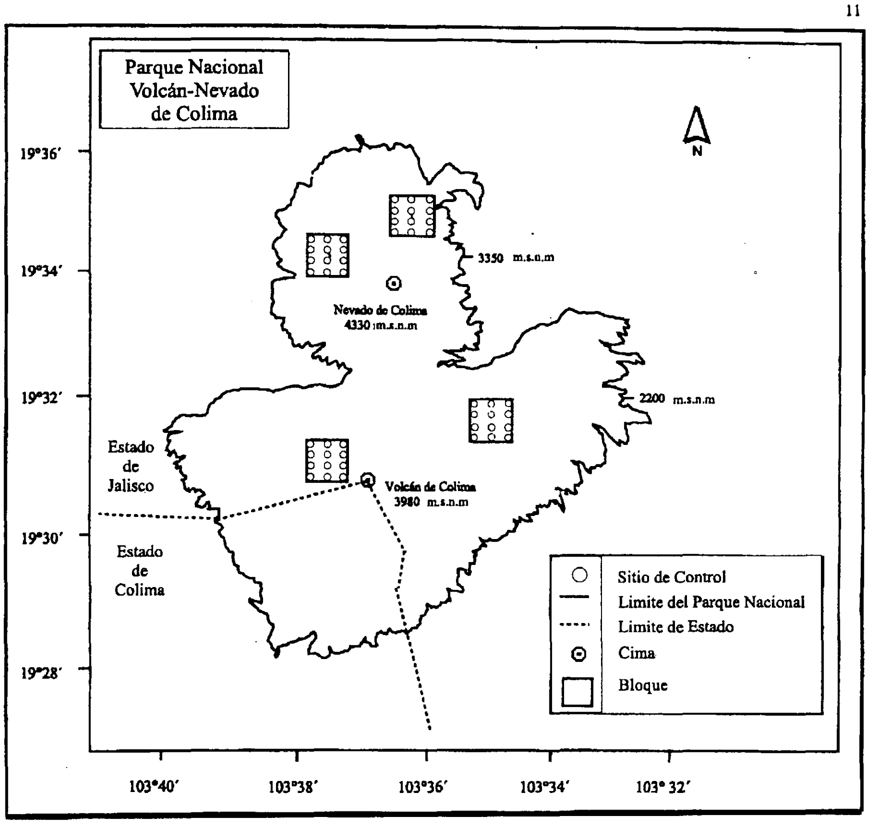
Figura 5.—Carta de los sitios de control permanentes del Campo Experimental Bosque - Escuela

Tabla 3

Cal. Suelo	1;1		1;2		1;3		1;4		2;3		2;4		2;5	
N/ha	74		103		157		231		139		223		192	
m²/ha	3.0		4.7		7.5		10.5		7.6		9.0		11.0	
I. Shannon	1.62		1.63		1.15		0.67		1.53		1.61		1.89	
Orden	**Especies**	**IVI**	**Especies**	**IVI**	**Especies**	**IVI**	**Especies**	**IVI**	**Especies**	**IVI**	**Especies**	**IVI**	**Especies**	**IVI**
1	*P. oocarpa*	119	*P. oocarpa*	130	*Q. resinosa*	166	*Q. resinosa*	185	*Q. resinosa*	131	*Q. resinosa*	130.5	*Q. resinosa*	105
2	*Q. resinosa*	48	*Q. resinosa*	82	*P. oocarpa*	77	*P. oocarpa*	89	*P. oocarpa*	75	*P. oocarpa*	62.5	*P. oocarpa*	46
3	*Q. viminea*	40	*C. rosei*	22	*C. rosei*	26	*C. rosei*	26	*C. rosei*	26	*C. rosei*	27.7	*A. pennatula*	26
4	*L. acapulcen*	38	*L. Acapulcen*	22	*A. pennatula*	8			*A. pennatula*	21	*A. maxicana*	18.7	*C. rosei*	20
5	*C. rosei*	35	*Q. viminea*	12	*Q. magnoli*	6			*Q. viminea*	14	*Q. castanea*	15.5	*Q. laeta*	20
6	*A. pennatula*	13	*A. pennatula*	9	*A. mexicana*	5			*A. mexicana*	13	*A. pennatula*	14.2	*Q. magnoli*	17
7	*G. ulmifolia*	8	*Q. magnoli*	5	*Q. laeta*	5			*Q. magnoli*	6	*Q. viminea*	12.3	*P. ferruginea*	17
8			*Bursera sp.*	3	*L. acapulcen*	3			*L. acapulcen*	5	*Q. laetea*	7.2	*G. ulmifolia*	15
9			*Q. laeta*	3	*P. ferruginea*	2			*P. devoniana*	4	*Q. magnoli*	3.9	*Q. castanea*	10
10			*P. devoniana*	3	*Q. praineana*	1			*F. goldmanii*	2	*L. acapulcen*	3.0	*A. mexicana*	7
11			*G. ulmifolia*	3					*F. petiolaris*	2	*Ficus sp.*	2.0	*L. acapulcen*	6
12			*A. mexicana*	2					*Q. castanea*	1	*P. devoniana*	0.9	*A. farnesiana*	3
13			*F. petiolaris*	1					*Q. laeta*	1	*F. goldmanii*	0.8	*Ficus sp.*	3
14			*A. farneciana*	1					*Phoebe phsy.*	0	*P. ferruginea*	0.5	*Phoebe phsy.*	3
15			*P. ferruginea*	1							*F. petiolaris*	0.4	*D. regia*	2

Significado de las calidades del Suelo:

1;1 Pobre muy seco. 1;2 Pobre seco. 1;3 Pobre semiseco. 1;3 Pobre semihúmedo. 2;3 Medio semiseco. 2:4 Medio semihúmedo y 2;5 Medio húmedo



Bloques y sitios de control dentro del Parque Nacional

Figura 6.—Bloques y sitios de control dentro del Parque Nacional

Tabla 4.—Indicadores de dinámica en el Parque Nacional

Exposición	**Este (Nevado)**		**Oeste (Nevado)**		**Este (Volcán)**		**Oeste (Volcán)**	
N/ha	235		205		225		200	
m²/ha	29.2		18.8		37.3		14.4	
Indice de Shannon	0.94		0		1.79		0.52	
Ord.	**Especie**	**IVI**	**Especie**	**IVI**	**Especie**	**IVI**	**Especie**	**IVI**
1	*A. religiosa*	132	*P. hartwegii*	300	*A. religiosa*	101	*P. hartwegii*	240
2	*P. hartwegii*	124			*Q. laurina*	74	*A. religiosa*	45
3	*Q. laurina*	34			*P. pseudostrobus*	42	*C. lindleyi*	5
4	*C. lindleyi*	10			*C. hartwegii*	23		
5					*C. discolor*	15		
6					*A. xalapensis*	11		
7					*T. pringlei*	12		
8					*A. firmifolia*	15		
9					*Rubeaceae*	7		
Total		**300**		**300**		**300**		**300**

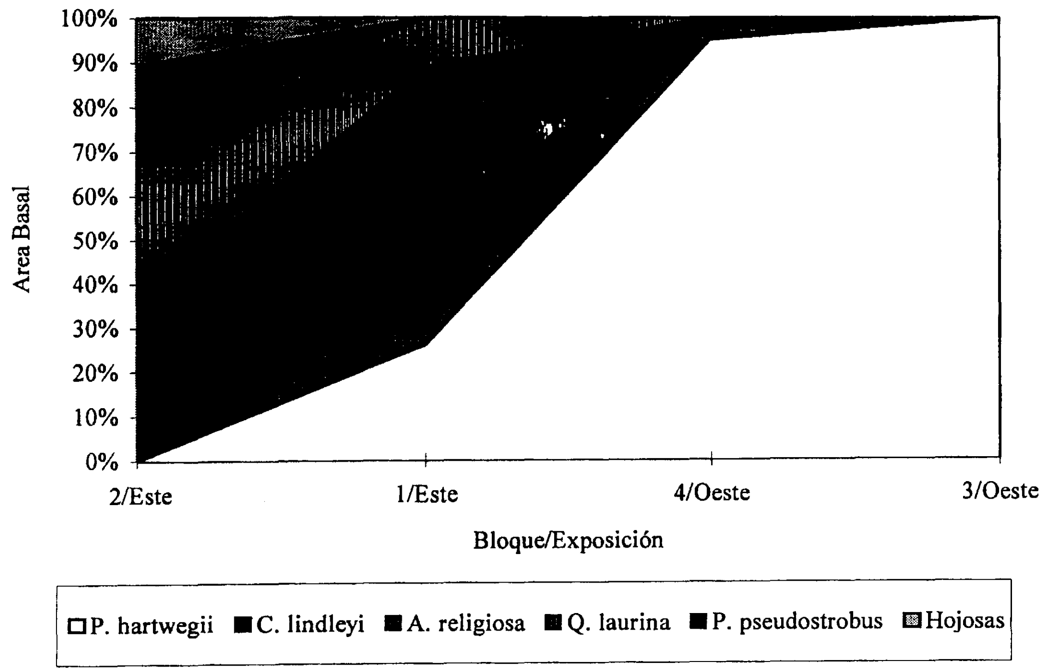


Figura 7.—Dominancia relativa de las especie del Parque Nacional

dasonómicos son indicadores de los cambios positivos o negativos muy valiosos para evaluar la dinámica de recursos.

La Sierra La Primavera y el Parque Nacional, al igual que otras áreas protegidas del país se encuentran en un proceso de degradación, causado principalmente por factores antropogénicos como la sobreexplotación de los recursos naturales. En general existe una falta de planificación, operación y manejo, aunada a una falta de recursos económicos, humanos, infraestructura y de equipo, además es notable la falta de participación de la comunidad en el establecimiento y manejo de estos sistemas, los programas de específicos han sido escasos o nulos y los pocos trabajos se concretan a ser estudios de investigación básica, por lo tanto el manejo es generalmente intuitivo, en lugar de estar basados en un sistema de monitoreo y evaluación acorde a las necesidades de cada área en particular. Es importante señalar, que uno de los problemas más fuertes dentro de las áreas protegidas es la tenencia de la tierra, además la mayoría no están bien demarcadas en el campo y esto ocasiona muchas disputas legales y complica cualquier intento en poner en practica un esquema de manejo. La tabla 5 presenta algunas problemáticas observadas en las áreas protegidas del Estado de Jalisco.

Donde: 1 = Parque Nacional Nevado de Colima, 2= Reserva de la Biosfera de Manantlán, 3= Reserva de la Biosfera Chamela, 4= Zona de protección forestal y refugio de la fauna silvestre, (Sierra La Primavera), 5= Zona de protección forestal y faunica (Sierra de Quila), 6= Zona de protección de arribazón de tortuga marina.

Por lo tanto, el empleo de nuevos conceptos científicos de investigación, recreación, protección al medio ambiente y sustentabilidad de los recursos naturales deben en el futuro ser prioritarios, de esta manera la realización de medidas de protección, desarrollo planeación forestal y ecológica se efectuaran de una manera más eficiente.

Tabla 5.—Problemáticas que presentan las áreas protegidas del Estado de Jalisco.

	Areas protegidas					
Principales problemas	1	2	3	4	5	6
Sin plan de manejo	X		X		X	X
Acciones antropogénicas:						
Sobreexplotación, sobre-pastoreo, casería furtiva, etc.	X	X	X	X	X	
Incendios	X	X	X	X	X	X
Degradación de ecosistemas	X	X	X	X	X	X
Sin señalamientos	X	X		X	X	X
Tenencia de la tierra	X	X		X	X	

Literatura

Abreviaciones:

CIDASA	: Compañía Industrial de Atenquique, S.A.
INE	: Instituto Nacional de Ecológia
IUCN	: Union Mundial para la Naturaleza
LEGEEPA.	: Ley general de equilibrio ecológico y la protección al ambiente
SAG.	: Secretaría de Agricultura y Ganadería
SARH.	: Secretaría de Agricultura y Recursos Hidráulicos
SEMARNAP.	: Secretaría de Medio Ambiente, Recursos Naturales y Pesca
SFF.	: Subsecretaría Forestal y de la Fauna Silvestre

Akça, A., 1993: Zur Methodik und Bedeutung der kontinuierlichen Forstinventuren. Revista Allgemeine Forst- und Jagdzeitung, 1993. Alemania., pp. 193-198

Akça, A.; Beisch, T.; Terwey, F. & Rümbler, R., 1996: Zur Planung und Kontrolle in einem Beispielbetrieb für naturnahe Forstwirtschaft in Nordrhein-Westfalen mit Hilfe von permanenten Probeflächen. Revista Allg. Forst- u. Jagdztg, 167 (1-2). Alemania.

Beisch T., 1996: Trees Programm. Universidad de Goettingen, Alemania.

CIDASA., 1989: Plan de manejo integral forestal de la región de Atenquique 1989-2038. Estudios Básicos I, A1, A2. México.

Dahms F. 1994: Estudio ecopedológico del Bosque-Escuela de la Universidad de Guadalajara. Tesis de diplomado, Universidad de Goettingen, Alemania.

García E. 1973: Modificación al sistema de clasificación climatica de Koeppen. UNAM, México. D.F.

Gobierno del Estado de Jalisco, 1993: Informe sobre las Areas Naturales Protegidas en el Estado de Jalisco, para la Unión Internacional de la Conservación de la Naturaleza (IUCN). Comisión Estatal de Ecología. México.

INE., 1996: Programa del Medio Ambiente 1995-200. SEMARNAP, México.

IUCN., 1993: Parques y progreso. Ed. IUCN publications service. unit.

IUCN., 1994: Richtlinien für Management-Kategorien von Schutzgebieten. Deutsche Übersetzung von Fönad, Grafenau.

Lamprecht H., 1986. Silvicultura en los Trópicos. Ed. Parey. Alemania.

LEGEEPA., 1997: Ley general de equilibrio ecológico y protección al ambiente. Delitos ambientales. SEMARNAP. México.

SARH 1986: Estudio agrológico del Bosque-Escuela de la Universidad de Guadalajara. Reporte técnico.

SARH 1993: Diagnóstico del Parque Nacional "El Nevado de Colima, Jal.". SFF. México.

SARH 1994: Inventario Forestal Periódico del Estado de Jalisco. SFF. México.

SEMARNAP 1995: Programa de áreas naturales protegidas de México 1995-2000. México.

SEMARNAP 1996: Los Parques Nacionales de México. Instituto Nacional de Ecológia, Departamento de Parques Nacionales. México.

Schmid-Haas, P.; Baumann, E.; Werner, J., 1993: Kontrollstichproben: Aufnahmeeinstruktion, 3. überarbeitete Auflage. Berichte EAFV, Viena, Austria (186), pp. 5-11

Villavicencio, G. R., 1998: Waldmeßkundliche Aufnahme in den wichtigsten Waldtypen des Nationalparks "Volcán Nevado de Colima" im Westwn Mexikos mit Hilfe von permanenten Probekreisen. Tesis de Maestría, Universidad de Göttingen, Alemania.

Wolff, B., 1992: Betriebs- und bestandesweise Holzvorratinventur auf der Basis von permanenten terrestrischen und Luftbild-Stichproben. Tesis Doctoral, Universidad de Göttingen, Alemania.

Anexos

Anexo 1

Categoría UICN	Decreto Oficial	LEGEEPA,1988
I Reservas científicas/Reservas Naturales Estrictas	Estación de Biología (EB) Estación Científica (EC) Reserva Ecológica (RE)	Reserva Ecológica
II Parques Nacionales Parques Estatales	Parque Nacional (PN) Parque Nacional Marino (PNM) Parque Estatal (PE)	Parque Nacional
III Monumentos Naturales	Monumentos Nacional (MN)	Monumentos Nacional
IV Santuarios o Refugios de vida silvestre/ Reservas Naturales Manejadas/Reserva de Recursos	Zona de Protección Forestal (ZPF) Refugio de Fauna Silvestre (RFS) Reserva Natural (RN) Biotopo Natural y Típico (BNT) Reserva y Sitios de Refugio de Tortugas Marinas (RSTM)	Parque Marino Nacional Areas de Protección de Recursos Naturales Area de Protección de Flora y Fauna
V Areas Recreativas/ Culturales	Parque Educativo (PED) Parque Natural Históricc (PNH) Centro de Interpretación de la Naturaleza(CIN)	Parque Urbano Zona sujetas a conservación ecológica
VI Reservas de la Biosfera	Reservas de la Biosfera (RB)	Reservas de la Biosfera Reserva Especial de la Biósfera

Industry Perspectives on Implementing and Analyzing an Annual Forest Inventory[1]

Paul C. Van Deusen[2]

Abstract—The USDA Forest Service is moving from a periodic forest inventory to an annual system. The change to an annual system will provide challenges both statistically and logistically. This change has been generally well received by U.S. forest industry for a number of reasons. Periodic inventories served us well in the past, but have failed to keep up with modern information needs. The focus here is on discussing some of the statistical challenges and demonstrating that they can be met with current technology. The conclusion is that annual forest inventory systems make sense in the modern era where current information is essential for meeting regulatory requirements, ensuring sustainability, and providing products from our forests.

The USDA Forest Service Forest Inventory and Analysis Program (FIA) is the only source of reliable, national scope information on U.S. forest resources. Historically, FIA has conducted periodic inventories within States on a 10-15 year cycle. In recent years, this cycle has tended to lengthen due to flat budgets and requirements to measure new variables. In the South, pine fiber rotations are shrinking below 20 years, so the periodic inventory is approaching being out of date by a full rotation. While industry inventories its own land, the majority of the fiber supply for most mills does not come from company owned lands. Concern about FIA was formally expressed in 2 Blue Ribbon Panel (BRP) reports written by forestry experts from industry, academia, government and environmental organizations. Among other things, the first report (BRP I) in 1992 called for a decrease in the FIA survey cycle to 5 years. Some short-lived progress was made in this direction, but FIA cycles were of unprecedented length 5 years after BRP I. A second report (BRP II) came out in 1998 including statements such as "the lack of major improvement in FIA is leading to the loss of important ecologic and economic benefits to society by hindering our ability to monitor forest health and sustainability." BRP II called for initiating an annual inventory system where a proportion of plots would be measured every year in every State. Following BRP II, the Research Title of the 1998 Farm Bill mandated that FIA move to an annual system where 20% of the FIA plots are measured annually in each State.

The move to an annual system is a momentous event for FIA that rivals any other change since FIA's inception. Such a change entails risk, but, from forest industries view, the change is needed. There are several reasons why an annual system makes good sense. 1) Politically, annual systems will allow FIA to maintain their contacts within a State, which is hard to do with the 10 year hiatus that currently exists. 2) Budgetarily, regular annual budgets will enable greater participation by the States, i.e. it's difficult to generate a budget at irregular intervals. 3) Informationally, the annual system will provide current data that meshes seamlessly across States, which is not a characteristic of the current system.

The value of current information will be the focus of the remainder of this paper, since that is what motivates industry to support an annual system. Some comparisons will be made between capabilities afforded by annual versus periodic systems to: 1) provide estimates of means, 2) provide estimates of change, 3) detect trend changes, and 4) incorporate remote sensing technology.

Mean Estimates

Periodic surveys measure all N plots in a short amount of time, ideally over 1 year. An annual inventory taking a 20% sample measures N/5 plots each year. Therefore, a naive analysis would suggest that confidence intervals for the annual inventory estimate are $\sqrt{5}$ times larger than for the periodic estimate. This result assumes that only the current year's 20% sample is used to compute the desired mean. This is an unfair comparison since periodic surveys of a State often take 2 or 3 years to complete and estimates are then based on averaging all plots together. Following this same approach, annual inventories can use moving average estimators over the current and previous 4 years to derive estimates that will have confidence intervals nearly as narrow as from the periodic survey. An important caveat is that the periodic survey only provides an estimate roughly every 10 years leaving the user to interpolate for intermediate years with unknown confidence.

Forests grow slowly, and previous year data contain nearly as much information about current forest characteristics as current year data, unless a major disturbance has occurred. Likewise, data from several years earlier still contain valuable information. A well constructed moving average estimator can down-weight the earlier years to take advantage of this information. Moving average estimators can be constructed in a number of ways. For example, Van Deusen (1998) demonstrates how to use a mixed estimator, which is closely related to the Kalman filter.

There are other approaches to analyzing annual data that can improve upon the naive approach as well. For example, unmeasured plots could have their current values imputed or modeled, and these imputed values could be incorporated

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into the estimate. With very accurate imputation, the results of this approach could allow one to obtain results that are nearly as good as if all plots were measured annually. Statistical methods for dealing with imputed or modeled values include multiple imputation and double sampling (Fairweather and Turner 1983, Rubin 1987, Hansen 1990, Van Deusen 1997, Reams and Van Deusen 1998).

Change Estimates

Change estimates from periodic surveys indicate the difference between current values and those of 10 years earlier. The disadvantage here is that there is no way to know if the change occurred smoothly throughout the period or in some irregular manner. Annual inventories allow for annual change estimates, which supports a more sensitive ability to monitor trend. This is generally a positive attribute, but could lead one to react prematurely to temporary trends or artifacts of sampling error.

In spite of the danger of premature reaction, changes in trend should be detectable sooner with an annual inventory than with a periodic system. Trend monitoring will be facilitated by an annual system because the development of a trend can be followed from one year to the next. However, there is currently a need for research in this area. Statistical methods need to be proposed for testing the null hypothesis of no-trend versus the alternative of increasing or decreasing trend. Studies are needed to determine the impact of changing cycle length, i.e. measuring a different proportion of plots each year, on the power of these tests. This will be important to weed out the irrelevant blips that will inevitably occur if simple annual means are plotted. In fact, it would be very surprising if raw sample means from an annual inventory produced a smooth trend.

Remote Sensing

Traditionally, the FIA program has produced area estimates of forest and non-forest using double sampling. The process consists of interpreting a large number of sample points on aerial photographs and subsampling a proportion of the points on the ground. Complete forest type maps would be difficult to produce from photography due to the tremendous amount of manual interpretation required. The annual system's requirements for regular generation of land-use and land-cover maps would be prohibitively expensive with aerial photography. Satellite based imagery provides the basic data needed to classify cover-types of large areas in an automated, cost effective and timely manner. The three most readily available (at this time) satellite sensors are the thematic mapper (TM), SPOT, and AVHRR. Presently, TM data is preferred because TM has greater spectral resolution than SPOT, and better spectral and spatial resolution than AVHRR.

To estimate map class area totals and variances FIA may be able to use two-phase or double sampling where the less accurate data is the map whose accuracy is in question, and the more accurate but costly data is the FIA ground sample. A sampling scheme designed to evaluate and correct for map area misclassification is as follows: A sample of n points/pixels is located on the map and the true and map categories are determined for each point. The n points are allocated as a simple random sample. This results in a two way contingency table where n_{ij} is the number of points in the sample whose true category is "i" and whose map category is "j". Formulas for estimating the true probabilities of interest are given in Card (1982) along with variance estimates. Methods for estimating change in category proportions between two times are given in Van Deusen (1994) along with variance formulas. Coincidentally, the estimators for the true map proportions are the same for simple random sampling (srs) or stratified sampling of map pixels. However, variance estimators are different under the two sampling strategies.

Judicious use of remote sensing can provide benefits to the annual system beyond the ability to produce complete cover maps. Efforts to model unmeasured plots will be aided if the disturbance status of the plot is known. The USDA Forest Service's North Central region is already conducting research on disturbance detection. Likewise, better modeling capability would allow for reducing the number of ground samples while maintaining estimate precision.

Discussion

Changing from a periodic inventory to an annual system involves some risk. However, annual inventories have been under study by the North Central FIA since 1992 and in the South since 1995. The North Central annual inventory system (AFIS) was based on measuring disturbed plots with a higher probability than undisturbed plots. The southern system (SAFIS) was based on measuring an equal proportion annually with systematic coverage. The AFIS design may have some advantage from an efficiency perspective, but it is more difficult to statistically analyze. The SAFIS design was selected because of its simplicity and robustness. This reduces the risk. The 1998 Farm Bill called for implementing a SAFIS-like design for this reason.

An inventory based on regular annual samples differs from the periodic survey primarily in the timing of plot visits. The same plots are used and the same measurements are made under both systems. Therefore, the biggest uncertainty lies in logistical issues. If the logistical problems can be solved then the annual inventory will succeed. Experience so far in States like Minnesota, Virginia and Georgia indicates that the new system will be a success.

Even though logistics will create the initial hurdles, research on statistical analysis and remote sensing will be required to get the most out the annual data. Initial procedures to analyze the data and to implement remote sensing should be ready when enough data to begin assessing trends are available. The annual systematic design lends itself to several analysis options and to remote sensing methodologies as well. The robust design will allow for adaptive improvement of the analysis techniques as experience with the system is gained.

I see little downside to an annual inventory system relative to the periodic system. It has already been demonstrated in several States that the data can be efficiently collected. However, the selection of an analysis method has not been finalized. Confidence interval width will depend on the analysis method used, so it may be some time before a comparison with the periodic system is complete. This comparison is also complicated by the fact that there is no estimate or confidence interval for intermediate years for a periodic inventory.

The data collected under an annual inventory system are identical to what was collected under a periodic system, unless changes are made for unrelated reasons. Therefore, database management will be quite similar except for the fact that annual data will be continuously arriving. Users will want data access more frequently because hard copy reports will not be released annually. Industrial users, in particular, will want to access the data and perform custom analyses on a regular basis. It would be ideal if software were available on the internet to both access and analyze these data. In fact, FIA has already made progress in this direction and should be congratulated, but more is needed.

Industrial users view FIA as providing the only data that are broad in scope and focused on the forest resource. FIA data are critical to assuring long term forest sustainability in which forest industry has a vested interest. The data that it will produce are so important that failure of the annual system is not an option.

Literature Cited

Card, D.H. 1982. Using known map category marginal frequencies to improve estimates of thematic map accuracy. Photogrammetric Engineering and Remote Sensing. 48(3):431-439.

Fairweather, S.E. and B.J. Turner. 1983. The use of simulated remeasurements in double sampling for successive forest inventory. In Proceedings, Renewable Resource Inventories for Monitoring Changes and Trends. August 15-19, 1983, Corvallis, Oregon. John F. Bell and Toby Atterbury, editors. Pg. 609-612.

Hansen, M.H. 1990. A comprehensive sampling system for forest inventory based on an individual tree growth model. PhD dissertation. Univ. of Minnesota. St. Paul, Minn.

Reams, G.A. and P.C. Van Deusen. The Southern annual forest inventory system. IN PRESS. Journal of Ag. Biol & Env. Stat. Special issue: Environmental Monitoring Survey Over Time.

Rubin, D.B. 1987. Multiple Imputation for Nonresponse in Surveys. Wiley.

Van Deusen, P.C. 1994. Correcting bias in change estimates from thematic maps. Remote Sens. Environ. 50:67-73.

Van Deusen, P.C. 1997. Annual forest inventory statistical concepts with emphasis on multiple imputation. Canadian Journal Forest Research 27:379-384.

Van Deusen, P.C. 1998. Alternative sampling designs and estimators for annual surveys. IN: Proceedings of International Conference on the Inventory and Monitoring of Forested Ecosystems. Boise, ID. August 1998. Eds. M. Hansen and S. Fairweather. USDA Forest Service General Tech. Report.

Reporting on the State of Ecosystems: Experiences with Integrating Monitoring and SOE Activities in Canada and North America[1]

Ed B. Wiken[2]
David A. Gauthier[3]

Abstract—"The forests of Canada or the forests of North America"—phrases like these sound all too familiar and simple. However in the world of scientific, social and economic endeavours, this is proving to be a troublesome assumption. While Mexico, United States and Canada share fairly open borders, the boundary lines of these nations and even those of the smaller states and provinces that comprise them have inadvertently become barriers to many things beyond immigration and trade. Borders and jurisdictions are often more than physical obstructions. They influence the words which people use, their perspectives, their values and so on. When differing nations, provinces and states attempt to merge into a broader envelope to report on ecosystem conservation and management, the transition is fraught with difficulties and misunderstandings.

How could the forest industry and landscapes of Canada, for example, affect the livelihood of conservationists and peasants in Mexico? Why would forestry and land use practices in Mexico's mountainous regions affect the numbers of Monarch butterflies summering in southern Ontario?

It has only been in the last couple of decades that understanding ecology at the national and continental levels has become so important to Mexico, USA and Canada. The fundamental reason to look at issues and concerns on an ecosystem basis is not a case of always truly having foresight. Rather, it is primarily reactionary—a response to the loss of species and wildlife habitats, spreading pollution problems, health threats, declining resources and deteriorating ecosystems. These ecological changes in what many feel to be the continent's core renewable resource stocks (i.e. whole ecosystems, forests, wildlife) are increasingly being viewed as factors of national an international security.

What are some of the tools that can be applied to improve the collection of ecosystem information? What will provide a different low cost foundation for co-operation and decision making? In the early 1990's, a collaborative project was initiated to refine a consistent and broadly based ecological framework of Canada that would enhance the capability of governmental and non-governmental organizations to monitor, inventory, assess and report on the nature, condition and trends of ecosystems in Canada. The work was conducted by federal agencies, universities, non-government groups and institutes in the ten provinces and two territories, and was facilitated by the federal Department of the Environment. Three core hierarchical levels of ecosystems where delineated: 20 ecozones (15 terrestrial and 5 marine) for assessments and reporting at the broadest national or continental scales; 217 ecoregions that were further subdivided into 1500 ecodistricts. Recently, this ecosystem framework has been complemented by a parallel system produced through an initiative undertaken by the Commission for Environmental Cooperation for North America. The U.S. Geological Survey has extended this further to cover South America.

Main Points

- The forests are an interactive system enveloping large parts of the North American continent, member nations and indeed homes of many people. Forest ecosystems envelopes all organisms (including people) and their associated environment. Our success in sustaining the quality and carrying capacity of these ecosystems or any of its subset ecosystems will depend on acknowledging this relationship and acting in a timely, effective and relevant manner.
- An ecosystem approach recognizes the comprehensive nature of forests, the earth (i.e. ecosphere) and their ecosystems, large and small. In contrast, nation states, sectors and most scientific disciplines divide forests and other ecosystems in rather arbitrary and inward looking ways.
- An ability to report in a comprehensive and ecosystem based manner on forested ecosystems and their component resources at a continental, national and state/provincial levels is strategic as it offers a mechanism to thread together the larger ecosystem picture. Without this ability, the efforts to report on the status, trends and stressors affecting forested ecosystems remain piecemeal and incomplete. Non-sustainable, intolerable and ill-planned actions affecting life support systems in forests and surrounding ecosystems can result.
- For development to be ecologically sustainable, it must be based on an ecosystem perspective. While local and smaller ecosystems may be managed on the basis of country level information, regional and macro ecosystems cannot.

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- Ecosystem conditions and trends should be regularly monitored and researched. These activities are the critical data engines behind the development of information

Rationale for Multiple Purpose Inventorying and Monitoring

Why should Scandinavian countries care about the inventorying and monitoring of North American forested ecosystems? Why are Canadians concerned about looking at forest sustainability within its borders (i.e. national/provincial/sectoral reports) as well as with its neighbour the United States and even with seemingly distant places like Mexico? Why should citizens from Brazil care about forest monitoring and inventorying activities in North America? People around the world, are becoming increasingly aware of:

- the "shrinking" distances concerning potential impacts and the wealth of forest resources;
- the "expanding" geography of cause-to-effect relationships with forest issues; and
- the "lengthening" time periods that must be considered in sustaining forest resources.

The long-range transport of airborne pollutants from Northern Africa and Russia to Canada's arctic, the losses and threats to wildlife habitats and biodiversity throughout the world, the changes to and causes of the global ozone layer, the long term persistence of chemicals, and the slow recovery of exhausted landscapes and seascapes are among the many examples of general ecosystem degradation. Failure to understand the basic and underlying connections between human actions and environmental consequences have and will continue to lead to serious ecological consequences. Often the harm done has been directly self-imposed by people and, sometimes, it has been inadvertent. A century ago, few could have imagined that landscapes, oceans and biological (i.e. timber, wildlife) resources could have reached points of exhaustion and total depletion. It could hardly be conceivable that ecosystems and their inherent resources could be driven to such states!

Ecosystems are the basic life-sustaining systems and knowing their present state, the trends leading to that state and the future momentum are critical. State of the Ecosystem (SOE) reports foster such information and is fundamental in the decision-making processes concerning highly valued-forested ecosystems. Ecosystems are shared products. Each ecosystem has an increasing number of interested parties, stakeholders, resource managers, policy makers, ENGOs, planners and the general public that want to be involved in decision making (WCED, 1987; IUCN et al. 1991; UNCED, 1992). SOE work is demanding in its scope and implications, and needs a substantive and well-structured base in its supporting inventory and monitoring activities.

Results Defining an Approach

The Canadian approach to reporting evolved from something that was an informative overview of 'bits and pieces' of the environment in the mid-80's to a case (Government of Canada, 1996) which was much more inclusive, objective, functional, pertinent, authoritative and ecosystematic. But what were the other underlying concepts that guided the SOE and how does this affect inventories and monitoring? There were at least three key conceptual considerations: the management concept; the scientific concept; and the sequence and linkage concepts.

Management Concept

Our capacity to manage ecosystems and their resources have been summarized under five themes and have provided the management context for reporting (Rowe et al. 1991) as well as for supportive processes like monitoring and science (Anderson et al. 1992):

1. Frontier Economics	=exploit the land/sea where possible and then move on
2. Integrated Resource	=direct efforts to managing commercially used resources
3. Sustainable Use and Conservation	=sustain the use and conservation of ecosystems and their resources
4. Selective Environmentalism	=practice limited environmental conservation/protection
5. Deep Environmentalism	=return to nature's ways and abandon technology

None of these individual generalizations entirely fit one time or place in Canada or indeed elsewhere. However, they are convenient tools for thought. *Frontier economics* and *deep environmentalism* represent extremes and have minor support in most countries. Most of the federal and provincial governments and industries in Canada operate within the auspices of *integrated resource management* and *selective environmentalism*. Increasingly, there is a move towards *sustainable use and conservation*, which is still largely in the form of guiding principles and goals.

Having *sustainable resource use and conservation* as an objective encourages a process to think, plan and act in terms of ecosystems. Figure 1 generalizes the elements in an eight-step model (Wiken, 1997). The issues concerning forested ecosystems in particular are robust and some say complex. The breadth of concerns (box 1) is not surprising considering the wealth and diversity of forests on this continent (box 2). Land use, pollution and land conversions have been among many factors affecting the state of today's forests. In some cases, the changes have been dramatic and negative for timber harvesting through to wildlife habitat protection; in recent years, some changes have been less obtrusive and impacting (box 3). The alterations have raised numerous environmental, economic and social values, and thus reflected numerous perspectives (boxes 4,5 & 6). Actions, policies and strategies have been implemented to address new expectations (box 7) in forestry but the future outcome may not necessarily be that clear yet (box 8). Improved inventories and monitoring networks are vital backdrops throughout the application of this model.

Scientific Concept

An ecosystem approach sounds simple and perhaps just vogue. Including people as parts of ecosystem and man

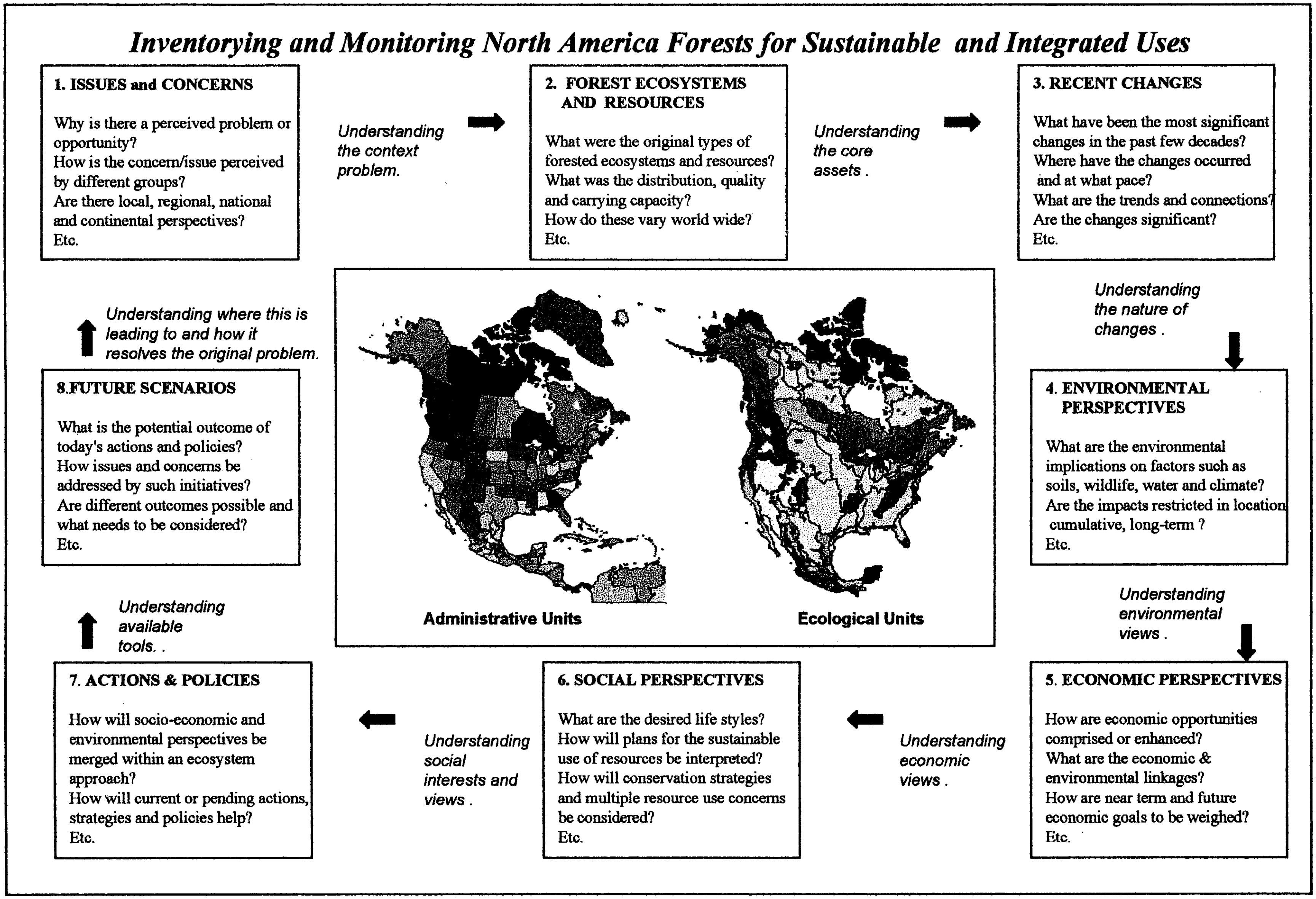

Figure 1.—Generalized eight-step issue analysis model.

modified ecosystems in the approach have proven tasking. This meant trying to capture the social, economic and cultural aspects, not just human demographics like their numbers, places of habitation, waste products, etc. The ecosystem framework became a unifying basis for merging the results of disparate monitoring networks and inventories. It was an effective tool to draw attention to the happenings, trends and conditions within ecosystems first, instead of a partitioned view through more artificially determined country/state/provincial boundaries. The distinction here was important. When jurisdictional boundaries are used as first order reporting units there is an indirect sense of blame and fault that emerges before the fundamental question of 'state or condition' of the ecosystem(s) is assessed. Once an objective assessment is made, then it becomes more important to know what jurisdictions have the authority and power to sustain and promote best practices, and to address and rectify others.

For decades, it has been convenient to simply think of forests as timber factories. Associated forest resources—habitat, land, water, fish, trees, and animals—were largely thought of as secondary assets that were managed and used in isolation. However, it is increasingly apparent that, one way or another, everything is connected. The use of one resource always has some immediate or long-term impact on people and on other resources or ecosystems.

The ecosystem approach involves many things including ecological carrying capacity, ecological footprint (Rees and Wackernagel, 1994), ecological integrity and health, ecosystem sustainability, and ecosystem biodiversity. Having once looked at the ecosystems as something apart from ourselves (Wiken et al. 1996), to be exploited or overcome, we now see ourselves much more as an integral part of it. Our success in maintaining the quality and productivity of forested ecosystems will depend on acknowledging the human relationships/roles and acting accordingly in a broader ecosystem context.

Sequence and Linkage Concept

The basic notion of thinking, planning and acting in terms of ecosystems involves a sequence of activities. The SOE report represents a certain stage in this process. It is not independent from other activities but rather a segment of an interactive loop. SOE only works well if there is a foundation for knowledge through monitoring and inventories, and if there is a process to sustain or improve that knowledge. The activities generally include:

• A concept and a strategy to follow.	Ecosystem approach.
• A framework for organizing knowledge	Ecological land classification
• A means to build an understanding.	Ecological monitoring and inventories
• An overview of the conditions/trends	State of ecosystem reporting
• A way of making choices.	Planning, assessments and research.
• A means to look ahead.	Modelling and scenarios

Data, Information, Indictors, State and Decisions

What is happening? Why is it happening? Why is it significant? What will likely be the outcome? Jumping from data to information, indicators to state or decisions to wisdom are major leaps. The reasons are not because the concepts and principles are not clear but rather that we are encumbered by a work doctrine that is filled with the habit and inertia of history.

Common Failings in Monitoring

Data is the basis of information that eventually leads to critical stages of decision-making (Figure 2). What data does

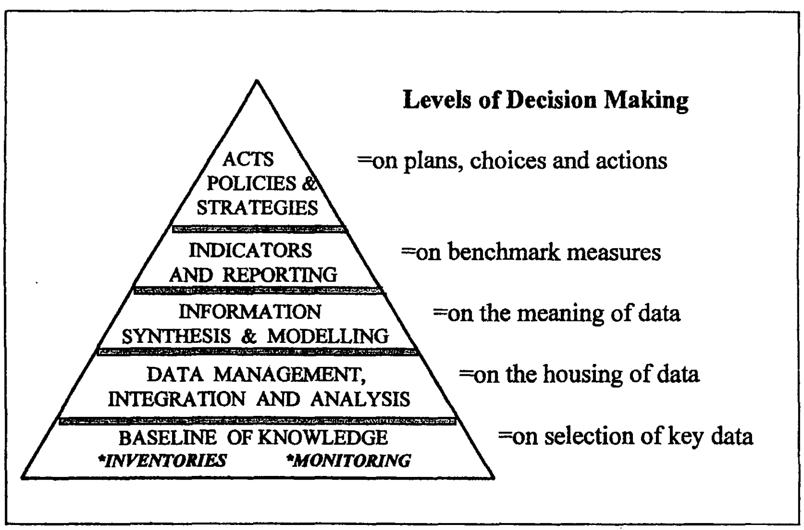

Figure 2.—Decision support pyramid.

exist is typically spread among many specialized agencies that typically focus on one aspect/sector of the environment (e.g. wildlife, atmosphere, fresh water, and oceans). By contrast, there is oddly more consolidation of socio-economic data. When the data are drawn together, the picture is expectedly incomplete. As well, there are problems with data standards and quality, the time periods over which the data have been collected and its currency, and the types of environmental and socio-economic parameters that were measured. Finally, the purposes for which the information was gathered over the years differ greatly and the data therefore is seldom applicable to today's needs (Wiken, 1995; Wiken, 1995).

All of these constraints make it difficult to build a broad and integrated view on ecosystem level issues. Existing data often has to be appropriately extrapolated geographically to fill-in gaps, used as proxies for ideal parameters or employed to infer cause and effect relationships. Existing information is at its limits of practical use with many of today's goals and problems. This is why SOE must constantly be viewed as an iterative process that provides feedback and continuity within the research, monitoring and modelling communities.

The underlying problem is with the foundation of the decision-support pyramid (Figure 2). The existing data, science and information systems were primarily designed for other purposes. You can only retrofit this situation to a certain degree until new baseline systems must be considered. What are some of the outstanding contrasts between the properties of existing data and monitoring networks versus the types of needs that seem to be inherent to initiatives like sustainable resources use?

Synopsis of Existing Baseline	**Sustainable Development Needs**
=Few long term data records	=Long term views advocated
=Limited capabilities to integrate information	=Integrated views sought
=Ecosystem level science weak	=Systems perspective needed
=Geographically biased monitoring networks	=Country/continent wide interests
=Largely intended for sectoral purposes	=Comprehensive assessments needed
=Stronger data on physical parameters	=Increasing need for biological parameters
=Non-standardized and biased data	=Objective & authoritative assessments

Creating a Systems View

As has been done in the USA and Canada, the Commission for Environmental Cooperation (CEC) sponsored an initiative to characterize and map North American ecosystems (Ecosystem Working Group, 1997). The intent was to illustrate the composition and net product of many interacting components, processes and functions. Supplementary information is required to more fully depict the dynamism and complexity, both spatially and temporally, of these ecosystems.

As an example, the Great Plains ecological region has characteristics easily defined in a geographic sense. They include the extent of prairie soils, plains, and areas of cereal grain production and natural grassland communities. In contrast, other characteristics (in a mapping sense) that have a major influence on prairie ecology may not be readily seen. For example, although weather and hydrological patterns may be reflected in the types of vegetation and soil present, they require different and often longer-term techniques to assess and evaluate.

Three levels of ecological generalization (Wiken and Gauthier, 1996) were delineated in a hierarchical manner and this is consistent with more in-depth country level ecosystem classifications of ecozones, ecoprovinces, ecoregions and ecodistricts (Wiken et al. 1996). The CEC report focuses on Levels I and II. Firstly, North America has been delineated into 15 broad ***Level I Ecological Regions***. This level of the ecological hierarchy provides a context at global or inter-continental scales. As well, 52 ***Level II Ecological Regions*** have been delineated and are intended to be nested within the Level I units. For example, the Level I unit, *Tropical Evergreen Forests*, covering coastal southern portions of the United States and Mexico, is comprised of six Level II units. Level II ecological regions are useful for national and sub-continental overviews. As an example, Level II ecological regions are referred to as 'ecozones' in Canada, and the national State of the Environment Report in Canada uses Ecozone units for a major part of its analysis (Government of Canada, 1996. Level III units (about 200) for the continent will be delineated and reported on in the next phase of this initiative; level III is generally equivalent to the ecoprovince level of ecosystem definition. Level III regions are nested within Level II regions that, in turn, are subdivisions of Level I.

The CEC initiative was intended to provide a foundation for a more unified ecosystem perspective, especially one that would support the development continental SOE reports. The framework is an inexpensive way to promote an ecosystem view, and currently serves as a protocol to exchange and aggregate data/information. The ecosystem framework has also been instructive in depicting the ecology of North America.

Responsibilities for Monitoring

Who should lead or guide forest inventorying and monitoring activities in North America? The national governments? National environmental non-government organizations (i.e. ENGOs) or commissions? Industries? Universities? An 'arm's length' and independent North American institution? The answer is not clear nor should there be a singular answer for all jurisdictions. Universities feel they are more scientifically authoritative. ENGOs feel they are more socially objective. National governments feel they can offer the greatest degree of basic infrastructure support and science.

Moving Between Nations

The problems with the data/information/indicator/state cycle quickly gets compounded when you move between countries like the USA and Mexico. National inventories and monitoring networks are commonly designed differently, use different standards, information architectures, and serve different purposes and take on different biases.

When the data are shared/merged for SOE or indicator objectives as in the CEC's North American report, the information typically goes to the lowest common denominator between all the nations; this may be due to the data or the framework upon which it is based. In Canada, we progressed beyond using solely jurisdictional frameworks and migrated towards increasingly using ecosystem boundaries as a framework. However in the ongoing North American report, the majority of the data is being reported according to jurisdictional boundaries, as it is the most common denominator. Jurisdictional units in this case—nations, states, provinces, territories—vary greatly in size. Canada and the USA are similar in size but Canada has 12 main jurisdictions whereas the US has roughly 50. This leads to difficulties in terms of geographical scales that are often incomparable.

Understanding and solving today's problems will require a greater degree of ecological knowledge, data, information and monitoring than ever before. Industries, governments, and individuals need a more comprehensive approach to enable them to predict the effects of ongoing activities, to determine which activities are sustainable and to guide their actions in the future. The decision process and requirements are simply different than before and we can no longer rely on going to a warehouse with old parts to construct a new engine. Sustainable development and ecosystem initiatives have to be powered by different machinery to impart some real sense of wisdom. We were clearly capable of dealing with the 'bits and pieces' in Canada (Wiken, 1996) as were others are around the world (Rosemarin, 1995). Seeing the larger picture, accounting for wider groups of interests and looking for a long-term vision were proving to be elusive capabilities.

Unifying inventories and monitoring networks offers other forms of convenience such as consolidated, unbiased and balanced information. However, the impact and use is beyond the data collection function alone. It is a catalyst that:

- promotes co-operation and standardization of data;
- encourages different and innovative forms of monitoring;
- fosters development of better information systems;
- cultivates improved ecosystem and integrated resource sciences;
- promotes ecosystem approaches;
- broadens understanding of positions of other organizations and groups;
- strengths the capacity for analysis and assessments; and
- supports decision-making in tasking planning and management fora.

Conclusions

Concerns about forests suggest that we need to be guided by a fairly comprehensive and ecosystem based approach, not for any abstract set of reasons but for practical and even selfish ones. Our cultural and socioeconomic systems are subsets of the ecosystem approach. Inappropriate management of forested ecosystems can jeopardize our inherent well being and that of the ecosystems of which we are an integral part.

The underlying principles for monitoring and inventories must use a holistic. You cannot manage the forest wildlife, for example, if you do not understand both the ecosystem of which they are a part and the land use activities that affect them. The interdependencies that exist between the biological (i.e. plants, animals, people) and physical components, the various cycles and processes, and the connections with adjacent or distant ecosystems must be understood for decision making to be effective, timely and relevant. Together, they can provide a realistic basis for renewed attitudes and practices to safeguard the continent's forested ecosystems.

Literature Cited

Anderson, J., T. Kurvits and E. B. Wiken. 1992. A National Ecological Monitoring and Assessment Network: The Concept. In Proceedings of the National Ecological Monitoring and Research Workshop. SOE Occasional Paper No.1, Environment Canada, Ottawa, K1A OH3. pp. 3-12.

Ecosystem Working Group. 1997. Ecological Regions of North America. ISBN 2-922305-20-1. Commission for Environmental Cooperation, Montreal, Quebec, H2Y 1N9 Canada.

Government of Canada. 1996. Sate of the Environment Report. Ottawa, Ontario K1A OE7.

IUCN/UNEP/WWF (World Conservation Union, United Nations Environment Programme, World Wide Fund for Nature). 1991. Caring for the Earth: a strategy for sustainable living. Gland, Switzerland. 228 pp.

Rees, W. and M. Wackernagel. 1994. Ecological Footprints and Appropriated Carrying Capacity: Measuring the Natural Capital Requirements of the Human Economy. In Investing in Natural Capital: The Ecological Economics Approach to Sustainability (A_m Jansson, M. Hammer, C. Folke, and R. Costanza, eds.) Island Press, Washington.

Rowe, J. S., E. Wiken and J. Collinson. 1991. Where we live. Chapter #1 in the 1991 State of the Environment Report. Ottawa, Ontario K1A OE7.

Rosemarin, A. 1995. A piecemeal society. Vol. 2, No. 1 of the Stockholm Environmental Institute Bulletin. Stockholm, Sweden. pp. 4-5.

UNCED (United Nations Conference on Environment and Development). 1992. Agenda 21. New York: United Nations Publications.

WCED (World Commission on Environment and Development). 1987. Our common future. Oxford: Oxford University Press.

Wiken, Ed. B. 1995. Environmental/ecological monitoring: strategies for transition (some experience and examples from a Canadian review). In Moscow Seminar Proceedings (pp. 121-131) for The Development of the Unified State Environmental Monitoring System in the Russian Federation. Pub GA/205024-95/6. GRID Arendal, Norway.

Wiken, Ed B. 1995. Developing and applying a national ecosystem concept in Canada. In Proceedings of the North American Workshop on Monitoring for ecological assessment of terrestrial and aquatic ecosystems. pp.39-46. U.S. D.S. Technical Report RM-GTR-284. Fort Collins. Colorado 80526.

Wiken, E. 1996. Ecosystems: frameworks for thought. In IUCN World Conservation 1/96. CH-1196 Gland, Switzerland

Wiken, Ed B. and D. Gauthier. 1996. Conservation and ecology in North America. In proceedings of Caring for Home Place. Canadian Plains Research Center and University Extension Press. University of Regina. Regina, Saskatchewan.

Wiken, E. B., D. Gauthier, I. B. Marshall, H. Hirvonen and K. Lawton. 1997. A perspective on Canadian ecosystems: the terrestrial and marine ecozones. Canadian Council on Ecological Areas Occasional Paper #14. Ottawa, Ontario. K1H 5Y9 Canada

Wiken, E. B. 1997. State of the Environment Reporting in Canada and North America: An Overview of the Concepts and Applications. pp. C13-C18 in proceedings of the First National Workshop on the State of the Environment Reporting Workshop. SOER Occasional Paper No. 1. ISBN: 0-7974-1744-3. Government of the Republic Zimbabwe. Ministry of Environment and Tourism. Harare, Zimbabwe.

Ecological Monitoring for the Northwest Forest Plan: a Comparison to Other Major Ecosystem Initiatives[1]

David E. Busch[2]

Abstract—The Northwest Forest Plan has certain aspects that set it apart from other regional-scale ecosystem initiatives implemented over the past decade in North America. Some of these differences have influenced the innovation possible in planning and implementing a monitoring program for the Forest Plan. This paper compares monitoring for two other large-scale ecosystem initiatives with monitoring for the regional plan that has altered ecosystem management in the northwestern U.S. to conserve late successional forest and associated aquatic environments. In addition to Forest Plan monitoring, the focus is on ecological monitoring associated with the efforts to restore south Florida's ecosystems and monitoring conducted in ecosystems of the lower Colorado River. Despite obvious ecological and institutional differences, the objectives and unprecedented scope of monitoring associated with these initiatives are similar. Examples are drawn from forested communities in the three areas, with an emphasis on monitoring approaches being utilized at the upland-aquatic interface. Providing the basis for this comparison are elements of the Forest Plan monitoring strategy for riparian ecosystems, monitoring of hydrological restoration of the Florida Everglades, and monitoring of southwestern riparian forests.

The purpose of this paper is to compare the ecological monitoring programs associated with three major North American ecosystem initiatives, each of which affects important forested habitats. To achieve this end, the important ecological and institutional differences among initiatives must be contrasted. However, there are some important features that these initiatives have in common.

The initiatives being compared are 1) the Northwest Forest Plan, the strategy by which management of late successional forest and associated aquatic ecosystems has been altered in the Pacific Northwest region of the U.S.; 2) restoration of the lower Colorado River in the U.S. and Mexico, specifically the rehabilitation of riparian forest systems that support regionally significant wildlife diversity and abundance; and 3) restoration of south Florida's Everglades ecosystem, which directly affects slash pine (*Pinus elliottii* var. *densa*) forests and hardwood hammocks.

These ecosystem initiatives share a high level of commitment from organizations ranging from the top levels of government to a plurality of private citizens in the affected regions. This commitment has been associated with a level of funding that has enabled restoration efforts to proceed. However, support for monitoring over the long term has generally proven to be less certain.

Although vertebrate population monitoring is typically only one element of a comprehensive monitoring program, these initiatives share a genesis rooted in crises surrounding the status of individual wildlife species or groups. For the Northwest Forest Plan, the species of greatest concern was the northern spotted owl (*Strix occidentalis caurina*, Thomas et al. 1990), with concerns about the marbled murrelet (*Brachyramphus marmoratus*) and anadromous fish populations also of high or increasing importance. Concern for imperiled avian populations in southwestern riparian ecosystems has driven much of the effort to preserve and restore gallery forests along the lower Colorado River and similar floodplain environments (Ohmart et al. 1988). Conservation of the Everglades ecosystem has long been tied to the status of wading bird populations, but organisms such as the Florida panther (*Felis concolor coryii*) are also linked to the restoration of forested habitats in south Florida (Smith and Bass 1994).

Given these commonalities, variation in three aspects of ecosystem monitoring helps to differentiate the monitoring being implemented for the Northwest Forest Plan from that occurring in the south Florida and lower Colorado River regions. These three aspects are:

- the institutional drivers that mandate ecological monitoring programs
- the forcing functions that influence ecosystem processes and structure
- the conceptual factors that serve as a basis for monitoring

This paper explores how the Forest Plan monitoring program differs from monitoring for the other two regional initiatives with respect to these aspects. Following a brief discussion of the geographic setting of the three regional initiatives, the focus will be on factors pertinent to forest ecosystem monitoring, particularly those pertinent to monitoring at the interface of forested and aquatic systems.

Geographic Scope

Stemming largely from the impasse between timber production on federal lands in the Pacific Northwest and the attainment of the goals of the Endangered Species Act, the Northwest Forest Plan covers the range of the federally-threatened northern spotted owl. This area includes over 9 million hectares (22 million acres) of forested public land

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encompassing 19 National Forests and 5 Bureau of Land Management Districts. The area covered by the Plan extends from the San Francisco Bay in California to the Canadian border with Washington, and from the Pacific coast to east of the crest of the Cascade Mountains.

Flowing from Glen Canyon Dam to the Gulf of California, the lower Colorado River is the principal drainage in the interior southwestern U.S. and extreme northwestern Mexico. Contrasting sharply with its surrounding desert landscape, the lower Colorado floodplain is covered by riparian vegetation including gallery forests dominated by cottonwood (*Populus fremontii*), willow (*Salix gooddingii*), and mesquite (*Prosopis* spp.) which have over the last 50-60 years been replaced in many places by exotic *Tamarix chinensis* scrub.

South Florida ecosystem initiatives are focused on the Kissimmee River drainage, Lake Okeechobee, and the area between the Miami Rock Ridge and Florida's southwest coast including Florida Bay. The lower mainland part of this drainage network (south of Lake Okeechobee) comprises the greater Florida Everglades. Forested habitats within the Everglades include pine rockland savannas, hardwood hammocks, and baldcypress domes.

Institutional Aspects

Each of the regional ecosystems has been exposed to intensive scrutiny through environmental assessment activity associated with the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), and other environmental legislation and regulation. A series of such assessments has been conducted along the lower Colorado River in association with the Glen Canyon Dam Environmental Studies, the Colorado River Basin Salinity Control Project, and similar programs. Requirements for comprehensive, long-term ecological monitoring of terrestrial environments appear to be lacking for many of the lower Colorado River ecosystem projects. However, an important component of the Glen Canyon Environmental Studies is the development of a long-term monitoring plan for the Grand Canyon area (National Research Council 1994, Marzolf et al. 1998). Although this plan does not encompass the entire lower Colorado River region, a number of long-term ecological studies (cf. Ohmart et al. 1988) have taken place in riparian forests below the Grand Canyon.

Restoration of the Florida Everglades is rooted in legislation and intergovernmental agreements at both the federal and state level. A 1993 Interagency Agreement was the basis for unifying the comprehensive federal restoration effort under an interagency South Florida Ecosystem Restoration Task Force. More recently, commitments strengthening this effort were made in the form of the Department of the Interior's Critical Ecosystem Studies Initiative and a new strategic science planning effort aimed at integrating agency research and monitoring programs. The need to establish ecological endpoints or success criteria rooted in ecological management principles is recognized as critical to the restoration of south Florida ecosystems (Harwell et al. 1996). However, it has proven difficult to define ecological endpoints and the way in which progress toward such endpoints could be monitored. Although ecological monitoring is recognized for its importance in determining the scientific credibility of restoration efforts being planned and conducted, Everglades monitoring programs have lacked focus due to uncertainty about the relative value of potential indicators in the light of overall restoration objectives.

Of the ecosystem initiatives considered, monitoring for the Northwest Forest Plan has perhaps the strongest basis in the decisions of the courts. Conflicting legal claims brought timber programs on federal lands in western Washington and Oregon, and northwestern California to a near standstill in the early 1990's. The President's announcement of a "Forest Plan for a Sustainable Economy and a Sustainable Environment" catalyzed a process to design an interagency strategy for managing forest resources (Tuchman et al. 1996). With the issuance of a joint Record of Decision by the Secretaries of Agriculture and Interior, the management direction for federal forest lands and aquatic resources throughout the Pacific Northwest was extensively altered to conserve ecosystems, species, economic viability, and social values (Pipkin 1998).

The Forest Plan includes an explicit delineation of a monitoring framework in the Standards and Guidelines accompanying the Record of Decision. Monitoring was given additional strength in the summary judicial decision where it is stated: "Monitoring is central to the Plan's validity. If it is not funded, or not done for any reason, the plan will have to be reconsidered." (Dwyer 1994).

Similar to the south Florida restoration efforts, a cabinet-level Interagency Steering Committee is the starting point for federal participation in Northwest Forest Plan implementation. A Memorandum of Understanding (MOU) outlines the role of this committee as well as regional committees of federal executives and non-federal advisors with key roles in implementing the Plan. This MOU recognizes the importance of developing a credible interagency monitoring program, through the efforts of a Research and Monitoring Group tasked with bringing an independent science perspective to intergovernmental forums and activities (Pipkin 1998).

Ecological Aspects

The influence of hydrological and geochemical factors on both Everglades and lower Colorado ecosystems is widely recognized. Beginning in the early 1900's, river regulation and channel modification projects brought about a need for understanding the dynamics of water flow in the Colorado River. Because of this, a series of hydrological gaging stations was established and has produced a long-term record of this important variable influencing the lower Colorado River environment. Colorado River salinity is also closely monitored, due largely to concerns about the quality of water delivered for use in the United States and Mexico. Hydrological and salinity monitoring records are thus available for ecological monitoring projects in riparian forest ecosystems.

Questions about whether the river's hydrology and salinity influence the riparian forest community were clarified by demonstrating the direct association of the river, the floodplain groundwater system, and plant communities dominated by riparian trees and shrubs (Busch et al. 1992, Busch and Smith 1995). Adding an element of ecological complexity, exotic vegetation and fire also interact to alter Colorado River floodplain ecosystem structure and processes (Busch 1995, Smith et al. 1998). A systematic monitoring strategy for Grand Canyon riparian vegetation has been articulated (National Research Council 1994). Elsewhere along the lower Colorado River, periodic mapping of floodplain forests has been conducted (Younker and Andersen 1986).

Work on south Florida ecosystems is similar to that conducted along the lower Colorado River with respect to the utilization for ecological studies of an extensive hydrological record generated during the era of development, and more recent restoration (Busch et al. 1998). This research has been extended to an examination of the linkages of pineland and hardwood communities to hydrological factors within the Everglades ecosystem (Ewe et al. In press). The effects of fire (Gunderson and Snyder 1994) and exotic vegetation (White 1994) are substantial in forested environments within the Everglades. Accordingly, much of the information on the status and trends of woody vegetation within these environments comes from monitoring associated with fire and exotic vegetation management programs. Monitoring of species-habitat relationships has furthered the development of landscape models to support Everglades restoration programs (DeAngelis et al. 1998). However, status and trend determinations based on modeled ecological relationships remain problematic due to the lack of adequate baseline information on topography and vegetation.

Although anthropogenic perturbation of the environment is a common theme in each of the ecosystem initiatives considered, the Northwest Forest Plan differs from the others in the direct effects that human actions have on terrestrial systems. Human influence in the form of forest management occurs against a backdrop of biogeochemistry and disturbance like that of the other two ecosystems. Where reregulation of flows in the Colorado River and the Everglades is envisioned as the principal means of ecosystem restoration, forestry practices under the Forest Plan have been revised sharply from those in place through much of this century. This revision has resulted in a system designed to manage across broad landscapes for ecological complexity and a broad array of goods and services (Kohm and Franklin 1997) and has produced a correspondingly intricate set of ecosystem factors relevant to monitoring.

Because of the Forest Plan's roots in the impasse over threatened species, the status and trends of northern spotted owl and marbled murrelet populations were assigned the initial priority in the Plan's system of effectiveness monitoring (Mulder et al. In press). Given the importance of late-successional and old-growth forests to these and other species, monitoring of forest vegetation was also accorded high priority (Hemstrom et al. In press). These monitoring elements are currently being implemented, while monitoring of elements involving arguably greater ecological complexity (aquatic and riparian ecosystems, forest biodiversity) remain in the planning and development stage.

Certain basic components are integrated by design in each of the Forest Plan monitoring programs (Mulder et al. In press). The late successional/old growth monitoring module is the fundamental source of vegetation cover information for each of the other population- or ecosystem-based modules. Trends in the monitored systems are assumed to have a direct or indirect linkage to the status of forest vegetation. Furthermore, there is an assumption that the relationships of species and habitats to forest landscape parameters can be simulated and predicted using ecological models. Thus, a status and trend detection system is envisioned where the level of population monitoring would be reduced in favor of monitoring habitat, with habitat source data originating in the forest vegetation monitoring program. The development of a model-based trend detection system must await the clarification of habitat relationships before models can be derived and verified. This capability may presently exist for the northern spotted owl, but most of the other monitoring elements require additional development. In this respect, Northwest Forest Plan monitoring lags behind the potential demonstrated by system simulations developed to support Everglades restoration (DeAngelis et al. 1994).

An explicit statement of the steps required to design monitoring programs was developed for the Northwest Forest Plan (Mulder et al. In press). The steps are:

- state the goals of the monitoring program
- identify the environmental stressors relating to management goals
- develop a conceptual model linking relevant ecosystem components
- identify candidate indicators most responsive to environmental stressors
- estimate the status and trends of the indicators
- generate expected values for indicator variables
- link monitoring results to decision making

Although seemingly straight-forward, it has proven necessary to revisit these steps during monitoring plan development to assure that the process remains focused. Moreover, explicit articulation of the plan development and implementation process has proven critical to making progress toward stated goals.

Nowhere does an explicit statement of intent apply better than to the development of a conceptual framework for monitoring. Attempts to develop monitoring programs for ecosystem initiatives have stagnated in the absence of sound conceptual models. The conceptual model for Forest Plan aquatic and riparian environments provides an example describing ecosystem attributes pertinent to monitoring (Fig. 1). The model portrays a physical landscape template that varies approximately at the scale of the biogeographic provinces comprising the Forest Plan region. The model also describes upslope, riparian, and steam channel subsystems and the degree of influence that these watershed subsystems have on each other. General and key ecosystem processes are specified, the latter set being the source of indicators for monitoring status and trend. The influence of anthropogenic and natural stressors on ecosystem processes is taken into account in selecting indicators, as is the influence of habitat related processes and stressors on riparian and aquatic biota. Although seemingly elaborate, this model is a highly-generalized depiction of a complex system. Models like this have served to focus dialogue at all stages of Forest Plan monitoring program development. It is likely that problems with the logical coherence of other monitoring

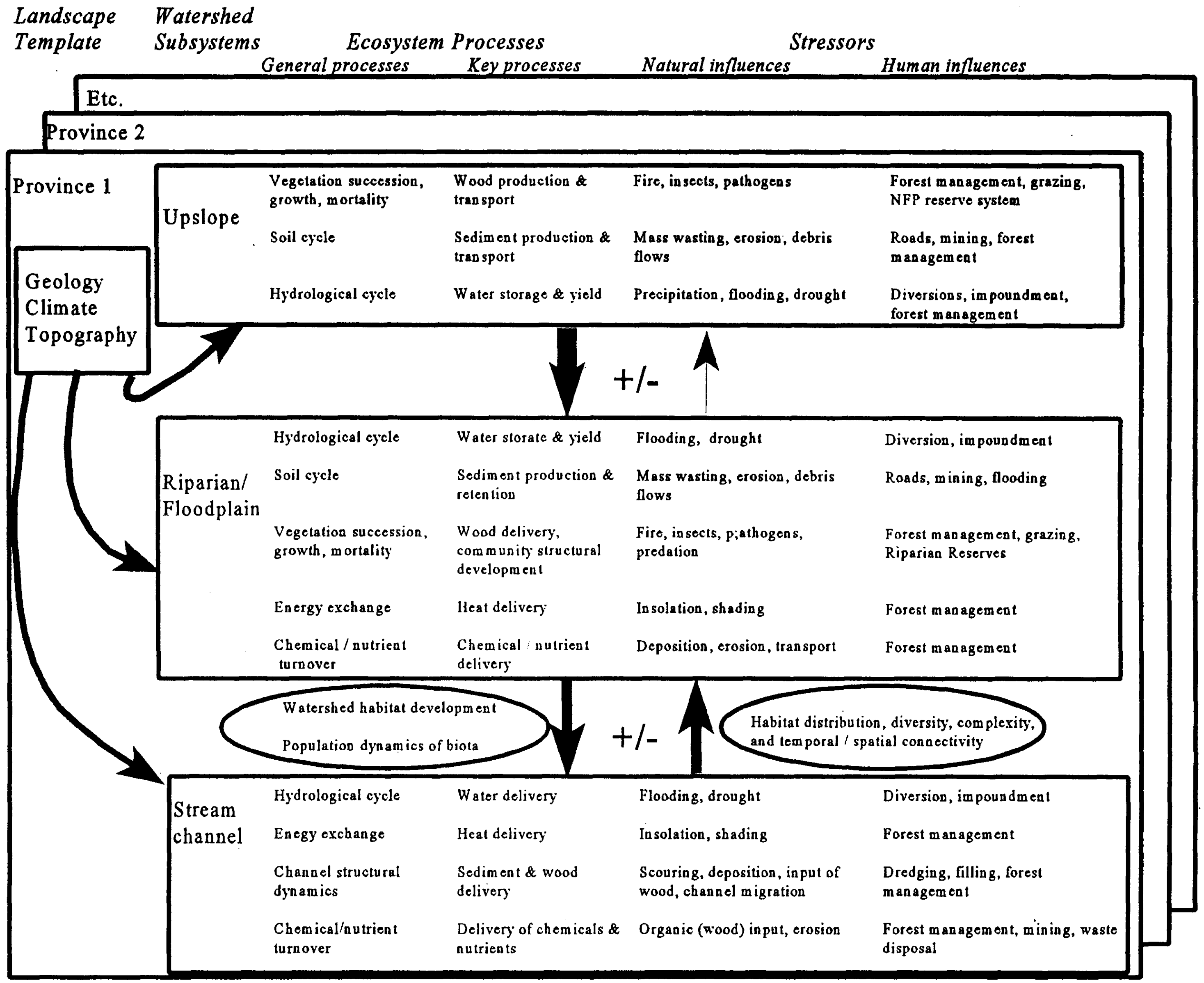

Figure 1.—A conceptual model for monitoring the effectiveness of the Northwest Forest Plan in restoring aquatic and riparian ecosystems.

programs (National Research Council 1994) could be circumvented by specifying a clearer conceptual framework.

Conceptual Aspects

Each of the ecosystem initiatives evaluated here has embraced the concept of adaptive management wherein ecological monitoring plays a pivotal role (Holling 1978). Under this concept, the status of the resource condition monitored is dependent upon stressors that are affected by land management practices (Fig. 2). Land management policy and practices are also affected by regulatory policy and practice. Feedback affecting both land management and regulatory policy comes directly from the monitoring and research programs that are integral to ecosystem initiative implementation. Indeed, it has been pointed out that monitoring programs themselves must be adaptive to some degree to account for obstacles that limit the ability to design long-term monitoring programs in the face of unpredictable changes that are certain to occur in the future (Ringold et al. 1996).

Despite the wide philosophical acceptance of such adaptive approaches to ecosystem management, case studies reveal few instances where management uncertainty has been successfully resolved by adaptive management (Walters 1997). However, most monitoring programs are not well-established considering the time lags associated with biological and physical ecosystem restoration responses. Given the minimum 50 year life envisioned for the Forest Plan, we are still near the beginning of the process of monitoring the effects of altered land management policy and practice. Assuming that fledgling monitoring programs can become institutionalized, adaptive management will have a chance to more fully serve as a unifying theme for regional ecosystem initiatives.

Status and trend detection for the Forest Plan adopted a three-phase approach utilizing implementation, effectiveness, and validation monitoring (Tuchman et al. 1996). With the acceptance of such a phased approach within federal land management agencies (Noss and Cooperrider 1994), this monitoring program structure has been accepted as a part of the Plan. A similar monitoring framework is integrated into experimental water release programs for the Grand Canyon. Such program elements have been less well-articulated for Everglades ecosystem monitoring. Concerns have arisen over certain monitoring conventions embodied in this type of monitoring approach. Potential problems have been pointed out with the use of ecological indicators to overcome ecosystem complexity, and with scale in stressor-response modeling designs (Morrison and Marcot 1995, Lee and Bradshaw 1998). Despite this, Forest Plan monitoring programs generally conform with broadly-recognized design recommendations relative to sampling and scaling, trend detection, the identification of stressors, and specification of uncertainty (Dixon et al. 1998).

It is presently somewhat unclear how monitoring for any of the three initiatives fits within national or international monitoring frameworks (Bricker and Ruggiero 1998). Due to the limited distribution and specialized nature of the forested environment in south Florida and the lower Colorado River floodplain regions, a lack of fit with national and international forest monitoring programs would not be surprising. Aspects of Forest Plan monitoring are thought to be consistent with comprehensive national evaluations of natural resources within the United States (Mulder et al. In press). However, explicit linkages to national programs such as Forest Health Monitoring or the Forest Inventory and Analysis (Lewis et al. 1996) have not been detailed. One of the great challenges in framing national monitoring programs is their relevance to monitoring of important regional initiatives. Beyond this, extending the consistency of national and regional programs to the local or project scale is another consideration that must be more coherently addressed.

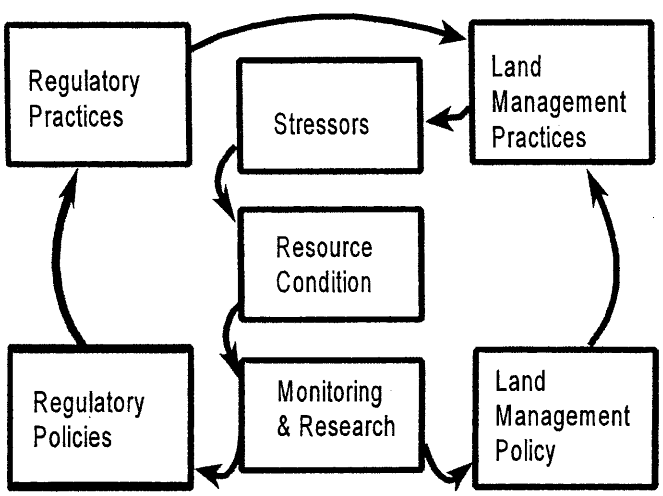

Figure 2.—The monitoring and the adaptive management process for the Northwest Forest Plan.

Summary and Conclusions

The three regional ecosystem initiatives share similar levels of public support stemming to a great degree from the solutions they offer for the preservation of threatened vertebrate populations. While addressing focal species that are thought to be imperiled, all three initiatives have gone beyond simple population and habitat monitoring to include evaluations of the status and trends of a broad range of ecosystem indicators. Although each initiative has an extensive legal and regulatory background, Northwest Forest Plan monitoring appears to have the strongest explicit linkage to decisions of the courts.

Hydrological and geochemical factors have been recognized as the primary drivers in Everglades and lower Colorado River ecosystems, including important forested environments within these systems. The overlay of terrestrial land management upon natural ecosystem processes is stronger for the Forest Plan that for the other initiatives. Partly because of this, evaluation of the status and trends of late successional and old growth forest vegetation is at the heart of the Plan's monitoring program. Predictive monitoring using modeled relationships is an important future step for Forest Plan monitoring, but the development of essential system simulations lags behind that of the Everglades initiative. Despite this, the basis for ecological monitoring is well-developed and understood by those responsible for implementing the Forest Plan. Conceptual models depicting important ecosystem attributes, such as the relationship of forested upland to riparian and aquatic system components, has proven critical to the development and implementation of the Forest Plan monitoring program. Without attention to conceptual frameworks, monitoring programs have tended to founder.

The importance of ecological monitoring to strategies embracing adaptive management is recognized in each of the initiatives considered here. Given the time lags associated with management-induced ecosystem change, it is premature to expect fledgling monitoring programs to exert strong direction in land management decisions early in the course of such major ecosystem initiatives. With greater maturity of monitoring systems and databases, the influence of monitoring programs is expected to increase as is our understanding of the role of regional initiative monitoring in national monitoring frameworks.

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Literature Cited

Bricker, O.P.; Ruggiero, M.A. 1998. Toward a national program for monitoring environmental resources. Ecological Applications 8:326-329.

Busch, D.E.; Ingraham, N.L.; Smith, S.D. 1992. Water uptake in woody riparian phreatophytes of the southwestern United States: a stable isotope study. Ecological Applications 2:450-459.

Busch, D.E. 1995. Effects of fire on southwestern riparian plant community structure. Southwestern Naturalist 40:259-267.

Busch, D.E.; Smith, S.D. 1995. Mechanisms associated with the decline of woody species in riparian ecosystems of the southwestern United States. Ecological Monographs 65:347-370.

Busch, D.E.; Loftus, W.F.; Bass, O.L. Jr. 1998. Long-term hydrologic effects on marsh plant community structure in the southern Everglades. Wetlands 18:230-241.

DeAngelis, D.L.; Gross, L.J.; Huston, M.A.; Wolff, W.F.; Fleming, D.M.; Comiskey, E.J.; Sylvester, S.M. 1998. Landscape modeling for Everglades ecosystem restoration. Ecosystems 1:64-75.

Dixon, P.M.; Olsen, A.R., Kahn, B.M. 1998. Measuring trends in ecological resources. Ecological Applications 8:225-227.

Dwyer, W.L. 1994. Order on motions for a summary judgement regarding 1994 Forest Plan. U.S. District Court, Western District of Washington. Seattle, WA. 69 pp.

Ewe, S.M.L.; Sternberg, L.S.L.; Busch, D.E. In press. Water-use patterns of woody species in pineland and hammock communities of south Florida. Forest Ecology and Management.

Gunderson, L.H.; Snyder, J.R. 1994. Fire patterns in the southern Everglades. pp. 291-306 IN Davis, S.M. and Ogden, J.C., editors. Everglades, the ecosystem and its restoration. St. Lucie. Delray Beach, FL. 826 pp.

Harwell, MA.; Long, J.F.; Bartuska, A.M.; Gentile, J.H.; Harwell, C.C.; Myers, V.; Ogden, J.C. 1996. Ecosystem management to achieve ecological sustainability: the case of south Florida. Environmental Management 20:497-521.

Hemstrom, M.; Spies, T.; Palmer, C.; Kiester, R.; Tepley, J.; McDonald, P.; Warbington, R. In press. Late-successional and old-growth forest effectiveness monitoring plan for the Northwest Forest Plan. General Technical Report PNW-GTR-438. USDA Forest Service, Pacific Northwest Research Station. Portland, OR. 37 p.

Holling, C.S. 1978. Adaptive environmental assessment and management. Wiley. New York, NY.

Kohm, K.A.; Franklin, J.F. 1997. Creating a forestry for the 21st century. Island Press. Washington, D.C. 475pp.

Lee, D.C.; Bradshaw, G.A. 1998. Making monitoring work for managers. Internet publication at http://www.icbemp.gov/spatial/lee_monitor/preface.html

Lewis, T.E.; Cassell, D.L.; Cline, S.P.; Alexander, S.A.; Stolte, K.W.; Smith, W.D. 1996. Selecting and testing indicators of forest health. Pages 140-156 IN C. Aguirre-Bravo (Ed.). North American workshop on monitoring for ecological assessment of terrestrial and aquatic ecosystems. General Technical Report RM-GTR-284. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 305 pp.

Marzolf, G.R.; Valdez, R.A.; Schmidt, J.C.; Webb, R.H. 1998. Perspectives on river restoration in the Grand Canyon. Bulletin of the Ecological Society of America 79:250-254.

Morrison, M.L.; Marcot, B.G. 1995. An evaluation of resource inventory and monitoring program used in national forest planning. Environmental Management 19:147-156.

Mulder, B.S.; Noon, B.R.; Spies, T.A.; Raphael, M.G.; Palmer, C.J.; Olsen, A.R., Reeves, G.H.; Welsh, H.H. In press. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. General Technical Report PNW-GTR- 437. USDA Forest Service, Pacific Northwest Research Station. Portland, OR.

National Research Council. 1994. Review of the draft federal long-term monitoring plan for the Colorado River below Glen Canyon Dam. National Academy of Sciences. Washington, D.C. 30 pp.

Noss, R.F.; Cooperrider, A.Y. 1994. Saving nature's legacy: protecting and restoring biodiversity. Island Press. Washington, D.C.

Ohmart, R.D.; Anderson, B.W.; Hunter, W.C. 1988. The ecology of the lower Colorado River from Davis Dam to the Mexico-United States international boundary: a community profile. Biological Report 85(7.19) U.S. Fish and Wildlife Service. Washington, D.C.

Pipkin, J. 1998. The Northwest Forest Plan revisited. U.S. Department of the Interior, Office of Policy Analysis. Washington, D.C. 117 pp.

Ringold, P.L.; Alegria, J.; Czaplewski, R.L.; Mulder, B.S.; Tolle, T.; Burnett, K. 1996. Adaptive monitoring design for ecosystem management. Ecological Applications 6:745-747.

Smith, T.R.; Bass, O.L. Jr. 1994. Landscape, white-tailed deer, and the distribution of Florida panthers in the Everglades. pp. 693-708 IN Davis, S.M. and Ogden, J.C., editors. Everglades, the ecosystem and its restoration. St. Lucie. Delray Beach, FL. 826 pp.

Smith, S.D.; Devitt, D.A.; Sala, A.; Cleverly, J.R.; Busch, D.E. 1998. Water relations of riparian plants from warm desert regions. Wetlands 18:687-696.

Thomas, J.W.; Forsman, E.D.; Lint, J.B.; Meslow, E.C.; Noon, B.R.; Verner, J. 1990. A conservation strategy for the Northern Spotted Owl, Interagency scientific committee to address the conservation of the northern spotted owl. USDA Forest Service, Pacific Northwest Region, Portland, OR. 427 pp.

Tuchmann, E.T.; Connaughton, K.P.; Freedman, L.E.; Moriwaki, C.B. 1996. The Northwest Forest Plan, a report to the President and Congress. USDA Forest Service, Pacific Northwest Research Station. Portland, OR. 235 p.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1:1-22.

White, P.S. 1994. Synthesis: vegetation pattern and process in the Everglades ecosystem. pp. 445-460 IN Davis, S.M. and Ogden, J.C., editors. Everglades, the ecosystem and its restoration. St. Lucie. Delray Beach, FL. 826 pp.

Younker, G.L.; Andersen, C.W. 1986. Mapping methods and vegetation changes along the lower Colorado River between Davis Dam and the border with Mexico. U.S. Bureau of Reclamation. Boulder City, NV.

Canadian Perspectives on Biodiversity Inventory and Monitoring[1]

Judy Loo[2]

Abstract—The Canadian government has committed to reporting on various aspects of biodiversity, but, with some notable exceptions, implementation of programs to achieve such monitoring has been problematic. Most of Canada's forest land is managed by the provinces. Responsibility for resource inventory and monitoring lies with the provinces as well. Coordination and resources are lacking to ensure cohesive responses to federal information needs. Though Canada has a national ecological land classification (ELC) system, it is not used by all provincial management agencies. Thus the ELC is not effective for national level monitoring or reporting. As well, Canada lacks a coordinated vegetation monitoring system.

There are a number of noteworthy partnership approaches to biodiversity inventory and monitoring in Canada, however. The Model Forest Network consisting of ten working forests, which represent the major forested ecozones across the country, provides focal points for development of workable criteria, indicators, and monitoring systems. Within the Canadian Forest Service, a project known as NatGRID (National Geo-Referenced Information for Decision-makers), applies leading-edge technology to characterize and model the biophysical environment in relation to plant and animal distributions. Conservation Data Centers have been established in all regions of Canada and track rare and uncommon species and habitats. In addition, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), with representatives from federal, provincial and private agencies, monitors and assigns nationally recognized status designations to species at risk in Canada. The World Wildlife Fund has produced a national regions map of Canada and conducted a gap analysis to determine how well protected areas represent ecological diversity. Efforts are underway to assess the need and, where required, to develop gene conservation strategies for Canada's trees at risk. In particular, status reports have been completed for commercially important species on the west coast, conservation work is underway in Ontario's endangered Carolinian forest and status assessments are being carried out in the east coast provinces.

Overview

I was asked to speak about the strengths and weaknesses of biodiversity inventory and monitoring in Canada. I will mention what I see as weaknesses first, then I will discuss briefly some specific examples of noteworthy initiatives. In particular, I will focus on a few programs having grassroots or partnership origins, that will not be explained in detail by other speakers.

The Canadian government has committed to reporting on various aspects of biodiversity, but establishing programs to achieve the necessary monitoring has been difficult. International and national commitments have been made with respect to the Biodiversity Convention, Canada's Biodiversity Strategy, The National Forest Strategy, the Canadian Forest Service (CFS) Biodiversity Action Plan, and others. For example Canada's Biodiversity Strategy calls for development and implementation of monitoring programs to "better understand the functional linkages in ecosystems." The CFS Biodiversity Action Plan requires biological monitoring as well, but specifically mentions partnerships with other agencies or interests. Canada has been very active internationally in developing Criteria and Indicators (C&I) of sustainable forest management, but the nationally adopted C&I set has not yet been applied across the country, and no special resources have been designated for this purpose.

Several factors cause difficulty in country-wide implementation of inventory or monitoring programs. First, commitments are often made by the federal government but the provincial government has land management responsibility, so the provinces are expected to develop and carry out programs that are required to meet federal objectives, but without the benefit of additional financial resources. Another factor is that a number of government agencies, both federal and provincial have an interest in the country's natural resources. Coordination and cooperation of any program involving various agencies are difficult, because of the different interests involved. Cost recovery policies for climate, digital elevation, and remote sensing data are also problematic. Government departments charge any users, including other government agencies for access to the data that are required for setting up monitoring programs. Over large areas, the costs may be prohibitive, effectively reducing the number and scope of projects. The net result is that few new programs have been implemented and little new monitoring activity is taking place to meet the commitments that are being made.

Provinces and territories are each carrying out their own inventory programs, at least for commercially important resources, and in some cases information collected through provincial programs is, or could be used to assess biodiversity, but country-wide standards and coordination for data collection and reporting are lacking. Thus, though the capability for data collection, management and spatial representation is very high locally, the data with relevance to biodiversity collected in one part of the country may not be comparable to that collected in a different province. In particular, there is not a consistent ecological land classification or unified definition of forest types that is accepted

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.
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province-wide. Thus summarizing inventory data from across the country is difficult. A new national inventory system is being developed but there is no plan at present for how to include biodiversity estimates or indicators. The Canadian Forest Service has initiated a project to define forest ecosystems of Canada in collaboration with each of the provinces. The aim is to produce a baseline description of the composition of Canada's forests. In the short run, this will constitute more of a national site classification than an ecological land classification, though the intention is to develop a full ecological land classification for forest land eventually.

At present, Canada lacks a vegetation monitoring system. The ARNEWS plot system could provide a means for vegetation monitoring at a coarse scale. ARNEWS is the Acid Rain National Early Warning System, established in Canada in 1984 in response to concerns about forest health in the face of environmental change. ARNEWS uses a common set of measurements, including a small subset of vegetation presence/absence assessments, taken on permanent sample plots established by the Canadian Forest Service. Plots have been located across Canada in eight forested terrestrial ecozones. Emphasis was placed on the commercially important tree species. Though the infrastructure is in place to carry out vegetation monitoring in this plot system, such monitoring has not been implemented.

Though Canada has been active internationally in developing and promoting criteria and indicators of sustainable forest management, the implementation of the nationally adopted set (Canadian Council of Forest Ministers' Criteria and Indicators) has been slow, with little application in the provinces and no additional resources allocated to the initiatives.

Examples of Biodiversity Inventory and Monitoring Initiatives

There are a number of noteworthy partnership and grassroots approaches to biodiversity inventory and monitoring in Canada. The Model Forest Network consisting of ten large forest areas with multiple ownerships, representing the major forested ecozones across the country, provides focal points for development of workable criteria, indicators, and monitoring systems. Each of the Model Forests is different and is following a somewhat different approach to monitoring and inventorying biodiversity, but the present 5-year phase of the Model Forest Program focuses on local level criteria and indicators, including biodiversity. In some cases Canada's nationally accepted set of Criteria and Indicators (CCFM) is being used as the indicator monitoring framework. In other cases, a new set of indicators, with more local specificity, is being developed. The significance of this program is that practical approaches to monitoring biodiversity at a local scale are being developed and tested in each forest zone of Canada.

Gap analyses provide an example of one type of biodiversity assessment work that has been carried out locally in four of the ten Canadian model forests. In the Fundy Model Forest in New Brunswick, gap analysis was conducted at a fine scale to identify and determine the distribution of all the uncommon plant community types, and the plant species designated as uncommon, rare, threatened or endangered. The gap analysis assessed whether these community types and species were sufficiently covered by existing protected areas. Subsequent work has been undertaken to protect those that are not currently protected. This work covered only a small area, but it does serve as a model for application elsewhere. In the process of conducting the analyses, baseline data that would be required to carry out vegetative monitoring, was collected.

Another example of a Canadian Forest Service (CFS) led project that is expected to be very useful in biodiversity monitoring and inventory is known as "NatGrid" (National Geo-Referenced Information for Decision-makers). This project, which is being extended across the country, applies leading edge technology for characterizing and modeling components of the bio-physical environment such as climate and topography and their relationships to plant and animal distributions, abundance and productivity. Analysis of existing site data using a Geographic Information System and application of statistical models is an important aspect of the work. The spatial nature of the models will be useful in the development of criteria and indicators for sustainable forestry and will provide an empirical basis for identifying representative locations for permanent andtemporary forest plots. The approach is also useful in predicting where uncommon habitats are likely to be found and in predicting species ranges.

Other relatively strong areas within the Canadian Forest Service as well as some provincial forestry departments include insect and fungus taxonomy and genetics. Insect and fungus specimens including indigenous and exotic species are housed at CFS research centres across the country and could serve as reference collections for use in monitoring. The collections were established by the Forest Insect and Disease Survey (FIDS) when that program was a large component of the work of the Canadian Forest Service, and the focus was on insect pests and disease organisms. In recent years, interest has broadened to address biodiversity questions. The associated databases are as important as the specimen collections. For example, they provide information about the appearance of exotic insects or fungal organisms. This information could be important in determining the source and following the movement of such organisms.

Genetics has traditionally been a strong component of the Canadian Forest Service and of some provincial forest research programs. Recently the focus has expanded from the traditional purpose of supporting genetic improvement of commercial tree species to include the evaluation of genetic diversity in natural populations of a variety of commercial and non-commercial species. This allows development and implementation of gene conservation strategies for tree species at risk. In British Columbia, Ontario, and in the Maritime provinces some progress has been made in assessing status of tree and some shrub species as a first step in developing gene conservation strategies for species at risk. Periodic status assessments will require a system for population monitoring.

Conservation Data Centers (CDC) now serve all the provinces of Canada, in addition to all the states in the U.S. and some Mexican states. Conservation Data Centers are computer-assisted inventories of biological and ecological features; primarily concentrating on species or habitats considered to be at risk. The databases provide a means for monitoring the less common biodiversity features within the jurisdiction where the center is located. The centers generally employ biologists as well as database managers, providing field assessment and interpretive capability. Conservation Data Centers are initiated by the Nature Conservancy, and are supported by a variety of funding sources including provincial and federal government agencies, contributions from the private sector, and from foundations. The CDCs are under local control, with management structure varying from center to center, but the data is collected and stored in a manner that is consistent across the country, and across the continent.

Another initiative that is broad-based and not solely dependent upon government agencies is the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC maintains lists of species at risk including the designations: extinct, extirpated, endangered, threatened, and vulnerable. Designated species do not have legal protection, but because of the credible scientific evaluations, status designations are well respected. COSEWIC's mandate covers mammals, birds, reptiles, amphibians, fish, mollusks, lepidopterans, vascular plants, mosses, and lichens. Status reports are prepared following a consistent format, including information about population size now and in the past, and distribution of the species. Changes in these parameters over time are monitored and threats are assessed. Membership of COSEWIC consists of representatives from each provincial and territorial government, four federal government agencies, and three national conservation organizations. Subcommittees are struck to carry out the work of the group, consisting of knowledgeable people from museums, universities or the above agencies.

The efforts of World Wildlife Fund deserve mention as the organization has produced a natural areas map of Canada and they have used it to conduct a gap analysis for assessing adequacy of representation of ecological features in protected areas. They continue to monitor the protected status of ecosystems across the country, so are contributing to the information base about ecosystem diversity.

Conclusions

Implementation of country-wide inventory and monitoring of biodiversity is difficult, expensive and complicated by the division of federal and provincial responsibilities. Many plans and strategies are in place but the coordination and fiscal and human resources to carry them out are still lacking.

The programs and initiatives that are working well tend to be broad-based, cooperative, and driven at least in part by interests outside of government. It is my opinion that these types of initiatives will continue to be important, and will expand in scope, particularly if government funds continue to shrink. There is a need for government agencies to encourage and strengthen grassroots, multi-stakeholder approaches to monitoring biodiversity, including making greater use of naturalist groups and other volunteer networks. I expect that the forest industry will contribute more to biodiversity monitoring and inventorying efforts as marketplace pressures result in increased ecological responsibility.

It is incumbent on the federal government to provide consistent frameworks and formats and to establish greater capability for collecting, maintaining and reporting on the data generated by the various sources.

Measuring And Monitoring Biodiversity in Nature Reserves, Forests, and Grasslands in the United States[1]

Thomas J. Stohlgren[2]

Abstract—Amazingly little is known about the biodiversity of the U.S. due to a lack of systematic, multi-scale surveys of multiple biological groups. Even the best studied areas, the U.S. National Parks, report a knowledge of only 50% to 80% (or less) of their species of vascular plants, birds, mammals, reptiles, amphibians, and fishes. More is known about "charismatic megafauna" and less is known about small creatures that contribute most to biodiversity. Wildlife surveys are not often coordinated with habitat surveys or controlled studies, so little is known about the causes of population trends. Often, poor sampling designs and field techniques are used to survey and monitor biodiversity. Many existing monitoring programs are poorly standardized and are not cost-effective. New resource inventory and monitoring programs must be carefully designed, statistically sound, peer reviewed, and well supported.

I discuss commonly used vegetation sampling designs that are poorly suited for monitoring plant diversity, grazing effects, and exotic plant invasions. I then discuss new approaches to surveying and monitoring large natural areas such as forests and grasslands. The new approaches rely on multi-phase sampling techniques: using two resolutions of remotely sensed information, cluster sampling for map accuracy assessments, and multi-scale field sampling techniques of multiple biological groups.

The protection of forest biodiversity relies on our ability to: (1) rapidly assess hot spots of biodiversity and areas of unique species assemblages at landscape scales; (2) quantify and predict spatial and temporal trends of key species; (3) maintain natural disturbance regimes and key ecological processes; (4) prevent detrimental effects of exotic species; and (5) limit harmful human activities. Our challenges in North America (and the world) are to: (1) develop and test various design strategies (optimum sampling strategy) and multiple-scale field methods for inventorying and monitoring multiple biological groups and ecosystem processes; (2) conduct standardized monitoring of key indicators of multiple stresses to biodiversity; and (3) develop better mapping, information management, and predictive modeling capabilities at multiple spatial scales.

The Status of Biotic Inventories

How much do we really know about the biodiversity in natural areas in the U.S.? In 1995, my colleagues and I found that managers in National Park System units thought their species lists of vascular plants, birds, mammals, reptiles, amphibians, and fishes were, on average, only 50% to 80% (or less) complete (Stohlgren et al. 1995c). Most national parks and monuments knew far less about the diversity of aquatic and terrestrial invertebrates and non-vascular plants (Stohlgren and Quinn 1992).

There are many reasons why biodiversity data are uncommon in many national parks, national forests, state parks, and other natural areas. First, large-scale, systematic surveys for several biological groups are rarely conducted. The best studied group, vascular plants, is often surveyed with various "searching" techniques by different crews of botanists over the years. Because crews often searched selected areas (usually not remote or steep) with various levels of taxonomic skills, the spatial and taxonomic completeness of species lists was uncertain. In Rocky Mountain National Park, Colorado, for example, vascular plant collections over 80 years yielded about 920 species. However, large-scale, systematic plant surveys between 1989 and 1992 added more than 100 species to the Park's species list (Stohlgren et al. 1997a). Similarly, animal studies have fallen short of inventorying biodiversity. More attention has been paid to "charismatic megafauna," large predators and game animals, so less is known about small creatures that contribute most to biodiversity. Also, many studies involving small mammals, selected invertebrates (usually butterflies), amphibians, and fishes have been conducted in small study sites, making it difficult to generate complete species lists for larger landscapes (Stohlgren et al. 1995c).

Second, many field sampling techniques were poorly designed to capture large numbers of species. Survey and monitoring techniques for vascular plants, for example, often relied on small (e.g., 20 cm x 50 cm) quadrats or points along linear transects (Parker 1951, Daubenmire 1959). These transect based-techniques often missed about half the plant species in the local area due to their small sampling area and the patchy, nonlinear nature of species distributions (Stohlgren et al. 1998a). Similar methods problems affect inventory and monitoring of animals.

Third, little has been done to investigate the relationship of diversity between multiple biological groups. While there may be predictable relationships in the spatial patterning of diversity of multiple biological groups on the landscape, these surveys have usually taken place in relatively small areas, such as the rare and expensive "all taxa biodiversity inventories" underway in Costa Rica (Janzen 1997) and planned for Great Smoky Mountain National Park. Although much of the diversity of life is found in smaller creatures such as insects and soil organisms, these systems have been very poorly surveyed in nearly all natural areas. We are left with preciously little information on the

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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biodiversity in most natural areas in the U.S. Improving research on the diversity of relationships of multiple biological groups would greatly increase our knowledge of ecosystem biodiversity.

The Status of Biotic Monitoring Programs

Several monitoring programs have been designed to assess single biological groups. The U.S. Geological Survey's Breeding Bird Survey uses volunteer bird enthusiasts to survey thousands of kilometers of roadways each year. The program has proved invaluable for detecting significant trends in many species of birds throughout the U.S.. However, the survey techniques are questionable for many rare, remote, and high-elevation birds species, and population trends are not easily linked to habitat change or other causes. Similarly, the USDA Forest Health Monitoring Program provides adequate monitoring of tree species diversity in the U.S., and has recently expanded their surveys to include understory vegetation. However, non-forested areas are not monitored, rare habitats may be missed by the sampling design, and little information is collected on animal diversity.

There is an urgent need to develop strategies to quantify the biological diversity of landscapes and regions (e.g., Magurran 1988, Wilson 1988, Soulé and Kohm 1989, Peters and Lovejoy 1992, Noss and Cooperrider 1994). A starting point would be linking vegetation analyses across scales (Franklin 1993, Short and Hestbeck 1995). There are active research programs, for example, to quantify some aspects of biological diversity at national and statewide scales (Palmer et al. 1991, Messer et al. 1991, Austin and Heyligers 1991, Scott et al. 1993). However, there are no generally accepted "off-the-shelf" sampling protocols for biological monitoring at landscape scales (Stohlgren et al. 1995a).

Few monitoring programs are specifically designed to monitor biodiversity. The best example may be the Smithsonian Institution's biodiversity monitoring plots (Dallmeier 1992), where species of trees, birds, reptiles, amphibians, and some invertebrates are measured in selected 1.0 ha plots. The expense of establishing long-term plots that large often limits the number of replicate plots that can be established in a given landscape. Therefore, it is often unknown how representative these few sampling plots are in relation to the larger, unsampled landscape. Thus, these plots are designed primarily to monitor the diversity within 1.0 ha plots over time, rather than monitoring the changes in biodiversity throughout a landscape or natural area. If progress is to be made in surveying and monitoring biodiversity, new cost-efficient, unbiased sampling designs are needed to assess multiple biological groups at multiple spatial scales with known levels of precision, accuracy, and completeness.

Landscape-Scale Assessments of Biodiversity: A Methodology In Progress

Our research team is designing field techniques to survey and monitor biodiversity at landscape scales (Stohlgren et al. 1997a,b, c, Simonson 1998, Suzuki et al. 1998). We focus on improving field techniques for vascular plants, butterflies, and birds. The study design relies on multi-phase sampling, unbiased site selection using stratified random sampling in common and rare habitats, multi-scale field sampling by professional taxonomists, cluster sampling, and accuracy assessments (Figure 1).

Multi-Phase Sampling

Multi-phase sampling allows the extrapolation of information from high-resolution field data of selected study sites to the larger, unsampled landscape (Kalkhan et al. 1995). Typically, this requires the use of two sets of remotely sensed imagery (Figure 1). For example, low-resolution but inexpensive satellite imagery can be linked to high-resolution aerial photographs and ground truth data, which are more expensive and accurate, but spatially limited. Statistical techniques can assess the changes in accuracy and precision when extrapolating site-specific field data to the larger landscape (Kalkhan et al. 1998). Separate error matrices are developed between the classifications on the satellite image and the aerial photography, and between the aerial photography and ground observations. The error matrix provides the user with information on the accuracy of individual categories, and both errors of commission and omission in the classification (Congalton 1991). Validating the accuracy of maps of biological data using multi-phase sampling requires accurate estimates of bias and variance at multiple spatial scales (Maybeck 1979, Kalkhan et al. 1995). Since we cannot afford to collect detailed data on biological diversity at all sites, multi-phase sampling is a cost-efficient necessity in landscape-scale assessments (Kalkhan et al. 1995, 1998).

Unbiased Site Selection Using Stratified Random Sampling in Common and Rare Habitats

For many long-term biodiversity monitoring plots (Dallmeier 1992) and forest dynamics studies (Hawk et al. 1978, Riegel et al. 1988), investigators have selected "typical" sample units (or "reference stands"). It is not a coincidence that many of these typical plots are close to roads, on flat terrain, and are commonly very dissimilar to the surrounding landscape. Only data produced from unbiased study plots can be evaluated by the theorems of probability theory (Krebs 1989). Unbiased plot selection using random sampling, stratified random sampling, or systematic sampling provides ecologists with an important tool to extrapolate information from plots to landscapes, and from landscapes to regions (Stohlgren 1994, Kalkhan et al. 1998).

Sample sites are selected in an unbiased manner using remotely sensed information and a stratified random sampling design (Figure 1). High-resolution aerial photography can be used to stratify vegetation to include homogeneous plant communities (typically recognized in most vegetation mapping efforts), heterogeneous communities of special interest (e.g., ecotones and ecoclines, mixed stands and communities), and keystone ecosystems. Keystone ecosystems are ecosystems that contain high plant species richness, distinctive species compositions, or distinctive

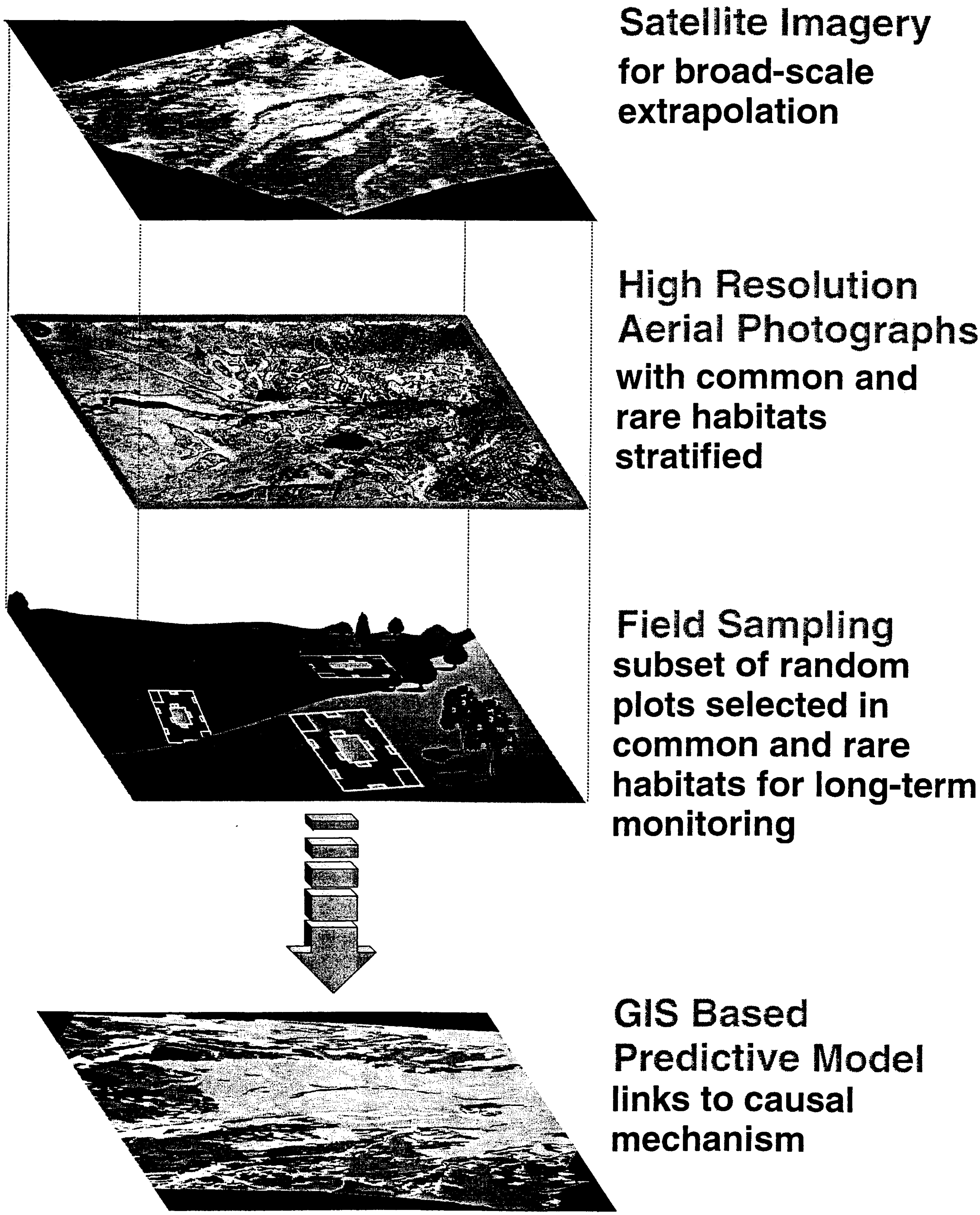

Figure 1.—Generalized multi-phase sampling design for biodiversity used in several landscape-scale studies (adapted from Stohlgren et al. 1995b, 1997a,b,c, 1998c).

ecological processes that benefit many other species and ecosystems (Stohlgren et al. 1997a,b). The size of the minimum mapping unit must be selected to accommodate particular keystone ecosystems such as aspen (Stohlgren et al. 1997c). After a preliminary vegetation map is prepared, four or five ground truth plot locations per vegetation type are selected randomly using a randomizing function in a geographic information system (GIS), or with a grid system on a plastic overlay atop the aerial photograph. We then locate the points in the field with the aid of the photographs, other maps, and a compass, and check and map the locations with a global positioning system (GPS; Figure 1).

Multi-Scale Field Sampling

At each ground truth sampling point, a Modified-Whittaker nested vegetation sampling plot is established (Stohlgren et al. 1995b). The Modified-Whittaker plot (Figure 2) is 20 m x 50 m, with ten 0.5 m x 2 m (1-m^2) subplots arranged systematically inside the plot, and a 5 m x 20 m (100-m^2) subplot in the plot center. Two 2 m x 5 m (10-m^2) subplots are placed in opposite corners of the plot (Figure 2). Both the percent cover and average height-by-species are recorded in the 1-m^2 subplots. Cumulative species (additional species found in the subplot or plot) are recorded successively in the ten 1-m^2 subplots, the two 10-m^2 subplots, the 100-m^2 subplot, and the remaining unsampled areas of the 20 m x 50 m plot. For small vegetation communities, the dimensions of all the subplots and plots can be shrunk proportionately.

Cumulative species data from the 1-m^2, 10-m^2, and 100-m^2 subplots from each 1000-m^2 plot can be fit to linear regressions of cumulative species-area curves, species-log(area) curves and log(species)-log(area) curves. To validate the selected model, the estimated total number of species in each 1000-m^2 plot based on the 1-m^2, 10-m^2, and 100-m^2 data can be compared to the observed number of species recorded in each plot. The regression model with the least difference between observed and expected values should be used.

Butterflies are surveyed in six 10-m^2 subplots, a 100-m^2 subplot, and in the 1000-m^2 plots in the spring and early summer on warm, sunny afternoons (Simonson 1998). Birds are sampled at two spatial scales (50 m radius and 100 m radius) for three five-minute intervals. This multi-scale approach assesses aspects of spatial and temporal variability within and between habitats (Figure 2).

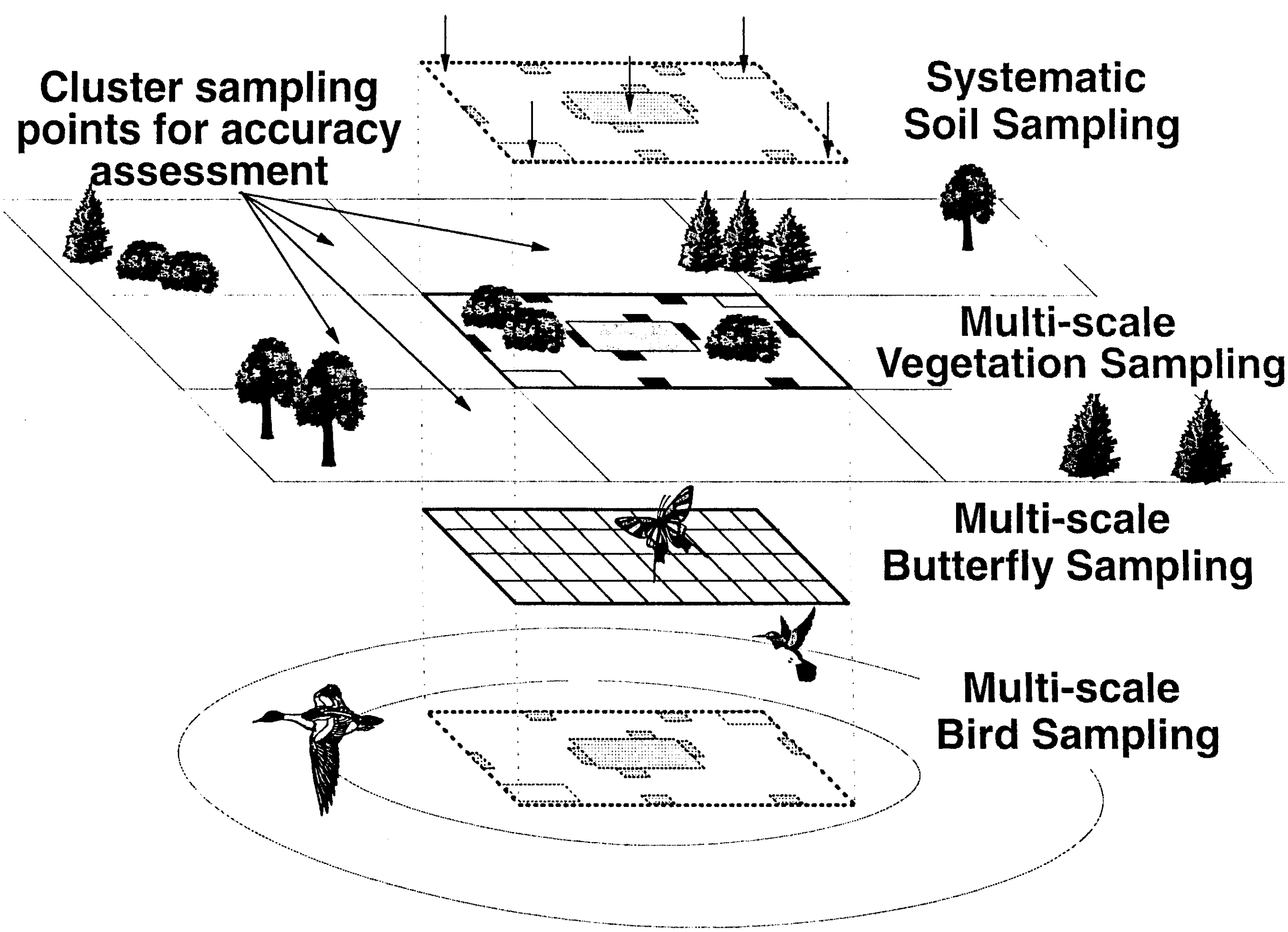

Figure 2.—Generalized multi-scale sampling design for biodiversity used in several landscape-scale studies (adapted from Stohlgren et al. 1995b, 1997a,b,c, 1998c).

Cluster Sampling and Accuracy Assessments

Much of the expense of field sampling is getting field crews to and from sample sites. In addition, assessing the accuracy of maps of biological data is often limited by small sample sizes of ground truth data. Cluster sampling is a cost-efficient technique that optimizes field crew efforts by collecting ancillary data around the primary sampling site. For example, a field crew may travel to a randomly selected remote site to collect data on the diversity of plants, birds, and butterflies. While at the site, they also collect additional data on the vegetation classes surrounding the sample point (i.e., at cardinal directions 100 meters from the plot corners) to assess the accuracy of the vegetation map that is used to extrapolate the species diversity data (Figure 2).

Attributes of Strong Monitoring Programs

There is no shortage of advice available on the design of monitoring programs (Hinds 1984, Hurlbert 1984, Strayer 1986, Eberhardt and Thomas 1991, Palmer 1993). The attributes that follow (Table 1) are based on several previous studies, and much trial and error (Stohlgren 1994, Stohlgren et al. 1995b, 1997a,b,c, 1998a,b). Obviously, a long-term commitment of funding and support are essential, as is strong leadership and cooperation within and among monitoring programs.

Lessons Learned

1. Scale Matters. The appropriate scale of study is determined by many factors including cost, the minimum amount of information needed to make current and future management decisions, and the extent to which the investigators wish to extrapolate results. Often data at one spatial scale can be contradicted by data collected at another spatial scale. In 1-m^2 plots in the Central Grasslands, for example, exotic plant species were found to invade areas of low native plant diversity. In four 1000-m^2 plots in the same areas, exotic plant species were found to invade areas of high native plant diversity (Stohlgren et al. 1999). Sampling vegetation at multiple spatial scales (Fig. 1) is important to understand species-area relationships and to evaluate local- and broad-scale patterns of plant diversity (Shmida 1984, Stohlgren et al. 1995b, 1997a,b). Multi-scale sampling techniques have worked well in desert environments (Stohlgren et al. 1998c), grasslands (Stohlgren et al. 1998a,b), montane forests (Stohlgren et al. 1997a,b), and tropical rain forests (S. Mistry, Smithsonian Institution, unpublished data).

2. Resolution Matters. Coarse-scale maps, with large minimum mapping units and few classes, will miss rare habitats (Stohlgren et al. 1997c). In Rocky Mountain National Park, Colorado, stands of aspen (*Populus tremuloides*), which are important contributors to plant, bird, and butterfly species diversity (DeByle 1985a,b, Simonson 1998), are severely missed with the commonly used 2-ha minimum mapping unit. Coarse-scale maps may miss rare habitats such as riparian zones, wetlands, and other small, unique habitats, thus grossly underestimating biodiversity (Stohlgren et al. 1997c).

3. Taxonomic Expertise Matters. Having taxonomic experts in the field is essential. Everywhere our research teams have sampled, we have found that most species are rare, and small areas of any landscape can contain hundreds of species. For example, a 754-ha area of Rocky Mountain National Park, Colorado, contained over 550 plant species (Stohlgren et al. 1997a). In vegetation types throughout the Rocky Mountains and Central Grasslands, about 50% of the plant species at each sampling site have <1% foliar cover. In ten 0.1 ha vegetation plots in tropical forests in Peru, 250 out of 500+ species of trees were represented by a single individual (S. Mistry, Smithsonian Institution, unpublished

Table 1.—Key monitoring program attributes and reasons for the attributes.

Key monitoring program attributes	Reason
1. Clearly define goals and objectives	Sees that priority management needs are met
2. Use a multi-scale sampling design	Insures extrapolation to larger unsampled areas
3. Stratify/monitor common and rare habitats	Rare habitats contain much of the biodivesity
4. Sample multiple taxonomic groups	Improves cost-efficiency, maximize information
5. Sample key environmental factors	Soils and topography data improve models
6. Reduce bias in site selection	Allows for unbiased extrapolations
7. Assess species-area relationships	Projects results to larger, unsampled area
8. Assess species accumulation with time	Assesses effects of duration of sampling for animals
9. Assess within-strata variation	Evaluates appropriate sample size per strata
10. Assess between-strata variation	Evaluates appropriate sample size for the study
11. Assess effects of spatial scale on results	Study results are often scale-dependent
12. Assess effects of resolution on results	Asks the question "What did we miss?"
13. Develop spatially explicit predictive models	Extrapolates data to larger unsampled area
14. Validate the models with new data	Proves the accuracy and precision of models
15. Provide adequate funds for data management	Usually this is grossly underestimated
16. Provide comparable data to other programs	Strengthens small programs, allows for synthesis
17. Seek periodic statistical and program review	Improves program, strengthens credibility
18. Make data accessible	Improves use of data, creates credibility
19. Publish results frequently	Creates and maintains credibility
20. Provide adequate outreach	Shows that the monitoring program is meeting goals

data). Most species are rare, and knowledgeable taxonomists are needed to identify and monitor species diversity. Poorly trained para-taxonomists and volunteers may capture common, dominant species at each site, while missing key aspects of biological diversity.

4. Assessing Multiple Biological Groups, Habitats, and Environmental Factors Matters. One way to optimize information and understand ecological determinants of diversity is to sample multiple biological groups, habitats, and environmental data in interdisciplinary teams at co-located sites, rather than sampling different groups in different places at different times. For example, in Rocky Mountain National Park, our research is coordinated between plant, butterfly, and bird taxonomists. By coordinating our efforts to sample different biological groups on the same sites, our understanding of many layers of diversity increases. In this way, multi-taxa predictive models can be developed for the larger, unsampled landscape (Fig. 1).

5. Sampling Design is the Key. The most important phase of an inventory and monitoring program is the design phase. Surveys are expensive and long-term monitoring is more so. Much of the cost associated with inventory and monitoring projects is getting field crews to and from sampling sites. There are many ways to reduce costs and maximize information gain, including cluster sampling, multi-scale sampling, and sampling multiple biological groups. No single sampling design will answer all monitoring questions. Cost constraints and the spatial and temporal variation of biological diversity will always restrict monitoring capabilities. However, well-designed multi-scale monitoring techniques that are tested in several vegetation types and biomes may have distinct advantages over many currently used single-scale and single-objective techniques.

Recommendations for Monitoring Forest Biodiversity

The protection of forest biodiversity relies on our ability to: (1) rapidly assess hot spots of biodiversity and areas of unique species assemblages at landscape scales; (2) quantify and predict spatial and temporal trends of key species; (3) maintain natural disturbance regimes and key ecological processes; (4) prevent the detrimental effects of exotic species; and (5) limit harmful human activities.

With continued population growth and current patterns of urbanization and development (Vitousek et al. 1997), it is urgent that we identify and map hot spots of biodiversity, areas of unique species assemblages, and areas most vulnerable to change (Stohlgren et al. 1997a). This must be done at local, regional, national, and international scales to guide inevitable human developments to less-important and more resilient sites, and to guide site selection for open space, parks, or other less-developed landscapes for conservation. The hot spots of diversity and areas of unique plant assemblages, identified quickly on the basis of plant species richness and composition, should be surveyed for other biological groups and environmental data.

Quantifying the spatial patterns of key indicator species relative to environmental data is the first step towards monitoring and predicting temporal trends of the species. Not all species can be monitored at all locations so key indicator species and sensitive habitats must be selected. Conducting broad-based surveys prior to establishing long-term monitoring sites is very important. This way, sites can be randomly selected from a larger sample of survey sites to allow for an unbiased extrapolation of results. Meanwhile, an understanding of temporal variation in key indicator species is usually only possible after several years of monitoring (Hinds 1984, Eberhardt and Thomas 1991). Thus, sampling design is an iterative process. A finding of high temporal and spatial variation may require establishing additional monitoring sites, or waiting longer to detect significant change.

Maintaining natural disturbance regimes and key ecological processes may be important in protecting native species. Most forest species are adapted to living in a landscape with occasional wildfires, blow-downs, hurricanes, floods, or insect outbreaks. In the Rocky Mountains, fire suppression may result in a loss of aspen and riparian habitat, and an increase in the spatial extent of closed-canopy forests. Because aspen, riparian, and open forest types have higher diversity than closed-canopy forests, fire suppression could greatly reduce habitat for many species of plants, birds, and butterflies (DeByle 1985a,b, Stohlgren et al. 1997a, Simonson 1998). Likewise, riparian plants and aquatic species that rely on occasional floods will do poorly in environments of constant or lower water tables caused by dams and water diversions.

It will become increasingly difficult to prevent exotic species from gaining dominance in natural systems (Vitousek et al. 1996). Plant species are invading riparian zones (Stohlgren et al. 1998b) and along roads. These "evil corridors" provide access for invasive plants throughout forested and grassland ecosystems. Non-native insects and diseases such as gypsy moth, chestnut blight, and white pine blister rust are escalating problems with potentially severe indirect consequences to biological diversity (Vitousek et al. 1996). Exotic fishes have effected native species in most interior U.S. waters. Our best hope is to detect and control invasive species early in the invasion process.

Our ultimate social challenge is to limit human activities that harm our ecosystems (Vitousek et al. 1997). Modern society is likely to continue converting land from forests or grassland to agricultural and urban landscapes, excessively using natural resources, altering hydrologic and fire regimes, and spreading invasive species. The rate at which we continue these activities will likely define the rate of the loss of biodiversity.

Monitoring biodiversity in the U.S. is in its infancy (Bricker and Ruggiero 1988). Current national-level monitoring focuses on a few outweighing species such as dominant trees, common birds, and vascular plants. Local-scale monitoring is uncoordinated, with little opportunity to compare data on multiple biological groups at multiple spatial scales. Ideas are surfacing about the need for a new network of "index sites" for monitoring biodiversity and long-term change in 200 or more sites in many of the Nation's ecosystems (H. Ron Pulliam, personal communication). Given the current dearth of comparable information on biodiversty in natural areas (Stohlgren et al. 1995c), I think that such a monitoring network is badly needed.

Conclusions

Our science and land management challenges in North America (and the world) are to: (1) develop and test various design strategies (optimum sampling strategy) and multiple-scale field methods designed for inventorying and monitoring multiple biological groups and ecosystem processes; (2) conduct standardized monitoring of key indicators of multiple stresses to biodiversity; and (3) develop better mapping, information management, and predictive modeling capabilities at multiple spatial scales.

I am optimistic that surveying, monitoring, and predicting patterns of biodiversity can guide responsible land management decisions. Science can help guide decision-makers to avoid development in hot spots of biodiversity and where unique species assemblages occur. Science also can guide restoration and mitigation activities. A new, well-designed network of index sites to monitor biodiversity in national parks, wildlife refuges, national forests and grasslands, and other natural areas is needed.

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Literature Cited

Austin, M.P. and P.C. Heyligers. 1991. New approach to vegetation survey design: Gradsect sampling. Pages 31-36 *in* C.R. Margules and M.P. Austin, eds. Nature Conservation: Cost Effective Biological Surveys and Data Analysis. CSIRO, Australia.

Bricker, O.P. and M.A. Ruggerio. 1998. Toward a national program for monitoring environmental resources. Ecological Applications 8:326-329.

Congalton, R. G. 1991. A review of assessing the accuracy of classification of remotely sensed data. Remote Sensing and the Environment 37:35-46.

Dallmeier, F., ed. 1992. Long-term Monitoring of Biological Diversity in Tropical Forest Areas: Methods For Establishment and Inventory of Permanent Plots. MAB Digest 11. United Nations Educational, Scientific, and Cultural Organization (UNESCO), Paris, France.

Daubenmire, R.F. 1959. Canopy coverage method of vegetation analysis. Northwest Scientist 33:43-64.

DeByle, N.V. 1985a. Wildlife. Pages 135-152 *in* Aspen: Ecology and Management in the Western United States. USDA Forest Service General Technical Report RM-119, Ft. Collins, Colorado.

DeByle, N.V. 1985b. Animal impacts. Pages 115-123 *in* Aspen: Ecology and Management in the Western United States. USDA Forest Service General Technical Report RM-119, Ft. Collins, Colorado.

Eberhardt, L.L. and J.M. Thomas. 1991. Designing environmental field studies. Ecological Monographs 61(1):53-73.

Franklin, J.F. 1993. Preserving biodiversity: species, ecosystems, or landscapes? Ecological Applications 3:202-206.

Hawk, G.M., J.F. Franklin, W.A. McKee, and R.B. Brown. 1978. H.J. Andrews Experimental Forest reference stand system: establish and use history. USDA Forest Service Bulletin 12. U.S. International Biosphere Program.

Hinds, W.T. 1984. Towards monitoring of long-term trends in terrestrial ecosystems. Environmental Conservation 11:11-18.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Janzen, D.H. 1997. Wildland biodiversity management in the tropics. Pages 411-431 *in* M.L. Reaka-Kudla, D.E. Wilson, and E.O. Wilson (eds). Biodiversity II. Understanding and protecting our biological resources. Joseph Henry Press, Washington, D.C.

Kalkhan, M.A., T. J. Stohlgren, and M. Coughenour. 1995. An investigation of biodiversity and landscape-scale gap patterns using double sampling: a GIS approach. Pages 708-712 *in* Proceedings of the Ninth Conference on Geographic Information Systems. Vancouver, British Columbia, Canada.

Kalkhan, M.A., R.M. Reich, and T.J. Stohlgren. 1998. Assessing the accuracy of Thematic Mapper classification using double sampling. International Journal of Remote Sensing 19:2049-2060.

Krebs, C.J. 1989. Ecological Methodology. Harper & Row, New York.

Magurran, A.E. 1988. Ecological Diversity and its Measurement. Princeton University Press, Princeton, NJ.

Maybeck, P.S. 1979. Stochastic Models, Estimation, and Control. Vol. 1. Academic Press, New York.

Messer, J.J., R.A. Linthurst, and W.S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environmental Monitoring and Assessment 17:67-78.

Noss, R.F., and A.Y. Cooperrider. 1994. Savings Nature's Legacy: Protecting and Restoring Biodiversity. Island Press, Washington, D.C.

Palmer, C.J., K.H. Ritters, J. Strickland, D.C. Cassell, G.E. Byers, M.L. Papp, and C.I. Liff. 1991. Monitoring and research strategy for forests - Environmental Monitoring and Assessment Program (EMAP). EPA/600/4-91/012. United States Environmental Protection Agency, Washington, D.C.

Palmer, M.W. 1993. Potential biases in site and species selection for ecological monitoring. Environmental Monitoring and Assessment 26:277-282.

Parker, K.W. 1951. A method for measuring trend in range condition in National Forest Ranges. USDA Forest Service. Washington, D.C.

Peters, R.L., and T.E. Lovejoy, eds. 1992. Global Warming and Biological Diversity. Yale University Press, New Haven, CT.

Riegel, G.M., S.E. Green, M.E. Harmon, and J.F. Franklin. 1988. Characteristics of mixed conifer forest reference stands at Sequoia National Park, California. USDI National Park Service CPSU Technical Report No. 32. University of California, Davis, CA.

Scott, M.J., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, J. Ulliman, and R.G. Wright. 1993. GAP Analysis: A Geographic Approach to Protection of Biological Diversity. Wildlife Monographs 123:1-41.

Shmida, A. 1984. Whittaker's plant diversity sampling method. Israel Journal of Botany 33:41-46.

Short, H. L., and J. B. Hestbeck. 1995. National Biotic Resource Inventories and GAP Analysis: problems of scale and unproven assumptions limit a national program. Bioscience 45: 535-539.

Simonson, S. 1998. Rapid assessment of butterfly diversity: a method for landscape assessment. Masters Thesis. Department of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO. 50 pages.

Soulé, M.E., and K.A. Kohm. 1989. Research Priorities for Conservation Biology. Island Press, Washington, D.C.

Stohlgren, T.J. 1994. Planning long-term vegetation studies at landscape scales. Pages 209-241 *in* T. Powell and J. Steele, eds. Ecological Time Series. Chapman and Hall, New York.

Stohlgren, T.J., and J.F. Quinn. 1992. An assessment of biotic inventories in western U.S. national parks. Natural Areas Journal 12:145-154.

Stohlgren, T.J., D. Binkley, T.T. Veblen, and W.L. Baker. 1995a. Attributes of landscape-scale, long-term studies: malpractice insurance for landscape ecologists. Environmental Monitoring and Assessment 36: 1-25.

Stohlgren, T.J., M.B. Falkner, and L.D. Schell. 1995b. A modified-Whittaker nested vegetation sampling method. Vegetatio 117:113-121.

Stohlgren, T.J., J.F. Quinn, M. Ruggiero, and G. Waggoner. 1995c. Status of biotic inventories in U.S. National Parks. Biological Conservation 71: 97-106.

Stohlgren, T.J., G.W. Chong, M.A. Kalkhan, and L.D. Schell. 1997a. Rapid assessment of plant diversity patterns: A methodology for landscapes. Ecological Monitoring and Assessment 48:25-43.

Stohlgren, T.J., M.B. Coughenour, G.W. Chong, D. Binkley, M. Kalkhan, L.D. Schell, D. Buckley, and J. Berry. 1997b. Landscape analysis of plant diversity. Landscape Ecology 12:155-170.

Stohlgren, T.J., G.W. Chong, M.A. Kalkhan, and L.D. Schell. 1997c. Multi-scale sampling of Plant Diversity: Effects of the minimum mapping unit. Ecological Applications 7:1064-1074.

Stohlgren, T.J., K.A. Bull., Y. Otsuki. 1998a. Comparison of Rangeland Sampling Techniques in the Central Grasslands. Journal of Range Management 51:164-172.

Stohlgren, T.J., K.A. Bull, Y. Otsuki, C. Villa, and M. Lee. 1998b. Riparian zones as havens for exotic plant species. Plant Ecology 138:113-125.

Stohlgren, T.J., J. Belnap, G.W. Chong, and R. Reich. 1998c. A plan to assess native and exotic plant diversity and cryptobiotic crusts in the Grand Staircase-Escalante National Monument. *In* Proceedings of the First Science Conference in the Grand Staircase-Escalante National Monument, Salt Lake City, Utah. (In Press).

Stohlgren, T.J., D. Binkley, G.W. Chong, M.A. Kalkhan, L.D. Schell, K.A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and Y. Son. 1999. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs (In Press).

Strayer, D., J.S. Glitzenstein, C.G. Jones, J. Kolasa, G.E. Lichens, M.J. McDonnell, G.G. Parker, and S.T.A. Pickett. 1986. Long-term ecological studies: an illustrated account of their design, operation, and importance to ecology. Institute of Ecosystem Studies Occasional Publication Number 2. Millbrook, NY.

Suzuki, K., H. Suzuki, D. Binkley, and T.J. Stohlgren. 1998. Aspen regeneration in the Colorado Front Range: differences at local and landscape scales. Landscape Ecology (In Press).

Vitousek, P.M., C.M. D'Antonio, L.L. Loope, and R. Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84:468-478.

Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo. 1997. Human domination of Earth's ecosystems. Science 277:494-499.

Wilson. E. O. 1988. The current state of biological diversity. Pages 3-18 *in* Biodiversity. E. O. Wilson and F. M. Peter. eds. National Academy Press, Washington, DC.

Conservation and Development Approaches to Integrated Inventory and Monitoring for Adaptive Management[1]

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Abstract—In 1996 the Smithsonian's Monitoring and Assessment of Biodiversity Program (SI/MAB) and Shell Prospecting and Development B.V. Peru, in cooperation with Peruvian and international organizations launched a multi-disciplinary assessment and monitoring program for the Camisea region of Peru. The area is located east of the Andes along the Urubamba River. Located northwest of the Manu National Park, the area is considered one of the most species rich regions of the world. One of the largest gas reservoirs for South America is located in this biologically and culturally sensitive area.

The project was designed to evaluate the impact of development on biodiversity following an adaptive management process—setting objectives, carrying out an assessment and monitoring plan for forest biodiversity, evaluation, and decisionmaking. The cyclical nature of the process was maintained through refining the objectives and management decisions based on the results. Thus, adaptive management gives managers the flexibility to adjust on-the-ground practices. This scheme of cooperation allowed more sound development decisions including the decision to avoid the creation of permanent roads, locating the gas processing plant in a biologically less sensitive area, the revegetation of disturbed sites with native species, and the use of underground pipelines.

Six biological components (vegetation, mammals, arthropods, amphibian and reptiles, birds and aquatic systems) were inventoried in the initial assessment phase. The sites were selected to provide information on areas that would be potentially impacted by development. In addition, a strong local community program was established, and two workshops resulted in the implementation of a training program to build in-country capacity for biodiversity monitoring. A conceptual multi-disciplinary model for monitoring was developed to assess the impact of gas extraction, processing, and transport on the local biodiversity.

The Camisea project is now coming to an end due to the Peruvian Government and Shell being unable to agree on the natural gas distribution, and subsequent monitoring phases will not continue. Nevertheless, we have had the opportunity to forge a relationship with industry that was beneficial for conservation. In addition, we feel that Shell's approach has now created a precedent that may well be incorporated into the industry by other companies. As conservation biologists we must be prepared to seek and forge other similar relationships that can benefit our natural environment.

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Natural influences and human actions continually bring about changes in ecosystems. Examples of such natural events at large scales include hurricanes and typhoons, extended out-of-season droughts, and volcanic eruptions. Human-induced effects comprise a large and varied spectrum—from acid rain or dust deposition and the introduction of exotic species to rapid landscape alterations caused by development. It is becoming increasingly clear that species are less able to adapt to natural changes at local and regional scales when those changes are compounded by human-caused alterations (UNEP 1995).

Appropriate management of forest ecosystems requires the ability to measure the impact of such changes, but this information is not easily obtained. Monitoring can aid in evaluating existing management approaches and their impacts on forest ecosystems, providing data needed to ensure that the effects of management are within a previously defined range. The value of the information is enhanced through monitoring programs that cover large spatial and temporal scales. As a minimum requirement, properly designed monitoring should discriminate between changes induced by human and natural phenomena to pinpoint the most effective management choices.

Monitoring programs, even when initially supported by considerable financial and personnel investments may be of little value if the results are not analyzed and put to use. This is often related to a lack of well-defined program objectives and/or insufficient long-term support. A clear statement of goals, objectives, methodologies, and avenues of disseminating data are key to designing and implementing monitoring programs. This in turn will enable policymakers and resource managers to make more informed decisions about sustainable use and conservation of ecosystem resources.

Forest biodiversity monitoring is a science in the process of development. Most of the initial approaches were oriented to improving the prospects of intense logging in temperate forests. For the more complex tropical forest ecosystems, researchers continue to define the most appropriate methodologies for biodiversity sampling and monitoring.

In this paper, we describe the evolving framework initiated by the Smithsonian Institution's Monitoring and Assessment of Biodiversity (SI/MAB) Program (formerly Man and the Biosphere Program) for multi-taxa forest biodiversity monitoring. The SI/MAB program operates through an international network of forest biodiversity monitoring plots. In particular, we address our experience of integrated science, conservation, and development in the Lower Urubamba Region, Peru, through a cooperative partnership with Shell Prospecting and Development (Peru) B.V. (SPDP). This area is of particular interest being one of the most biodiverse regions in Amazonia, yet little prior information is available.

Si/Mab and the Monitoring Process

SI/MAB was created in 1986 to develop protocols for monitoring biodiversity in tropical areas. Since then, we have conducted extensive long-term forest biodiversity research and developed a model education and outreach effort for conservation biologists. Over the past three years, the program has developed guidelines for establishing monitoring in an adaptive management framework in order to provide decision-makers with quality information enabling them to make informed decisions concerning the impact of their activities on the natural environment.

Research

The program has developed a solid foundation based on the research activities that are aimed to (1) test and implement protocols for long-term multi-taxa monitoring in forested habitats; (2) provide a data management and analytical procedures that allow rapid assessment and dissemination of the information; and (3) coordinate the International Network of Biodiversity Monitoring sites (INBM) to facilitate information exchange, dissemination, and data quality standards. It is envisioned that the protocols will enable users to integrate scientific research methods and analysis with strategies for getting the resulting information into the hands of a wider range of users—in particular, decision-makers and resource managers involved with issues of sustainable use and conservation of natural resources.

SI/MAB staff, aided by researchers throughout the international network of forested sites, has developed vegetation protocols that have been adopted at nearly 300 research sites in 23 countries. These protocols facilitate the transfer of comparable data, and provide a framework for data analysis and dissemination (Dallmeier 1992; Dallmeier and Comiskey 1996; 1998b; 1998c). In addition, BioMon (Biodiversity Monitoring Database) has been developed to enable researchers to use consistent protocols for data management thus further facilitating data exchange and comparison (Comiskey 1995; Comiskey et al. 1994; Comiskey and Mosher 1999).

Education

The international network's success is due in part to SI/MAB's dedication to information dissemination on conservation biology. Over 50 workshops and training courses have been held since 1986, reaching over 1,300 people from more than 42 countries. Since 1993, we have hosted the five-week International Biodiversity Monitoring Course that provides participants with a solid framework for establishing long-term multi-taxa monitoring projects. Two additional training courses have been added to the curriculum in 1998 and 1999. The Smithsonian Environmental Leadership and Communication Course provides communication skills for effective conservation and development, and the Economic and Policy Solutions for Ecosystem Conservation, to be held for the first time in 1999, will focus primarily on policy issues in Latin America and the Caribbean. SI/MAB has also hosted numerous symposia in the United States, Taiwan, Peru, and Bolivia, enabling us to reach a wide range of researchers.

Adaptive Management and the Monitoring Process

In order to ensure that monitoring efforts succeed, it is important to provide the conservation community, decision-makers, and industry with high quality information on biodiversity to enable informed decision-making. An adaptive management cycle is used to set objectives, conduct assessment and monitoring, evaluate the results, and make decisions that affect the region (Fig. 1). This process is achieved when the information from one level in the cycle is fed to the next, thus influencing the decisions for future monitoring (Dallmeier 1996; Dallmeier and Comiskey 1998a). Thus, adaptive management enables managers to make informed on-the-ground decisions. SI/MAB has put this experience to the test in cooperation with Shell Prospecting and Development in the Lower Urubamba region of Peru. The remainder of this paper will review our experiences.

Urubamba/Camisea Project

Background

The discovery of natural gas and liquids reserves in the Lower Urubamba Region of Peru in the mid-1980s provided the country with an attractive prospect for converting its growing energy deficit into a positive balance. In addition to cleaner energy, the project afforded the opportunity to attract significant investment in new industries. Shell Prospecting and Development (Peru) B.V. (SPDP) in cooperation with its silent partner Mobil, entered a two year appraisal phase (May 1996 to May 1998). At the end of this phase, SPDP would decide whether to enter a field development phase estimated to last 40 years. SPDP plans included drilling four wells, completing a logistics base, establishment flow lines and a gas plant, and constructing a pipeline across the Andes to coastal facilities. Nevertheless, at the end of the two-year appraisal SPDP was unable to reach an agreement with the Peruvian government concerning the assurance of gas markets, and has since terminated their development plan.

In 1996, the Smithsonian Institution's Monitoring and Assessment of Biodiversity Program joined SPDP in a unique venture aimed at achieving environmentally sensitive development of natural gas and condensate resources[1]. The biologically rich Amazonian lowlands of Peru represent an exciting opportunity to integrate science, conservation, and development through careful

[1]Collaborators included Peruvian scientists from the Museo de Historia Natural of the Universidad Nacional Mayor de San Marcos, Universidad San Antonio Abad del Cusco, and Universidad Nacional de la Libertad (Trujillo).

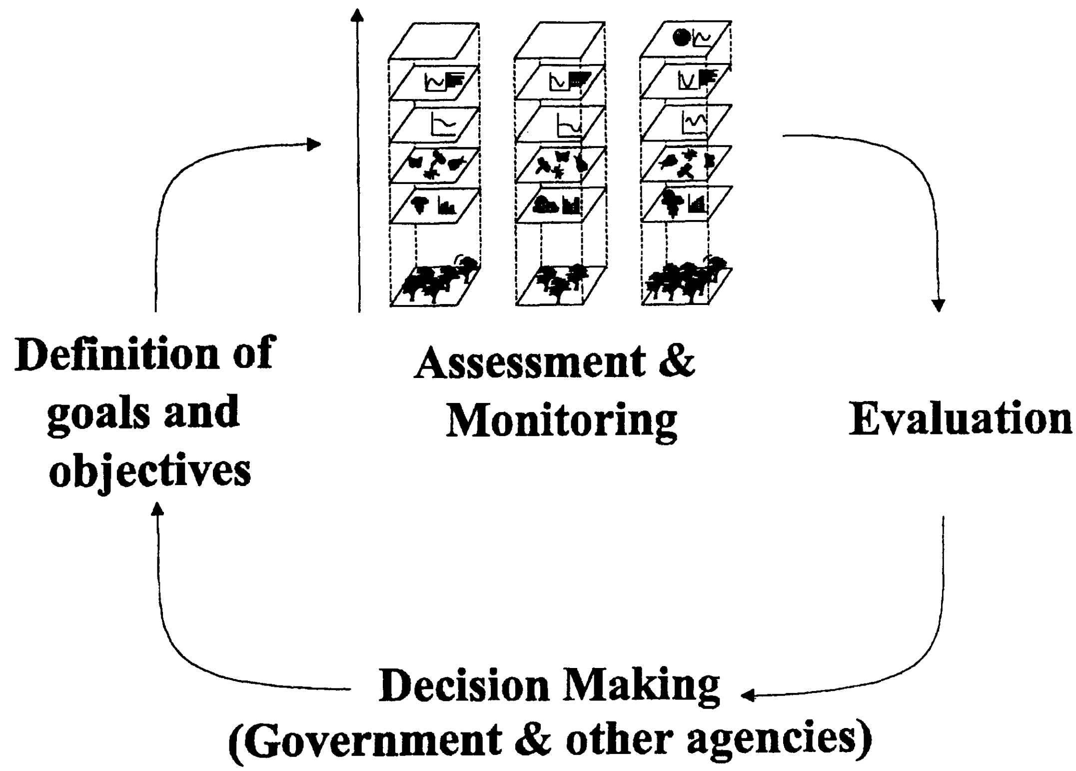

Figure 1.—Adaptive management framework used by SI/MAB for monitoring biodiveristy in the Lower Urubamba Region, Peru.

planning, assessment, monitoring, and decision-making. The Smithsonian's primary responsibilities were to: (1) enact a biodiversity assessment in the study area, (2) conduct long-term monitoring in the vicinities of the sites where SPDP and its partners were drilling gas wells, along the Urubamba and Camisea rivers, and along the proposed pipeline route, and (3) distribute the results in a timely fashion, providing information to assist in management decisions. The work was accomplished by multi-disciplinary teams of researchers under guidelines devised by SI/MAB for long-term, multi-taxa forest biodiversity monitoring at permanent research sites.

Site Description

The area is located east of the Andes Mountains in the Urubamba River valley northwest of the Manu National Park (Fig. 2). The area's lowlands, hills, and mountains vary in elevation, from less than 500 m (lowland rain forest) and 500 to 1,000 m (highland rain forest) with slopes ranging from 25% to 70%. Little is known about most of the plant and animal species that inhabit the lower Urubamba region. The study area encompasses many different climatic zones, soil types, and eco-geological patterns in a relatively small space, suggesting an ecosystem that is complex, and potentially rich in places. A factor that may contribute to high species diversity for both plants and animals in the Urubamba River valley is its status as a potential Pleistocene refuge (Prance 1982).

Examples of decision-making process

The objectives of the scientific portion of the project were to link vegetation information to data about other taxa to be assessed and monitored, and apply the results to decisions about management practices at the well sites and in the region. The assessments were targeted to six biologically diverse groups—vegetation (trees, shrubs, ferns); aquatic systems (water quality, invertebrates, fishes); invertebrates (insects, snails, spiders); amphibians and reptiles (frogs, salamanders, snakes, lizards); birds; and small, medium, and large mammals.

Six phases of the project were completed during SPDPs appraisal phase. Phase I involved a relatively quick assessment of the biological and cultural diversity in the Lower Urubamba region. The initial results revealed high levels of diversity in an area where few prior studies had been conducted, emphasizing the importance of linking conservation and development needs. This was followed by a workshop in September of 1996 to set the parameters for a biodiversity assessment and monitoring program. Participants included representatives of government institutions, non-governmental organizations, the scientific community, and local Native groups. A report on Phase I identified some of the initial findings and partner organizations (Udvardy and Sandoval 1997).

During Phase II researchers conducted biodiversity assessments and established several multi-scale and permanent biodiversity monitoring plots at two of the well sites, San Martin-3 and Cashiriari-2 (Dallmeier and Alonso 1997).

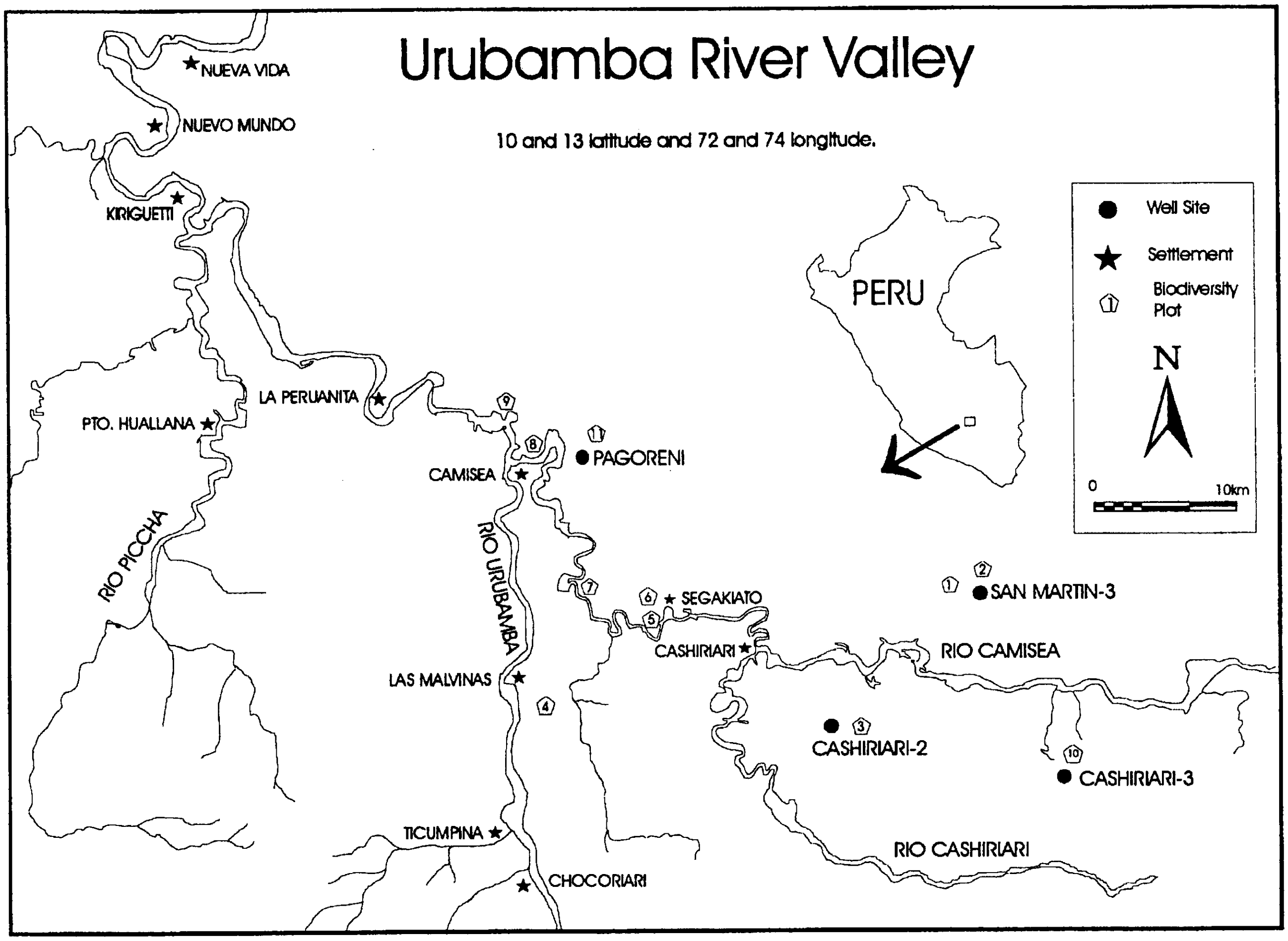

Figure 2.—Location of the study sites in the Lower Urubamba Region, Peru.

Assessment for five selected groups, vegetation, invertebrates, amphibians and reptiles, birds, and mammals, was completed in 1997. Based on this first field experience at the well sites, we were able to devise a plan for monitoring the impact of the well sites on the local biodiversity.

In Phase III, work was conducted at the Cashiriari-3 Well Site and at selected points along the Camisea and Urubamba Rivers. As in the preceding phase of the project, multidisciplinary research teams focused on the overall goal of linking vegetation information to data about other taxa that are being assessed and monitored (Alonso and Dallmeier 1998). Intensive training of young Peruvian scientists was conducted to augment in-country capacity for long-term biodiversity monitoring. Assessment of the riverine sites, and in particular the location of the proposed gas plant revealed a diverse flora and fauna for the studied groups. We recommended that local and regional biodiversity be monitored on a regular basis in the future to assess the impacts of developing the gas plant. The information from the assessments was provided to SPDP for incorporation into management decisions. Based on this information, SPDP made the final decision on the location of the gas plant.

We launched Phase IV in January 1998 with two workshops—one in Washington, D.C. and the other in Lima. The purposes of the workshops were to describe the integrated plan and scope of the monitoring program and define the sampling protocols and management approaches needed to carry out the project activities. More than 100 researchers and specialists attended the two workshops. Alonso and Dallmeier (1999) describe the standardized protocols for biodiversity assessment and monitoring that resulted from the workshops.

To address the immense task of assessing biodiversity at the well sites and along the proposed pipeline route, an intensive training program for young Peruvian biologists was planned for Phase IV at the Pagoreni well site. The initial training sessions were conducted under the direction of personnel from the Smithsonian's Institute for Conservation Biology and the SI/MAB Program. Smithsonian counterparts from Peruvian institutions and other international entities also participated as instructors. Fifty-five national and international biologists were involved in eight weeks of training.

Based on the levels of high biological diversity encountered in this and previous phases, and the likely physical impacts from road construction in the steep terrain of the Urubamba region, we suggested SPDP continue with their "off-shore" policy of helicopter use and no permanent roads. Recommendations were also made as to how to reduce the impact in the case that temporary roads were built. The information was presented to SPDP, who upon evaluation of the different alternatives decided to accept our recommendations, and to continue with their off-shore policy and not build any roads (Alonso and Dallmeier 1999).

During Phase V, the primary focus was aimed at assessing the diversity along the proposed pipeline route that would carry natural gas and condensates from the Lower Urubamba Region, over the Andes to a proposed processing plant at the Pacific coast. Ten sampling sites along the route were selected for assessment and long-term monitoring. The first two montane sites were sampled as SPDP and the Peruvian government decided not to proceed with full field development. One of the options considered by SPDP was the installation of an underground pipeline. Their major concern revolved upon the potential effects of tree roots, and the depth at which the pipeline should be buried. A special report was prepared by SI/MAB for the SPDP on the depth of plant roots (Mistry 1999). This information was then used by engineers to define the most appropriate course of action.

Phase VI arose from the need to finalize the project following SPDPs decision not to proceed with full field development. All of the well sites were visited by the field crews in order to obtain a second season assessment on the component taxa. This information will provide an initial baseline in the event that those companies in charge of future development continue to encourage biodiversity monitoring.

The Future

Our experience with SPDP has been extremely positive. We were able to conduct work in a pristine tropical forest that had received very little prior attention. More importantly, we were able to establish a high level of rapport with high level SPDP managers, and by providing them with information concerning the local biodiversity and their activities, we were able to influence the decision-making process and increase biodiversity conservation awareness. Now that the Urubamba project has come to an end, we feel that it is our responsibility to ensure that our experience is transmitted to other conservation biologists who in turn may be able to conduct similar projects. This will be achieved by disseminating the information in a timely fashion to as wide an audience as possible, including the lay public, development corporations, and other scientists. In the same way that Environmental Impact Assessments are required in most countries, we hope that in the future Biodiversity Assessment and Monitoring too will be required as part of any development project. We feel strongly that SPDP has made a big step in the right direction to creating a precedent that other companies may feel that have to follow. This can only be of benefit for the preservation of biodiversity for future generations.

Summary

Though conservation and development are often viewed as mutually exclusive, our experiences with SPDP state otherwise in the Lower Urubamba region. The growing human population continues to create pressure on the world's natural resources, and with it the need to find solutions that will help minimize the effect of development on biodiversity. It is our responsibility as conservation biologists to ensure that we are able to work with developers to minimize the potential impact on our natural environment by providing them with the information necessary to make informed decisions. Only through establishing these partnerships can we hope to improve the way that development proceeds in the pristine and remote regions of the world such as the Amazon rain forests of South America.

References

Alonso, A. and F. Dallmeier, Eds. (1998). Biodiversity Assessment of the Lower Urubamba Region, Peru. Cashiriari-3 Well Site and the Camisea and Urubamba Rivers. SI/MAB Series #2. Smithsonian Institution/MAB Biodiversity Program. Washington, DC.

Alonso, A. and F. Dallmeier, Eds. (1999). Biodiversity Assessment of the Lower Urubamba Region, Peru. Pagoreni Well Site: Assessment and Training. SI/MAB Series #3. Smithsonian Institution/MAB Biodiversity Program. Washington, DC.

Comiskey, J. A. (1995). BioMon: Biodiversity Monitoring Database Ver. 2.01. SI/MAB, Smithsonian Institution, Washington, DC.

Comiskey, J. A., G. Ayzanoa, and F. Dallmeier. (1994). A data management system for monitoring forest dynamics. *Journal Tropical Forest Science* 7: 419-427.

Comiskey, J. A. and R. Mosher. (1999). BioMon: Biodiversity Monitoring Database for Windows Ver. 2.0. SI/MAB, Smithsonian Institution, Washington, DC.

Dallmeier, F. (1992). Long-term monitoring of biological diversity in tropical forest areas. Methods for establishment and inventory of permanent plots. MAB Digest Series, 11. UNESCO. Paris.

Dallmeier, F. (1996). Biodiversity inventories and monitoring: essential elements for integrating conservation principles with resource development projects. *In*: Biodiversity in Managed Landscapes: Theory and Practice (Szaro R. B. and D. W. Johnston, Eds.). Oxford University Press. New York, New York. pp 221-236.

Dallmeier, F. and A. Alonso, Eds. (1997). Biodiversity Assessment of the Lower Urubamba Region, Peru. San Martin-3 and Cashiriari-2 Well Sites. SI/MAB Series #1. Smithsonian Institution/MAB Biodiversity Program. Washington, DC.

Dallmeier, F. and J. A. Comiskey. (1996). From the forest to the user: a methodology update. *In*: Manu: The biodiversity of southeastern Peru; la biodiversidad del sureste del Peru (Wilson, D. and A. Sandoval, Eds.). Smithsonian Institution Press. Washington, DC. pp 41-56.

Dallmeier, F. and J. A. Comiskey. (1998a). Forest biodiversity assessment, monitoring, and evaluation for adaptive management. *In*: Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies (Dallmeier, F. and J. A. Comiskey, Eds.). Man and the Biosphere Series, Vol 20. UNESCO and The Parthenon Publishing Group. Carnforth, Lancashire, UK. pp 3-15.

Dallmeier, F. and J. A. Comiskey, Eds. (1998b). Forest Biodiversity in North, Central and South America and the Caribbean: Research and Monitoring. Man and the Biosphere Series, Vol 21. UNESCO and The Parthenon Publishing Group. Carnforth, Lancashire, UK.

Dallmeier, F. and J. A. Comiskey, Eds. (1998c). Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies. Man and the Biosphere Series, Vol 20. UNESCO and The Parthenon Publishing Group. Carnforth, Lancashire, UK. 671 pp.

Mistry, S. (1999). Depth of plant roots: implications for the Camisea pipelines and florwlines. *In*: Biodiversity Assessment of the Lower Urubamba Region, Peru. Pagoreni Well Site: Assessment and Training. SI/MAB Series #3 (Alonso, A. and F. Dallmeier, Eds.). Smithsonian Institution/MAB Biodiversity Program. Washington, DC. pp 289-298.

Prance, G. T. (1982). Forest refuges: evidence from woody angiosperms. *In*: Biological Diversification in the Tropics (Prance, G. T., Ed.). Columbia University Press. New York. pp 137-156.

Udvardy, S. and A. Sandoval, Eds. (1997). Proceedings from the workshop on Biological and Cultural Diversity of the Lower Urubamba, Peru. Biodiversity Programs, Smithsonian Institution. Washington, DC. 185 pp.

UNEP. (1995). Global Biodiversity Assessment. United Nations Environment Programme and Cambridge University Press. Cambridge, UK.

Situacion Actual de la Biodiversidad de Mexico[1]

José Concepción Boyás Delgado[2]

Resumen—México está incluido en la lista de los 12 países que poseen la mayor diversidad biológica, considerados como «megadiversos", los cuales en conjunto albergan entre el 60 y 70% de la biodiversidad mundial. El sureste de México, conforma el área de mayor biodiversidad y forman parte de una de las áreas críticas de la diversidad biológica mundial.

La biodiversidad de la República Mexicana es alta en los niveles de ecosistema y de especies; en el caso de la diversidad genética, ésta es poco conocida. A nivel de ecosistema se han registrado en México hasta 32 tipos de vegetación. A nivel de especies, México ocupa el cuarto lugar en el ámbito mundial en cuanto al numero de especies conocidas; a nivel de grupos taxonómicos, nuestro país representa el primer lugar en diversidad de reptiles, el segundo lugar en mamíferos y el cuarto lugar en anfibios y plantas. En relación con la diversidad genética nuestro país es el centro de diversificación de numerosos taxa y además es un centro importante de domesticación de especies vegetales. En términos generales, en México se encuentra el 10% de la diversidad biológica mundial, además dentro del territorio nacional se han registrado un gran numero de endemismos: más de 9 500 especies vegetales y más de 800 especies de vertebrados.

La riqueza biológica de los ecosistemas de México esta sujeta a diferentes presiones que la ponen en riesgo; dentro de las principales causas que han propiciado la pérdida de la biodiversidad destacan la deforestación, la sobre-explotación, la destrucción de habitats, la comercialización ilegal de especies e incendios forestales Debido a las presiones anteriores, una gran cantidad de especies se encuentra amenazadas; se estima que más del 50% de especies de vertebrados y aproximadamente el 4% de plantas vasculares se encuentran amenazadas.

Con el propósito de salvaguardar la biodiversidad, México ha implementado la creación de áreas naturales protegidas, las cuales suman en total 134, que cubren una superficie aproximada de 18. 1 millones de hectáreas en la que también se considera el área marina. Asimismo, nuestro país ha estado colaborando en distintos programas y acuerdos internacionales enfocados hacia la conservación y uso sustentable de la biodiversidad, particularmente con Estados Unidos y Canadá, así como con Organizaciones Internacionales tales como la FAO, PNUMA y UNESCO entre otras.

Biodiversidad es sinónimo de la diversidad biológica. En su forma mas simple la biodiversidad es el conjunto de organismos vivientes vegetales y animales. Para algunos autores biodiversidad significa la variedad de vida en todas sus formas (UICN, 1989); para otros la biodiversidad es la variedad de los organismos del mundo, incluyendo su diversidad genética (Reid y Miller, 1989). En un sentido científico, la biodiversidad es la variedad genética, taxonómica y ecosistemica de los organismos vivientes en un área determinada, de un ambiente o del planeta total (McAllister, 1991a).

El URI y Col. (1991) proponen cuatro categorías para el estudio de la biodiversidad: (a) Diversidad de ecosistemas, (b) Diversidad de especies. (c) Diversidad genética y (d) Diversidad cultural.

La mayoría de las naciones del mundo están realizando esfuerzos para conocer, valorar, usar y conservar la biodiversidad, sin embargo a pesar de ello, la humanidad esta destruyendo la biodiversidad del planeta en nombre de un desarrollo económico. La perdida de la diversidad biológica puede empobrecer la vida humana y alterar su curso de desarrollo, ya que este recurso ha proporcionado a la humanidad una gran cantidad de bienes y servicios: alimentos, medicinas, productos industriales, agua, mejoramiento de la calidad de aire, recreación, protección del suelo y de la fauna silvestre (URI y Col., 1991).

Con el propósito de salvaguardar la biodiversidad se han obtenido tres argumentos fundamentales que justifican su conservación: su utilidad a la humanidad, el derecho a la vida y sus funciones en la ecosfera (McAllister, 1991b). Asimismo se ha establecido un Programa Estratégico de la Biodiversidad. (URI y Col.,1991), el cual contempla diez principios básicos para valorar la biodiversidad y propiciar su conservación.

Con esta misma preocupación México ha desarrollado distintos trabajos abocados hacia el conocimiento de la biodiversidad; dentro de estos, destacan los trabajos de compilación de Sarukhán y Dirzo (1992) con el apoyo de la CONABIO, el de Ramamoorthy y Col. (1998), el de Flores y Geréz (1994) y el de la CONABIO (1997), los cuales abordan diferentes tópicos sobre la biodversidad de México.

Con un enfoque similar, en este articulo se presenta una síntesis sobre los aspectos más relevantes de la biodiversidad terrestre mexicana, para lo cual se han seleccionado los siguientes tópicos: (1) evaluación de la biodiversidad, (2) causas de la riqueza de la diversidad biológica de México, (3) usos de la biodiversidad, (4) causas de amenaza de la biodiversidad y (5) acciones para la conservación de la biodiversidad.

Evaluacion de la Biodiversidad de Mexico

Con el propósito de ganar claridad, en este capitulo se describe sucintamente el estado actual de conocimiento que se tiene en relación con las evaluaciones sobre la diversidad biológica en los distintos niveles de estudio.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Diversidad de ecosistemas

En México se han utilizado varios criterios para clasificar la diversidad de los ecosistemas terrestres, sin embargo la mayoría de ellos toman como principal criterio de clasificación a los tipos de vegetación presentes en el territorio nacional. En general se puede distinguir la siguiente clasificación de los ecosistemas mexicanos: (a) habitats terrestres, (b) ecoregiones, (c) tipos de vegetación y (d) zonas forestales.

Habitats terrestres—La clasificación de habitats terrestres fue propuesta por Toledo y Ordóñez (1998), quienes en función de los tipos de vegetación y el clima, definieron cinco hábitats terrestres: trópico húmedo, trópico subhúmedo, templado húmedo, templado subhúmedo y árido-semiárido (Cuadro 1). El hábitat árido-semiárido cubre cerca del 50% de la superficie del país; le siguen en orden de importancia el habitat templado subhúmedo con 19.7%, el habitat tropical cálido-subhúmedo que ocupa 17.5% y el habitat tropical húmeda que se distribuye en 11% del país.

Ecorregiones—El concepto de ecorregión fue introducido por Dinerstein y Col. (1995) el cual fue utilizado para evaluar las regiones naturales de América Latina y el Caribe; este sistema emplea un esquema jerárquico dividido en ecosistemas, estos en habitats y estos a su vez en ecoregiones (Cuadro 2). De acuerdo con esta clasificación, México ocupa el primer lugar en diversidad ecológica de América Latina y el Caribe al incluir dentro de su territorio a los cinco tipos de ecosistemas (100%), 9 de los 11 tipos de hábitats (82%) y 51 de las 191 ecorregiones identificadas (26.7%).

Tipos de vegetación—Uno de los criterios mas utilizados en México para evaluar la diversidad de ecosistemas es a través de los tipos de vegetación, de los cuales existen varias clasificaciones al respecto; en nuestro país una de las clasificaciones mas conocidas es la de Rzedowski (1978), quien mediante criterios fisonómicos y climáticos principalmente define 9 tipos de vegetación terrestres, de los cuales los de mayor extensión superficial son el matorral xerófilo y el bosque de coníferas y encinos que cubren respectivamente el 40% y 20% del territorio nacional (Cuadro 3)

Zonas forestales—Una clasificación simple de la diversidad de los ecosistemas ha sido formulada por la SARH (1994) en sus trabajos del Inventario nacional Forestal, agrupando a los distintos tipos de vegetación en tres ecosistemas principales: bosques, selvas y vegetación de zonas áridas (Cuadro 4). De acuerdo con esta información la superficie forestal total de México es de 141.7 millones de hectáreas, es decir, el 72% de la superficie nacional; a nivel de cosiste terrestre, el 30% de la superficie nacional corresponde a vegetación de zonas áridas, el 16% a bosques, el 12% a selvas, el 13% a zonas forestales perturbadas y el 2% a vegetación hidrófila y halófila.

Cuadro 1.—Principales habitats terrestres de México

Hábitat	Superficie (Mill. ha)	Vegetación Dominante	Clima
Trópico húmedo	22	Bosque tropical húmedo	Cálido húmedo
Trópico subhumedo	40	Bosque tropical caducifolio	Cálido subhúmedo
Templado húmedo	1	Bosques mixtos	Semicálido húmedo
Templado subhúmedo	33	Bosque de pino y encino	Templado subhúmedo
Arido y semiárido	99	Matorrales y pastizales	Arido

FUENTE: Toledo y Ordóñez (1993)

Cuadro 2.—Ecorregiones de América Latina y el Caribe (AL y C)

Tipo de ecosistema	Tipo de habitat	No. de ecorregiones En AL y C	No. de ecorregiones En México
Bosques tropicales de hoja ancha	Bosques humedos tropicales de hoja ancha	55	5
	Bosques secos tropicales de hoja ancha	31	8
Bosques de coníferas y bosques templados de hoja ancha	Bosques templados	3	0
	Bosques tropicales y subtropicales de coníferas	16	10
Pastizales/sabanas/ matorrales	Pastizales, sabanas y matorrales	16	4
	Pastizales inundables	13	4
	Pastizales montanos	12	1
Formaciones xéricas	Matorrales mediterráneos	2	1
	Desiertos y matorrales	27	13
	Restingas	3	0
Manglares	Manglares	13	5
	Total de ecorregiones	191	51

FUENTE: Dinerstein y Col. (1995)

Cuadro 3.—Tipos de vegetación de México y su extensión territorial.

Tipo de vegetación	Superficie (Mill. de ha)	Porcentaje de la superficie del país
Bosque tropìcal perennifolio	11	5.5
Bosque tropical subcaducifolio	4	2
Bosque tropical caducifolio	9	4.5
Bosque espinoso	5	2.5
Pastizal	10	5
Matorral xerófilo	40	20
Bosque de *Quercus*	5	2.5
Bosque de coníferas	15	7.5
Bosque mesófilo de montaña	1	0.5

FUENTE: Rzedowski (1978).

Cuadro 4.—Ecosistemas y tipos de vegetación de México.

Ecosistema	Tipo de vegetación	Superficie (Mill. de ha)	Porcentaje
Bosques	Coniferas	6.3	4.5
	Pino-encino	10.9	7.8
	Encino	9.5	6.7
	Bosque mesofilo de montaña	1.4	1.0
	Bosque fragmentado	3.5	2.5
Selvas	Selva alta y mediana	5.8	4.1
	Selva baja	10.9	7.8
	Selva fragmentada	6.7	4.7
	Otros	1.3	0.9
Vegetación de zonas áridas	Matorral espinoso	11.4	8.1
	Matorral submontano	5.7	4.0
	Matorral xerófilo	41.3	29.3
Otros Ecosistemas	Zonas forestales perturbadas	22.2	15.7
	Vegetación hidrofila y halófila	4.1	2.9
Total forestal		141	100

FUENTE: SARH(1994)

Diversidad de Especies

En el contexto internacional, México es uno de los 12 países que en conjunto agrupan entre el 60 y el 70% de la biodiversidad total del planeta; por tal motivo este país esta considerado como megadiverso (Mittermeier y Goettsch, 1992).

Nuestro país en solamente el 1.3% de la superficie terrestre, concentra el 10% de la biodiversidad mundial, ocupando el primer lugar en cuanto al número de especies de reptiles, el segundo lugar en mamíferos, el cuarto lugar en anfibios, el onceavo lugar en aves y el cuarto lugar en plantas vasculares; en lo referente a invertebrados no se tiene actualmente la información precisa, pero se conoce que México agrupa a 52 de las 1012 especies reconocidas de mariposas. (SEMARNAP, 1997) (Cuadro 5).

De acuerdo con la información actual, la biodiversidad total de México es de aproximadamente 69 000 especies conocidas, sin embargo esta cifra aumentará notablemente conforme avance el conocimiento y las recolecciones de los distintos grupos taxonómicos, debido a que falta profundizar en las investigaciones de los grupos taxonómicos inferiores y en la exploración de áreas silvestres poco conocidas (Cuadro 6).

Tomando en consideración las cifras anteriores, se puede inferir que México alberga mas del 10% de la biodiversidad mundial; sin embargo, estos datos aun son muy parciales ya que las estimaciones de la biodiversidad es mas completa para los grupos taxonómicos de vertebrados y de la flora fanerogámica, pero no es el mismo caso para los invertebrados y la flora criptogámica.

Cuadro 5.—Países con mayor diversidad de especies de vertebrados y plantas

Grupo	País y número de especies				
Plantas	Brasil	Colombia	China	**México**	Australia
	55 000	45 000	30 000	**26 000**	25 000
Anfibios	Brasil	Colombia	Ecuador	**México**	Indonesia
516	407	358	282	**270**	
Reptiles	**México**	Australia	Indonesia	Brasil	India
	707	597	529	462	433
Mamíferos	Indonesia	**México**	Brasil	China	Zaire
	519	**439**	421	410	409

FUENTE: Mittermeier y Goettsch (1992)

Cuadro 6.—Riqueza biológica de México agrupada en grupos taxonómicos

Grupo taxonómico	No. de especies en el mundo	No. de especies México	%de México a nivel mundial	Referencia
Protozoarios	40 000	1 014		Lopez-Ochoterena, 1993
Lepidopteros	200 000	25 000		Llorente y Martinez, 1998
Coleopteros	160 000	7 988		CONABIO, 1997
Apoidea	20 000	1589		Ayala y col. 1998
Anfibios	4 014	285		Flores, 1998
Reptiles	5 965	693		Flores, 1998
Aves	9 500	1 054		Flores y Geréz, 1994
Mamíferos	4 091	4 91		Cervantes y col., 1994
Hongos	70 000	6 000		Guzmán, 1995
Briofitas	20 000	2 000		Delgadillo, 1998
Pteridofitas	9 000	1 100		Riba, 1998
Gimnospermas	650	89		Toledo y Ordoñez, 1998
Angiospermas	235 000	22 000		Rzedowski, 1992
Total		69 303		

De acuerdo con Rzedowski (1998), dentro de la flora fanerogámica, las familias con el mayor numero de especies conocidas para México son: Compositae (2400), Leguminosae (1800), Gramineae (950), Orchidaceae (920), Cactaceae (900) y Rubiaceae (510).

A nivel de tipos de vegetación, los ecosistemas con mayor diversidad florística son el bosque de coníferas, el bosque tropical caducifolio y el matorral xerófilo, los cuales integran mas del 20% cada uno de la flora total del país (Cuadro 7); sin embargo una mención especial merece el bosque mesofilo de montaña, el cual solamente cubre el 1% de la superficie forestal de la Republica Mexicana pero incluye el 10% de las especies del total nacional (Rzedowski, 1998).

México no solamente se distingue por su gran diversidad de especies sino también por su alto índice de endemismos, es decir, de especies que solamente se encuentran en los límites geopolíticos del país (Cuadro 8); mas de 800 especies de vertebrados son endémicas, destacando los anfibios con el 62% de endemismo en el territorio mexicano (Mittermeier y Goettsch, 1992).

Dentro de la flora mexicana se han registrado más de 9 000 especies de fanerógamas endémicas (Rzedowski, 1998), de las cuales las familias con los más altos porcentajes de endemismo son Cactaceae con 79% (Arias, 1993), Agavaceae con 67% (Garcia y Galván, 1995), Nolinaceae con 65% (García y Galván, 1995) y Pinaceae con 44% (Styles, 1998).

Cuadro 7.—Diversidad de especies por tipo de vegetación en México

Tipo de vegetación	% de la superficie forestal del país	No. de especies	% con respecto al total de la flora
Matorral xerófilo y pastizales	50	6000	20
Bosque de coniferas	21	7000	24
Bosque mesofilo de montaña	1	3000	10
Bosque tropical perennifolio	11	5000	17
Bosque tropical caducifolio	17	6000	20
Vegetación acuática y subacuática	—	1000	3
Vegetación ruderal y arvense	—	2000	3

FUENTE: Rzedowski (1998)

Cuadro 8.—Endemismos en México de algunos grupos taxonómicos

Grupo taxonómico	No. total de especies	No. de especies endémicas	% de especies endémicas	Fuente
Pteridofitas	1000	190	19	Riba, 1998
Pinaceae	48	21	44	Styles, 1998
Angiospermae	22 000	9300	48	Rzedowski, 1998
Anfibios	295	174	60	Flores y Geréz, 1994
Reptiles	705	368	52	Flores y Geréz, 1994
Aves	1060	89	8	Flores y Geréz, 1994
Mamíferos	491	141	29	Flores y Geréz, 1994

Por su parte, los bosques templado fríos de pino y encino de México son los más diversos de la Tierra, con 55 especies de pino y 138 especies de encino, de las cuales el 85% de las especies de pino y el 70% de las especies de encino son endémicas del territorio mexicano (INEGI-SEMARNAP, 1998).

En relación con los tipos de vegetación también se presentan endemismos interesantes, destacando el bosque de coniferas y encino en el cual se registra el 70% de endemismos de la flora total conocida para México; le siguen en importancia de endemismos el matorral xerófilo y el bosque tropical caducifolio con el 60 y el 40% de endemismos respectivamente (Rzedowski, 1998). Un caso notable también lo es el bosque mesofilo de montaña que a pesar de tener una superficie muy reducida en el país (1% del territorio nacional) alberga un alto porcentaje de endemismos (30%).

Diversidad Genética

La diversidad genética de las especies vegetales y animales silvestres de México es muy poco conocida; el número de especies estudiadas es muy pequeño, considerando su enorme diversidad biológica y a pesar de que este país es el centro de diversificación de numerosos grupos taxonómicos como son los pinos, encinos, cactáceas y reptiles. La mayoría de los estudios sobre diversidad genética en este país se han concentrado hacia especies agrícolas y ganaderas de mayor importancia (INEGI-SEMARNAP, 1998).

México es un centro importante de domesticación de especies vegetales, en el cual se han registrado aproximadamente 118 especies de plantas domesticadas, pertenecientes a 70 géneros y 39 familias; esta cifra aumenta notablemente si se consideran a los cultivares o variedades de cada una de estas especies, como es el caso del frijol y del maíz (Hernández X., 1993). A nivel de grupo taxonómico, las siguientes familias agrupan el mayor número de especies domesticadas: Cactaceae, Leguminosae, Asteraceae, Agavaceae, Annonaceae y Cucurbitaceae (Cuadro 9).

Cuadro 9.—Familias vegetales con mayor numero de especies domesticadas en México.

Familia	No. de géneros	No. de especies
Cactaceae	4	16
Leguminosae	9	14
Asteraceae	5	9
Agavaceae	2	7
Annonaceae	1	6
Cucurbitaceae	3	6
Sapotaceae	3	5
Anacardiaceae	3	4
Euphorbiaceae	4	4
Solanaceae	3	4
Amaranthaceae	1	3
Rutaceae	1	3
Sterculiaceae	1	3

FUENTE: Hernández X. (1993)

Diversidad Etnobotánica

México también es uno de los paises con mayor diversidad cultural, ya que cuenta con 8 millones de personas que hablan alguno de los 54 idiomas indigenas de este país; esta riqueza cultural combinada con su riqueza florística ha diversificado las interrelaciones planta-hombre (Bye, 1998); tomando en cuenta este fundamento, se han realizado varias investigaciones de carácter etnobotánico en distintas regiones del país, con el propósito principal de rescatar el conocimiento tradicional que las comunidades indígenas tienen sobre el aprovechamiento de la flora silvestre. Con este enfoque de trabajo se han obtenido catálogos de especies útiles agupadas en diferentes categorías antropocéntricas (categorías de uso), dentro de las cuales destacan los usos medicinales, comestibles, construcción rural, leñas y artesanías.

No existe en México todavía un inventario etnobotánico completo; sin embargo se estima que en este país existen alrededor de 5 000 angiospermas útiles, es decir, el 23% de la flora nacional (Caballero, 1987); de estas aproximadamente 3 300 especies tienen algun uso medicinal (Bye y Col., 1990). En una de las regiones del sur de México, Boyás y Col. (1993) registraron mas de mas de 400 especies útiles del bosque tropical caducifolio, agupadas en 12 categorías antropocéntricas: medicinales, construcción rural, leñas, postes para cercos, implementos agrícolas, artesanales, comestibles, forrajeras, industriales, ornamentales, tutores y ceremoniales, destacando numéricamente dentro de estas, las especies medicinales.

Asimismo, INEGI-SEMARNAP (1998) reporta 200 especies útiles en el bosque tropical perennifolio, 300 especies con algún uso tradicional en los bosques templado fríos y más de 450 especies útiles en a vegetación de zonas áridas y semiáridas de México.

Causas de la Biodiversidad de Mexico

La megadiversidad de México se debe a factores biogeográficos, físicos e históricos; estos factores han contribuido a formar un mosaico ambiental muy heterogéneo, lo cual ha propiciado la formación de una gran variedad de habitats y formas de vida en este país (Sarukhán y Col., 1996).

De acuerdo con los biogeografos, la mayor parte del territorio mexicano se encuentra entre dos grandes regiones: la Neotropical (que corresponde a Centroamérica y Sudamérica) y la Neartica o Boreal (que corresponde a Norteamérica), las cuales hicieron contacto hace aproximadamente seis millones de años (CONABIO, 1997). Debido a esta situación, México constituye una zona biogeográficamente compuesta, donde el contacto entre biotas ancestrales ha dado como resultado una rica mezcla de fauna y flora con diferentes historias biogeográficas (Flores y Gerez, 1994).

Desde el punto de vista físico, los factores climáticos, fisiograficos y edáficos en forma conjunta han propiciado una gran variedad de ambientes que han sido determinantes en la riqueza biológica de México. Desde el punto de vista climático, México tiene dentro de su territorio a la mayoría de los climas conocidos en el mundo; topográficamente nuestro país está dividido en 15 regiones o provincias fisiográficas y en lo que respecta a suelos, la República

Mexicana posee 23 (mas del 80%) de las categorías de suelos conocidas en el mundo.

Desde el punto de vista histórico, la diversidad biológica de México ha sido influenciada por los cambios climáticos severos ocurridos durante el Pleistoceno, cuando los glaciares se extendieron a latitudes tales que nuestro país estuvo bajo la influencia de climas fríos y templados. Este evento provocó el establecimiento de especies de climas fríos, mientras que las especies de climas tropicales se extinguieron en gran parte de las áreas que ocupaban, restringiéndose a ciertas zonas denominadas refugios pleistocénicos. El aislamiento que sufrieron las especies en estos refugios dio origen al surgimiento de nuevas especies, las cuales ampliaron su área de distribución una vez que los glaciares se retiraron. Este proceso produjo un incremento considerable en el número de especies, por lo que se puede decir que un buen número de las especies presentes en México son de origen relativamente reciente y de naturaleza endémica. (Cordero y Morales, 1998 *in* CONABIO, 1997).

Uso de la Biodiversidad en Mexico

El uso de la biodiversidad en México se puede agrupar en dos tipos de valores: servicios ambientales y usos directos comerciales o tradicionales. En el primer rubro se pueden reconocer la regulación del clima, la protección de mantos acuíferos, la protección del suelo, ecoturismo, secuestro de carbono y fijación del nitrógeno; en el segundo rubro se ubican todos los aprovechamientos directos que se tienen de las especies vegetales y animales.

Servicios Ambientales

Los bosques y selvas influyen en la regulación del clima, la captación de agua y la protección de cuencas y suelos manteniendo los procesos ambientales; sin embargo en nuestro país no se han realizado evaluaciones puntuales sobre el valor de uso de estos servicios ambientales.

El ecoturismo en las áreas naturales de México representa alrededor del 5% en relación con el turismo tradicional, no obstante se espera que en los próximos años esta actividad se fomente en forma considerable, ya se han detectado 850 sitios de alto potencial ecoturistico (SEMARNAP, 1995).

En relación con el secuestro de carbono, se sabe que los bosques son almacenes naturales de carbono que ayudan a mitigar el calentamiento global; en este sentido varios países actualmente se encuentran dispuestos a pagar por mantener este servicio que los bosques brindan y cuyos beneficios pueden y deben llegar directamente a los dueños de los bosques (CONABIO, 1997). Se ha estimado que la captura de carbono por los bosques y selvas de México, tiene un costo que varía de 650 a 3400 dólares por hectárea (INEGI-SEMARNAP, 1998).

Usos Directos

Los usos directos de la biodiversidad mexicana se pueden agrupar en productos forestales maderables, productos forestales no maderables y aprovechamiento de fauna silvestre.

Los productos forestales maderables de México se obtienen básicamente de los bosques templados y de las selvas tropicales; se estima a nivel nacional una superficie de 21 millones de hectáreas con potencial maderable comercial; el volumen maderable estimado a nivel nacional es de 2 800 millones de metros cúbicos, de los cuales 1 800 millones corresponden a bosques templados 1 000 millones a selvas (SARH, 1994). Las especies de mayor comercialización son el pino, el oyamel, el encino y especies tropicales comerciales como el cedro y la caoba..

Durante 1994, el pino aportó más de 80% de las divisas generadas por el sector forestal, seguido por el encino (5.5%) y las maderas corrientes tropicales (4.9%), lo que indica que el sector forestal maderable es poco diversificado dependiente de muy pocas especies (Téllez, 1994).

En cuanto a la producción vegetal no maderable, se han estimado en los últimos 34 años un promedio de 75 000 toneladas de productos no maderables; la mayor parte de la producción no maderable está representada por la resina de pino (53%), cera de candelilla (12%), pencas de maguey (7%), pimienta (5.5%) y el fuste de yuca (7%) (Dirección General Forestal, 1997). Sin embargo se calcula que existen mas de 250 productos no maderables que incluyen hojas, frutos, rizomas, resinas, gomas ceras, cortezas y hongos, de los cuales 70 de estos productos se encuentran regulados (INEGI_SEMARNAP, 1998).

En relación con las plantas útiles, se han registrado para México mas de 1 300 especies útiles, de las cuales alrededor de 1 100 especies se consideran como comerciales (Cuadro 10). Se estima que en los bosques templados potencialmente se pueden generar hasta 528 millones de dólares por la comercialización de especies no maderables y 729 millones de dólares en los bosques tropicales por este rubro ((INEGI_SEMARNAP, 1998). En el bosque tropical caducifolio existe una gran diversidad de especies útiles, ya que se han inventariado mas de 400 especies silvestres con usos comerciales y tradicionales (Boyás y col., 1993).

Dentro de las distintas categorías de uso de las especies vegetales sobresalen las medicinales, de las cuales se han registrado aproximadamente 4000 especies de plantas con uso medicinal (15% de la flora total nacional), de estas, el 6% han sido validadas desde el punto de vista clínico y farmacológico (CONABIO, 1997).

La fauna silvestre de México es aprovechada para distintos fines: cacería cinegética, comercialización de productos o ejemplares, así como para uso alimenticio y medicinal.

Mediante la cacería cinegética se han obtenido ingresos promedio por temporada de.4 millones de dólares (Pérez-Gil y Col., 1996 *in* CONABIO, 1997). Las especies de fauna

Cuadro 10.—Productos no maderables por tipo de ecosistema

Tipo de ecosistema	No. de especies	Especies útiles actuales	Especies comerciales
Selvas altas	5 000	200	30
Selvas bajas*	6 000	400	25
Bosques templados	7 000	300	30
Zonas áridas y semiáridas	6 000	450	25
Totales	20 000	1350	110

FUENTE: CONABIO, 1997; Boyás, 1993*.

silvestre que tienen mayor interés cinegético en nuestro país son el venado cola blanca, venado bura, el borrego cimarrón, gato montés, coyote, conejos, liebres, patos, gansos y palomas.

El valor total de las exportaciones de vertebrados silvestres de México, durante los años de 1982 a 1992, ascendió a la cantidad de $107 733 958 060. Durante esos años México exportó vertebrados silvestres a 44 países, siendo los principales, por el valor económico de la exportación, los siguientes: Estados Unidos con 61%, Japón con 9% y Canadá con 6.5% (Pérez-Gil y Col., 1996 *in* CONABIO, 1997). La captura y aprovechamiento de aves canoras y de ornato es otra forma de uso de la fauna silvestre; esta ultima actividad ha proporcionado emplean mas de 3 400 familias del país (CONABIO, 1997). Otra forma de aprovechamiento de la fauna silvestre es en la industria de pieles, en la cual existen altas cotizaciones para la piel de venado, víbora de cascabel e iguana negra.

Todavía no esta sistematizada en México la información sobre el uso alimenticio de la fauna silvestre por parte de las comunidades rurales; sin embargo se conoce que un gran número de grupos étnicos y comunidades rurales del país obtienen su fuente de proteínas de una gran variedad de vertebrados e invertebrados silvestres; en algunas de las regiones rurales de México la proteína animal de origen silvestre o carne de monte contribuye hasta con 70% de la dieta de la población (CONABIO, 1997). También se sabe que desde la época prehispánica se utilizan como alimento distintas especies de insectos, de los cuales actualmente se cuenta con un registro de 398 especies comestibles (Elorduy, 1996).

Tampoco se encuentra bien documentada la información sobre especies medicinales de fauna silvestre, sin embargo se cuenta con referencias de que en el bosque tropical caducifolio del sur de México el uso medicinal de la fauna silvestre tiene una gran influencia en las comunidades rurales de esta región (Boyás, 1993).

Causas de Amenaza de la Biodiversidad de Mexico

Las principales amenazas que atentan contra la biodiversidad mexicana, se pueden ubicar a dos niveles: a nivel de ecosistema y a nivel de especie. Dentro de las amenazas principales a nivel de ecosistema se identifican la destrucción del hábitat, la deforestación, la agricultura, la ganadería, la erosión y los incendios forestales. A nivel de especies, las principales causas de amenaza son la sobreexplotación, el comercio ilegal e irracional (tráfico de especies) y la introducción de especies.

Causas de Amenaza a Nivel de Ecosistema

La destrucción de los hábitats naturales es una de las causas más severas que ha propiciado la pérdida de la biodiversidad a nivel mundial (Ehrlich and Ehrlich, 1992); en México no es la excepción. La destrucción de hábitats se debe fundamentalmente al desarrollo no regulado de asentamientos humanos y creación de centros turistico-recreativos no planificados adecuadamente dentro de las zonas de vida silvestre; esta situación a su vez ha sido provocada por la explosión demográfica que ha experimentado nuestro país en los últimos 50 años.

México está considerado entre los piases con mayor tasa de deforestación en el mundo, causada por actividades agropecuarias y asentamientos humanos irregulares principalmente; las ultimas estimaciones nacionales revelan que nuestro país tiene una tasa de deforetación que varia de 300 mil ha (SARH, 1994) hasta cerca de 700 mil ha (FAO, 1993). Por esta causa el país ha perdido más de 95% de sus bosques tropicales húmedos (incluyendo selvas perennifolias y bosques mesófilos), más de la mitad de sus bosques templados y posiblemente mas de la mitad del acervo original de la biodiversidad de las zonas áridas (CONABIO, 1997).

La superficie del territorio nacional dedicada a la agricultura es de aproximadamente 20 millones de hectáreas desde hace casi dos décadas, año con año se abren nuevas tierras al cultivo, por lo cual el país se encuentra ya en el límite de su superficie con potencial agrícola. Sólo una cuarta parte son tierras con pendientes que permiten la mecanización y que cuentan con sistemas de riego (5 millones de hectáreas). Del resto, la mayoría se ubica en pendientes abruptas de gran fragilidad y fácilmente erosionables (SEMARNAP, 1997).

La superficie ganadera también crece a costa de los ecosistemas terrestres de México; solamente en el periodo de 1950 y 1990 la superficie dedicada a las actividades ganaderas pasó de 50 millones de hectáreas a cerca de 130 millones de hectáreas, es decir, cerca de dos terceras partes del territorio nacional (SEMARNAP, 1997); solamente en el sureste del país, la transformación de tierras forestales en pastizales tuvo un aumento del 150% en el periodo de 1970 a 1979 (Lazos, 1996 *in* CONABIO, 1997).

La erosión del suelo es considerada como uno de los problemas ecológicos más severos de los recursos naturales renovables de México. De los casi 200 millones de hectáreas del territorio nacional, 154 millones están sujetos a diversos grados de erosión, lo que representa 78.3% de la superficie del país (SEDESOL, 1994a).

Otro de los factores que disminuyen la riqueza biológica de México son los incendios forestales; como indicador basta decir que solamente en el año de 1998 se registraron 14300 incendios forestales que afectaron a aproximadamente a 583 000 ha (SEMARNAP, 1998).

Causas de Amenaza a Nivel de Especie

La sobreexplotación de especies terrestres en México ha provocado una dramática disminución de las poblaciones silvestres de especies vegetales y animales; generalmente esta sobreexplotación se concentra en aquellas especies de mayor interés comercial o de uso tradicional, provocando que varias especies se encuentren en riesgo de amenaza en vías de extinción, como es el caso de la iguana negra (*Ctenosaura pectinata*), en el estado de Guerrero.

El comercio ilegal incluye a especies de vertebrados e invertebrados, y de plantas vasculares y no vasculares de los diversos ecosistemas del país. Algunas agencias especializadas en el tráfico de especies estiman que esta actividad es la tercera en importancia de entre las actividades ilícitas, de acuerdo con los ingresos que genera, después del tráfico de drogas y de armas (CONABIO, 1997; las especies de aves, cactáceas y orquídeas endémicas son las más afectadas por el tráfico ilícito, al contar con mercados internacionales importantes y estar localizadas en áreas restringidas (INE, 1997). Asimismo, en esta categoría se pueden incluir a las especies medicinales, de las cuales poco control se tiene en el tráfico de las mismas.

La introducción de especies exóticas afecta la permanencia y la estabilidad de las poblaciones silvestres locales y sus ecosistemas, ya que un nuevo depredador competidor o un agente patógeno, pueden poner en peligro rápidamente a especies que no pueden desarrollarse conjuntamente con los intrusos; algunos de estos aspectos han sido documentados en algunas islas del norte de México (CONABIO,1997).

Cuadro 11.—Numero de especies terrestres registradas en la NOM-059-Ecol-1994 (SEDESOL, 1994b)

Grupo	En peligro	Amenazadas	Raras	Protección especial
Mamíferos	32	31	47	11
Aves	30	84	122	3
Reptiles	13	40	84	29
Anfibios	1	7	38	2
Plantas	56	159	186	31
Hongos	10	9	28	6

FUENTE: SEMARNAP (1997)

Especies en Riesgo de Amenaza

Las especies legalmente protegidas en México se encuentran registradas en la Norma Oficial Mexicana (NOM-059- ECOL 1994) la cual fue editada por SEDESOL (1994b). En este artículo se presentan las especies y subespecies de flora y fauna silvestre terrestres y acuáticas que se encuentran en peligro de extinción, raras, amenazadas y las que se encuentran sujetas a protección especial; dentro de estas categorías también se reportan las especies endémicas, de las que se establecen las especificaciones para su protección (Cuadro 11).

la NOM-059- ECOL 1994 incluye 950 especies de plantas de fanerogamas y hongos, de las cuales 466 (49%) son endémicas. La mayor parte de especies de plantas superiores y hongos (45%) se encuentran en la categoría de raras en la Norma Oficial antes citada y solamente el 14% se consideran en peligro de extinción. Las familias botánicas con mayor número de especies amenazadas o en peligro de extinción son las cactáceas, orquídeas, palmas, cicadáceas y agaves (CONABIO, 1997).

La NOM-059- ECOL 1994 incluye 1 420 especies de vertebrados, de las cuales 783 (55%) son endémicas; la mayor parte de las especies de este gran grupo taxonómico (49%) se agrupan en la categoría de raros y el 12% se considera en peligro de extinción; los grupos mas afectados son las aves y los reptiles (CONABIO, 1997).

Especies Extintas de México

Las especies extintas son aquéllas que ya no se encuentran en su área de distribución geográfica debido a múltiples factores; para un país, se considera como especie desaparecida aquélla cuyas poblaciones ya no existen en su territorio pero siguen presentes en otros países (Ceballos, 1993).

Se ha calculado conservadoramente una pérdida de 3 a 9% de las especies del planeta para el año 2000; si se mantiene el ritmo actual de extinción, el número de especies actuales se reducirá a la mitad para el año 2050 (Ehrlich y Ehrlich, 1992).

Se tienen estimaciones que desde el siglo XVII hasta la actualidad, se han extinguido 910 especies en el mundo; en el caso de México, se han extinguido 15 especies de plantas y 32 de vertebrados (Cuadro 12), es decir, el 5.2% de las extinciones del mundo de los últimos 400 años (CONABIO, 1997).

Acciones para la Conservacion de la Biodiversidad

El Gobierno mexicano ha mostrado un gran interés en participar dentro de los esfuerzos internacionales para lograr la conservación de la biodiversidad, dentro de los cuales cabe destacar el Convenio sobre la Diversidad Biológica el cual funge como un instrumento jurídico mundial que pretende revertir la tendencia de la pérdida de la biodiversidad. Este Convenio fue acordado en la Conferencia de las Naciones Unidas sobre el Medio Ambiente y el Desarrollo, conocida como "cumbre de la tierra", la cual se celebró en la ciudad de Río de Janeiro el 5 de junio de 1992.

Los tres objetivos del Convenio sobre Diversidad Biológica son: la conservación de la biodiversidad, el aprovecahamiento sostenible de los recursos y la equitatividad de los beneficios obtenidos del aprovechamiento de la biodiversidad.

Cuadro 12.—Numero de especies de vegetales y animales terrestres que se han extinguido en México

Grupo Taxonómico	Especies extintas en México	Especies extintas en el mundo	Fuente
Plantas	15	595	WCMC, 1992 *in* CONABIO, 1997
Anfibios	2	5	UICN, 1996; 1998
Reptiles	0	21	UICN, 1996; 1998
Aves	8	108	UICN, 1996; Ceballos, 1993
Mamíferos	4	89	UICN, 1996; Ceballos, 1993
Total	31	817	

Cuadro 13.—Numero de áreas naturales protegidas y superficie por categoría.

Categoría	No. de Areas	% del total de Areas	Superficie (ha)	% de la superficie total protegida
Reserva de la Biosfera	19	15.2	7 697 236	43.5
Parque Nacional	61	48.8	1 376 882	7.8
Monumento Natural	3	2.4	13	0.1
Area de Protección de Recursos Naturales	33	26.4	6 925 816	39.2
Area de Protección de Flora y Fauna	9	7.2	1 660 502	9.4
Total	125	100	17 660 449	100

FUENTE: CONABIO (1997).

Dentro de estos amplios objetivos cada país deberá desarrollar estrategias, planes y programas para la utilización sostenible de la diversidad biológica bajo sus alcances y perspectivas nacionales. En este sentido, el Gobierno de México fundó la Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), que es la Institución encargada de formular la estrategia nacional, con la cual han colaborado diversas Instituciones nacionales encargadas del manejo sustentable de los recursos naturales del país, entre ellas el Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP).

Desde el punto de vista legal, En México se implementó la Ley General del Equilibrio Ecológico y Protección del Ambiente (1997) en la cual se presentan los lineamientos para salvaguardar y aprovechar de manera sustentable la biodiversidad del territorio nacional.

Por otra parte, se ha establecido un programa denominado Sistema Nacional de Areas Naturales Protegidas dependiente de la Secretaría del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP) el cual contempla el manejo y conservación de distintas áreas que por su biodiversidad y características ecológicas tienen especial relevancia para el país; no obstante es necesario mencionar que este sistema de áreas protegidas aún no es suficientemente representativo de la diversidad biológica del país y tampoco ha alcanzado niveles operativos óptimos.

Actualmente en México existen seis categorías de áreas naturales protegidas que están siendo administradas y manejadas por la SEMARNAP, una Instancia Federal del Gobierno Mexicano; estas áreas corresponden a las siguientes categorías: Reservas de la Biosfera, Parque Nacional, Monumento Natural, Arrea de Protección de Recursos Naturales, Arrea de Protección de Flora y Fauna y Santuarios.

En total México cuenta con 115 áreas naturales protegidas de interés forestal (Cuadro 13), las cuales en su conjunto cubren una superficie total de 18 millones de hectáreas aproximadamente, en las que también se considera el área marina, es decir, casi el 9% del territorio nacional (CONABIO, 1997).

En cuanto a los tipos de vegetación conocidos para México, las áreas naturales protegidas cubren la mayoría de los ecosistemas existentes en la República Mexicana; el bosque tropical perennifolio y el matorral xerófilo son los ecosistemas que tienen mayor superficie protegida (Cuadro 14).

A nivel internacional México ha establecido varios convenios de colaboración relacionados con el uso y conservación de la biodiversidad terrestre; en el Cuadro 15 se citan algunos de los más importantes.

Conclusiones

- México tiene avances importantes en la evaluación de la biodiversidad, sin embargo aun existen "lagunas" en inventarios de flora y fauna de varias regiones naturales.
- Las evaluaciones que se tienen actualmente en cuanto a la diversidad de ecosistemas de México son satisfactorias.
- En relación con la evaluación de la diversidad a nivel de especie, se ha generado mayor conocimiento en los grupos taxonómicos superiores; la información sobre los grupos taxonomicos de invertebrados todavía es muy incompleta.
- La diversidad genética terrestre silvestre es muy poco conocida
- Existe una fuerte tendencia a evaluar la diversidad etnobotánica, sin embargo, se carece todavía de un inventario etnobotánico nacional.
- No se ha evaluado satisfactoriamente la biodiversidad desde el punto de vista económico.
- Los servicios ambientales de la biodiversidad no han sido evaluados satisfactoriamente; sin embargo se ha documentado parcialmente la información sobre los usos directos de la biodiversidad.

Cuadro 14.—Superficie protegida en México por tipo de vegetación

Vegetación	Superficie protegida (km^2)	% protegido
Bosque de coníferas y encino	4 867.96	1.29
Bosque espinoso	1 297.81	1.14
Bosque mesófilo de montaña	1 049.74	5.86
Bosque tropical caducifolio	2 881.54	1.07
Bosque tropical perenifolio	14 884.99	7.68
Bosque tropical subcaducifolio	1 151.9	1.82
Matorral xerófilo	44 896.02	6.12
Pastizal	1 369.30	0.86
Vegetación acuática y subacuática	8 073.07	35.06
Mar	33 477.62	—
Total	113 949.95	—

FUENTE: CONABIO (1997).

Cuadro 15.—Convenios internacionales de México sobre diversidad biológica

Convenio o Acuerdo	Objetivo principal
Comité trilateral México-Estados Unidos—Canadá	Conservación y manejo de vida Silvestre
Convenio de Diversidad Biológica	Uso y conservación de la biodiversidad
Comisión de cooperación Ambiental	Uso sustentable de los recursos naturales
Convención sobre el Comercio internacional de especies Amenazadas de Fauna y Flora silvestres	Regulación del comercio de especies amenazadas
Convenio Mexico estados Unidos de América para la protección de aves migratorias y mamíferos de interés cinegético	Protección y aprovechamiento racional de aves migratorias
Programa MAB-UNESCO	Manejo de Reservas de la Biosfera
Convenio Binacional México- Canadá	Protección de la mariposa monarca
Programa Frontera XXI México-USA	Manejo de áreas protegidas y biodiversidad
Corredor Biológico Mesoamericano	Desarrollo de áreas naturales protegidas

- El conocimiento sobre monitoreo y manejo sustentable de la biodiversidad se encuentra en fases incipientes.
- Los programas de manejo y conservación de la biodiversidad en las áreas naturales protegidas no han sido operados en forma suficiente.
- Existe una alta presión antropogénica en las áreas forestales que afectan negativamente a la biodiversidad
- En México existen normas oficiales que protegen a las especies amenazadas y en riesgo de extinción.
- México cuenta con una legislación que regula los aprovechamientos de la biodiversidad.
- México ha creado un Organismo Federal dirigido a atender el uso y conocimiento de la biodiversidad nacional.
- Nuestro país ha implementado diversas acciones para conservar su biodiversidad.
- México colabora con otros países en distintos proyectos a favor de la conservación de la biodivesidad.

Algunas Recomendaciones

a) Fortalecer las Instituciones relacionadas con la biodiversidad.
b) Ampliar la conservación de ecosistemas clave.
c) Establecimiento de un Centro de banco de datos sobre la biodiversidad nacional.
d) Fortalecer la investigación en inventarios, monitoreo, aprovechamiento y manejo de la biodiversidad.
e) Implementar técnicas sobre la valoración económica sobre la biodiversidad terrestre.
f) Aplicar los programas de Manejo de las áreas naturales protegidas.
g) Fortalecer los Programas cooperativos Institucionales sobre la biodiversidad, a nivel nacional e internacional.
h) Implementar programas de inversión que sean sustentables en el uso de la biodiversidad.

Bibliografia Citada

Arias, S. 1993. Cactáceas: Conservación y Diversidad en México. En: Gío, R. y E. López-Ochoterena (eds.). Diversidad Biológica en México. Revista de la Sociedad Mexicana de Historia Natural, Vol. XLIV.

Ayala, R., T.L. Griswold y S. H. Bullock. 1998. Las Abejas Nativas de México. En Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México

Boyás D., J. C., M.A. Cervantes, J. Javelly, M.M. Linares, F.Solares, R.M. Soto, I.Naufal y L. Sandoval. 1993. Diagnóstico Forestal del Estado de Morelos.INIFAP. Publicación Especial No. 7. México.

Ceballos, G. 1993. Especies en peligro de extinción. En: Flores, O. y A. Navarro (comps.). Biología y problemática de los vertebrados en México. Revista Ciencias, 7: 5-10.

Cervantes, F.A., A. Castro y J. Ramírez. 1994. Mamíferos terrestres nativos de México. Anales del Instituto de Biología UNAM, Serie Zoología, Vol. 65 (5): 177-190.

CONABIO. 1997. Biodiversidad de México: Estudio de País. CONABIO. México.

Delgadillo, C. 1998. Diversidad de la Brioflora Mexicana. En: Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.

Dinerstein, E., D.M. Olson, D.J. Graham, A.L. Webster, S.A. Primm, M.P. Bookbinder y G. Ledec. 1995. Conservation Assessment of the Terrestrial Ecoregions of Latin America and the Caribbean. The World Bank / The World Wildlife Fund. Washington D.C.

Elourdy J. 1996. Insectos Comestibles. Una Dieta para el Futuro?. Bidiversitas.Año 2 No. 5.

Ehrlich A. And P. Ehrlich. 1992. Causes and Consequences of the Disapperance of Biodiversity. En Sarukhán, J. y R. Dirzo (comps.). México ante los Retos de la Biodiversidad. CONABIO. México

FAO. 1993. Forest Resources Assesssment 1990. Tropical Countries. Organización Mundial de Alimento y Agricultura. Forestry Paper, 112.

Flores, O. 1998. Herpetofauna de Mexico: Distribución y endemismo. En: Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.

Flores, O. y P. Gerez. 1994. Biodiversidad y conservación en México: vertebrados, vegetación y uso del suelo. UNAM/CONABIO. México.

García, A. y R. Galván. 1995. Riqueza de las Familias Agavaceae y Nolinaceae en México. Boletín de la Sociedad Botánica de México No. 56: 7-24.

Guzmán, G. 1995. La Diversidad de Hongos en México. *Ciencias*, No. 39: 52-57.

Hernández-Xolocotzi, E. 1993. Aspectos de la domesticación de Plantas en México: una Apreciación Personal. En: Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.

INEGI-SEMARNAP. 1998. Estadísticas del Medio Ambiente. México 1997. INEGI. México.

López-Ochoterena, E. 1993. Notas sobre la Diversidad de Protozoarios de México. En: Revista de la Sociedad Mexicana de Historia Natural, Vol. XLIV. México.

Llorente, J.,y A.L. Martínez. 1998. Análisis Conservacionista de las Mariposas Mexicanas: Papilionidae (Lepidoptera, Papilionoidea). En Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución.Instituto de Biología. UNAM. México

Mc Allister, D. 1991a. What is Biodiversity. Biodiversity. Workpapers. Canadian Museum of Nature. Ontario, Canada.
Mc Allister, D. 1991b. Why Save Biodiversity. Workpapers. Canadian Museum of Nature. Ontario, Canada.
Mittermeier, R. y C. Goettsch. 1992. La importancia de la diversidad biológica de México. En: Sarukhán, J. y R. Dirzo (comps.). México ante los retos de la biodiversidad. CONABIO. México.
Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). 1998. Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.
Reid W. And K. Miller. 1989. Keeping Options Alive: the Scientific Basis for Conserving Biodiversity. WRI. Washington, D.C.
Riba, R. 1998. Pteridofitas Mexicanas: Distribución y Endemismo. En: Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.
Rzedowski, J. 1978. Vegetación de México. Ed. Limusa. México.
Rzedowski, J. 1992. Diversidad del Universo Vegetal de México: Perspectivas de un Conocimiento Sólido. En: Sarukhán, J. y R. Dirzo (comps.). México ante los retos de la biodiversidad. CONABIO. México.
Rzedowski, J. 1993. Diversidad y Orígenes de la Flora Fanerogámica de México. En Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.
SARH. 1994. Inventario Nacional Forestal Periódico. Memoria Nacional. Subsecretaría Forestal y de Fauna Silvestre-SARH. México.
Sarukhán, J. y R. Dirzo (comps.).1992. México ante los Retos de la Biodiversidad. CONABIO. México
Sarukhán, J., J. Soberón y J. Larson-Guerra. 1996. Biological Conservations in a High Beta-diversity Country. En: Di Castri, F. y T. Younès (eds.). Biodiversity Science and Development: Towards a New Partnership. CAB International.
SEDESOL. 1994a. Plan de Acción para Combatir la Desertificación en México. FAO/SEDESOL/CONAZA. México
SEDESOL. 1994b. Norma Oficial Mexicana NOM-059-Ecol-1994. Diario Oficial de la Federación, t. CDLXXXVIII, núm. 10, 16 de mayo de 1994. México
SEMARNAP. 1997. Programa de Conservación de la Vida Silvestre y Diversificación Productiva en el Sector Rural. SEMARNAP. México.
SEMARNAP. 1995. Programa Forestal y de Suelo 1995-2000.
SEMARNAP. 1998. Los Incendios en México (1998). SEMARNAP. México.
Styles, B.T. 1998. El Género *Pinus*: su Panorama en México.En Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.
Téllez, K.L. 1994. La Modernización del Sector Agropecuario y Forestal. Una visión de la Modernización en México. Fondo de Cultura Económica. México
Toledo, V.M. y M. Ordóñez. 1998. El Panorama de la Biodiversidad de Mëxico: una Revisión de los Habitats Terrestres. En: Ramamoorthy, T.P., R. Bye, A. Lot y J. Fa (eds.). Diversidad Biológica de México: Origenes y Distribución. Instituto de Biología. UNAM. México.
UICN. 1989. World Conservation Strategy for the 1990's. The 2nd World Conservation Strategy Project. World Conservation Centre. Gland, Switzerland.
UICN, 1996. 1996 IUCN Red List of Threatened Animals. Unión Internacional para la Conservación de la Naturaleza, Gland, Suiza.
UICN, 1998. IUCN Red List of Threatened "Database Search Results" www.wcmc.org.uk/cgi-bin
WRI, IUCN and UNEP. 1991. Biodiversity Strategy and Action Plan.

Biodiversity of Tamaulipan Thornscrub in Relation to Fragmentation[1]

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Abstract—Tamaulipan thornscrub has often been removed in northeastern Mexico to give way to agriculture and induced grasslands for cattle. This results in over 90% of thornscrub being either removed or severely modified, with a few remaining fragments varying in size and distance to nearby fragments (isolation). Fragment size ranges from isolated trees in induced buffel grasslands to 300 ha of "continuous vegetation".

Remaining fragments are by no means conserved, as they are over-utilized for grazing goats, extraction of timber, fuel-wood and medicinal plants. Ecosystem fragmentation and isolation of fragments has an impact on the dynamics of thornscrub by reducing population sizes, promoting genetic erosion, and perhaps local extinction of species with large habitat requirements.

In here we present some measurements of plant, bird, ants, and beetles diversity, as well as some implications on seed parasitism, removal and dispersal. Results contrast species richness under isolated *Prosopis* and *Ebenopsis* trees and thornscrub fragments from less than 10 to over 100 ha. Preliminary results imply that fragment size is not related to species number, but to ecosystem function. Seed removal rates were slower under isolated mesquite trees than under similar trees in continuous vegetation. Seed production was higher for isolated mesquite trees than for similar size ones inside continuous vegetation. Seed parasitism (while still inside the vines) was higher for the latter.

Imminent loss of biological diversity and the risk of the acceleration of this loss, brings out the need to objectively evaluate the role of biodiversity in ecosystem function, productivity and stability (Aizen and Feisinger 1994; Didham et al. 1996; Grime 1997). The effect of biodiversity in ecosystem viability requires sophisticated equipment, perhaps as a result of this it is only being considered in few studies (Richardson and Cowling 1993; Hooper and Vitousek 1997; Tilman et al. 1997). The effect that an enriched CO_2 atmosphere and climate change might have on biodiversity is still elusive due to varying models of prediction. Fragmentation, however of most of the plant communities around the world has an impact on species composition that has been increasingly documented in tropical forest (Lawrence 1990; Robinson et al. 1992; Adler 1994), temperate forest (Bright 1993; Heske 1995; Fitzgibbon 1997) and grasslands (Herkert 1994). These studies show a relationship between fragment size of remaining vegetation and species composition similar to island theory (a larger area will include more species). Results so far, deal mainly with birds (Askins et al. 1992), mammals (Fonseca and Robinson 1990; Foster and Gaines 1991) and occasionally invertebrates (Kruess and Tscharntke 1994).

Tamaulipan Thornscrub has often been removed in northeastern Mexico to give way to agriculture and induced grasslands for cattle. This results in over 90% of thornscrub being either removed or severely modified with a few remaining fragments varying in size and distance to nearby fragments. Fragment size ranges from isolated trees in induced buffel grasslands to 300 ha of "continuous vegetation".

Remaining fragments are by no means conserved, as they are over-utilized for grazing goats, and extraction of timber, fuel-wood, and medicinal plants. The impact per fragment is on the increase as fragments are reduced in size, quality and number while human population keeps growing.

Ecosystem fragmentation and isolation is likely to impact the dynamics of thornscrub by reducing population size, promoting genetic erosion, and perhaps inducing local extinction of species with large-habitat requirement (McCoy and Mushinsky 1994; Murcia 1995).

This paper presents preliminary results of a broad study on the effects that fragmentation of Tamaulipan Thornscrub has on species diversity, and ecosystem processes[4].

Methods

This study was conducted in Linares, Nuevo Leon, Mexico (24° 47' N., 99° 32' W. 360 m.a.s.l.). Linares has a mean annual rainfall of 810.6 mm, which falls mainly in the summer (Cavazos and Molina, 1992). Mean annual temperature is 22.4 °C, with 41.1 °C and –2.3 °C being the mean maximum and mean minimum daily temperatures (Cavazos and Molina, 1992). The highest temperatures occur on July and August; the lowest precipitation also occurs at this time (Cavazos and Hastenrath, 1990).

Tamaulipan thornscrub is dense vegetation with an average height of shrubs and trees (mainly legumes) of 4 m (Reid et al. 1987; Jurado et al. 1998). This vegetation has been

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removed to give way to agriculture and induced grasslands and thus only 10% of its original area remains in isolated fragments.

All taxa were analyzed comparing at least three replicates for anyone treatment (i.e. size of fragment). Variables analyzed included number of species and diversity indexes (Shanon and Simpson). Since the patterns were similar only results dealing with numbers of species are presented here. In this study we compared species composition and diversity indexes among different fragment sizes using the same unit effort. We feel that the question of differences in species number due to larger area is rather uninteresting.

Plant Diversity

For this variable only adult perennial plants were considered, they were measured using 100 m by 4 m plots (Medina 1996). Plots were set in the center of each fragment, and a total of 10 fragments for each size category were used. Fragments were divided in two size classes those close to 10 ha, and those larger than 100 ha. These analyses were carried out in spring 1996.

Bird Diversity

Birds were monitored in two ways: (i) by direct observation, and (ii) by trapping with the use of mist nets. Both methods were done three days each month from sunrise till noon from July 1996 to June 1997. A total of 6 mist nets were used for each treatment (using two nets per replicate).

Ant and Beetle Diversity

Ants and beetles were trapped using pitfall-baited traps with additional openings at 5 cm depth for ants that rarely visit the soil surface (Ávila 1997). Each trap set included 5 traps separated 1 m from each other, there were three replicates for each fragment size. For this study we included isolated trees as the smallest possible fragment, these included three *Prosopis laevigata* (mesquite), and three *Ebenopsis ebano* (ebano), isolated from nearest fragments by at least 200 m. Replicates of the same tree species inside fragments were also considered.

Ants and beetles were initially identified as morpho-species, and later keyed with the aid of experts to the nearest possible taxa (genera and family for most cases). Invertebrates were sampled during two seasons, spring and autumn 1996. Further research on beetles is currently being conducted.

Seed Production

Seeds were estimated from number of estimated vines, for 20 mesquites. Three people simultaneously counted all the vines they could see in 5 minutes on different angles of the same tree (seed counters were set with their back toward the stem, so each one could see the third part of the crown). This was done selecting similar size trees, half of them immersed in continuous vegetation, and the rest isolated at least 200 m from the nearest thornscrub fragment. Seed production has been determined only once, as this research is still in progress.

Seed Removal

Under the same trees used to estimate seed production, we provided seeds of ebano (the largest and most attractive seed in thornscrub) in Petri dishes. There were 10 seeds in each one of three replicates for isolated, immersed, and border trees. The latter were similar size trees that were growing on the edge of fragments.

Seed Parasitism

Parasites in seeds of mesquite were estimated by recording the presence of holes in vines collected from under isolated and immersed trees during seed production (Summer 1998).

Results and Discussion

The trend for more species (or higher diversity) found for larger fragments elsewhere was not supported here. For all taxa studied, species number, Shanon and Simpson diversity indexes were not different among different fragment sizes (Fig. 1). This result was consistent when considering different taxa, different seasons and different experimental designs.

To try to explain how fragment size did not affect number of species three options are discussed:

1. Habitat deterioration—it is possible that because thornscrub is highly impacted by logging and goat grazing, large fragments do not have the "pristine" vegetation quality, required to host large numbers of species.
2. Species crowding—Perhaps as a result of recent fragmentation, and lower competition due to an increased

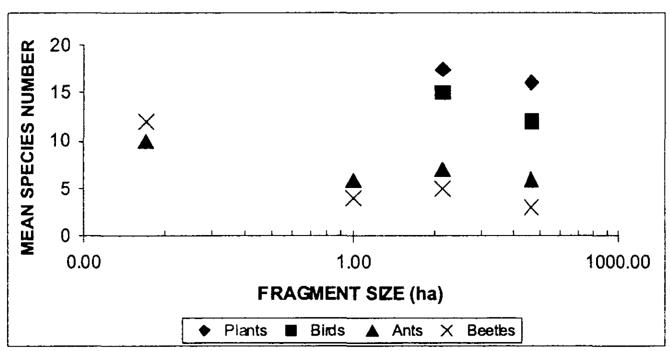

Figure 1.—Mean Number of species of plants, birds, ants and beetles. No trend for fewer species in smaller fragments was found for any taxa. Plants were measured in 100 m x 4 m plots, using ten replicate fragments for each size. Birds were trapped from sunrise till noon, during three days each month for one year using 2 mist nets per replicate and three replicates per fragment size. Ants and beetles were trapped with baited pitfall traps in spring and autumn, using three replicates per fragment size and 5 traps per replicate.

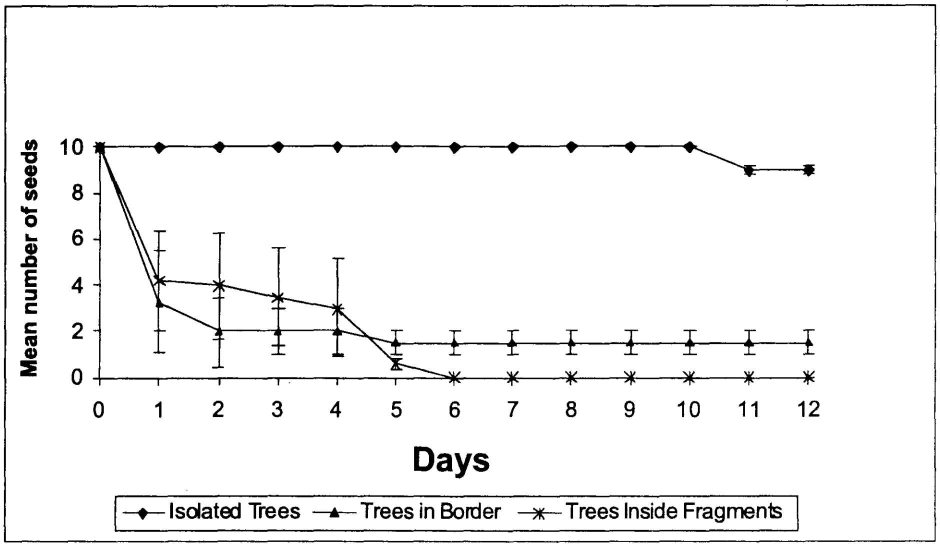

Figure 2.—Mean seed removal of seeds (*Ebenopsis ebano*) under 3 isolated, 3 immersed and 3 margin mesquites in a 12 day period in Summer 1998. Seed depots for each replicate included 10 seeds. Error bars represent confidence limits at $\alpha = 0.05$.

edge effect, very small fragments have more dense populations and hence diversity per unit area equals that of larger fragments.

3. Large fragments are too small—it is possible that remaining fragments are too small to represent original ecosystem properties (including diversity), and thus we are comparing between small and very small fragments.

Further and detailed studies are required to test for such potential causes of our preliminary results.

The rate of seed removal, however was affected by tree isolation, in that seeds under isolated trees were removed in lower number and at a slower pace than those in the vegetation edge, and these in turn from those under trees inside fragments (Fig. 2). The implication for this is that seed removers (most likely rodents) are at a higher risk of being prayed at the vegetation edge, and even more so under isolated trees, than under continuous ornscrub. Considering seed removal alone, isolated trees have greater chances of establishing seedlings under their canopy, though perhaps a smaller chance of being incidentally dispersed. Further studies using different species of seeds are currently under way. Studies dealing with seedling establishment are in design.

The number of seeds produced by vine was similar for isolated trees (16.34±1.3 mean±C.I. $\alpha = 0.05$) and trees in continuous vegetation (15.7±2.36). Vine production, and hence seed production per tree, was significantly higher for isolated trees (Fig. 3). There were more seeds with parasites in the vines of mesquites in continuous vegetation (Fig. 3).

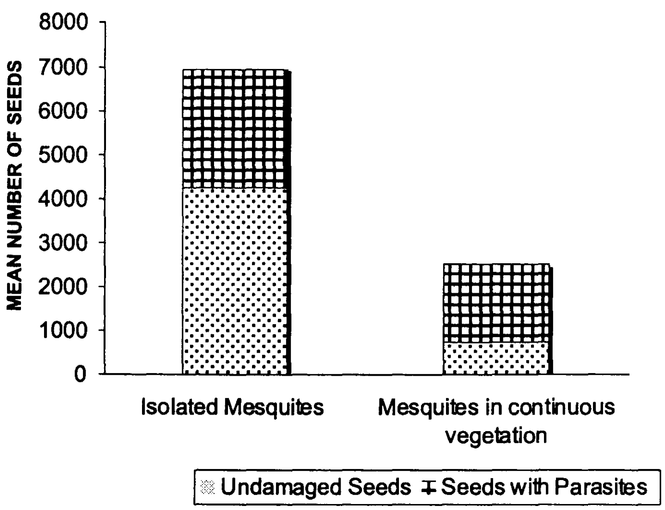

Figure 3.—Seeds of Isolated mesquites and mesquites immersed in continuous vegetation. Each mean represents the average of three trees. Means between isolated and immersed mesquites are different (α =0.05).

Literature Cited

Adler, G. H. 1994. Tropical forest fragmentation and isolate promote asynchrony among populations of a frugivorous rodent. Journal of Animal Ecology. 63(2): 903-911.

Aizen M. A. & Feinsinger P. (1994). Habitat fragmentation, native insect pollinators, and feral honey bees in Argentina "Chaco Serrano". Ecological Applications 4(2), 1994, 378-392 pp.

Askins, R. A., D. N. Ewert and R. L. Norton. 1992. Abundance of wintering migrants in fragmented and continuous forests in the U.S. Virgin Island. in: J. M. Hagan and D. W. Johnston (Editors) Ecology and conservation of neotropical migrant landbirds. Smith

Ávila, G. M. 1997. Diversidad de hormigas en fragmentos de matorral tamaulipeco en Linares, Nuevo León, México. Tesis de Licenciatura. Facultad de Ciencias Forestales. Universidad Autónoma de Nuevo León. 65 p.

Bright, P. W. 1993. Habitat fragmentation-problems and prediction for British mammals. Mammal Review 23 (3/4): 101-111.

Cavazos, T. and S. Hastenrath. 1990. Convection and rainfall over Mexico and their modulation by the southern oscillation. Int. J. ClimGatol., 10: 377-386.

Cavazos, T. and V. M. Molina. 1992. Climatic records for the citrus region of Nuevo León. Reporte Técnico Facultad de Ciencias Forestales. Universidad Autonoma de Nuevo Leon. 1:1-65 pp.

Didham, R. K., J. Ghazoul, N. E Stork, and A. J. Davis. 1996. Insects in fragmented forest: A functional approach. Trends in Ecology and Evolution. 11(6): 255-260.

Fitzgibbon, C. D. 1997. Small mammals in farm woodlands. The effects of habitat, isolation and surrounding land-use patterns. Journal of Applied Ecology. 34: 530-539.

Fonseca, G. A. B. and J. G. Robinson. 1990. Forest size and structure: Competitive and predatory effects on small mammal communities. Biological Conservation 53: 265-294.

Foster, J. and M. S. Gaines. 1991. The effects of a successional habitat mosaic on small mammal community. Ecology 72(4): 1358-1373.

Grime, J.P. 1997. Biodiversity and ecosystem function: The debate deepens. Science 277:1260-1261.

Herkert, J. A. 1994. The effects of habitat fragmentation on midwestern grassland bird communities. Ecological Applications, 4(3): 461-471.

Heske, E. J. 1995. Mammalian abundances on forest-farm edges versus forest interior in Southern Illinois: Is there an edge effect? Journal of Mammology 76(2) 562-568.

Hooper, D.U. and Vitousek, P. 1997. The effects of plant composition and diversity on ecosystem processes. Science. 277:1302-1305.

Jurado, E., Flores, J., Navar, J. and Jiménez, J. 1998. Seedling establishment under native tamaulipan thornscrub and *Leucaena leucocephala* plantation. Forest Ecology and Management 105:151-157.

Kruess, A. and T. Tscharntke. 1994. Habitat fragmentation, species loss, and biological control. Science 264: 1581-1584.

Laurance, W. F. 1990. Comparative responses of five arboreal marsupials to tropical forest fragmentation. Journal of Mammalogy 71(4): 641-653.

Medina, C. 1996. Fitodiversidad en relación al tamaño de fragmentos remanentes de matorral en Linares, N.L. México. Tesis. Ingeniero Forestal, UANL.

McCoy, E. D. and H. R. Mushinsky, 1994. Effects fragmentation on the richness of vertebrates in the Florida scrub habitat. Ecology: 75(2): 446-457.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution 10(2): 58-62.

Reid, N. Stafford, S. M., Beyer-Münzel, P., Marroquín, J. S., (1987). A research strategy for ecological survey: Floristics and land strategies for classification and management of native vegetation for food production in arid zones. Tucson, USDA, FOR

Richardson, D.M. y Cowling, R.M. 1993. Biodiversity and ecosystem processes: opportunities in Mediterranean-type ecosystems. Trends in Ecology and Evolution. 8:79-81.

Robbins, Ch. S., B. A. Dowell, D. K. Dawson, J. Colón, R. Estrada, A. Sutton, R. Sutton, and D. Weyer. 1992. Comparison of Neotropical migrant landbird populations wintering in tropical forest, isolated forest fragments, and agricultural habitats. in: J.

Tilman, D., Knops, J., Wedlin, D., Reich, P., Ritchie, M. and Siemman, E. 1997. The influence of functional diversity and composition ecosystem process. Science. 277:1300-1302.

Rapid Assessment of Endemic Bird Areas in Michoacan, Mexico[1]

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Abstract—Non-sustainable land use practices in the state of Michoacan, Mexico, have perturbed endemic bird habitats for several decades. Endemic birds have a restricted geographic and ecological distribution. This feature makes them suitable to be used as indicators of biological diversity and environmental perturbation. Forty-one Mexican endemic species have been recorded in 11 temperate and 3 tropical vegetation types in Michoacan (59,000 km^2). This paper demonstrates the use of a geographic information system to locate and display spatially explicit endemic bird richness areas based on the potential distribution of individual endemic species in Michoacan. Relationships of endemic species with natural vegetation and altitudinal distribution were used as indicators of potential habitat. Low endemic bird richness areas (one to five species) totaled 1,558,417 ha with an almost random distribution throughout the state. Medium richness areas (six to 10 endemic species) summed 1,084,534 ha, most of them distributed in the Sierra Madre del Sur and along the southern escarpment of the Neovolcanic Belt. High richness areas (11 to 16 endemic species) include 1,864,117 ha concentrated in the less disturbed deciduous tropical forests of the Balsas Basin and in the highest coniferous forests of the neovolcanic belt. Conservation efforts must concentrate on these areas. However, areas with low or medium species richness can be of importance for the conservation of individual species and their habitats.

Wildlife species play a critical role in ecosystem functioning and are often indicators of ecosystem health. In Mexico and other Latin American countries, nonsustainable use of forests and rangelands has lead to local disappearances of many endemic and migratory species. Biological diversity in western Mexico is believed to be exceptionally high where a wide variety of vegetation types occurs within a limited geographical area (Ramamoorthy et al. 1993). Continued population declines of plant and animal species, especially those critical in food processing, insect pest control, ecosystem health, and medicine, may not only lead to a reduction in global diversity but also to a decline in health of forested ecosystems.

To maintain biological diversity resource managers need both fine-filtered (local level) and coarse-filtered (state or larger spatial level) information describing vertebrate species occurrences in different vegetation types. By analyzing regional patterns of species endangerment and endemism critical habitats can be identified and conserved. Species-rich habitats at the local level may not contribute greatly to regional biological diversity if these habitats are managed for common species and are unable to support and sustain populations of rare, endemic, or vulnerable species.

Rapid assessment sampling provides information that can be synthesized at different spatial scales to identify areas of high vertebrate species diversity and endemism, and to prioritize habitats in need of increased conservation efforts. Region-wide classification maps based on rapid assessment inventories are highly successful tools for identifying geographically important areas and for monitoring spatial and temporal changes in biological resources.

In the state of Michoacan, located in western Mexico, 492 bird species have been recorded, including 282 terrestrial birds (Villaseñor and Villaseñor 1994). Forty-one of these species are endemic to Mexico (American Ornithologists' Union 1998), and represent 40.6% of 101 species classified by Escalante et al. (1993) as true endemics to the country. All species have distribution limits that can be mapped. These limits are established by obvious factors such as: vegetation, climate, altitude, physical barriers, or soil types. Vegetation is one of the most reliable indicators of animal species distribution and their habitats. Animals respond to actual vegetation, not to the potential for vegetation presence. From a landscape approach, the dominant vegetation cover, represented as a successional phase or a climax community, will determine which animal species are present.

Distribution maps are essentially propositions about the probability of presence or absence of one species in one area. Distribution maps showing individual record localities can be used to predict the presence of a species in the gaps between records if the natural communities of which it is usually a member are present. Thus, mapped areas where no species records have been reported but where the community is similar to that of locality records can be considered potential habitat. To the degree which natural communities are represented by vegetation types, vegetation maps can be used as indicative of a species distribution (Csiuti 1994).

Knowing the distributional limits of a species and its habitat use patterns or associations with particular vegetation types makes it possible to use a geographic information system to create a large-scale or medium-scale distribution map. Because this process is not based solely on localities of specimen records, unexplored regions within the species range that have suitable habitat are included, whereas areas with unsuitable habit are excluded. Depending on the species habitat specificity, the map can be a very refined prediction about the distribution of a species (Scott et al. 1993, Csiuti 1994).

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Endemic species are more sensitive to changes in habitats than widespread species, and their local populations may react negatively to habitat perturbations by declining or going extinct. Because the distributions of endemic species are typically restricted, the species richness and abundance of endemics can be used as indicators of biological diversity status at a regional scale. Levels of avian endemism are positively correlated with levels of endemism of other life forms (Bibby et al. 1993), suggesting that birds may be useful predictors of overall patterns of biological diversity throughout a region.

The objective of this paper is to illustrate how managers can use a geographic information system to locate and demarcate areas of high bird species diversity based on the distribution of potential habitat of endemic birds in the state of Michoacan, Mexico. As indicators of potential habitat we used natural vegetation types with which endemic species are usually associated as well as altitudinal distributions of species.

Methods

Study Area

Michoacan extent is 59,864 km^2. It is the fifth estate in Mexico with the highest bird species diversity (Flores-Villela and Gerez 1989). Two thirds of its territory are still covered by natural vegetation (SARH 1991, SDAF 1995). Altitudes range from sea level to 3,840 meters. There are two great physiographic provinces: the Neovolcanic Belt (temperate-cold climate), and the Sierra Madre del Sur, which includes the Balsas Basin (dry tropical climate) and the coastal area (INEGI 1995). Protected natural areas total six national parks, with a total of 25,000 ha, and one special biosphere reserve (Monarch butterfly reserve, 19,000 ha), all of which are distributed along the Neovolcanic Belt.

Bird Species

Of the 101 endemic species found in Mexico, 41 have been recorded in Michoacan (Villaseñor y Villaseñor 1994). In our study we included only 36 species, excluding extirpated or extinct species, such as the eared trogon (*Euptilotis neoxenus*) and the imperial woodpecker (*Campephilus imperialis*), regional migrants such as the thick-billed parrot (*Rhynchopsitta pachyryncha*), species with only one recorded locality in the estate like the white-fronted swift (*Cypseloides storeri*), and Strickland´s woodpecker (*Picoides stricklandi*) whose distribution is not well understood.

Information Sources

We used field verification as a primary source of information about species distribution by vegetation type, geographic locality, and altitude (e.g., García et al. 1998). To supplement our field surveys, we consulted bird collection data bases at the Facultad de Biologia at Universidad Michoacana de San Nicolas de Hidalgo (curator Laura Villaseñor) and Instituto de Biologia at Universidad Nacional Autonoma de Mexico (curator Patricia Escalante). A third information source was scientific publications reported by Michoacan authors who collected and observed birds from 1935 to the Present. The fourth information source was INEGI cartographic products: (1) land use and vegetation maps (1984, scale 1:500,000) and (2) digital elevation models, 1994.

Verification of Species Distribution

Point counts were used to determine presence and distribution of the species selected (Ralph et al. 1995). Five ten-minute point counts were conducted at a total of 130 sites selected using a stratified sampling scheme (García et al 1995, 1998). The sampling method was designed to sample both common and rare vegetation types and associated bird species. Each point count station was separated by 200 meters. From May to July 1994, 63 sites (315 point counts) were sampled. During the same months of 1995, 67 additional sites (335 point counts) were sampled.

Vegetation Map Verification

The INEGI land use and vegetation base map were verified at the micro scale (within a sampling site or particular vegetation type) and at the macro scale (among vegetation types or landscapes). In the first case, vegetation vertical structure and floristic composition were measured at the five point count stations of each sampling site (see Ralph et al. 1993 for methodology). More details are found in García et al. (1995, 1998). At the macro scale, black-and-white photographs (scale 1:25,000, 1990 and 1992), and a INEGI space-map (Espaciomapa MORELIA E-14-1, scale 1:250,000, generated from a 1993 Landsat TM image) were used to verify and update the vegetation map.

Processes to Generate Digital Maps

Data obtained from the sources specified above were grouped to form six sets of information used to generate predictive maps of the distribution of endemic bird species and species richness areas with a geographic information system:

1) A digitized map of vegetation types.
2) A digitized map of geographic entities (municipalities).
3) A digitized map of altitude ranges.
4) A data base assigning species presence or absence to each municipality.
5) A data base associating each species with vegetation types, and
6) A data base associating each species with altitude ranges.

All maps were digitized and processed with PC ARC/INFO ver. 3.5 and ArcView GIS ver. 3.1a. The altitude range map was generated from INEGI digital elevation models processed with IDRISI ver. 4.1.

Accuracy of the Digital Vegetation Map

To evaluate how closely the digital vegetation map corresponded to field-verified data, it was overlapped with a GPS sample-point digital map. Only 39% of the 1995 GPS points corresponded with the vegetation types assigned to each intersected polygon. The 1994 GPS coincided with 57.8% of intersected polygons. In both years 49.2% of GPS points coincided with their corresponding vegetation polygons. Field verification of vegetation was clearly valuable for improving accuracy of vegetation cover maps.

Procedure to Model Species Distributions and Endemic Species Richness Areas:

1. Generation of a Composite Digital Map.

The digital vegetation map, altitude map, and municipalities map were overlapped to generate a composite map. The resulting digital map contained 28,434 polygons, each one assigned to a vegetation type, an altitude range, and a municipality.

2. Attribute Allocation.

Using an automatic procedure each species was assigned to each polygon as an individual attribute.

3. Species Presence/Absence Assignation.

Two relational data bases are required: one to indicate associations among species and vegetation types, and another one to indicate their altitudinal distribution. The data bases format is a matrix with the species arranged as rows, and vegetation types or altitudinal ranges arranged as columns. Using the four information sources, we filled in matrices with "0"s to indicate species absence and "1"s to indicate presence (Table 1). Polygons in the composite map were coded interactively according to features defining each species distribution.

The result was a single composite digital map with each attribute being a bird species linked to each polygon. This

Table 1.—Distribution of endemic bird species by general vegetation types in the estate of Michoacan, Mexico. Secondary and primary successional phases are lumped together. Cells are filled with "1" to indicate presence, an "0" to indicate absence. Common English names and scientific names follow the AOU (1998) classification.

Species	Vegetation Types[1]											
	1	2	3	4	5	6	7	8	9	10	11	12
West Mexican Chachalaca (*Ortalis poliocephala*)	1	1	1	0	0	0	0	0	0	0	0	0
Long-tailed Wood-partridge (*Dendrortyx maccroura*)	0	0	0	1	1	1	1	1	0	0	0	0
Banded Quail (*Philortyx fasciatus*)	0	1	0	0	0	0	0	0	0	0	0	0
Lilac-crowned Parrot (*Amazona finschi*)	1	1	0	0	0	0	0	0	0	0	0	0
Balsas Screech-owl (*Otus seductus*)	0	1	1	0	0	0	0	0	0	0	0	0
Dusky Hummingbird (*Cynanthus sordidus*)	0	1	1	0	0	0	0	0	0	0	0	0
Bumblebee Hummingbird (*Atthis heloisa*)	0	0	0	1	0	0	1	1	0	0	0	0
Citreoline Trogon (*Trogon citreolus*)	0	1	1	0	0	0	0	0	0	0	0	0
Gray-crowned Woodpecker (*Piculus auricularis*)	1	1	0	0	0	0	0	1	0	0	0	0
Golden-checked Woodpecker (*Melanerpes chrysogenys*)	1	1	0	0	0	0	0	0	0	0	0	0
White-striped Woodcreeper (*Lepidocolaptes leucogaster*)	0	0	0	1	1	1	1	1	1	0	0	0
Flammulated Flycatcher (*Deltarhynchus flammulatus*)	0	1	1	0	0	0	0	0	0	0	0	0
Pileated Flycatcher (*Xenotriccus mexicnus*)	0	0	1	0	0	0	0	0	0	1	0	0
Pine Flycatcher (*Empidonax affinis*)	0	0	0	0	1	0	1	1	0	0	0	0
Gray-barred Wren (*Camylorhynchus megalopterus*)	0	0	0	1	1	0	1	1	1	1	0	0
Spotted Wren (*Camylorhynchus gularis*)	0	0	0	0	0	0	1	1	1	1	0	0
Sinaloa Wren (*Thryothorus sinaloa*)	1	1	1	0	0	0	0	0	0	0	0	0
Happy Wren (*Thryothorus felix*)	1	1	1	0	0	0	0	0	0	0	0	0
Blue Mockingbird (*Melanotis caerulescens*)	0	0	0	1	0	1	1	1	1	0	0	0
Rufous-backed Robin (*Turdus rufopalliatus*)	1	1	1	0	1	0	0	1	1	1	0	0
Golden Vireo (*Vireo hypochryseus*)	1	1	1	0	0	0	0	0	0	0	0	0
Dwarf Vireo (*Vireo nelsoni*)	0	0	0	0	0	0	1	1	1	1	1	0
Red Warbler (*Ergaticus ruber*)	0	0	0	1	1	0	1	1	0	1	0	0
Black-polled Yellowthroat (*Geothlypis speciosa*)	0	0	0	0	0	0	0	0	0	0	0	1
Red-headed Tanager (*Piranga erithrocephala*)	0	0	0	1	0	0	0	1	0	0	0	0
Green-striped Brush -finch (*Buarremon virenticeps*)	0	0	0	1	1	1	0	1	0	0	0	0
Rufous-capped Brush-finch (*Atlapetes pileatus*)	0	0	0	1	0	0	1	1	1	1	0	0
Rusty-crowned Ground-sparrow (*Melozone kieneri*)	0	0	0	0	0	0	1	0	1	1	1	0
Black-chested Sparrow (*Aimophila humeralis*)	0	1	1	0	0	0	0	0	0	0	0	0
Red-breasted Chat (*Granatellus venustus*)	1	1	1	0	0	0	0	0	0	0	0	0
Orange-breasted Bunting (*Passerina lechlanlerii*)	1	1	1	0	0	0	0	0	0	0	0	0
Collared Towhee (*Pipilo ocai*)	0	0	0	1	1	1	1	1	0	0	0	0
Striped Sparrow (*Oriturus superciliosus*)	0	0	0	0	0	0	1	0	0	0	0	0
Yellow-winged Cacique (*Cacicus melanicterus*)	1	1	0	0	0	0	0	0	0	0	0	0
San Blas Jay (*Cyanocorax sanblasianus*)	1	1	0	0	0	0	0	0	0	0	0	0
Russet Nightingale-trush (*Catharus occidentalis*)	0	0	0	1	1	1	1	1	1	1	0	0
Total	12	18	13	11	9	6	14	16	9	9	2	1

1.- Vegetation codes: 1.- Medium tropical subdeciduous forest; 2.- Low tropical deciduous forest; 3.- Low tropical thorn forest; 4.- Mesophylous montane forest; 5.- Fir forest; 6.- Fir-pine forest; 7.- Pine forest; 8.- Pine-oak forest; 9.- Oak-pine forest; 10.- Oak forest; 11.- Subtropical scrub; 12.- Highland marsh procedure avoided the creation of several separated maps, one for each species. Using the geographic information system the modeled distribution of each species can be displayed individually or used in tabular format. Moreover, adding new attributes to the composite map in any desired combination of species can be used to determine species richness in each polygon. Although this approach works well for common species, it tends to overestimate the distributions of rare species or those with highly fragmented distributions which are more difficult to predict. In these cases is more useful to use points to indicate individual records.

4. Estimation of Species Richness for Each Polygon. This procedure is relatively simple. Species richness (i.e., number of species) for each polygon was calculated adding all values of "1" for each species present in the polygon. The resulting value was assigned as an attribute.

5. Cartographic Output.

An endemic bird areas map was composed and produced using ArcView GIS. This map depicts richness areas from 1 to 16 species.

Table 2.—Enemic bird species richness values (numbers of species) in 15 undisturbed vegetation types in the state of Michoacan, Mexico. Secondary successional phases are not included.

Vegetation Type	Richness
Low tropical deciduous forest	16
Pine-oak forest	14
Pine forest	12
Medium tropical subdeciduous forest	12
Thorn tropical forest	11
Mesophylous montane forest	11
Fir forest	8
Oak-pine forest	8
Oak forest	6
Fir-pine forest	5
Subtropical scrub	2
Highland marsh	1
Grassland	1
Chaparral	0
Halophylous vegetation	0

Results

Extent of area occupied by each vegetation type and land use category was calculated directly from maps. Areas devoid of natural vegetation (agriculture, water bodies and urban areas) occupied a third of the state surface (29%). The remaining 71% of Michoacan was covered by 14 vegetation types and their different successional stages. The non-disturbed pine-oak forest had the greatest extent (700,986 ha), followed by non-disturbed low deciduous tropical forest (679,453 ha). Our results are based on the assumption that avian species richness in Michoacan is proportional to vegetation availability or extent.

Endemic bird species richness values within each polygon varied from a minimum of 1 species to a maximum of 16 species (Table 2). As indicated above, vegetation types having greater extent showed highest species richness values. The non-disturbed low deciduous tropical forest had highest richness of endemic species (16 species), followed by non-disturbed pine-oak forest (14 species) and pine forest (12 species). Exceptions to this pattern were vegetation types with a small extent in Michoacan: the mesophylous montane forest ("cloud forest") with 8,127 ha and a richness of 11 species, and the medium deciduous tropical forest with 12 species.

Conclusions

Prediction of species presence at the stand scale (a few hectares) is subject to natural patterns of environmental heterogeneity (Csuti 1994). The methods outlined in this paper are better suited to predicting species occurrences in general vegetation types at the landscape level (Morrison et al. 1998).

The areas with the highest values of endemic bird species richness were located in two main regions: the pine-oak forests of the southern escarpment and the Purepecha Range in the Neovolcanic Belt, and the tropical deciduous forests of the Balsas Basin in the municipalities of Arteaga and Tumbiscatio. Calculating mean endemic species richness by vegetation type at a specific locality rather than throughout the extent of the type, however, would produce a higher value in mesophylous montane forest than in low deciduous tropical forest and pine or pine-oak forests (e.g., García 1998). In other words, the influence of forest extent on species richness values must be compensated for when prioritizing conservation areas. We recommend that areas of high biological diversity identified in this paper become the focus of major conservation efforts and also be identified as potentially sensitive to human perturbation caused by land use changes. However, areas with low values of species richness can be critical to breeding and survivorship of endangered individual species, such as the black-polled yellowthroat (*Geothlypis speciosa*), found only in highland marshes in central Mexico, which showed a richness value of 1 (Table 1). Such areas must also be protected because each endangered species contributes to regional biological diversity even though local diversity of the area used by the endangered species may be low.

Finally, it should be noted that predictions of potential bird species distributions and species richness areas are not an end, but rather are the first steps toward prioritizing areas requiring more intensive studies, surveys, and conservation efforts.

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Literature Cited

American Ornithologists' Union. 1998. Check-list of North American Birds. 7th ed. American Ornithologists' Union, Washington, D.C.

Bibby, C. J., N. J. Collar, M. J. Crosby, M. F. Heath, Ch. Imboden, T. H. Johnson, A. J. Long, A. J. Stattersfield, and S. J. Thirgood. 1992. Putting biodiversity on the map: priority areas for global conservation. International Council for Bird Preservation, Cambridge, U.K.

Csuti, B. 1994. Methods for developing terrestrial vertebrate distribution maps for Gap Analysis (version 1). In J. M. Scott and M. D. Jennings (eds.), A Handbook for Gap Analysis Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow.

Escalante, P. A. G. Navarro and A. T. Peterson. 1993. A geographic, ecological and historical analysis of land bird diversity in Mexico. Pp. 281-307 in Ramamoorthy, T. P., R. Bye, A. Lot, and J. Fa (eds.). Biological Diversity of Mexico: Origins and Distribution. Oxford Univ. Press.

Flores-Villela, O. y P. Geréz F. 1989. Patrimonio Vivo de México: Un Diagnóstico de la Diversidad Biológica. Resumen Ejecutivo. Conservation International, Washington, D.C.

García, S., D. M. Finch, and G. Chávez León. 1995. Abundance, species richness, and habitat use of land birds of the Lake Patzcuaro Watershed, Michoacán, México. Pp. 138-146 in C. Aguirre-Bravo et al. (tech. eds.), Partnerships for Sustainable Forest Ecosystem Management: Fifth Mexico/U.S. Biennial Symposium; 1994 October 17-20; Guadalajara, Jal. Mexico. Gen. Tech. Rep. RM-GTR-266. U.S. Forest Service, Fort Collins, Colorado.

García, S., D. M. Finch, and G. Chávez León. 1998. Patterns of forest use and endemism in resident bird communities of north-central Michoacan, Mexico. Forest Ecology and Management 4414:1-21.

INEGI. 1995. Estadísticas del Medio Ambiente, México 1994. Instituto Nacional de Estadística, Geografía e Informática. Aguascalientes, Ags.

Morrison, M. L., B. G. Marcot and R. W. Mannan. 1998. Wildlife-Habitat Relationships. Concepts & Applications. University of Wisconsin Press, Madison, Wisconsin.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F DeSante. 1993. Handbook of field methods for monitoring landbirds. Gen.Tech. Rep. PSW-GTR-144. U.S. Forest Service, Pacific Southwest Research Station, Berkley, CA. 41 p.

Ralph, C. J., J. R. Sauer and S. Droege (tech. eds.). 1995. Monitoring bird populations by point counts. Gen. Tech. Rep. PSW-GTR-149, Albany, CA: Pacific Southwest Research Station, USDA Forest Service. 187 pp.

Ramamoorthy, T. P., R. Bye, A. Lot, and J. Fa (eds.). 1993. Biological Diversity of Mexico: Origins and Distribution. Oxford Univ. Press.

SARH. 1991. Inventario Nacional de Gran Visión. Secretaría de Agricultura y Recursos Hidráulicos. México, D.F.

Scott, J. M. F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards, J. Ulliman, and G. Wright. 1993. Gap analysis: A geographic approach to protection of biological diversity. Wildlife Monograph No. 123:1-41.

SDAF. 1995. Inventario Forestal Estatal. Memorias Regionales. Secretaría de Desarrollo Agropecuario y Forestal, Gobierno del Estado de Michoacán, Morelia, Michoacán.

Villaseñor, L. y F. Villaseñor. 1994. Especies y subespecies de aves del Estado de Michoacán, México. Biológicas 2: 67-91.

Horizontal and Vertical Stand Structure Analysis of Uneven-Aged Pine-Juniper-Oak Mixed Forest ecosystem in Northeastern Mexico[1]

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Abstract—A stand structure investigation was carried out in a large uneven-aged mixed pine-juniper-oak stand, located in the training forest of the forestry faculty of the Universidad Autónoma de Nuevo León in the Sierra Madre Oriental, Nuevo León, Mexico. The main objective of this research was to develop an adequate stand structure analysis, which to complex conditions of Mexican diverse, uneven-aged conifer-hardwood natural forests (*Pinus pseudostrobus, Juniperus flaccida, Quercus rysophylla, Q. canbyi, Q. laceyi, Q. polymorpha, Arbutus xalapensis, Juglans mollis, Rhus virens, Prunus serotina y Cercis canadensis*).

The recommended inventory procedure was a combination of total tree measurements and detailed investigations with the aid of the "Structural Group of Four" as described by Füldner (1995). The data of the full enumeration were used to determine the abundance (n/ha) and dominance ($g_{1,3}$/ha) of individual tree species, as well as a homogeneity indicator for total stand and different tree species. Representative samples were used to estimate frequency of tree species, diameter differentiation (TD) and height differentiation (TH), as well as the mingling (DM) for total stand and the different tree species. These procedures were used to estimate horizontal structure.

With the aid of the heights of all sample-trees, the tree species were distributed on three height zones (based on number and basal area of the trees) to determine vertical structure analysis. In this case *Pinus pseudostrobus* was found in the upper zone and the other species were distributed in the second and third height zones.

This research emphasizes the importance of a detailed, horizontal and vertical stand structure analysis in forest ecosystem according to the tree species.

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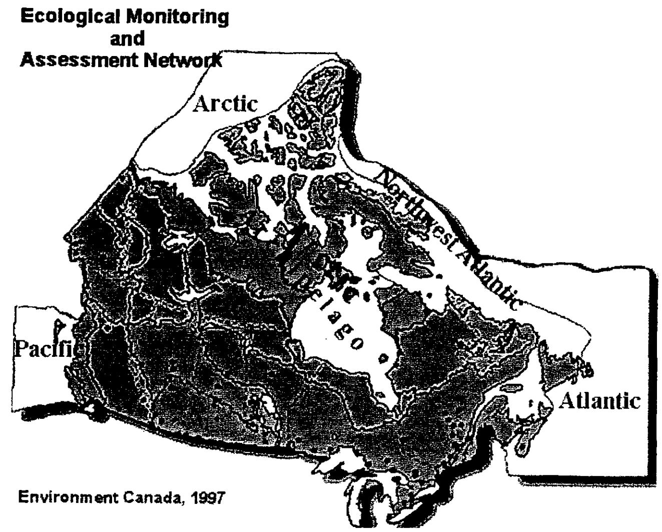
Building the Ecological Monitoring and Assessment Network: the Canadian Experience[1]

Hague H. Vaughan[2]

Abstract—The Ecological Monitoring and Assessment Network (EMAN) was developed in response to a number of needs and pressures including the decline of traditional monitoring networks in Canada, the regionalization of natural resource assessment and management and the increasingly nationwide if not global nature of current issues. EMAN is a national ecological monitoring network which includes 93 sites across the country characterized by long-term multi-disciplinary environmental work that is conducted by a multitude of agencies (142 partners and counting). In addition, less formal networks are in place or under development based on partnerships and the design of standardized protocols which generate scientifically valid data but which can be carried out by nonscientists. Examples include biodiversity monitoring plots, Frogwatch, and phenology-based networks. Environment Canada is the coordinating partner for the network.

Resumen—La red de monitoreo y evaluación ecológica (eman) se desarrolló en respuesta a varias necesidades y presiones incluyendo la declinación de redes de monitoreo tradicionales en canadá, la regionalización, evaluación y manejo de los recursos naturales. Eman es una red nacional de monitoreo ecológico de aproximadamente 93 sitios a través del país caracterizada por trabajo ambiental multi-disciplinario a largo plazo que es dirigida por una multitud de agencias (142).



EMAN's focus is the detection and reporting of change in Canadian ecosystems, including the description of the spatial and temporal patterns of observed change, in order to most effectively provide both a context for regional or local observations and the early identification of circumstances where research, management or policy initiatives might be needed. With its focus on the detection, distribution and reporting of ecosystem changes, EMAN has the ability to provide:

- a national perspective on changes occurring in Canadian ecosystems affected by the multitude of stresses on the environment;
- an early warning system that identifies new ecosystem changes as they emerge;
- consistent nationwide information related to the success of, or need for, controls and other resource management initiatives; and
- sound recommendations for appropriate follow-up initiatives in research, focused studies or assessment.

As a direct result, or as a product of specific follow-up investigations, information will be provided to Canadians so they are better able to make decisions on the conservation and sustainability of their ecosystems.

The past four years have been the "building" years for the network—getting the principles of long-term ecological monitoring entrenched, and bringing partners on board to participate in the network. The next steps are to ensure that the network is used, and is useful. In February 1998, the EMAN Coordinating Office formed a 17 member focus group to undertake a program audit and peer-review so as to evaluate how far EMAN has come and where its future directions should be.

The network successes identified are many, including:

- Developing Partnerships for a New Initiative
- Building a Large Network of Monitoring Sites
- Standardizing Methods for Monitoring Biodiversity Change in Canada's Ecosystems
- Establishing Long-Term Biodiversity Monitoring Plots
- Sponsoring the Assessment of Scientific Data
- Hosting EMAN National Science Meeting
- Activating Biosphere Reserves
- Leveraging Resources
- Communicating through the EMAN Website
- Adopting and Promoting the Use of the National Ecological Framework

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While the network accomplishments over the past four years far outweighed the network shortcomings, the views of the focus group pinpointed some network weaknesses which included that:

- the budget is too small for its scope of activities;
- the EMAN mandate appears to be not focused;
- the connection to policy is weak;
- there is weak coordination and support within Environment Canada; and
- the network's regional coordination is weak;

Many of these concerns are being addressed through a number of new initiatives and the refinement of existing approaches including:

- Consulting with Environment Canada Regions and other programs in order to establish and ensure relations, roles and linkages
- Building an Indicators of Change Network based on standardizing 20-25 parameters at existing sites augmented with specific components such as biodiversity and indigenous knowledge.
- Building a network of cooperating natural resource organization networks and information data bases through the development of partnerships to address areas of joint interest
- Building an broad Observation Network including amphibians, phenology, reptiles and birds
- Coordinating the inter-site or interagency Analysis and Interpretation of Network Data

Others require an increased emphasis on marketing the role and direction of EMAN and promoting cooperative partnerships within Environment Canada.

Lessons that may well be applicable to the creation or maintenance of similar networks elsewhere include:

1. Answer questions and focus on products: creation of the perfect set of sites, the perfect set of parameters, the perfect analyses, QA/QC, data management, etc. are all laudable but not if they come at the cost of communications with those you are trying to affect or who are paying you for information;
2. Build a focus on the needs of decision-makers and policy formulators;
3. All money is soft money: lasting partnerships are a better guarantee of security;
4. Communicate to excess with partners, the public, and particularly others in your own organization.
5. The EMAN operational method of "grease and glue" intervention funding is one worth considering.

Complementary Roles of Research and Monitoring: Lessons From the U.S. LTER Program and Tierra Del Fuego[1]

Jerry F. Franklin[2]
Mark E. Harmon[3]
Frederick J. Swanson[4]

Abstract—Although monitoring and research often are considered distinct, they are actually closely related activities which should be tightly linked. Development and operation of meaningful monitoring programs depends upon research and scientific expertise at all stages. First, design of monitoring programs always requires scientific knowledge, and often supportive research to inform the selection of parameters and sampling design—including how, where, and when to sample. The highly idiosyncratic nature of project-based monitoring programs makes involvement of scientific experts particularly critical at the design stage. Second, scientific expertise is important in QA/QC. Third, research (often) and scientific expertise (always) are needed to interpret the results of monitoring programs—i.e., the ecological significance of a statistical change in an ecological parameter. The immense challenge of interpreting the significance of changes in ecological parameters rarely has been considered. Fourth, some types of monitoring only can be accomplished by an intensive research-quality effort indistinguishable from traditional research. For example, accurate assessments of long-term nutrient balances and soil productivity, a goal often identified in monitoring protocols (e.g., in the Santiago Accord), requires complex field and analytic capabilities.

Monitoring also can make major contributions to ecological research programs by producing research-quality data that can be used directly by scientists in their investigations. For example, repeated measures of ecosystem processes can yield new insights into factors and events that control ecosystem behavior. Monitoring also can highlight important phenomena or spatial or temporal patterns that need scientific attention, thereby defining priority research agendas. Examples in the following text are drawn from the H. J. Andrews Experimental Forest and Long-Term Ecological Research (LTER) site and a sustainable forestry project in Tierra del Fuego.

Resumen—Aunque el monitoreo y la investigación a menudo se consideran como actividades diferentes, nosotros las encontramos estrechamente relacionada, las cuales trabajan mejor cuando están ligadas. El desarrollo y conducta de los principlaes programas operativos del monitoreo son particularmente dependientes de la investigación y la especialización científica. Primero, el diseño de programas de monitoreo requiere del conocimiento científico y de investigación; problemas críticos que requieren esta entrada incluyen selección de parámetros y diseños de muestreo, incluyendo cómo, donde y cuándo muestrear segundo, científicos expertos son importantes en qa/qc. Tercero, la investigación (a menudo) y los científicos expertos (siempre) son necesarios para interpretar los resultados de programas de monitoreo; ej., La interpretación del significado ecológico de un cambio estadístico en algún parámetro. Algunos tipos de monitoreo sólo pueden ser logrados por un esfuerzo intensivo de la investigación de calidad.

Por ejemplo, la evaluación del balance de nutrientes asociados con la productividad de la tierra a largo plazo, una meta típica de los protocolos del monitoreo, únicamente puede ser realizada utilizando capacidades complejas de campo. El monitoreo también pueden hacer contribuciones mayores a los programas de la investigación ecológica; mucha investigación es, de hecho, indistinguible del monitoreo en que aquella involucra a menudo medidas cuidadosas y repetidas de organismos, procesos, o estructuras. La mayoría del monitoreo debería estar produciendo información de calidad que pueda ser usada por los científicos en sus investigaciones. Por ejemplo, medidas repetidas de procesos del ecosistema pueden producir nuevas señales en los factores y eventos que controlan el comportamiento de los ecosistemas. El monitoreo también puede resaltar fenómenos importantes de los patrones espaciales y Temporales que necesitan atención científica, ayudando a definir prioridades de investigación. Nosotros usaremos nuestras experiencias del sitio experimental de investigación ecológica a largo plazo (lter) h. J. Andrews y de un proyecto forestal sustentable en tierra del fuego para ilustrar estos conceptos.

Environmental and natural resource monitoring programs are expanding rapidly throughout the world, driven in part by the need for continuing assessments of conditions and trends in environmental and biotic variables at regional, national, and global scales. Moreover, managers and policy makers increasingly desire (and often are required legally) to quantitatively assess the effectiveness and impacts of natural resource management plans and activities. The test of sustainability hinges on monitoring the effects of selected practices; high-quality monitoring programs can provide early-warning signs of unsustainable practices. The current concepts of ecosystem and adaptive management incorporate monitoring as an essential component. Hence, major expansions in the scale, complexity, and investment in monitoring are certain, and the data generated are going to be of increasing importance.

Traditionally monitoring has been viewed as a management or regulatory activity unrelated to scientific research.

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Scientists often go to great pains to distance themselves and their activities from monitoring which they typically define as the routine collection of data for nonscientific purposes. Similarly many resource managers do not consider science or scientists to be essential participants in development and operation of their monitoring programs.

To the contrary, we assert that development, operation, and interpretation of credible natural resource monitoring programs only can be achieved with extensive scientific involvement. Results of scientific research and scientific expertise are needed in at least four major aspects of monitoring: (1) Design of monitoring programs, including the selection of parameters and development of the sampling design—where, when and how to sample as well as details of the statistical design; (2) quality control; (3) interpretation of results; and (4) periodic assessments of the effectiveness of the monitoring program ("adaptive management"). In addition, some monitoring objectives only can be achieved with scientific quality research efforts; much so-called "validation monitoring" falls into this category.

In this paper, we outline some important relationships between monitoring and research based on our experiences at the H. J. Andrews Long Term Ecological Research (LTER) site and in development of a monitoring plan for a sustainable forestry project in Tierra del Fuego. Our objective is to clarify the central importance of science and scientific expertise in development and operation of environmental and natural resource monitoring programs. We note that our perspective is primarily that of scientists who have been involved with development of operational monitoring programs at local and regional levels, rather than the design of national and international assessments that are typically standardized, top-down approaches. The distinction between large-scale assessment monitoring and monitoring the effectiveness of management programs on individual properties or for individual projects is an important one. Effectiveness of monitoring at local levels involves highly individualized, as opposed to highly standardized, programs.

Study Areas

Before considering the linkages of scientific research and monitoring some background on the ecosystems and properties on which we are basing our examples may be helpful to the reader.

The H. J. Andrews Experimental Forest and LTER is located in the Cascade Range of Oregon, USA (McKee 1998, Van Cleve and Martin 1991). This mountainous site has a mesic climate with an annual precipitation of 230 cm at the headquarters site; the rugged topography is underlain by a variety of volcanic formations. The primary vegetation type is temperate coniferous forest dominated by species, such as Douglas-fir (*Pseudotsuga menziesii),* western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and true firs (*Abies* spp.); about half is mature and old (500 years) primary forest while much of the remainder consists of young stands regenerated following timber harvest.

Research at the H. J. Andrews site began with its establishment in 1948 and includes long-term studies of hydrologic and nutrient cycling in small catchments. It was selected as a primary site for the U.S. International Biological Program's Coniferous Forest Biome project in 1968 (Edmonds 1982), and was awarded one of the first LTER grants in 1980 (Van Cleve and Martin 1991). The research program covers a broad range of topics including: structure and function of forest and associated stream ecosystems, geomorphic and other landscape-level processes, disturbance processes and ecosystem recovery, ecology of individual organisms, biodiversity, and the practical application of ecological information in resource policy development and practices.

Research findings and the expertise of the scientific cadre from the H. J. Andrews site have contributed extensively to development of ecosystem management practices for federal, state, and private forest lands within the temperate forests of northwestern North America. An outstanding example is in the development and implementation of the Northwest Forest Plan (Tuchman et al. 1996) on federal lands within the range of the northern spotted owl (*Strix occidentalis caurina*), including the development of legally-mandated monitoring programs. However, H. J. Andrews science and scientists also have been involved in developing plans for management at smaller spatial scales, such as individual national forests and portions of forests (e.g., Cissell et al. in press) as well as lands belonging to corporations and to native American tribes. This has afforded H. J. Andrews scientists much practical experience in the design and implementation of monitoring programs. Some recent activities (e.g., hydrology of experimental watersheds) also are treated as monitoring programs supplying critical data to land managers. Some monitoring programs are conducted partially as graduate student projects, thus generating research findings and educational benefits.

The Trillium Forestal sustainable forestry project (known as the Rio Condor Project) involves 235,000 ha of privately owned land in the Chilean portion of Tierra del Fuego. The mountainous landscapes involved are mosaics of forest, wetland ("turba"), steppe and alpine vegetation. The forested areas are typified best as a cold temperate regions with moderate rainfall (800 to 1000 cm) and high winds. The major tree species is lenga (*Nothofagus pumilio*) which forms pure stands over much of the region; most of these are primary forests of complex structure as a result of their age (200 years or more) and frequent creation of small gaps by high winds. Coigue (*Nothofagus betuloides*) is a significant species along the west coast and nirre (*Nothofagus antarctica*) occupies forest ecotones at timberline and with turba. Extensive baseline studies on ecological conditions and biota were conducted by the Independent Science Commission (ISC) (Arroyo et al. 1996) composed of academics nominated by the Chilean Academy of Sciences. A system of biological reserves totaling 65,000 ha (including 10,000 ha of commercial forest) was selected by the ISC and permanently reserved by Trillium Forestal as part of their management plan.

Trillium Forestal intends to manage much of the forest for timber production under the terms of a permit issued by the Chilean government following preparation and review of an Environmental Impact Statement. Included are commitments to use of native species, natural regeneration, a conservative silvicultural harvest system (shelterwood with 10% permanent reserves) and harvest schedule, and protection of sensitive areas such as riparian zones, steep slopes, and wetlands (in addition to the permanent biological reserves).

An extensive monitoring program is associated with this management program to meet the requirements and needs of several interested parties including the company, a forest certifying organization, governmental organizations, and the ISC. The National Environmental Commission of Chile (CONAMA) provided extensive direction to Trillium Forestal regarding monitoring required as a condition of the project's environmental permit; many of these requirements were derived from the principals and guidelines identified in the Santiago Declaration (The Montreal Process 1995). The monitoring plan was developed primarily by members of the ISC, particularly Chairperson Mary Kalin-Arroyo, in collaboration with the senior author (Franklin). Development of the plan was challenging because it involved several major stakeholders (government, company, academic committee and potential "green" certifier), had to address numerous governmental requirements, and needed, simultaneously, to be ecologically meaningful and practical in terms of field installation, operation and cost, all of this in a very remote region of the world.

The Role of Science in the Development of Monitoring Programs

Science and scientists can play an important roles in the design of monitoring programs, including decisions about which parameters should be monitored, methods for sampling, and sampling design (spatial and temporal pattern). These are, of course, the critical elements in any design—the what, when, where, and how of the monitoring program. The possibilities are infinite—but a strong, science-based understanding of the ecosystem is the foundation for designing an effective, efficient monitoring program.

Those who suppose that these critical issues will be resolved for them, perhaps with prescriptive guidebooks, are likely to be disappointed. Standardized monitoring programs probably will be characteristic of large-scale national and multinational programs intended to continually or periodically assess environmental conditions and trends related to development of national and global policies. However, most monitoring programs will be developed as elements of smaller-scale plans or programs to assess specific accomplishments and impacts. Examples include monitoring associated with plans for individual resource management areas (e.g., national forests, national parks, Indian reservations, and privately-owned tree farms) or for regional collections of resource management units, such as the Northwest Forest Plan for federal lands within the range of the northern spotted owl.

Our experience is that such monitoring programs are highly idiosyncratic and, therefore, not amenable to design using textbook models. While the broad categories or topical areas of monitoring may be similar in many of these programs, the appropriate selection of parameters varies widely with local circumstances (ecological and social). Similarly, appropriate answers to the questions of when, where and how will often vary among projects even when the same parameter has been selected.

Design issues are further complicated by the fact that monitoring programs are not likely to be hierarchical in structure. The notion of a neatly structured monitoring program in which sampling for various parameters is nested within a common sampling design (such as a set of forest sample plots arranged in a systematic grid) is unrealistic. In fact, operational monitoring programs are more likely to resemble "fruit salad"—they will be programs in which different parameters are monitored on contrasting temporal and spatial scales and, consequently, use different methodologies or technologies. For example, a monitoring program may incorporate a portfolio which includes population dynamics of key species, stream flow, and fire regimes.

The spatial and temporal complexity associated with different themes is illustrated by contrasts in the Rio Condor Project monitoring plan: (1) Some landscape-scale activities (e.g., miles of road, area of timber harvest) are to be monitored over the entire property at 5-year intervals using aerial photography or satellite images; (2) Riparian and stream conditions are to be monitored at 5-year intervals with ground-based, permanent sample areas placed on selected stream reaches and using a variety of sampling methodologies; and (3) Populations of high-profile (ecologically or socially sensitive) animal species, such as the red fox (*Pseudolopex culpaeus*), will be monitored over the entire property on an annual basis using techniques appropriate to the specific organisms.

Hence, challenges in design of monitoring programs include decisions about parameters (what), spatial and temporal scales of sampling for each of the parameters (where and when), issues of statistical design, and selection of sampling methods (how), such as specific instrumentation, plot design and sensors. Scientific research and expertise are key to all of these aspects of design.

Selection of Parameters

Selection of parameters is the first of the challenges. Almost any stakeholder can come up with a laundry list of "things which should be monitored." Often such lists are useful only as a starting point, and rarely reflect the realities of having to operate or finance the monitoring program!

Initially, it is important to identify which parameters are likely to be sensitive indicators of important ecological conditions—i.e., which are ecologically meaningful. There also are important practical realities. Can a candidate parameter be readily measured (or measured at all) using existing technologies? Many "parameters," which are often identified as essential parts of monitoring programs, are extremely difficult to measure and, hence impractical. For example, parameters such as annual primary productivity can be difficult to measure, whereas structural features of forest stands often are more practical to monitor. Many of the more complex parameters also may be relatively insensitive and/or slow to respond to changed environmental conditions as a result of ecosystem buffering. As a result, precise estimates of such parameters may be difficult to obtain. In addition, potential cost is an important factor—i.e., it is unrealistic to design monitoring programs that have costs which rival the value of the resource in question.

Identification of sensitive and practical (even surrogate) parameters for a monitoring program is a challenge to which science and scientists can make major contributions. Numerous examples of such contributions are found in monitoring programs developed for forest lands along the Pacific Coast of North America and in the Rio Condor monitoring proposals.

Many parameters ultimately incorporated into monitoring programs have emerged from research programs associated with the H. J. Andrews Experimental Forest and LTER program. The H. J. Andrews research program, in particular, has demonstrated the importance of coarse woody debris (CWD) in the functioning of forests and associated streams and rivers (e.g., Harmon et al. 1986, Maser et al. 1988). Coarse woody debris serves as critical habitat for many elements of biological diversity in both terrestrial and aquatic ecosystems. The link between this relatively easily measured structural element and many elements of biological diversity has made CWD an element of most monitoring programs in northwestern North America. Scientists also have contributed to the establishment of thresholds for minimum levels of CWD, and to the design of specific sampling programs such as on the Willamette National Forest, Oregon (Gregory and Ashkenar 1990).

Using gauged drainage basins (30 to 5000 ha), hydrologic research at the H. J. Andrews has provided critical information on peak streamflows associated with flood storm events. The U.S. Geological Survey has conducted basic monitoring of streamflow for many decades. Yet, these data have never been analyzed with regards to relationships among storm events, management practices, and timing and scale of peak flows. Jones and Grant (1996) developed and applied new analytical techniques to streamflow records from the gauged basins to assess the effects of land use and forest regrowth. Subsequently their conceptual framework and analytical methods provided new bases for interpreting the U.S. Geological Survey stream monitoring program, and for using it predictively.

Monitoring debris slides (small, rapid soil mass movement events) for 50 years on the H. J. Andrews has proven useful in evaluating the effects of roads, clearcuts, and plantation development on the response of forest watersheds to major floods (Swanson and Dyrness 1975). This research has been used to design monitoring programs for specific locations where slides are most likely to occur.

Similarly, the effects of clearcutting on forest fragmentation has been an important focus of landscape-level research at the H. J. Andrews. In a pioneering study, Franklin and Forman (1986) demonstrated the dramatic effects of dispersed patch clearcutting on various landscape parameters and processes. Significant thresholds in landscape indices such as connectivity and patch size, and in processes such as susceptibility to disturbances developed early in the harvest cycle (e.g., 25 to 30% of the landscape harvested) under a dispersed clearcut system. As a result of this project and subsequent landscape-level research, key landscape-level parameters were identified for monitoring programs on public forest lands throughout the United States and Canada.

Much research currently is focused on using remote sensing tools to assess forest structure over large areas. LIDAR imagery has helped assess forest canopy complexity, including its depth or number of layers and its horizontal variability. LIDAR is capable of distinguishing between structurally complex stands such as old-growth, and structurally simple stands such as plantations or young even-aged natural stands. As such LIDAR can be used to periodically assess the amount and distribution of old-growth forests.

These are just a few specific examples of ways in which research is providing the basis for selecting monitoring parameters. There are many others including the use of aquatic invertebrate communities as indicators of stream health (Hauer and Lamerti 1996).

Spatial and Temporal Aspects of Monitoring Protocols

Once a monitoring parameter has been selected, the next challenge is development of a sampling design—formalizing the answers to where, when, and how in a statistically robust design.

Developing sound estimates with sufficiently low error terms such that a statistically significant change might actually be identified raises immense questions. Spatial issues, for example, involve decisions about where the sampling will take place. Where are the sensitive locations in the landscape? This may not be as obvious as it appears. CONAMA directed Trillium Forestal to include aquatic monitoring as a part of the monitoring program for the Rio Condor Project. Initial direction called for physical, chemical, and biological monitoring at stations on the larger river systems. However, in the Rio Condor Project landscape the larger river systems largely are uncoupled from forested areas by extensive intervening areas of wetlands (turba or muskeg) or steppe or both; the wetlands strongly influence the chemical and sediment loads and hydrology of the major river systems. To further complicate the issue, most of these intervening lands have been heavily grazed by domestic livestock. Moreover, the streams and rivers have been grossly modified from natural conditions by introduced beaver (*Castor canadensis*) which are pervasive and abundant in all surface waters. Hence, monitoring on larger rivers is not likely to provide any insight into effects of forest management activities on aquatic organisms and processes. Ultimately, monitoring for aquatic ecosystems was focused upon "permanent reference reaches" located within or adjacent to forested portions of the landscape.

Temporal issues involve decisions about what sampling intervals will be used. Some monitoring is appropriate and technologically convenient to approach continuously (e.g., streamflow). Other ecosystem components are sampled most efficiently at regular intervals (e.g., forest stand development). Still others are efficiently sampled on an event basis (e.g., landslides and major river channel changes). The design of a monitoring program needs to reflect these differences—i.e., incorporate multiple temporal scales appropriate to the mix of parameters and objectives.

The *where* and *when* of a quantitative monitoring program ultimately must be formalized into a sampling design that will provide the basis for statistically valid measures of change. This can be difficult and may, in fact, be the decisive issue in choosing among proposed monitoring parameters. Hinds (1984) analyzed aspects of this issue and concluded that "...ecological processes that are most likely to respond to the stress of concern, so that relatively simple and well-defined measurements can be used..." are most appropriate.

As an example, Hinds found that needlefall is a useful indicator of stress conditions in coniferous forests of northwestern North America. He concluded that "...long-term trends in ecological structure or function are impossible to detect by the use of poorly-designed methods or intermittently-collected data...work must continue towards the development of long-term measurements that, in the manner of temperature in climatology, reflect widely useful and robust measurements." Confounding spatial changes with temporal changes also needs to carefully considered; the potential for this will vary widely with monitoring parameter and ecosystem type.

Monitoring changes in soil properties is an example of an area in which obtaining statistically credible estimates of change can be prohibitive in terms of cost. It is widely agreed that assessing changes in long-term site productivity is a critical element of resource-monitoring programs. For example, Criterion 4 of the Santiago Declaration includes as an indicator: "Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties" (The Montreal Process 1995). Yet, to develop statistical estimates of many soil parameters with acceptable error terms can be difficult and expensive even for a single harvested area; estimating values for such parameters for large areas over several years or decades is simply impractical with traditional soil sampling methodology.

Scientific research and expertise is likely to be critical to developing statistically-valid sampling designs and, more fundamentally to determining whether such quantitative approaches are feasible for a specific parameter or set of parameters. Designing a monitoring program largely should be a scientific process comparable to development of a research project. It should include definition of objectives (which could, in fact, be done as a series of questions), selection of the critical response variables (monitoring parameters), and design of a sampling scheme (when, where, and how) which will fulfill the stated objectives. Science and scientists have major contributions to make in all stages of design—albeit the process must involve other considerations and participants.

Monitoring Using Traditional Scientific Approaches

Some important issues in monitoring do not lend themselves to routine monitoring efforts. Rather, they require efforts that essentially are equivalent to scientific research projects in design, implementation, and the direct involvement of scientific personnel. Some of the efforts described by the USDA Forest Service as "validation monitoring"—monitoring to examine the validity of basic management assumptions—fall into this category.

Accurate assessments of the direct impact of forest harvesting practices on organisms and ecological processes can be difficult or impossible using an extensive monitoring program which, by its nature, is of low intensity and has high levels of variability. Nevertheless quantitative information on the effects of forest management practices is ultimately essential to assess the long-term sustainability of a particular practice.

In the Rio Condor Project, two research projects have been identified as part of the monitoring program because of the complexity of the issues. These projects are designed to assess: (1) effects of forest harvest on biological diversity and important ecosystem processes (Harvesting and Biodiversity Study); and (2) effects of forest harvest on long-term site productivity and water quality (Site Productivity Study). These could be described as a very intensive component of the monitoring program or validation monitoring but, in fact, they are research projects. In both cases, they involve intensive integrated studies of ecosystem and organismal responses to forest harvesting with the objective of providing definitive tests of sustainability.

The objective of the Harvesting and Biodiversity Study is to assess the long-term effects of the primary Rio Condor harvest system (shelterwood with 10% permanent retention) on forest organisms and ecosystem processes. Are sensitive and important plant, animal, and fungal species maintained using this silvicultural approach? Response variables include: trees and vascular plants, cryptogams (mosses, lichens, liverworts), fungi, small mammals, birds (including owls, woodpeckers, and parrots), selected groups of invertebrates, and rates of litter decomposition. Specific foci are on: (1) persistence of species ("life-boating") and their role as inocula; and (2) re-establishment of species initially displaced by harvesting operations. The design of the study involves replicated comparisons of treated and control areas.

The Experimental Watershed Study is focused on: (1) long-term sustainability of forest productivity through a detailed study of nutrient and organic matter balances; and (2) effects of management on water quality and stream biota. As noted above, it is extremely difficult to assess long-term sustainability of a management program. Careful studies of nutrient and energy budgets are one way to provide definitive answers. Such studies are always technically challenging, particularly in Tierra del Fuego where atmospheric depositions of nutrients and moisture may be very important. Similarly, management impacts on hydrology, water quality, and aquatic organisms are most likely to be observed in areas where the forest and aquatic ecosystem are closely linked. The Experimental Watershed Study is based upon the model pioneered by Hubbard Brook LTER (Likens 1995) and will involve one or more sets of small catchments, each containing at least one treated watershed and a control.

The study of larger-scale hydrologic impacts of forest management is another example of research integral to monitoring programs and objectives. Researchers at H. J. Andrews LTER have used long-term data on stream flow to assess effects of land use, forest growth, natural disturbances, and climatic variability on streamflow. Streamflow properties of interest include peak (flood) flows, low flows, and seasonal and annual water yields. Potential cumulative effects of management practices is an important issue that has been essentially impossible to assess through traditional monitoring programs. At H. J. Andrews LTER, new analytical approaches have allowed scientists to refine analyses and conclude that there are major and persistent effects of roads and forest harvest on hydrologic regimes, including peak flood flows (Jones and Grant 1996). Very long-term and careful records (30 to 50 years) were needed to effectively address the issue of cumulative effects.

To summarize, it has been our goal in this section to make clear that some monitoring objectives can be achieved only with research-grade projects—whether they are described as scientific research or not. Such activities should be considered and supported as integral elements of monitoring programs.

It is equally true that monitoring programs can contribute very substantially to research programs—the same data may be used for very different purposes. In many cases, it is not possible to distinguish monitoring from long-term observations associated with experiments. Although some people have argued that all monitoring must be done with scientific rigor that effectively would make all monitoring data at least qualitatively suitable for scientific investigations, this is not likely to be achieved. However, the important point is that well-designed monitoring programs can be the source for many data sets critical to environmental science—data sets which could never be developed by traditional scientific institutions. It is important, therefore, that the potential scientific contribution of monitoring programs be kept in mind during their design and operation.

Both perspectives—science as a part of monitoring and monitoring as a contributor to science—have the additional benefit of encouraging active and continuing collaborations between the scientific and management communities with, in our opinion, net benefits to both.

The Role of Science in Quality Control

Scientists have major roles in assuring and assessing the quality of monitoring programs. This may take a highly technical form, such as in regularly assessing the quality of a program of water sampling and chemical analysis. Other quality control activities may involve periodic assessments of the technical competence of the personnel involved in monitoring and the degree to which sampling protocols are being observed.

Insuring high-quality data management is a frequently unrecognized part of the QA/QC program needed in monitoring. Scientists and scientific programs, such as the LTER program, have made major contributions to the conceptual and technical basis for management of large ecological data sets (Michener 1986, Stafford 1985, Stafford 1993, Stafford et al. 1984, Stafford et al. 1988). Scientific research programs have contributed to development of metadata standards, data formats, and on-line storage and retrieval systems. Increasingly sophisticated programs are being developed to screen data and identify outlier values and off-trend system behaviors which could be either errors or early warnings of environmental problems. The experience from ecological research programs can and should be widely applied in managing data from even modestly-sized monitoring programs.

An important part of operating a monitoring program and, specifically managing data will be making data available on a timely and comprehensive basis to a wide range of interested parties. Modern technology makes this possible. And modern societies are going to insist upon such access. This substantially elevates the importance of data management in monitoring, particularly in development of metadata and timely quality control on the data sets.

The Role of Science in Interpreting Results of Monitoring Programs

Interpreting the ecological significance of a change in a monitored parameter is not a trivial issue; it may be the most challenging element of an operational monitoring program. In a well-designed monitoring program, a statistically significant change may be observed—but is it ecologically significant?

One must have substantial knowledge to interpret the significance of observed changes in parameters. Results are rarely so straight-forward that critical values or thresholds can be easily identified. When changes are observed, many questions need to be answered before deciding upon a management or regulatory response. For example:

- Is the observed change (e.g., in soil pH) real or is it a sampling artifact?
- If the observed change is judged as "real", is this change permanent or temporary and, if temporary, what is the likely rate of recovery?
- What are the potential environmental consequences of a change of the magnitude observed?
- Were similar changes observed in undisturbed (control) environments or only in managed areas?

High natural levels of spatial and temporal variability are characteristic of forest and associated aquatic ecosystems, making it difficult to detect subtle changes in many physical and biological parameters. Such changes often can be identified only by collecting and analyzing data over very long periods (Likens 1983). Furthermore, many physical and biological responses to human manipulations, such as forest harvest, are temporary. Some parameters immediately begin to recover to pretreatment levels. As such, the rate of recovery may be more important than the initial change.

Assuming a real change in a parameter is detected, what are the potential consequences of that change? For example, what effect will a 2 percent reduction in soil organic matter or a 10% increase in the bulk density of soil have on long-term site productivity? Information that allows such interpretations is limited for many parameters and, even worse, often conflicting. Actual thresholds—points at which there are major changes in the relationship between the parameters and the response—may exist for some parameters but not for others. Moreover, information on such relationships rarely exists. High levels of buffering also may allow ecosystems to tolerate significant short- or mid-term shifts in individual parameters without serious long-term detriment.

Yet, another important is whether a response is due to a treatment, such as forest harvest, or whether it is part of a broader pattern of variability. For example, small mammal populations typically vary widely from year to year in response to such variables as food supply and predation.

Hence, a major shift in abundance of small mammal species on treated areas may reflect a natural cycle rather than a treatment effect. Monitoring of untreated (control) ecosystems is necessary to provide the context to distinguish treatment effects.

Such issues make involvement of science and scientists critical to interpretation of results from monitoring programs. Involvement may include new research to provide additional information, synthesis of existing information, and participation as consultant and/or on expert panel.

In addition, the above issues underscore the difficulties associated with establishment of critical thresholds as a routine part of legally mandated monitoring programs. Establishment of threshold values may be appropriate where monitoring is being approached as an auditing process to assure conformance with values specified in programmatic documents (e.g., an EIS) or government regulations. Examples might be minimum required values for tree regeneration or forest growth rates. However, an evaluative process is appropriate when monitoring is being conducted to identify patterns and rates of change (trends), and there is no established scientific basis for selection of thresholds—as in the soil examples noted above.

In the case of the Rio Condor Project, CONAMA initially identified "thresholds" for all proposed parameters. Some examples of these thresholds were: a decrease of more than 0.2 g/cm 3/year in bulk density; an annual decrease of more than 10% in organic matter content of upper 30 cm of soil; and reduction of 0.2 pH units in upper 30 cm. of soil. In fact, these thresholds were completely arbitrary with no scientific evidence that these were actually critical values. Ultimately an evaluative process was proposed and accepted as an alternative to arbitrary threshold processes. A technical working group will meet at five-year intervals to evaluate the values and trends in the monitoring data.

The Role of Science in Assessing and Modifying Monitoring Programs

The adaptive management concept needs to be applied in monitoring as well as management programs. Adaptive management assumes a continuing cycle in which new information is used as the basis for evaluating and modifying practices. Monitoring is a critical component of the adaptive management cycle; however, monitoring also needs to be adaptive.

Adaptive monitoring programs mean recognizing at the outset that such programs must evolve as we gain experience and learn more about what works. Any monitoring program should be viewed as a series of approximations which will be modified periodically as: (1) initial parameters fail to adequately fulfill our objectives or improved designs and measurement technologies for these parameters emerge; (2) new and improved parameters are identified through empirical or theoretical research or become feasible due to availability of new technologies; and (3) monitoring objectives change. Furthermore, all stakeholders need to be a part of this process.

The Trillium Forestal monitoring program recognized the adaptive nature of monitoring programs and made periodic assessment and revision part of the monitoring plan. Assessing and revising the monitoring plan was made a part of the five-year technical review of monitoring results mentioned in the preceding section.

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Literature Cited

Arroyo et al. 1996. Towards an ecologically sustainable forestry project: Concepts, analysis and recommendations. Independent Science Commission.

Cissel, J.H, F.J. Swanson, P.J. Weisberg. Landscape management using historical fire regimes: Blue River, Oregon. Ecological Applications (Submitted).

Edmonds, R. L., ed. 1982. Analysis of coniferous forest ecosystems in the Western United States, US/IBP Synthesis Ser 14. Hutchinson Ross Publishing Co: Stroudsburg, PA.

Franklin, J.F., R.T.T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. Landscape Ecology 1(1):5-18.

Gregory, S., L. Ashkenas. 1990. Field guide for riparian management, Willamette National Forest. U.S. Department of Agriculture, Forest Service, Willamette National Forest.

Harmon, M. E.; Franklin, J. F.; Swanson, F. J.; Sollins, P.; Gregory, S. V.; Lattin, J. D.; Anderson, N. H.; Cline, S. P.; Aumen, N. G.; Sedell, J. R.; Lienkaemper, G. W.; Cromack, K. Jr., and Cummins, K. W. 1986. Ecology of coarse woody debris in temperate ecosystems. *In* MacFadyen, A. and Ford, E. D., eds. Advances in ecological research, pp. 133-302. Academic Press, Inc, Orlando, FL.

Hauer, R. F., G. A. Lamberti (eds). 1996. Methods in stream ecology. Academic Press, New York.

Hinds, W. T. 1984. Towards monitoring of long-term trends in terrestrial ecosystems. Environmental Conservation 11(1):11-18.

Jones, J. A., G. E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, Western Cascades, Oregon. Water Resources Research 32(4):959-974.

Likens, G. E. 1983. A priority for ecological research. Bull. Ecol.Soc. Amer. 64: 234-243.

Likens, G. E., F. H. Bormann. 1995. Biogeochemistry of a forested ecosystem (2nd edition. Springer-Verlag: New York.

Maser, C., R.F. Tarrant, J.M. Trappe, J.F. Franklin, tech. eds. 1988. From the forest to the sea: A story of fallen trees. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; U.S. Department of the Interior, Bureau of Land Management Gen. Tech. Rep. PNW-GTR-229, Portland, OR.

McKee, A. 1998. H.J. Andrews Experimental Forest. Bulletin of the Ecological Society of America 79(4):241-246.

Michener, W. K. (ed). 1986. Research data management in the ecological sciences. University of South Carolina Press, Columbia, SC.

The Montreal Process. 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests.

Stafford, S.G. 1985. A statistics primer for foresters: The science of using data isn't just for researchers. Journal of Forestry 83(3):148-157.

Stafford, S.G.1993. Data, data everywhere but not a byte to read: Managing monitoring information. Environmental Monitoring and Assessment 26:125-141.

Stafford, S. G., P. B Alaback, G. J. Koerper, M.W. Klopsch. 1984. Creation of a forest science data bank. Journal of Forestry 82(7):432-433.

Stafford, S. G., G. Spycher, M.W. Klopsch. 1988. Evolution of the forest science data bank. Journal of Forestry 86(9):50-51.

Swanson, F. J., C.T. Dyrness. 1975. Impact of clear-cutting and road construction on soil erosion by landslides in the Western Cascade Range, Oregon. Geology 3(7):393-396.

Tuchman, E. T., K.P Connaughton, L.E. Freedman, C. B. Moriwaki. 1996. The northwest forest plan. A report to the president and congress. USDA Office of Forestry and Economic Assistance, Portland, OR.

Van Cleve, K., S Martin. 1991. Long-term ecological research in the United States: A network of research sites (6th edition). Long-Term Ecological Research Network Office, Seattle, WA.

A Comparative Analysis of Hydrologic Responses of Tropical Deciduous and Temperate Deciduous Watershed Ecosystems to Climatic Change[1]

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Abstract—Long-term monitoring of ecological and hydrological processes is critical to understanding ecosystem function and responses to anthropogenic and natural disturbances. Much of the world's knowledge of ecosystem responses to disturbance comes from long-term studies on gaged watersheds. However, there are relatively few long-term sites due to the large cost and commitment required to establish and maintain them. Knowledge gained from these sites is also important for predicting responses to future disturbances, such as climatic change, and these sites should be the focal point for the development and validation of predictive models. In this study, we apply a hydrologic model (PROSPER) using climate, vegetation, and soil parameters from watersheds in the mesic southeastern United States and in the dry tropical forests of western Mexico to assess the overall effects of climatic change (increased temperature and [CO_2]) on watershed hydrology. We found that evapotranspiration (ET) increased substantially in both ecosystem types, with increases ranging from 24 to 42%. These increases were directly attributable to changes in leaf energy balance and evaporative demand. Streamflow decreased more substantially, with virtually no streamflow under the greatest temperature increase scenario (+20%) at the site in western Mexico. Decreased stomatal conductance was not sufficient to offset the effects of increased temperature.

Resumen—La hidrología de los ecosistemas forestales arbolados es un integrador clave de respuestas funcionales al disturbio. El monitoreo a largo plazo de cuencas y clima proporciona la base para evaluar impactos potenciales de stresses, tales como el cambio climático del clima, en la función del ecosistema. En este estudio, nosotros usamos un modelo enfocado a evaluar los impactos del cambio climático en evapotranspiración en dos ecosistemas contrastantes: coweeta hydrologic laboratory (usa) y la estación de biología de chamela (México). coweeta es un sitio de investigación ecológica a largo plazo (us-lter) y es operada por el usda forest service research y chamela es una estación operada por la universidad nacional autónoma de México. Los dos consisten en una red de cuencas de monitoreo climático a largo plazo.Coweeta se localiza en las montañas apalaches del oeste de carolina, usa y se caracteriza por clima moderado húmedo (la temperatura media anual es de 12.6 °C y precipitación anual de 1786 mm). chamela se localiza en el estado de jalisco en la costa pacífica de México. La precipitación media anual es de 707 mm, con patrones estacionales pronunciados (80% de la precipitación cae entre Julio y Octubre), y la temperatura media anual es de 25 °C. Nosotros usamos el modelo hidrológico prosper para simular los impactos de cambio climático (aumentó temperatura y [CO_2]) en las respuestas hidrológicas de estos ecosistemas para evaluar diferencias en la magnitud de la respuesta y para evaluar diferencias en las variables clave. Nosotros también demostramos la importancia del monitoreo a largo plazo para evaluar los patrones de respuesta y validar la construcción del modelo.

Watershed scale analyses of hydrologic responses to disturbances requires a commitment to long-term monitoring and an understanding of the basic principles regulating the flow of water through the soil-plant-atmosphere continuum. Detecting disturbance caused departures in hydrologic parameters such as streamflow, soil moisture, or evapotranspiration (ET) from "undisturbed" conditions requires knowing the inherent variation in watershed processes, which can only be determined from long-term measurement and analyses. However, establishment and maintenance of long-term hydrologic studies is expensive and hence, there are relatively few gaged watersheds with long-term records in North America. Where small catchment studies have been employed, considerable knowledge on basic hydrologic principles, hydrologic responses to forest management (Swank and Johnson 1994, Swank and Vose 1994), and hydrologic effects of long-term chronic atmospheric deposition (Swank and Vose 1997) has been obtained.

Knowledge gained from long-term watershed studies will also be critical for assessing (and detecting) the potential effects of future disturbances, such as climatic change, on watershed processes. Examination of climate-vegetation-hydrology responses from historical climatic data provides some insight into potential future responses to climatic change; however, conditions in the next century (i.e., elevated temperature and [CO_2]) are likely to exceed the range of variability exhibited in historical data. Hence, modeling hydrologic responses—especially if the model is physiologically based, validated, and parameterized on gaged watersheds—provides a useful tool to evaluate watershed scale responses to climatic change.

The hydrologic behavior of a watershed is determined by precipitation input, as modified by soil moisture storage and ET use. Changes in any of these determining factors will influence hydrologic behavior. Climatic change (i.e., increased [CO_2], increased air temperature) has the

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potential to directly alter ET via changes in leaf energy balance, evaporative demand, and stomatal conductance. If substantial changes in ET occur as a result of climatic change, then watershed hydrologic behavior will also be altered with potential indirect effects on stream water, groundwater recharge, and soil moisture availability. These indirect responses could result into substantial effects on terrestrial and aquatic flora and fauna, and ecosystem processes such as nutrient and carbon cycling. Effects of climatic change on watershed hydrology has generally received less attention than potential effects on productivity. In part, this lack of attention might be due to a general consensus of increased water use efficiency (WUE) under elevated [CO_2] which is thought to offset drought effects (Norby and O'Neil 1991, Gunderson et al. 1993). However, most of these studies have not quantified the coincident effects of increased temperature on leaf energy balance and the potential feedbacks which might offset WUE gains. Similarly, most of these studies have been conducted under controlled greenhouse or garden conditions, and the soil-vegetation-atmospheric continuum has not been adequately represented.

The objective of our paper is to use a simulation model, PROSPER, to evaluate the effects of elevated air temperature (with and without changes in WUE) on key hydrologic parameters. Simulations were performed for two contrasting ecosystem types: the dry tropical forests of western Mexico and the mesic temperate deciduous forests of western North Carolina, USA. The primary purpose of this modeling exercise was not to provide exact predictions of watershed response, but rather to demonstrate the usefulness of a combined long-term measurement and modeling approach to understanding watershed processes in two contrasting ecosystems. Comparative studies are particularly useful for determining the robustness of model performance and for determining the general applicability of watershed ecosystem responses.

Description of PROSPER

We chose PROSPER to simulate hydrologic responses to climatic change because it has been validated and applied successfully in both conifer and hardwood forests in North America (Swift et al. 1975, Huff and Swank 1985, Vose and Swank 1992), and has performed well in regional ET assessments (USDA 1980). PROSPER was developed from first principles of physiological, physical, and climatological processes regulating watershed hydrology and refined using data from long-term disturbed and undisturbed gaged watersheds at the Coweeta Hydrologic Laboratory (see site description section below) (Swift et al. 1975, Huff and Swank 1985). The combination of physical and biological controls on ET allows the model to be sensitive to changes in air temperature (via effects on energy balance and evaporative demand) and [CO_2] (via effects on stomatal conductance). PROSPER has been described in detail elsewhere (Goldstein and Mankin 1972, Huff and Swank 1985), thus, only a general description is provided here. PROSPER is a phenomenological, one-dimensional model that links the soil, vegetation, and atmosphere. Plant and soil characteristics are combined in an ET surface that is characterized by a surface resistance to water vapor loss. This resistance, which is analogous to the relationship between stomatal resistance and leaf water potential, is a function of the water potential of the ET surface. Evapotranspiration is predicted by a combined energy balance-aerodynamic method that is a function of the surface resistance to vapor loss. PROSPER applies a water balance (through the use of electrical network equations) to the vegetation with the soil divided into layers. Hence, the flow of water within and between soil and plant is a function of soil conductivity, soil water potential, root characteristics for each soil layer, and surface water potential. Soil water flux during unsaturated soil conditions is governed by hydraulic conductivity, where hydraulic conductivity is estimated from the relationship between soil matric potential and moisture content using the procedure described in Luxmoore (1973). The version of PROSPER used in this study simulates ET and soil water redistribution between soil layers on a daily timestep.

PROSPER requires the following site-specific climatic data: solar radiation (daily total), precipitation (daily total), windspeed (daytime mean), air temperature (daytime mean), and vapor pressure (daytime mean). With the exception of precipitation, these data are used to compute evaporative demand in the energy balance-aerodynamic equation (Swift et al. 1975). In addition to climatic data, PROSPER requires several key soils and vegetation parameters (Table 1). Parameters shown in Table 1 represent "key" variables which substantially influence the simulation results. For the most part, these parameters were measured directly on the site; however, in some cases "best estimates" from the literature were utilized.

To evaluate the effects of climate change and elevated [CO_2] on hydrologic responses, we examined monthly and annual values of transpiration, ET, and drainage below the lowest soil layer. At Coweeta, drainage has been shown to be reflective of streamflow in all but the driest years (Vose and Swank 1992, Vose and Swank 1994), when drainage from soil water below the root zone is used to recharge a normally saturated deep soil layer. Shallow and coarse soils at Chamela would also suggests that drainage would be reflective of streamflow at Chamela.

Site Descriptions

Climate, soils, and vegetation data for the temperature deciduous forest were derived from a mixed hardwood forest (WS 2) at the United States Department of Agriculture, Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory, located in the Blue Ridge Provence of the southern Appalachian Mountains of western North Carolina, USA. The Coweeta Hydrologic Laboratory has been in continuous operation since 1934 and has been a National Science Foundation Long-Term Ecological Research Site since 1980. The climate is classified as marine, humid temperate with water surplus in all seasons (Swift et al. 1988). The average annual precipitation varies from 1700 mm at the lower elevations to 2500 mm on the upper slopes. The mean monthly temperature ranges from 3.6 °C in January to 20.2 °C in July. Watershed 2 is 12 ha gaged watershed (weir elevation = 670 m), has a relief of 300 m, and has a south aspect. Soils are deep (6 m) ultisols and are

Table 1.—Summary of key parameters required to run PROSPER.

Input parameter	Units	Coweeta	Chamela
Canopy and aboveground			
Leaf Area Index	$m^2\ m^{-2}$	6.0	5.0
Start leaf-out	Julian day	100	135
End leaf-out	Julian day	150	213
Start leaf-fall	Julian day	260	244
End leaf-fall	Julian Day	306	365
stomatal resistance (min)	$s\ cm^{-1}$	2.5	2.0
stomatal resistance (max)	$s\ cm^{-1}$	50.0	50.0
Soils and belowground			
Thickness of each soil layer	cm	0-30;30-90;90-180	0-50;50-100
Field capacity by layer	$cm^3\ cm^{-3}$	0-30 = 0.29 30-90 = 0.30 90-180 = 0.28	0-50 = 0.16 50-100 = 0.15
Root surface area (%)	$m^2\ m^{-2}$	0-30 = 0.20 (75%) 30-90 = 0.01 (25%)	0-50 = 0.10(85%) 50-100 = 0.06 (15%)

represented by typic hapludults and humic hapludults. Details of climate, vegetation, and soils are reported elsewhere (Swank and Crossley 1988).

Climate, vegetation, and soils data for the dry tropical forests were derived from a long-term ecosystem study initiated in 1981 at the Estacion de Biologia Chamela of the Universidad Nacional Autonoma de Mexico. Chamela is located in the state of Jalisco on the Pacific coast of Mexico. The climate of Chamela is influenced by tropical cyclones producing a highly variable annual rainfall regime (Garcia-Oliva et al. 1991). Mean precipitation is 707 mm (1977-1988) with more than a 500 mm difference between the wettest and driest year. Rainfall is strongly seasonal with 80% of the precipitation falling between July and October, with September being the wettest month. Temperature fluctuates little during the year and averages 25 °C. Data from watershed 1 (WS 1), a 15 ha gaged watershed ranging in elevation from 60 to 160 m, was primarily used to parameterize PROSPER. The predominant vegetation is the tropical deciduous forest type described by Rzedowski (1978), where leaf development and senescence patterns are controlled by rainfall. Soils are shallow (0.5 to 1 m) and predominantly sandy loams derived from rhyolite parent material. Details of the vegetation are reported in Maass et al. (1995) and Martinez-Yrizar et al. (1992) and details of the soils are reported in Maass et al. (1988).

Climate Change Scenarios

Estimates of changes in air temperature as a result of elevated [CO_2] vary considerably depending on the choice of global circulation model (GCM). For example, in the southern United States, air temperature responses range from +3 °C annually to +7 °C annually (McNulty et al. 1998). Estimates of changes in precipitation are more complex, with varying predictions in the timing of intra-annual rainfall patterns. In general, predicted changes in total annual precipitation are small (1 to 3%) (McNulty et al. 1998). We used actual climatic data for a "typical year" at our study sites, and altered air temperature by +10% and +20%, which resulted in increases in the range reported by GCM models (i.e., ~2 to 7 °C). Because of the greater uncertainty and smaller magnitude of predicted precipitation response to elevated [CO_2], we made no changes to precipitation amount or intra-annual distribution.

There are vastly different reports in the literature about the impacts of elevated [CO_2] on stomatal conductance and/or leaf level transpiration. Some of these differences are probably related to differences in species; however, varying results have also been reported within the same species. For example, Hennessey and Harinath (1998) report decreased stomatal conductance in loblolly pine (*Pinus taeda*) at mid-level [CO_2] increases, while Teskey et al. (1998) reported no increases at any level of elevated [CO_2]. The vast majority of studies have reported either no change or a decrease in stomatal conductance (Eamus and Jarvis 1989, Cuelemans and Mousseau 1994) which translates into decreased transpiration and increased water use efficiency (i.e., moles CO_2 assimilated per mole water transpired). To simulate the potential role of decreased stomatal conductance on mitigating the effects of increased temperature, we decreased stomatal conductance by 2-fold in the +20% temperature simulations. Because PROSPER's model structure is based on an electrical resistance analogy, the stomatal conductance response was accomplished by doubling stomatal resistance.

Results and Discussion

Hydrology Under Ambient Climate

They were substantial differences in hydrologic processes between the Chamela and Coweeta watersheds under ambient climatic conditions. At annual scales, ET was considerably greater at Coweeta (103.9 cm $year^{-1}$) than at Chamela (41.3 cm $year^{-1}$) (Table 2); however, ET at Chamela was 75% of precipitation vs. 57% at Coweeta. Hence, evaporative demand was greater at Chamela, but limited by precipitation inputs. As indicated by ET-precipitation patterns at each site, drainage was considerably greater at Coweeta (80 cm $year^{-1}$) than at Chamela (9 cm $year^{-1}$). These patterns and amounts are consistent with streamflow measure-

Table 2.—Predicted annual evapotranspiration and drainage under elevated air temperature and $[CO_2]$.

Climatic conditions	Coweeta ET	Coweeta Drainage	Chamela ET	Chamela Drainage
	cm/year			
ambient	103.9	79.6	41.3	10.2
+10% Temperature	134.2	49.6	51.2	1.6
+20% Temperature	148.7	35.4	53.8	0.2
+20% Temperature; 2x resistance	134.2	49.2	49.1	3.4

ments at each site, which show perennial streamflow at Coweeta and ephemeral streamflow at Chamela.

Monthly patterns reflect differences in the seasonality of climatic driving variables (especially precipitation) and leaf area index development and senescence patterns (Fig. 1a,b).

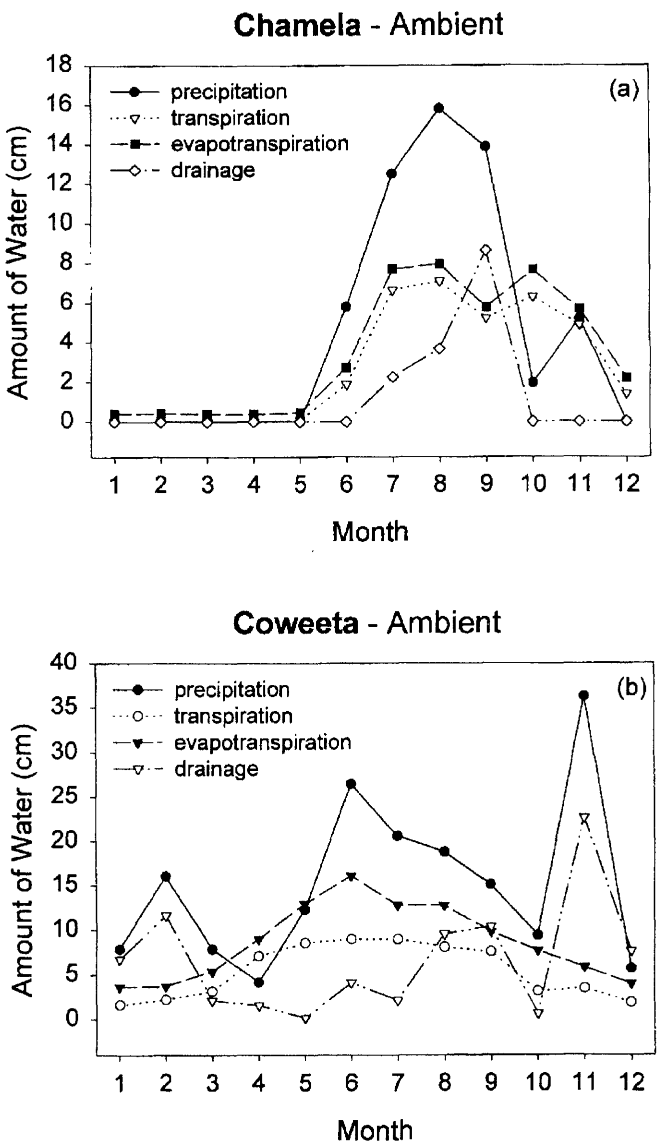

Figure 1.—Monthly precipitation, transpiration, evapotranspiration, and drainage under ambient climatic conditions for (a) Chamela and (b) Coweeta.

For example, precipitation patterns at Chamela resulted in no rainfall for a continuous six month period (December through May) (Fig. 1a). Beginning in June, rainfall stimulates leaf area growth at Chamela (Maass et al. 1995) and ET occurs. During June, rainfall inputs were not sufficient to produce drainage, as inputs were utilized in soil recharge and transpiration. Peak drainage occurred in September. In contrast, precipitation inputs at Coweeta were consistent, but variable throughout the year (Fig. 1b). At Coweeta, leaf area development and senescence patterns are not a function of rainfall. Instead, these seasonal patterns are a function of photoperiod and temperature, which are relatively consistent from year-to-year. In contrast to patterns observed at Chamela, drainage occurred throughout the year, with peak values occurring during the leaf-off period (November through April).

Large differences in leaf area phenology, soils, and ambient climatic patterns between Chamela and Coweeta presents an interesting contrast on how these ecosystems might respond hydrologically to climatic change. A priori, we expected that the magnitude of response to increased temperature would be considerably larger at Coweeta because of a cooler environment and more available soil water (due to deeper soils and greater precipitation) relative to Chamela.

Hydrology Under Elevated Temperature

At an annual scale, effects of elevated temperature on ET were considerable for both Coweeta and Chamela (Table 2 and Fig. 2). For a 10% increase in air temperature, ET increased 29% and 24% above ambient for Coweeta and Chamela, respectively. The effect of a 20% increase in temperature was disproportionately greater at Coweeta, where ET increased 43% and Chamela ET increased 30%. A substantially reduced stomatal conductance (2 x ambient stomatal resistance), mitigated the effects of the 20% increase in air temperature to an effect comparable to a 10% air temperature increase (i.e., 29% and 19% increase in ET for Coweeta and Chamela, respectively) (Fig. 2).

Effects on drainage were proportionally more significant at Chamela than at Coweeta (Fig. 3). At 10% increased temperature, drainage at Chamela decreased 84% and was essentially eliminated (98% decrease) at +20% air temperature. At Coweeta, drainage decreased 38% and 58% at +10% and +20% air temperature, respectively. Like results observed with ET, decreased stomatal conductance offset the responses to +20% air temperature to produce drainage

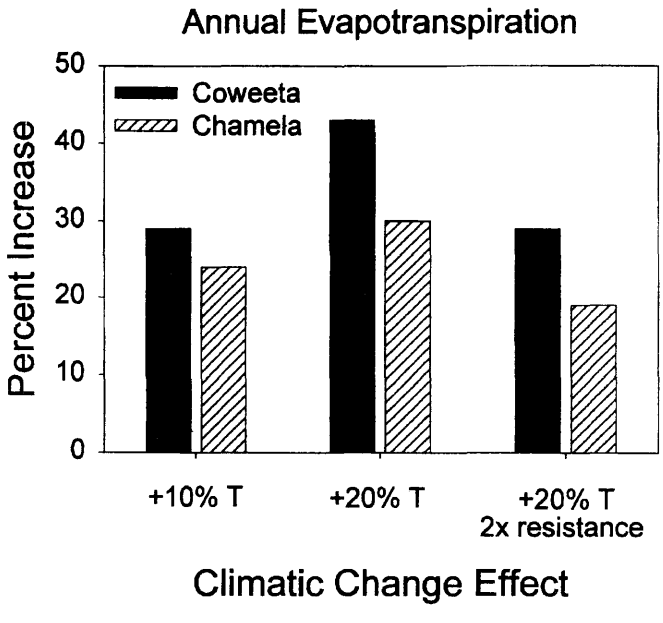

Figure 2.—Percent increase (above ambient) in annual evapotranspiration under elevated temperature and [CO_2].

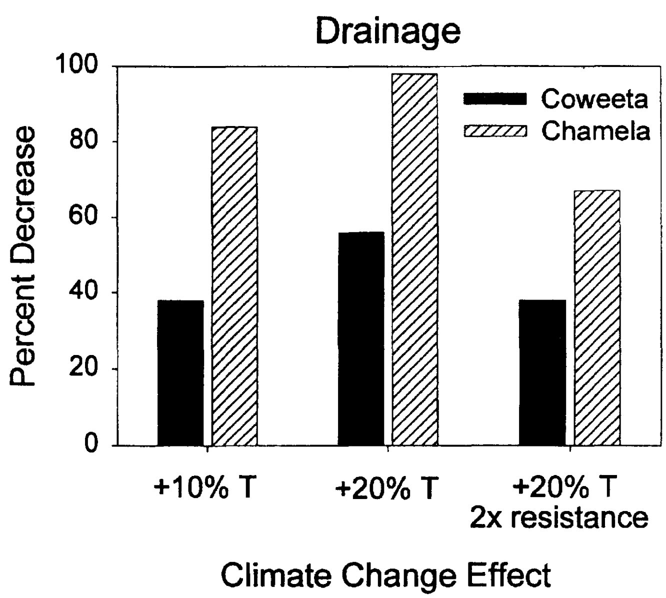

Figure 3.—Percent decrease in drainage (below ambient) in annual drainage under elevated temperature and [CO_2].

responses comparable to (Coweeta) or lower than (Chamela) those observed with a +10% air temperature change.

Elevated temperature altered monthly ET and drainage patterns at both Chamela (Fig. 4a,b,c) and Coweeta (Fig. 5a,b,c). For example, at Chamela, peak drainage occurred in September under ambient climatic conditions (Fig. 1a), but shifted to August under +20% air temperature (Fig. 4b). Changes were even more significant at Coweeta, where elevated temperature (+20%) essentially eliminated drainage from April through October (Fig. 5b). Over the long-term, changes of this magnitude would severely alter the hydrologic behavior of streams, perhaps shifting from perennial to ephemeral streamflow patterns. Implications for aquatic species adapted to perennial streamflow would be severe.

Results of these simulations indicate that substantial changes in watershed hydrology are possible with climatic change. They also indicate that while decreased stomatal conductance (i.e., increased water use efficiency) might mitigate some of the effects of elevated temperature, substantial alterations in ET and drainage will still occur. Our results concur with those reported by Borchers and Nielson (1998), who used large scale models incorporating changes in species composition and WUE, to simulate a 20 to 40% decrease in runoff (drainage) in the southern United States as a result of climate change. In contrast, McNulty et al. (1998) used a combined productivity and hydrology model (Pnet-IIS) and predicted that reductions in leaf area (due to increased respiration costs) would offset increased evaporative demand, and runoff could increase 40 to 80% in the

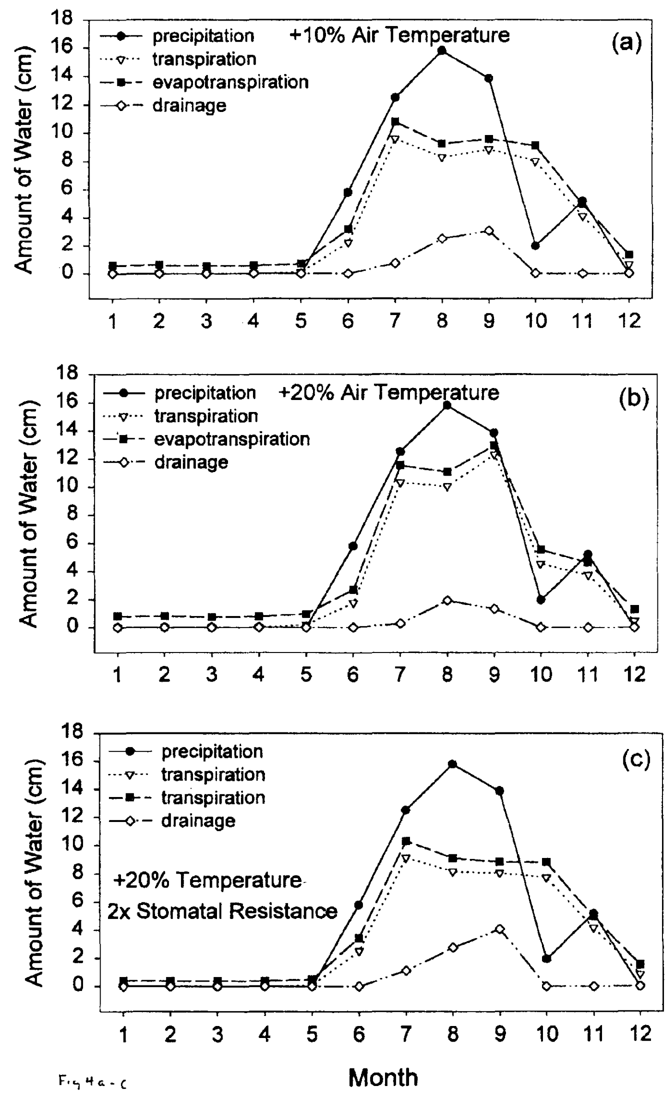

Figure 4.—Changes in monthly patterns of hydrologic parameters for Chamela.

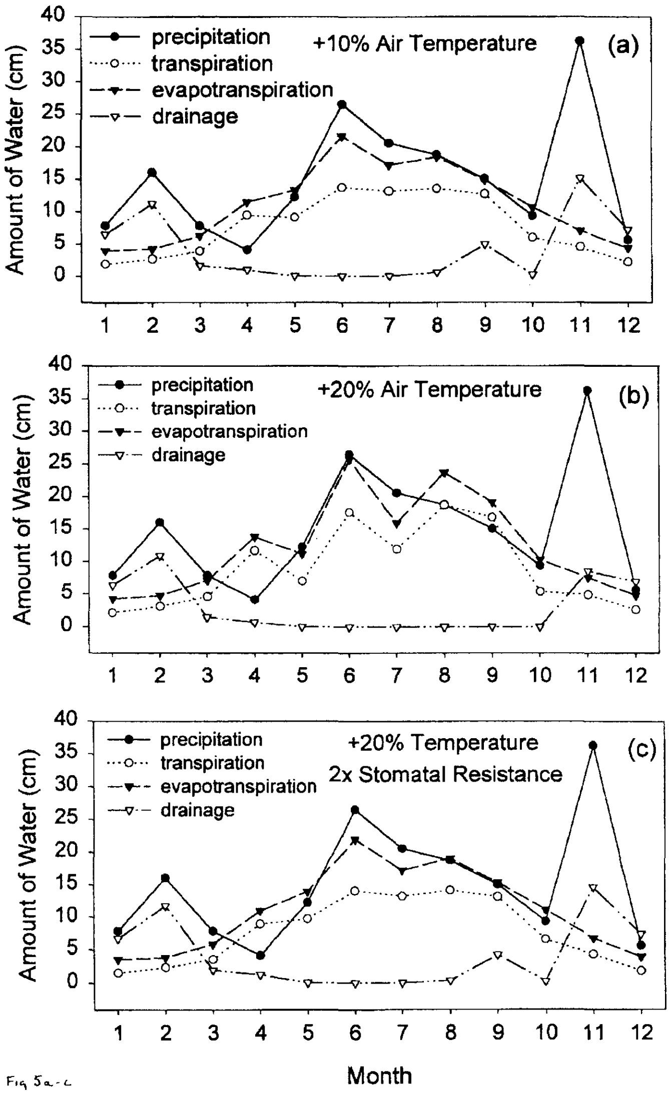

Figure 5.—Changes in monthly patterns of hydrologic parameters for Coweeta.

southern U.S. We did not consider the effects of increased temperature on leaf area or leaf area dynamics in our simulations because of considerable uncertainty about the role of respiration acclimation in mitigating the effects of increased temperature on leaf carbon balance (Amthor 1984). However, we know from sensitivity analyses of PROSPER and direct watershed-scale measurements (Swank et al. 1988) that changes in leaf area could have a substantial effect on our simulation results and this represents a considerable uncertainty in the results we obtained. Similarly, due to our short simulation interval (annual), we did not address the issue of changes in species composition. However, we suspect that changes in species composition alone would not substantially change the results we observed—the 2x change in stomatal conductance is comparable to the range in variability among likely replacement species.

Conclusions

While the results we obtained suggest major changes in ET and streamflow under future climatic regimes, several aspects of our approach merit caution in evaluating the results we obtained. First, [CO_2] increases and resultant changes in temperature and physiological processes are likely to occur incrementally over the next 50-60 years. Changes in species composition and/or acclimation to the changing climate may have an impact on how ecosystems respond. Second, our one-year simulations provide only a snapshot of potential responses. Long-term exposure to significantly elevated temperature and [CO_2] may eventually result in quite different results than we predicted. Finally, we also intend to run simulations over the range of precipitation patterns observed at both sites to understand the interactions between potential effects of temperature and elevated [CO_2] and precipitation amount. Quite different patterns of response might be expected under extremely dry or wet years.

One of the strengths of this analysis is the linkage of detailed long-term measurements with model development, parameterization, and validation. Previous applications of PROSPER at Coweeta have shown excellent correspondence between predicted and measured ET and streamflow. Good performance under ambient conditions strengthens confidence in extrapolations both to altered climatic regimes and to other sites. Data and knowledge from long-term watershed studies provide critical sites for model development and evaluation before widespread application across ecosystems and regions. We are taking a very similar approach to understanding hydrologic processes and driving variables at Chamela (i.e, long-term gaged watersheds) and the model will also be validated at Chamela in the near future.

Acknowledgments

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Literature Cited

Amthor, J.S., 1984. The role of maintenance respiration in plant growth. Plant, Cell, Environ. 7:561-569.

Borchers, J.G., and Neilson, R.P. 1998. Projected impacts of global climate change on forest and water resources of the southeastern United States. *In* R.A. Mickler and S. Fox (eds), The Productivity and Sustainability of Southern Forest Ecosystems in a Changing Environment, Ecological Studies 128. Springer, New York. Pp. 453-478.

Ceulemans, R., and Mousseau, M. 1994. Effects of elevated CO_2 on woody plants. New Phytol. 127:425-446.

Eamus, D., and Jarvis, P.G. 1989. The direct effects of increase in the global atmospheric CO_2 concentration on natural and commercial temperate trees and forests. Adv. Ecol. Res. 19:1-55.

Garcia-Oliva, F., Ezcurra, E., and Galicia, L. 1991. Pattern of rainfall distribution in the central Pacific coast of Mexico. Geogr. Ann. 73A(3-4):179-186.

Goldstein, R.A., and Mankin, J.B. 1972. Prosper: A model of atmosphere-plant-soil water flow. *In* Summer Computer Simulation Proceedings, San Diego, California, USA. Pp. 1176-1181.

Gunderson, C.A., Norby, R.J., and Wullschleger, S.D. 1993. Foliar gas exchange responses to two deciduous hardwoods during 3 years of growth in elevated CO_2: no loss of photosynthetic enhancement. Plant Cell Environ. 16:797-807.

Hennessey, T.C., and Harinath, V.K. 1998. Effects of elevated carbin dioxide, water, and nutrients on photosynthesis, stomatal conductance, and total chlorophyll content of young loblolly (*Pinus taeda* L.) trees. *In* R.A. Mickler and S. Fox (eds), The Productivity and Sustainability of Southern Forest Ecosystems in a Changing Environment, Ecological Studies 128. Springer, New York. Pp. 169-184.

Huff, D.D., and Swank, W.T. 1985. Modelling changes in forest evapotranspiration. *In* M.G. Anderson and T.P. Burt (eds), Hydrological Forecasting Wiley, New York. Pp. 125-151.

Luxmoore, R.J. 1973. Application of the Green and Corey Method for Computing Hydraulic Conductivity in Hydrologic Modeling. EDFB/IBP-74/4, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

Maass, J.M., Jordan, C., and Sarukhan, J. 1988. Soil erosion and nutrient losses in seasonal tropical agroecosystems under various management techniques. J. Appl. Ecol. 25:595-607.

Maass, J.M., Vose, J.M., Swank, W.T., and Martinez-Yrizar, A. 1995. Seasonal changes of leaf area index (LAI) in a tropical deciduous forest in west Mexico. For. Ecol. Manage. 74:171-180.

Martinez-Yrizar, A., Sarukhan, J., Perez-Jimenez, A., Rincon, E., Maass, J.M., Solis-Magallanes, A., and Cervantes, L. 1992. Aboveground phytomass of a tropical deciduous forest on the coast of Jalisco, Mexico. J. Trop. Ecol. 8:87-96.

McNulty, S.G., Vose, J.M., and Swank, W.T. 1998. Predictions and projections of pine productivity and hydrology in response to climate change across the southern United States. *In* R.A. Mickler and S. Fox (eds), The Productivity and Sustainability of Southern Forest Ecosystems in a Changing Environment, Ecological Studies 128. Springer, New York. Pp. 391-406.

Investigaciones a Largo Plazo en Productividad Forestal de Rodales Naturales de *Pinus Patula* en México: Long-term Forest Productivity Studies in Natural Stands of *Pinus Patula* in Mexico[1]

Alejandro Velázquez-Martínez[2]
Ana Rita Román-Jiménez[2]

Resumen—En este trabajo se presentan resultados de 13 años de investigación en rodales naturales de *Pinus patula* sujetos a aclareos en la Sierra Norte del estado de Puebla, en México. Estos incluyen relaciones alométricas creadas para el sitio, que se utilizaron para estimar área foliar, biomasa foliar y total, así como para determinar la eficiencia de crecimiento. Los modelos empíricos propuestos se basan en variables de crecimiento del rodal tales como el diámetro normal y la altura total, además de otros indicadores del incremento en volumen, todos ellos como una medida del impacto de las cortas de aclareo sobre la producción de biomasa y la eficiencia de crecimiento de esta especie. Así mismo se evaluaron los efectos del aclareo sobre la productividad del suelo, a través de la determinación del suministro de nitrógeno total, a partir del nitrógeno potencialmente mineralizable y de las tasas constantes de mineralización. Como complemento del estudio, se determinó la influencia de los aclareos sobre algunas propiedades de la madera de esta especie. Los resultados de estos estudios han servido como base para la formulación de nuevos proyectos sobre el impacto de las prescripciones silvícolas en la productividad forestal a largo plazo de algunos sitios en México, con énfasis en la importancia de ciertas especies fijadoras de nitrógeno.

Abstract—This paper summarizes results after 13 years of studies in natural stands of *Pinus patula* under thinning management in the Sierra Norte of Estado de Puebla, Mexico. These results include site-specific allometric relationships that have been developed to measure leaf area, foliage and total stem biomass, and growth efficiency. Empirical models are based on stand growth variables, such as diameter at breast height and total height, all of them suitables to assess thinning impact over stand biomass production and growth efficiency of the species. Additionally, thinning effects over soil productivity were evaluated, measuring total nitrogen and nitrogen mineralization rates in forest site. As complementary information, wood quality characteristics were assessed related to thinning. All these results have outlined the basis of new research projects about silvicultural management impact over long-term forest productivity of some areas in Mexico, focusing on nitrogen-fixer species of forest sites.

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La red de trabajo para la Investigación Ecológica a Largo Plazo (LTER, por sus siglas en inglés) es un proyecto desarrollado desde 1979 por investigadores de Estados Unidos de América, con soporte financiero del Fondo Nacional para la Ciencia en su División de Sistemas Bióticos y Recursos, bajo la premisa fundamental de que para poder planear adecuadamente la productividad de los sistemas terrestres y el impacto de los aprovechamientos y las actividades productivas sobre sus componentes, es necesario contar con información técnica en sitios que puedan evaluarse a lo largo de décadas e incluso siglos (Van Cleve y Martin 1991). Esta red se ha ampliado a nivel internacional y se ha dividido en distintas vertientes enfocadas a recursos particulares, como los cuerpos de agua y su dinámica (Meyer et al. 1993), los efectos climáticos de escala global sobre los ecosistemas (Greenland 1994) e investigaciones sobre ecosistemas no existentes en E.U.A. o sistemas frágiles de presencia única en el mundo, como la diversidad endémica de ciertas regiones tropicales (Nottrott et al. 1994).

Los informes internacionales, sin embargo, evidencian que en nuestro país no existe una red formal para la investigación ecológica a largo plazo, aunque se han realizado esfuerzos a nivel local bajo la responsabilidad de distintas Instituciones, entre ellas el Instituto de Ecología con áreas de reserva en el desierto subtropical chihuahuense y el bosque de pino-encino de Michilia; la UNAM con áreas de bosque tropical húmedo y seco en Los Tuxtlas y Chamela; la Universidad de Guadalajara, en la Reserva de la Biósfera Sierra de Manantlán y el Colegio de Postgraduados, Campus San Luis Potosí, para el estudio de zonas áridas y Campus Estado de México, con investigaciones donde el área de influencia es el bosque templado-frío (Montaña 1994). A pesar de ello, México no cuenta con un sitio forestal formalmente definido como un área para investigaciones ecológicas a largo plazo.

Los sitios para la evaluación de la productividad a largo plazo han sido limitados, por ejemplo, Amaranthus et al. (1995) describieron el planteamiento de un sitio experimental para evaluación de productividad a largo pazo en el Bosque Nacional Willamette en el límite de los estados de Oregon y Washington, E.U.A., donde la investigación cubrirá los aspectos de estructura, composición y sucesión vegetal, biomasa, materia orgánica, determinación de la capacidad productiva de los suelos y potencial de sustento para la fauna asociada. Desafortunadamente, los planteamientos de investigación forestal con este alcance no son fáciles en nuestro país, como tampoco lo es la planeación de los aprovechamientos más allá del mediano plazo, por distintas razones de índole social y político-económica (Escárpita e Iglesias 1993). A pesar de ello y en forma aislada, ciertos sitios como el Area Experimental Forestal "San Juan Tetla" en el estado de Puebla (INIFAP, con más de 35 años de evaluación), la Estación Forestal Zoquiapan (UACH, con más de 25 años) y la Región Chignahuapan-Zacatlán al norte de Puebla (Colegio de Postgraduados, 10 años), constituyen un registro de los distintos esfuerzos y grados de avance de la investigación forestal *in situ* en el país.

Es a éste último caso al que hará referencia el presente documento, la región Chignahuapan-Zacatlán, Pue. cuenta con una extensión de bosque templado-frío donde la especie dominante es *Pinus patula*, árbol con características silvícolas deseables que ha recibido apoyos para llevar a cabo investigación que permita explorar su potencial y planear su aprovechamiento. El Colegio de Postgraduados, Campus Estado de México, a través de la Especialidad Forestal, ha realizado investigación en el área durante los últimos 13 años y se han abordado en ella distintos aspectos de la estructura, composición y dinámica del bosque en respuesta a prescripciones silvícolas (Velázquez et al. 1994). Aunque no es un sitio formal de investigación a largo plazo, con carácter permanente y fondos e infraestructura propios, la investigación generada en la región ha permitido distintas aportaciones a la información forestal en el país.

Bases de la Investigación

Dadas las características de crecimiento de los cultivos arbóreos, principalmente su longevidad y la necesidad de tiempos relativamente largos para responder a prácticas de manejo o para lograr el volumen de cosecha, una de las primeras actividades para llevar a cabo la investigación forestal a largo plazo es el establecimiento de áreas experimentales permanentes.

Bajo esta premisa, en 1985, se establecieron parcelas permantentes para investigar la estructura de rodales naturales de *Pinus patula* y cuantificar su sensibilidad y respuesta a métodos silvícolas. En la región de Chignahuapan-Zacatlán, Pue., se delimitaron áreas experimentales permanentes de 0.1 ha en dos rodales de 10 a 20 y de 20 a 30 años de edad. Las parcelas permanentes se encuentran desde entonces en los predios Xopanac y Fracción IV de Atlamajac en esa región forestal del estado de Puebla, que geográficamente se encuentra ubicada entre los 19°51' y 20°00' de latitud Norte y 97°55' y 98°15' de longitud Oeste. Al año siguiente de establecidas las parcelas, se aplicó un aclareo libre que consistió en un corte direccional de individuos hacia características ubicadas sobre el promedio general de la población; ésto es, eliminar los árboles "lobo" presentes, el arbolado suprimido y uniformar las características del arbolado residual hacia una masa pura con aproximación a coetánea. Las intensidades de aclareo manejadas fueron 0%, 15%, 25% y 40% de eliminación de área basal, partiendo de 38.5 (Xopanac) y 42.0 (Atlamajac) $m^2\ ha^{-1}$ por rodal (Velázquez et al. 1992).

Para logar un seguimiento eficiente del arbolado se le numeró e identificó fitosociológicamente, además de registrar sus principales características morfológicas. Resulta claro, como un indicador de la importancia de los aclareos, que el resultado inmediato de esta práctica de uniformación de la masa es el incremento en el promedio de la población en cuanto a las características dasométricas relevantes en un rodal (Cuadro 1). El cambio en las características del rodal es muy importante desde el punto de vista de la estructura de la masa, debido a que tiene efectos no sólo en forma, sino también en tiempo.

Como puede verse, la reducción del volumen con respecto al inicial por efecto del aclareo no superó el 35% y la condición estructural del rodal mejoró, las características fueron más uniformes y se redujo a cero la tasa de mortalidad del rodal. Lo anterior confirma que para aprovechamientos subsecuentes un rodal adecuadamente intervenido garantizará la cantidad y la calidad de los volúmenes deseados para turnos sucesivos.

Los aclareos tienen influencia decisiva en las características del rodal, no sólo en el tradicional rendimiento en volumen, sino en otros parámetros y estimadores de productividad, como la producción de biomasa, el área foliar del árbol y la

Cuadro 1.—Valores promedio de las características dasométricas en dos rodales de *Pinus patula* en la región Chignahuapan-Zacatlán, Pue., antes y después del aclareo libre aplicado en 1985.

		Xopanac		Atlamajac	
Características dasométricas	**Unidades**	**Antes**	**Después**	**Antes**	**Después**
Número de árboles	árboles ha^{-1}	2052	1560	1413	808
Mortandad	árboles ha^{-1}	418	—	209	—
Diámetro normal	M	0.166	0.169	0.195	0.225
Edad	Años	21	20	31	33
Altura total	M	15.16	15.58	17.29	19.04
Altura de fuste limpio	M	9.53	9.60	9.91	10.73
Diámetro de copa	M	3.60	3.67	3.79	4.42
Área basal	$m^2\ ha^{-1}$	38.49	25.69	41.94	33.70
Tiempo de paso	Anillos	10.29	10.19	9.92	9.83
Grosor de corteza	Cm	1.38	1.46	2.05	2.05
Anchura de 10 anillos	Cm	2.15	2.34	2.53	2.46
Longitud de copa	M	5.64	5.98	7.38	8.31
Volumen de fuste limpio *	$m^3\ ha^{-1}$	238.43	160.31	270.16	235.04
Volumen total *	$m^3\ ha^{-1}$	320.93	220.14	398.83	352.91

*Sin corteza. Fuente: adaptado de Velázquez et al. (1992).

eficiencia de crecimiento. *Pinus patula* es una especie sensible a las condiciones de su ambiente de crecimiento y en bosques naturales responde particularmente a la densidad de sus rodales, con cambios incluso de las características morfológicas en respuesta a competencia. Este hecho comprueba que la especie puede aprovecharse comercialmente en gran escala y que tiene un elevado potencial de rendimiento; además, dada su sensibilidad al ambiente y al sitio éste potencial se eleva si se prescriben para ella los métodos silvícolas adecuados.

Incremento en Volumen

Después de los aclareos se llevó a cabo una investigación para definir el incremento en volumen del arbolado residual, con base en una categorización diamétrica se construyeron modelos de crecimiento esperado basados en el diámetro medio del arbolado, su volumen después del aclareo y el índice de sitio como parámetro dentro de la ecuación. Los modelos de la forma:

$$Y = a + b\,(\ln X) + c\,(IS)$$

Donde: Y = Incremento en volumen del árbol; a, b y c = parámetros del modelo; IS = índice de sitio.

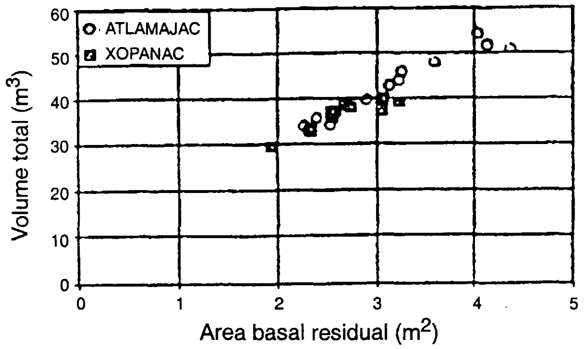
mostraron ajustes adecuados para la predicción de volumen bajo las condiciones de edad y sitio de los rodales y evidenciaron que el área basal se relacionó negativamente con el incremento esperado. Esto constituye un indicador directo del efecto de la competencia sobre el crecimiento a nivel rodal (De los Santos et al. 1993).

Al incluir en los modelos el efecto de la densidad y las modificaciones del volumen como resultado de los aclareos, las ecuaciones generadas son una aproximación al concepto de densidad óptima definido por Langsaeter (De los Santos et al. 1995). El efecto del número de árboles residuales sobre el incremento medio por árbol se mostró no lineal y con ciertos valores de tendencia asintótica, lo que refleja la importancia de la competencia sobre el crecimiento esperado por árbol; mientras que en la tendencia del volumen total del rodal en función del área basal residual este comportamiento asintótico es aún más evidente (Fig. 1).

Área Foliar

En las parcelas establecidas se realizaron muestreos destructivos para estimar la biomasa del follaje en función de su superficie en *Pinus patula*, el método empleado relacionó la superficie foliar con el peso seco del follaje del árbol, concepto definido como Area Foliar Específica (AFE); esta relación es dinámica en función de la edad del arbolado y la posición del fuste en que sea evaluada y es una medida de los flujos de carbono y energía, de la producción de biomasa, el índice de área foliar (IAF) y la eficiencia de crecimiento de árboles y rodales (Cano 1993). Los resultados mostraron que el AFE difiere significativamente entre cada categoría diamétrica de arbolado y además depende de la posición que el follaje ocupa en las copas; de modo que el AFE promedio para *P. patula* en las condiciones del sitio fue de 74.4 cm^2g^{-1}, pero disminuyó desde 97.5 cm^2g^{-1} en árboles de 5 cm de diámetro normal (DN) hasta 65.3 cm^2g^{-1} en árboles de 45 cm de DN (Cano et al. 1996). Estos hechos mostraron que si se quiere estimar la productividad aérea de un rodal es necesario que el análisis destructivo se realice con restricciones particulares en la muestra de arbolado utilizada, contemplando distintas edades y submuestras a diferentes alturas de fuste, lo que permitirá obtener una mayor precisión en las estimaciones y confiabilidad para extrapolar las funciones a nivel de superficie de terreno bajo condiciones ambientales similares. Además, la variación existente en el AFE a distinta posición del follaje en la copa y distintas categorías diamétricas (Cuadro 2) se relaciona directamente con el carácter fitosociológico de los rodales, pues los árboles dominantes presentan un AFE menor que los árboles suprimidos, resultado de estar más expuestos a la luz y tener mayor cantidad de fotosintetizados por unidad de área foliar (Cano et al. 1996). De este modo, el área foliar es también un indicador de eficiencia fotosintética, como respuesta del árbol a las condiciones ambientales existentes; este hecho relaciona los estimadores de productividad con el valor silvícola de los conceptos de calidad de sitio y de estación.

Otro de los aspectos de la utilidad del área foliar es la relación alométrica que existe entre ésta y el área de la albura en el fuste de un árbol, con base en ella es posible estimar el área foliar a través de variables que son más



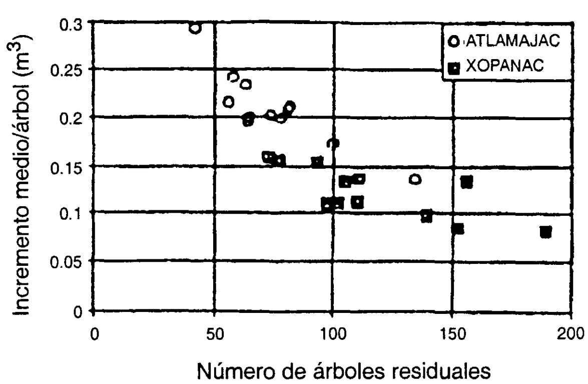


Figura 1.—Volumen total e incremento en volumen por árbol en función del área basal y la densidad de las parcelas de *Pinus patula* establecidas como sitios de investigación permanente en la región Chignahuapan-Zacatlán, Pue.

Cuadro 2.—Valores promedio de AFE (cm^2g^{-1}) por posición y edad del follaje en la copa para distintas categorías diamétricas en árboles de *Pinus patula*.

Categoría diámétrica (cm)	Posición en la copa			Edad del follaje (años)	
	Superior	Intermedia	Inferior	1	2
5	90.7 b	97.4 ab	103.5 a	98.6 a	89.1 b
10	85.9 b	88.1 b	99.1 a	85.5 a	80.2 b
15	86.5 b	88.5 ab	93.6 a	94.1 a	86.9 b
20	72.1 b	76.8 ab	79.6 a	78.8 a	75.6 a
25	70.0 b	76.8 ab	81.3 a	74.5 a	72.7 a
30	64.7 b	66.2 b	75.3 a	71.9 a	64.2 b
35	61.9 b	64.3 ab	69.7 a	67.4 a	64.5 a
40	64.2 b	67.2 ab	73.9 a	68.4 a	65.1 a
45	63.6 ab	63.7 ab	69.9 a	65.2 a	67.8 a
Promedio	73.3	76.5	82.9	78.3	74.0

Medias en una línea seguidas de la misma letra no son estadísticamente (p£0.05) diferentes.

fáciles de medir, como el diámetro normal (DN) con y sin corteza. En este sentido, Cano (1993) desarrolló el siguiente procedimiento: a) en un árbol dado, utilizando virutas de incremento se determina la longitud media del duramen, b) con la fórmula de área del círculo se obtiene el área del duramen y c) se resta el área del duramen del área basal total, el resultado es el área de la albura. Después, con base en relaciones alométricas, se realizan mediciones directas del área basal con y sin corteza que estiman el área foliar a través del siguiente modelo lineal:

$$\text{Ln } Y = \beta 1 * \text{Ln } X$$

Donde: Ln Y=expresión logarítmica del área foliar; $\beta 1=0.616$, pendiente de la regresión y Ln X=expresión logarítmica del área de albura a DN (1.3 m).

Estas estimaciones de la productividad, a través de relaciones matemáticas, tienen sustento en principios fisiológicos. La distribución vertical de la albura en el árbol muestra un patrón claramente definido, donde la anchura total de albura disminuye de las categorías diamétricas inferiores a las superiores y de la base del fuste hacia la parte superior; mientras la anchura de los anillos de albura se incrementa desde la base del fuste hasta la base de la copa viva, donde alcanza su valor máximo. Resultado de ello es que árboles de mayores categorías diamétricas soportan una menor cantidad de área foliar y que la relación área foliar:área de albura no permanece constante en las diferentes secciones de la copa de un árbol, hecho contrario al supuesto teórico tubular, lo que incide directamente en la estimación precisa del área foliar y por lo tanto de la productividad. Gracias a la precisión del modelo, el área de la albura es un estimador eficiente de la productividad en rodales maduros de *Pinus patula*, y en árboles jóvenes donde la proporción de duramen es mínima, el área basal con corteza es un estimador muy conveniente porque su medición es más sencilla (Cano 1993).

Producción de Biomasa

Castellanos (1993) realizó en los rodales descritos una estimación de la producción de biomasa de *Pinus patula*. Se encontraron para el rodal Xopanac, ecuaciones de regresión basadas en el diámetro normal (DN) del fuste, que con un ajuste logarítmico dieron estimaciones precisas de la biomasa total del árbol y sus componentes, con sólo una subestimación ligera del follaje. El modelo tiene la forma siguiente:

$$\ln Y = a + b \ln X$$

Donde: ln X es el logaritmo del DN con corteza (cm); a y b, los coeficientes de regresión del modelo para cada componente del árbol.

Las estimaciones de biomasa aérea total fueron de 165 Mg ha^{-1}, de los cuales el 72% corresponden a la madera del fuste, el 16% a la corteza, 9% a las ramas y 3% al follaje. Las ecuaciones resultaron confiables y sugeribles para condiciones ecológicas y silvícolas similares, y además permitieron estimar los incrementos anuales de biomasa aérea, que resultaron ser de 6.97 Mg ha^{-1}. También fue posible detectar las diferencias en los patrones de distribución de biomasa por categoría diamétrica; de este modo el follaje representó el 5.2% de la biomasa aérea total en árboles de 5 cm de DN y disminuyó progresivamente conforme aumentó el tamaño del árbol; es decir, en árboles de 45 cm DN representó el 1.9% (Castellanos et al. 1996). El promedio de biomasa de ramas fue 7 a 9% en todos los árboles, la estabilidad relativa de este valor muestra la regularidad de las dimensiones de la copa en *P. patula*. La biomasa del fuste con corteza constituyó el 86% en promedio de la biomasa aérea total (Cuadro 3).

Estos valores mostraron que en *Pinus patula* una gran cantidad de carbohidratos se destina a la producción de madera; el porcentaje que constituye el fuste limpio aumenta considerablemente conforme se incrementa la categoría diamétrica, lo que enfatiza la buena conformación del arbolado en términos silvícolas (copas pequeñas y con pocas ramas) y la importancia de la especie como recurso forestal de elevado valor económico.

Eficiencia de Crecimiento

La eficiencia de crecimiento (EC) de *Pinus patula* bajo condiciones naturales puede considerarse elevada, en comparación con otras especies de pinos. Además, el efecto de métodos silvícolas (como los aclareos) pueden aumentar la EC en distintas proporciones de acuerdo con la intensidad. De este modo, la producción de biomasa aérea por tiempo, es un parámentro importante para medir el resultado de los aclareos, ya que éstos modifican la composición, la estructura

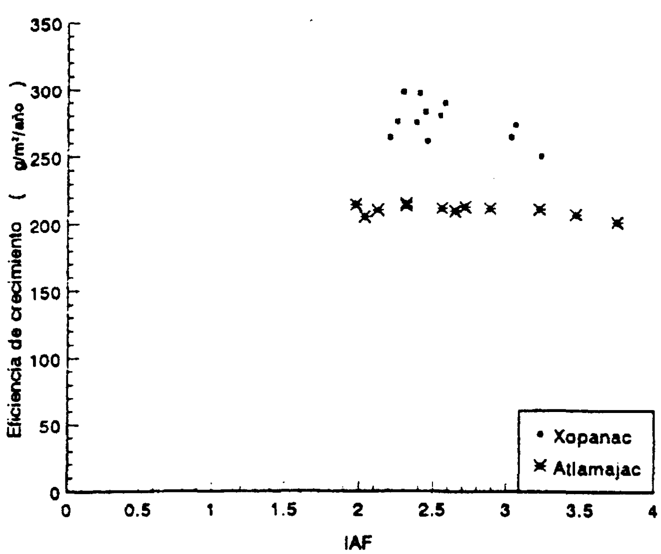
Cuadro 3.—Biomasa (kg) y distribución de biomasa (%) de los principales componentes de árboles de *Pinus patula* de diferente diámetro normal (DN) en Xopanac, Pue.

	Biomasa (kg)					Distribución (%)			
DN (cm)	Follaje	Ramas	Fuste C/C	Corteza	Árbol	Follaje	Ramas	Fuste C/C	Corteza
5	0.3	0.4	5.1	1.0	5.8	5.2	6.9	87.9	17.2
10	1.2	2.4	25.4	4.6	29.0	4.1	8.3	87.6	15.9
15	2.6	6.4	64.6	11.1	73.6	3.5	8.7	87.8	15.1
20	4.2	12.5	125.2	20.6	141.9	3.0	8.8	88.2	14.5
25	6.3	21.1	209.2	33.3	236.6	2.7	8.9	88.4	14.1
30	8.6	32.3	318.2	49.4	359.1	2.4	9.0	88.6	13.8
35	11.3	46.4	453.6	68.7	511.3	2.2	9.1	88.7	13.4
40	14.3	63.3	616.8	91.6	694.4	2.1	9.1	88.8	13.2
45	17.5	83.3	808.7	117.8	909.5	1.9	9.2	88.9	13.0

C/C=Con corteza. Las ecuaciones de regresión para los componentes son: Follaje = -3.750+1.738 (ln DN); ramas = -4.456+2.332 (ln DN); Fuste C/C = -2.061+2.300 (ln DN); corteza = -3.263+2.151 (ln DN) y árbol total = -1.862+2.77 (ln DN). Fuente: adaptado de Castellanos et al. (1996).

y el ciclo de nutrimentos de un sitio forestal (Velázquez 1990). Un análisis realizado por Claudio (1994) con datos de productividad de las parcelas permanentes durante el período 1990-1991 proporcionó una medida de la eficiencia de crecimiento (EC) de *P. patula* en rodales manejados. La relación entre el IAF y el incremento anual en la producción de biomasa es lineal y directa, por lo que la eficiencia de crecimiento resultó relativamente estable entre distintos valores de IAF (Fig. 2).

Sin embargo, debe notarse que en el caso del rodal Xopanac la relación es inversa, lo cual puede deberse a que el arbolado es más joven que en Atlamajac y además éste último tiene una mejor calidad de estación (De los Santos 1993; Arteaga 1985). Este hecho hace que la competencia sea más intensa en el rodal Xopanac, por lo que la EC depende de mantener un IAF óptimo (no mayor a 2 $m^2 m^{-2}$), mientras en Atlamajac la EC permanece constante en un intervalo de 2-4 $m^2 m^{-2}$ de



Fuente: Claudio (1994).

Figura 2.—Relación entre la eficiencia de crecimiento (EC) y el índice de área foliar (IAF) en dos rodales de *Pinus patula* en la región Chignahuapan-Zacatlán, Pue.

IAF (Claudio 1994). Los árboles más grandes en tamaño y edad requieren mayor energía para el mantenimiento del tejido no fotosintético en el tallo, ramas y raíces; además en condiciones de crecimiento pobres, el exceso de área foliar puede convertirse en una demanda de fotosintetizados.

Por otra parte, la densidad de los rodales mostró una relación inversa con el incremento promedio en biomasa aérea por árbol y la eficiencia de crecimiento de los dos rodales (Fig. 3).

El comportamiento diferente de las pendientes indica que la edad influye en la relación del incremento en biomasa aérea con el número de árboles existentes por hectárea. En este sentido, el rodal Atlamajac presenta la mayor pendiente, porque tiene árboles de mayores dimensiones y mayor IAF, por lo que su competencia es mayor por cada unidad de incremento en densidad del rodal. Al mismo tiempo mantiene relativamente su EC a pesar de la densidad, debido a su mejor calidad de estación. Esto significa que aún en sitios con condiciones ambientales favorables existe una cierta densidad crítica a partir de la cual, la relación mayor biomasa:mayor número de árboles no puede mantenerse. En función de estos resultados se podría establecer un límite máximo de área foliar con el cual optimizar la producción de biomasa de un sitio; así mismo se puede establecer la relación del IAF con la línea de densidad máxima o de mortalidad natural, con lo cual se podría determinar la zona III de Langsaeter con base en índices de densidad del IAF por hectárea.

Aun cuando las variaciones topográficas en ambos sitios no son de gran magnitud, hay que recordar, que las variaciones en productividad dentro de un tipo de ecosistema en particular, varía comúnmente a través de las unidades de paisaje, las cuales pueden verse como mosaicos compuestos de diferentes niveles de disponibilidad de los factores limitantes (agua, nutrimentos, etc.) para el crecimiento vegetal (Perry 1994).

La Repoblación Natural de *Pinus patula* y la Vegetación Competidora

Angeles (1995) analizó el efecto de la vegetación competidora sobre la repoblación natural de *P. patula* en el Ejido "La Mojonera" en Zacualtipán, Hgo. durante un año de crecimiento, bajo la premisa de que la vegetación herbácea

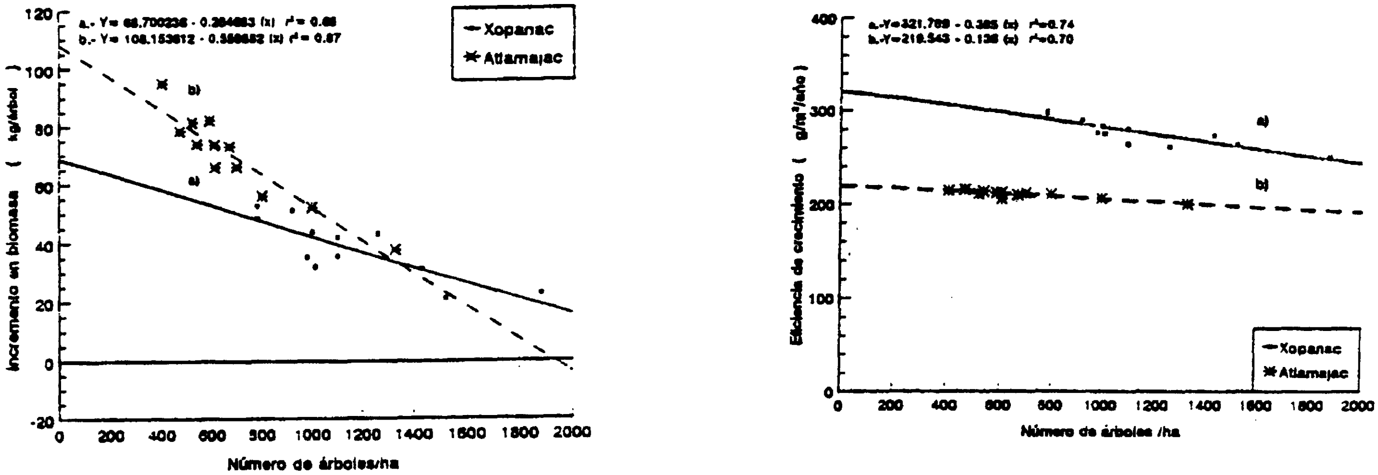
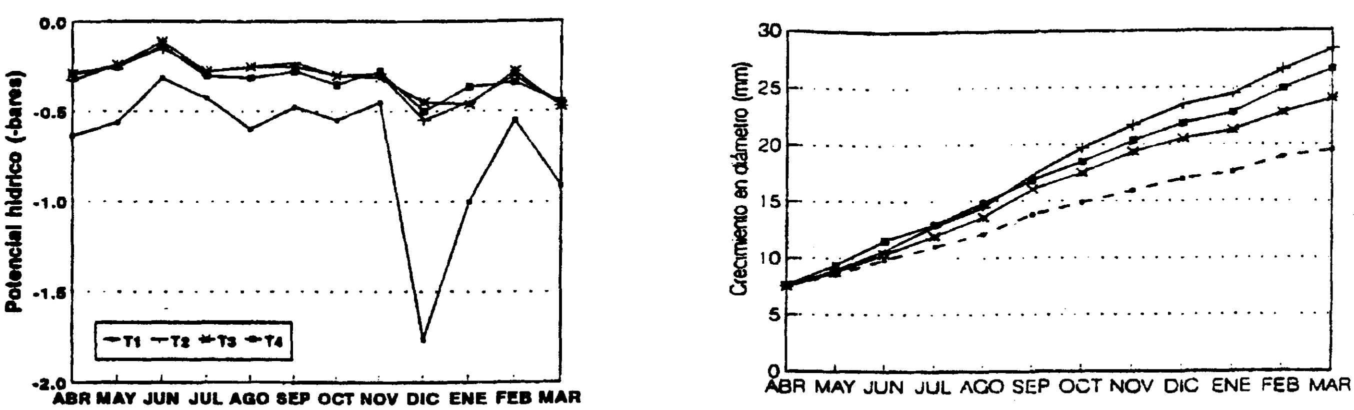


Figura 3.—Relación del incremento promedio en biomasa aérea y la eficiencia de crecimiento (EC) con la densidad de los rodales de *P. patula* estudiados.

presente compite con el pino en términos de agua, luz y nutrimentos; por lo que en el trabajo se evaluaron el crecimiento en altura, en diámetro, el potencial hídrico de las plantas y la radiación recibida por los brinzales. Los resultados mostraron que la presencia de la vegetación competidora en cantidades excesivas provocó la disminución del contenido de humedad en porcentaje del suelo, originando déficit hídrico en época seca (Fig. 4). Además, la cobertura herbácea, redujo drásticamente la radiación fotosintéticamente activa que se recibe a nivel del suelo, lo que originó seria competencia con los brinzales; la cantidad promedio de fotones fotosintéticos recibida a nivel del suelo en parcelas sin deshierbe (161.5 mmol m^{-2} s^{-1}) fue entre cinco y diez veces menor que en las parcelas deshierbadas (1697 mmol m^{-2} s^{-1}) en todas las fechas de muestreo (Angeles et al. 1997). Estos efectos combinados dieron como resultado la reducción del crecimiento absoluto y relativo de los brinzales de *P. patula*. Los resultados mostraron que la vegetación competidora no afectó en forma sistemática el crecimiento en altura, pero sí el del diámetro basal que fue 30% menor en presencia de la vegetación competidora con respecto al deshierbe más intensivo (ver Fig. 4).

Debido a lo anterior, se recomienda el control de la vegetación competidora inmediatamente después de cosechar el pino, de tal forma que la interferencia producida no ponga en riesgo el establecimiento del nuevo rodal. En las etapas de germinación y plántula, la presencia de vegetación competidora favorece a *P. patula* por el microambiente favorable producido a nivel del suelo, pero la tasa de crecimiento de la vegetación competidora es mucho más alta que la del pino y rápidamente le provocan a éste sombreado y restringen su actividad fotosintética. Por otra parte, los costos del deshierbe manual son relativamente bajos con el apoyo de ejidatarios forestales y las ventajas en aprovechamiento y generación de empleos valen la inversión a mediano y largo plazo. Al respecto, dos intervenciones



Fuente: Angeles (1995).

Figura 4.—Potencial hídrico (Mpa) y crecimiento en diámetro (mm) de brinzales de *Pinus patula* con distintas intensidades de manejo de vegetación competidora (T1=sin deshierbe; T2,T3,T4=deshierbe cada 2, 4 y 6 meses).

Cuadro 4.—Algunos parámetros edáficos de potencial de nutrición nitrogenada: materia orgánica (MO), nitrógeno total (N t) y nitrógeno mineralizable acumulado (N minac) en el rodal Atlamajac de *Pinus patula* sometido a cuatro intensidades de aclareo.

Parámetro	Profundidad de muestra	Intensidad de aclareo (%) 0	15	25	40	Valor Promedio
MO (%)	0-30	4.50	5.3	5.30	5.90	5.30
	30-60	1.90	2.0	1.90	2.40	2.00
N t (%)	0-30	0.16	0.16	0.20	0.21	0.18
	30-60	0.08	0.08	0.09	0.13	0.09
N minac (ppm)	0-30	74.00	89.00	83.00	86.00	81.00
	30-60	41.00	48.00	50.00	64.00	51.00

Fuente: adaptado de Gutiérrez et al. (1994).

anuales (una al inicio y otra al final de la temporada de lluvias) son óptimas desde el punto de vista de equilibrio entre los objetivos técnico-científicos, sociales y económicos (Angeles 1995).

Calidad de Madera

Los aclareos tienen también efecto sobre la calidad de la madera de *Pinus patula*, según mostraron los resultados de un trabajo sobre evaluación de densidad de madera y relación madera temprana/tardía en la región Chignahuapan-Zacatlán (Hernández et al. 1996). Los resultados indicaron efectos aparentemente contradictorios, ya que existió una disminución de la anchura de los anillos de crecimiento. Sin embargo, se observaron incrementos en los valores promedio de densidad de la madera (10% más que en rodales no aclareados) y proporción de madera tardía (28% más que sin aclareo). Respecto a los anillos individuales de los árboles analizados, puede decirse que aparentemente, el efecto principal del aclareo no fue aumentar la anchura de los anillos, sino más bien, evitar que se redujeran drásticamente por efecto de la edad, aunque el efecto general no pudo revertirse totalmente. Por otra parte, aunque los aclareos originan cambios casi inmediatos en la fisiología del árbol, éstos no empiezan a notarse en términos de acumulación de biomasa y ciclos de formación de madera, hasta después de dos o cuatro años, cuando se restablece el equilibrio de los procesos fisiológicos (Hernández et al. 1996).

Cambios en la Fertilidad del Suelo

Debido a que los nutrimentos disponibles, especialmente nitrógeno, inciden directamente en la productividad de un rodal, es posible esperar que el aporte de materia orgánica al suelo, por efecto de aclareos tendrá un efecto directo sobre el crecimiento arbóreo. Sin embargo, para evaluar la magnitud de dicho efecto es necesario medir cuantitativa y cualitativamente los nutrimentos disponibles. Con base en ello, Gutiérrez et al. (1994) midieron el N total, el contenido de materia orgánica (MO) y el N potencialmente mineralizable en las parcelas permanentes de *P. patula* en el estado de Puebla. Los resultados mostraron que conforme aumentó la intensidad de aclareo se incrementaron las variables consideradas. A siete años del aclareo, el incremento en MO fue de 3.2 a 3.9%, lo cual significa 6 Mg ha^{-1} o bien 105 kg ha^{-1} de N (Cuadro 4). También, los valores de N mineralizable acumulado se incrementaron proporcionalmente a la intensidad de los aclareos desde 127 hasta 150 ppm N; ésto sugiere una actividad microbiológica que se incrementa en igual orden, así como la cantidad de ácidos orgánicos disponibles y CO_2 disponible a través de la actividad respiratoria, todo lo cual puede ocasionar incrementos en la productividad de los rodales (Gutiérrez et al. 1994). Gracias a estos resultados, puede asegurarse que la magnitud de los cambios en la fertilidad de los suelos es perfectamente medible y por lo tanto, pueden estar disponibles datos precisos sobre el efecto benéfico de los aclareos, como método silvícola en el manejo de los rodales forestales.

Los ejemplos anteriormente expuestos forman parte de los resultados de las investigaciones realizadas en las regiones de Chignahuapan-Zacatlán, Pue. y Zacualtipán, Hgo., bajo la responsabilidad del grupo de trabajo de la Especialidad Forestal del Colegio de Postgraduados, Campus Estado de México. Puede decirse que las actividades desarrolladas han fortalecido la investigación silvícola a nivel nacional con una forma distinta de ver al bosque y sus procesos; de modo que actualmente se dispone de algunas bases científicas para el mejor manejo silvícola de los bosques de *Pinus patula* en el país. Este enfoque se ha propuesto conjuntar y conciliar en la evaluación de los sitios forestales de la zona de influencia del Colegio a los conceptos ecológico, fisiológico, técnico y social, con el propósito de aportar en el mediano plazo las bases para aprovechar y proteger de mejor manera los beneficios múltiples que el bosque proporciona, y encausar el aprovechamiento forestal hacia la sostenibilidad, meta global aun inalcanzada en México.

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Literatura Citada

Amaranthus, M.; R. Darbyshire; y B. Bormann. 1995. Long-term Ecosystem Productivity: Integrated Research Sites. *In*: Mead, D. J. e I. S. Cornforth (Eds.). Proceedings of the Trees and Soil Workshop. Lincoln University Press. Agronomy Society of New Zealand. Special Pub. No. 10. pp: 77-79.

Angeles P., G. 1995. Efecto de la vegetación competidora en el desarrollo inicial de *Pinus patula*. Tesis de Maestría en Ciencias. Colegio de Postgraduados. Montecillo, Méx. 114 p.

Angeles, G.; A. Velázquez; J. J. Vargas; H. Ramírez; y M. A. Musálem. 1997. Efecto del manejo de la vegetación en algunas variables de crecimiento de la repoblación natural en un rodal de *Pinus patula* en el estado de Hidalgo (México). Invest. Agr.: Sist. Recur. For. 6(1-2):119-131.

Angeles, G.; A. Velázquez; J. Vargas; y J. Velázquez. 1997. El control de malezas y la disponibilidad de luz y agua durante el establecimiento de un rodal natual de *Pinus patula*, en México. Invest. Agr.: Sist. Recur. For. 6(1-2):133-145.

Arteaga M., B. 1985. Indice de sitio para *Pinus patula* Schl. *et* Cham. en la región Chignahuapan-Zacatlán. Tesis de Maestría en Ciencias. Colegio de Postgraduados. Chapingo, Méx. 181 p.

Cano M., E. E. 1993. Relación alométrica entre el área foliar y el área de la albura en *Pinus patula* Schl. *et* Cham., en Zacatlán, Puebla. Tesis de Maestría en Ciencias. Colegio de Postgraduados. Montecillo, Méx. 89 p.

Cano M., E. E.; A. Velázquez M.; J. J. Vargas H.; C. Rodríguez F.; y A. M. Fierros G. 1996. Area foliar específica en *Pinus patula*: Efecto del tamaño del árbol, edad del follaje y posición en la copa. Agrociencia 30:117-122.

Castellanos B., J. F. 1993. Producción de biomasa y eficiencia de crecimiento en rodales coetáneos de *Pinus patula*. Tesis de Maestría en Ciencias. Colegio de Postgraduados. Montecillo, Méx. 75 p.

Castellanos, J. F.; A. Velázquez M.; J. Vargas H.; C. Rodríguez F.; y A. M. Fierros G. 1996. Producción de biomasa en un rodal de *Pinus patula*. Agrociencia 30:123-128.

Claudio G., L. E. 1994. Análisis comparativo de biomasa, área foliar y eficiencia de crcimiento en dos rodales de *Pinus patula* sometidos a aclareos. Tesis de Maestría en Ciencias. Colegio de Postgraduados. Montecillo, Méx. 66 p.

De los Santos P., H.M. 1993. Respuesta de crecimiento en rodales coetáneos de *Pinus patula* Schl. *et* Cham. relacionando variables de densidad y productividad. Tesis Profesional. UACH. Chapingo, Méx. 47 p.

De los Santos P., H. M.; A. Velázquez M.; H. Ramírez M. 1993. Modelos de crecimiento para rodales coetáneos de *Pinus patula* Schl. *et* Cham. aclareados a diferentes intensidades. *In*: Resúmenes del I Congreso Mexicano sobre Recursos Forestales. SOMEREFO. Saltillo, Coah. p: 44.

De los Santos P., H. M.; R. Valdez L.; y A. Velázquez M. 1995. Variación de rendimiento total y comercial en rodales aclareados de *Pinus patula*. *In*: Resúmenes del II Congreso Mexicano sobre Recursos Forestales. SOMEREFO. Montecillo, Méx. p: 38.

Escárpita H., A. y L. Iglesias G. 1993. Problemas legales e institucionales de la sostenibilidad. In: Manzanilla, H.; D. Shaw; C. Aguirre-Bravo; L. Iglesias G.; y R.H. Hamre. (Tech.Coords.) Making Sustainability Operational: Fouth Mexico/U.S. Symposium. Gen. Tech. Rep. RM-240. USDA/FS. Fort Collins, CO. USA. pp: 70-78.

Greenland, D. (Ed.). 1994. El Niño & Long-Term Ecological Research (LTER) Sites. Publication No. 18. LTER Network Office: University of Washington, Seattle, WA, USA. 57 p.

Gutiérrez G., B.; J. D. Etchevers; A. Velázquez M.; A. Gómez G.; G. Angeles P. y J. Santillán. 1994. Intensidades de aclareo e índices de suministro de nitrógeno edáfico en rodales naturales de *Pinus patula*. *In*: Resúmenes del Simposio y II Reunión Nacional de Silvicultura y Manejo de Recursos Forestales. Montecillo, Méx. p: 38.

Hernández L., A.; M. Martínez R.; J. J. Vargas H.; A. Velázquez M.; y G. Angeles P. 1996. Características de los anillos y densidad de la madera a diferentes alturas del fuste en rodales aclareados de *Pinus patula* Schl. *et* Cham. Ciencia Forestal 21(80):39-56.

Meyer, J.; T. Crocker; D. D'Angelo; W. Dodds; S. Findlay; M. Oswood; D. Repert; y D. Toetz. (Compls.) 1993. Stream Research in the Long-Term Ecological Research Network. LTER Publication No. 15. Long-Term Ecological Research (LTER) Network, Office. Seattle, WA. USA. 114 p.

Montaña, C. 1994. México: LTER Site Mapimí Biosphere Reserve. *In*: Nottrott, R. W.; J. F. Franklin; y J. R. Vande Castle (Compls.). International Networking in Long-Term Ecological Research. U.S. LTER Network Office. University of Washington. Seattle, WA. USA. pp:52-53.

Nottrott, R. W.; J. F. Franklin; y J. R. Vande Castle (Compls.). 1994. International Networking in Long-Term Ecological Research. U.S. LTER Network Office. University of Washington. Seattle, WA. USA. 106 p.

Perry, D. A. 1994. Forest Ecosystems. The Johns Hopkins University Press. 649 p.

Van Cleve, K. y S. Martin. (Ed.). 1991. Long-Term Ecological Research in The United States. A Network of Research Sites. Sixth Edition Revised, Publication No. 11. Long-Term Ecological Research Network Office. University of Washington. Seattle, WA. USA. 178 p.

Velázquez M., A. 1990. Interacting effects of stand density, site factors, and nutrients on productivity and productive efficency of Douglas-fir plantations in the Oregon Cascades. Ph.D. Thesis Dissertation. Oregon State University. Corvallis, OR. USA. 142 p.

Velázquez M., A.; M. de J. González G. y P. Hernández de la R. 1992. Análisis estructural de un bosque de *Pinus patula*, como resultado de la aplicación de aclareos en la Sierra Norte de Puebla. Agrociencia Serie: Rec. Nat. Renov. 2(1):13-25.

Velázquez M., A.; P. Hernández de la R.; H. M. de los Santos P.; G. Angeles P. y M. de J. González G. 1994. Estrategias de manejo silvícola en alcareos experimentales. *In*: Paredes V., G.L. (Ed.) Proceedings of the International Symposium on Systems Analysis and Management Decisions in Forestry, Valdivia, Chile. pp: 370-376.

Development of a Long-Term Ecological Monitoring Program in Denali National Park and Preserve, Alaska (USA)[1]

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Abstract—A Long-term Ecological Monitoring (LTEM) program began at Denali National Park and Preserve, Alaska (USA) in 1992, as a prototype for subarctic parks. The early history of the Denali LTEM program provides insight into the challenges that can arise during monitoring program development. The Denali program has thus far taken a watershed approach, involving collocation of study effort for a mix of abiotic and biotic attributes within a small, headwater stream (Rock Creek) which crosses the tundra-taiga boundary. An initial effort at integration and synthesis of meteorological, vegetation, small mammal and passerine bird data for the first 7 years of the program found few correlations, but power was low. We will now attempt to balance the intensive work in Rock Creek by developing a cost-effective sampling design that includes more of the park. We are also working to improve linkages between the monitoring program and park management decision-making and to strengthen data management and reporting mechanisms.

In 1992, the National Park Service (NPS) began to develop prototype, long-term ecological monitoring (LTEM) programs in selected parks representing major biogeographic regions within the United States. Denali National Park and Preserve (Alaska, Fig. 1), one of the first four parks in the program, was chosen as the testing ground for Alaska parks. Alaska has 23 national parks, covering 21.5 million ha. These parks represent 66% of the total land base of the U.S. national park system. Thus, lessons learned developing the Denali LTEM program could influence how monitoring is done over a significant proportion of U.S. park lands. Like Denali (2.4 million ha), the Alaska parks encompass vast, roadless areas, and access is a major constraint on park management, including monitoring.

Denali National Park and Preserve includes Mount McKinley (6,194 m)—the tallest mountain in North America. Its huge massif is highly glaciated, and 17% of the park is covered with glaciers. The surrounding park lands are ecotonal between alpine tundra and taiga. Denali receives over 350,000 visitors each summer and is one of the prime tourist destinations within the state. The main attraction (besides the mountain itself) is charismatic wildlife [e.g., grizzly bears (*Ursus arctos*), Dall sheep (*Ovis dalli*), wolves (*Canis lupus*)], seen from park buses traversing a 144-km gravel road into the park.

The NPS and U.S. Geological Survey (USGS), working as partners, are developing the Denali LTEM program. Scientists from the University of Alaska Fairbanks and ornithologists with two nonprofit organizations, the Alaska Bird Observatory and the Institute for Bird Populations, are also involved. The Denali LTEM program currently includes monitoring a broad array of attributes, including air and water quality, meteorology, soils, glaciers, fire, and bird (passerine and raptors), and mammal (charismatic and otherwise) populations. We report here on a major aspect of the monitoring program which has involved the use of a watershed approach to organize study effort for a mix of abiotic and biotic attributes within a single watershed, Rock Creek (Thorsteinson and Taylor 1997). Linkage of intensive studies within a watershed is expected to yield information about ecosystem relationships, a primary goal of the Denali LTEM program. The Rock Creek studies include collection of the typical data sets associated with watershed studies (e.g., atmospheric deposition, water chemistry), but also include collection of data on small mammal and bird populations.

In this paper, we have two thrusts. First, we discuss the manner in which the Denali LTEM program has been implemented and explain some of the challenges encountered. We then focus on a different aspect of the Denali story by presenting an analysis and synthesis of the 7-year dataset for Rock Creek, in an attempt to find relationships between abiotic factors (meteorology), vegetation, and vertebrate populations (small mammals and passerine birds).

Early History of the Long-Term Ecological Monitoring Program at Denali

The original proposal for the Denali LTEM program was written in late 1991. The proposal was written quickly, in response to a national *Call for Proposals* deadline with a short lead time. The proposal outlined a general scheme of monitoring that would concentrate on underlying components of the ecosystem. The proposal also outlined a study design based on watersheds. The park was divided into 5 major watersheds. The authors proposed to link studies of birds, small mammals and vegetation, set against

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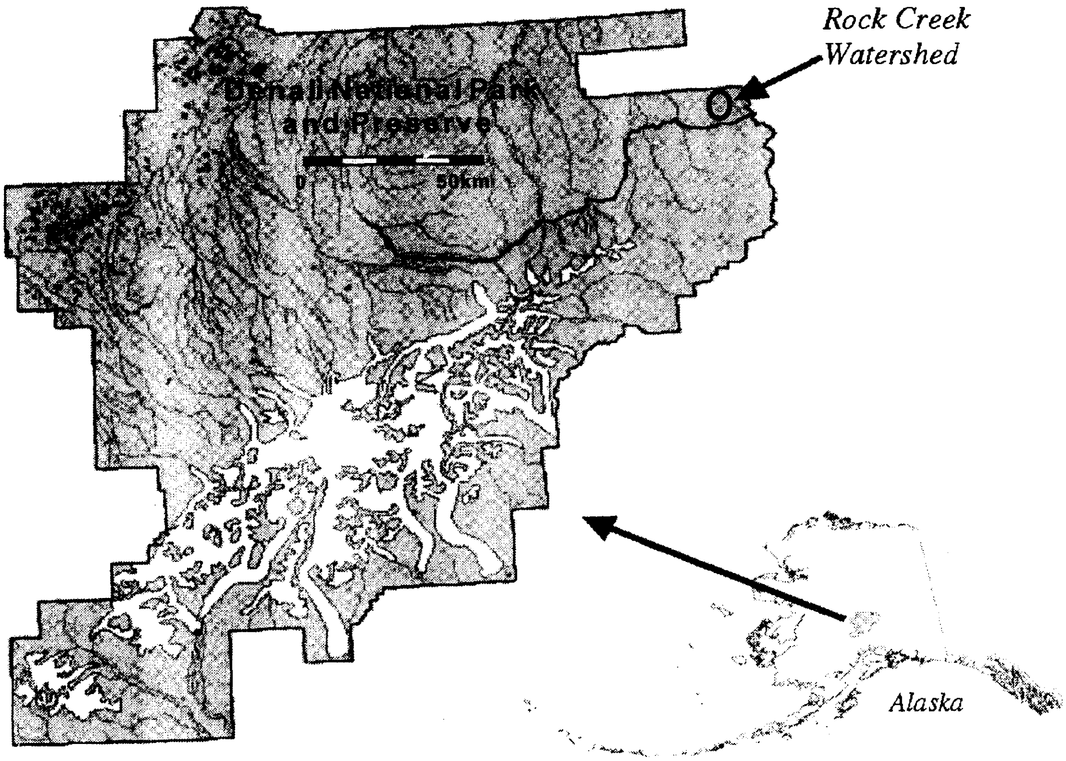

Figure 1.—Denali National Park and Preserve, Alaska, showing the location of the Rock Creek watershed long-term ecological monitoring site.

a backdrop of meteorological, soil, water and aquatic invertebrate studies. The program would start in one watershed, and eventually, with additional funding, expand to include the other 4 watersheds.

The idea of using watersheds as the basis for monitoring terrestrial ecosystems in Alaska parks originated at a NPS workshop held in 1989 (Peale et al. 1993). This conference included several presentations on existing programs organized around watersheds, including Hubbard Brook, the *sine qua non* of watershed studies. A follow-up report to the workshop further developed the watershed theme. The idea was espoused that NPS monitoring in Alaska should go beyond population monitoring of the charismatic megafauna and look at the broader ecosystem in an integrated fashion. Watersheds were advocated as a way to stratify the enormous territory of Alaska parks into ecologically meaningful units of manageable size.

The Denali proposal was successful, and just a few months after penning the proposal, park staff were faced with implementing it. The park moved immediately into the collection of data. Only partial funding was received in the initial year, which heavily influenced the selection of Rock Creek as the primary study site. The proposal had called for starting the LTEM program in the McKinley River watershed located near the end of the park road. As the field season drew near, park managers realized they could not afford to start work at such a remote location. They turned to Rock Creek, a small creek adjacent to park headquarters. The idea was to use Rock Creek as a place to quickly and cheaply test methodologies prior to implementation elsewhere in the park. However, the idea of using Rock Creek as a testing ground faded over the years as the Rock Creek work took on a life of its own.

In the early years of the Denali LTEM program, the funding and responsibility for program development was split between the park and other entities. At first, the split was between the park and the Alaska regional office of the NPS. Later, the split was between the park and the National Biological Service (NBS). The split responsibility for program development, involving personnel spread across organizations and duty stations, required the establishment of solid mechanisms for communication and coordination. The need for such mechanisms was not recognized immediately, and took several years to develop.

Another challenge arose during the course of the program's development as park staff began to realize the form that the monitoring program was taking. Rock Creek is on the eastern boundary of the park, and conditions in Rock Creek appeared to bear little relation to conditions in the rest of the park. The watershed approach, with its apparent focus on biogeochemical cycles, was considered esoteric, with little relation to park management issues. Reporting from the LTEM program was also minimal. Although study sites for various attributes were collocated within Rock Creek, no mechanisms were in place for the integration or sharing of data. These factors conspired to create a general aura of dissatisfaction with the LTEM program.

A national review of the Denali program in 1995 was also critical, especially of the decision to concentrate the monitoring effort in a single watershed. The park was directed to develop a clearer statement of objectives and to modify the conceptual design accordingly. In response, the park led an effort to move the monitoring program in the direction of providing information useful for management. In 1996, 2 workshops were held to identify likely anthropogenic and natural stressors to the Denali ecosystem, following Noon et al. (1998). The ecological consequences of the stressors acting on the Denali ecosystem would guide selection of the attributes to be monitored, at a variety of scales and organizational levels (i.e., landscape, community, population, individual, genetic).

The park is currently working closely with the USGS, Biological Resources Division (formerly the NBS) in writing a new conceptual plan for the LTEM program. The current focus of this joint planning effort is on improving linkages between the monitoring program and park management decision-making, broadening the geographic scope of the LTEM program, and improving data management and reporting.

Integration of Monitoring Data: Correlates of Small Mammal and Passerine Bird Abundance

Despite some of the difficulties in the early days of the Denali LTEM program, work continued in Rock Creek according to the original design. Thus, we now have 7 years of experience and data within the watershed on which we can begin to report. The intent of this exploratory synthesis is to examine fluctuations in several monitored components of the Rock Creek watershed. One of the themes of the LTEM program is to document the range of variation in measured attributes of the system. Our objective in the integration exercise is to determine possible causal mechanisms that could give rise to these variations. We chose to look first at inter-annual patterns in small mammal abundance and passerine bird abundance and productivity within Rock Creek. Were there meaningful similarities between vole abundance and bird abundance and productivity and some of the biotic and abiotic factors around them?

Methods

Small Mammal and Passerine Bird Populations

For small mammals, we used abundance estimates from the final sampling occasion of the field season, typically the first week of September, when abundance is at its annual maximum and estimates are the most reliable (see Rexstad 1994 for methodology). Data were from a single trapping grid in spruce forest, known as RF1. We computed abundance estimates (animals/ha) for the tundra vole (*Microtus oeconomus*) and red-backed vole (*Clethrionomys rutilis*) from 1992-1998.

Data on passerine birds in Rock Creek came from 2 separate monitoring efforts: (1) 4 point count transects with a total of 48 stations (Paton 1996) and (2) 3 constant-effort mist netting stations (DeSante 1997). The point count data provided 1 measure of population abundance: an annual Frequency of Occurrence (FO). The FO for a particular species was the proportion of point count stations where that species was observed in a given year based on several visits during the breeding season. The mist netting data, collected under auspices of the Monitoring Avian Productivity and Survivorship (MAPS) program (DeSante et al. 1995), provided measures of abundance and productivity. Capture rates for adults and young for the three mist net stations combined were calculated for constant efforts of 600 net-hours, to provide a measure of abundance based on catch-per-unit-effort (CPUE). The proportion of the constant effort catch that was young birds was used as a measure of productivity.

In our analyses of bird populations, we focused on species that occurred in sufficient abundance for point counts to accurately reflect annual fluctuations, i.e., those with a FO of 14% or greater (Paton 1996, Paton and Pogson 1996). These species were aggregated into guilds based upon their migratory strategy (Hayes 1995). *Permanent residents* remain near the Park boundaries throughout the year [gray jay (*Perisoreus canadensis*)], *irruptive migrants* are restricted to migration within Alaska [redpoll (*Carduelis* spp.)], *neararctic migrants* have ranges that extend beyond Alaska's borders [dark-eyed junco (*Junco hyemalis*) and varied thrush (*Ixoreus naevius*)], *short-distance neotropical migrants* remain north of South America [American robin (*Turdus migratorius*), orange-crowned warbler (*Vermivora celata*), white-crowned sparrow (*Zonotrichia leucophrys*), Wilson's warbler (*Wilsonia pusilla*) and yellow-rumped warbler (*Dendroica coronata*)], and *long-distant neotropical migrants* winter in South America [Swainson's thrush (*Catharus ustulatus*)].

Potential Correlates

As potential correlates, we computed annual summary statistics of data from the meteorological and vegetation studies within Rock Creek (Tables 1, 2). We also used several correlates from the bird studies as possible correlates of small mammal populations (and vice versa). Not all Denali LTEM projects were initiated at the same time, hence, data were not available for every attribute in each year (Table 1). All correlations tested the null hypothesis that $\rho = 0$. In these exploratory tests, we set $\alpha = 0.10$ to determine significance.

Three weather indices were calculated from meteorological data collected at park headquarters in the lower part of the Rock Creek drainage. These indices were a *Winter Severity Index*, calculated from the perspective of voles, and a *Spring Onset Index* and a *Spring Rainfall Index*, which we thought could be important to both voles and birds.

Winter Severity Index.—Because of their small size, voles are susceptible to low temperatures and can suffer high rates of mortality during extreme winter conditions. Temperatures experienced by voles in the subnivean environment can be moderated by an insulative snow layer that affords them protection from the worst of an arctic winter (Marchand 1982). Maximum buffering is achieved at snow depths of approximately 35 cm or greater. We defined the winter severity index for voles as a measure to incorporate daily minimum air temperature and snow depth.

The vole winter severity index (WSI) was defined as

$$WSI = \sum_{d \in \Delta} \max(0 - T_d, 0) \times \max(1 - S_d/35, 0) \qquad (1)$$

Table 1.—Time-sequence of attribute data from the long-term ecological monitoring program available for synthesis, Rock Creek Watershed, Denali National Park and Preserve, Alaska.

Attribute	1992	1993	1994	1995	1996	1997	1998
Meteorology[1]	x	x	x	x	x	x	x
Vegetation							
Picea glauca cone count[2]	x	x	x	x	x	x	
Picea glauca seed count[3]		x	x	x	x	x	
Berry count[4]			x	x	x	x	
Passerine Birds							
Point counts[5]		x	x	x	x	x	
Constant-effort mist netting[6]	x	x	x	x	x	x	
Small Mammals[7]	x	x	x	x	x	x	x

[1]Data collected at National Weather Service station located at Denali National Park and Preserve Headquarters since 1925. Includes daily minimum and maximum temperatures, precipitation and snow depth.
[2]Number of cones on marked trees (5 per plot) in 3 forested plots in Rock Creek Watershed.
[3]Number of seeds captured in 6 seed traps in each of 3 forested plots in Rock Creek Watershed.
[4]Number of berries on 3 forested plots in Rock Creek Watershed. Includes *Arctostaphylos rubra*, *Cornus canadensis*, *Empetrum nigrum*, *Geocaulon lividum*, *Vaccinium uliginosum* and *V. vitis-idaea*.
[5]Four off-road point count routes located in forested habitats in Rock Creek generate frequency of occurrence for passerine birds (see Paton and Pogson 1996).
[6]Constant-effort mist netting at 3 stations in Rock Creek watershed, generates estimates of annual survivorship and productivity for passerine birds, as part of the Monitoring Avian Productivity and Survivorship program (see DeSante et al. 1995, DeSante 1997).
[7]Mark-recapture trapping of small mammals on a plot in forested habitat in Rock Creek watershed generates an estimate of late summer population density (see Rexstad 1994).

Table 2.—Description of avian, vegetation, and meteorological measures used in correlation analysis, Rock Creek Watershed, Denali National Park and Preserve, Alaska. See text for complete data description.

Measure	Description
WSI	Winter Severity Index
SOI	Spring Onset Index
SRI	Spring Rainfall Index
RICH (Pt. Cnt.)	Number of avian species identified from Point Counts
FO 5	Mean frequency of observation of 5 most observed avian species
FO 10	Mean frequency of observation of 10 most observed avian species
RICH (MAPS)	Number of avian species identified with MAPS
PROD 5	Mean productivity of 5 most observed avian species
PROD 10	Mean productivity of 10 most observed avian species
CPUE 5	Mean adult catch per 600 net-hours of 5 most observed avian species
CPUE 10	Mean adult catch per 600 net-hours of 10 most observed avian species
CONE	Total *Picea* cone count from 15 trees (5 trees in each of 3 forest plots)
SEED	Total *Picea* seed count in 18 traps (6 traps in each of 3 forest plots)
CROW	Total crowberry count in 6 berry plots (2 plots in each of 3 forest sites)
BLUE	Total blueberry count in 6 berry plots (2 plots in each of 3 forest sites)
CRAN	Total cranberry count in 6 berry plots (2 plots in each of 3 forest sites)
BERRIES	Total of all berries in 6 berry plots (2 plots in each of 3 forest sites)

where Δ = the set of Julian dates used in the index, T_d = the minimum air temperature in degrees Celsius on day d, and S_d = the snow depth in centimeters on day d. When either $T_d \geq 0$ °C or $S_d \geq 35$ cm, the daily contribution to the index is zero. When $T_d < 0$ °C, the unweighted daily contribution is the difference between 0 °C and T_d. This value is then weighted by the amount of snow on the ground, ranging from a weight of 0 (≥35 cm) to a weight of 1 (0 cm). For a day with a minimum air temperature of –7 °C and 5 cm of snow on the ground, its unweighted contribution to the index is 7, which, when multiplied by its weight of 1-5/35, gives a weighted contribution of 6. For any given year, the daily values were summed across all days from 1 September of the previous year to 31 May of the current year to yield the WSI. With this definition, a larger index indicates a harder winter for voles.

Spring Onset Index.—Much biological activity in the arctic is constrained to a short period in the summer. The duration of summer impacts the productivity of plants and animals alike. We defined the spring onset index (SOI) as a measure involving daily mean air temperature that allowed an objective determination of the arrival of spring at Denali National Park and Preserve headquarters. It is a cumulative degree-day index that sums the degrees the mean daily temperature is above 5 °C and reports the Julian date that this measure first exceeds 50. A larger spring onset index indicates a later spring.

Spring Rainfall Index.—With a late spring, the ground remains saturated longer, delaying the rise in small mammal population abundance. Similarly, this delay can be caused by excessive precipitation, which can reduce bird productivity. We defined the spring rainfall index (SRI) as the cumulative rainfall in centimeters during the months of May and June.

The vegetation correlates we considered included two measures from monitoring studies of white spruce (*Picea glauca*), the dominant forest tree throughout forested regions within Denali park. These measures were annual cone counts and annual seed counts. The other vegetation measures included were from studies of annual berry production for three important berry-producing species: crowberry (*Empetrum nigrum*), blueberry (*Vaccinium uliginosum*) and cranberry (*Vaccinium vitis-idaea*).

Because such a large number of bird species was monitored, but relatively few species were present in numbers that allowed meaningful comparison, we calculated summary measures on 2 groups based on the point counts: a "Best 5" group and a "Best 10" group. The 'Best 5' species were identified as the 5 species with the largest FOs over all years. These species were American robin, dark-eyed junco, Swainson's thrush, varied thrush, and white-crowned sparrow. The 'Best 10' species included these 5 species plus gray jay, orange-crowned warbler, redpoll, Wilson's warbler, and yellow-rumped warbler. The mean FOs used were the mean FO of these 5 or 10 species for each year. Similarly, we used these groups with the mist-netting data to calculate mean CPUE and mean productivity.

As a measure of avian diversity in Denali National Park and Preserve, we calculated 2 measures of species richness from point count and MAPS data. Each richness measure was the total number of avian species identified annually by the respective program.

Results

Microtus and *Clethrionomys* abundance levels for 1992-1998 (Fig. 2) showed large inter-annual fluctuations with no correlation between them (R=0.43, P=0.33). Correlations and significance levels were then computed separately for each species (Table 3). *Microtus* abundance was correlated to WSI (P=0.02). *Clethrionomys* abundance was correlated to avian species richness (MAPS) (P=0.04) and was marginally related to Avian CPUE (Best 5) (P=0.10). Small mammal abundance was not significantly correlated with any of the other measures considered.

Passerine bird abundance and productivity for the various migratory guilds were correlated with a few of the measures considered (Tables 4, 5, and 6). For example, permanent resident frequency of observation was marginally correlated with cone count (P=0.07), point count richness (P=0.06), and crowberry count (P=0.10). Permanent resident productivity was correlated with winter severity (P=0.05) and marginally correlated with avian productivity (Best 5) (P=0.07). Permanent resident CPUE showed no correlation with any of the measures. Most significant correlations ($P \leq 0.05$) over all guilds were found with frequency of observation (6), compared to productivity (2) and CPUE (4).

Discussion

The c[illegible]elation analysis revealed few measures with a statistica[illegible]y significant correlation with small mammal abundance. However, several measures with a large positive or negative correlation could be significant with larger sample sizes. In addition, this correlation analysis only considers a single correlate at a time. Small mammal abundance is unlikely to be driven by one biotic or abiotic factor. Two

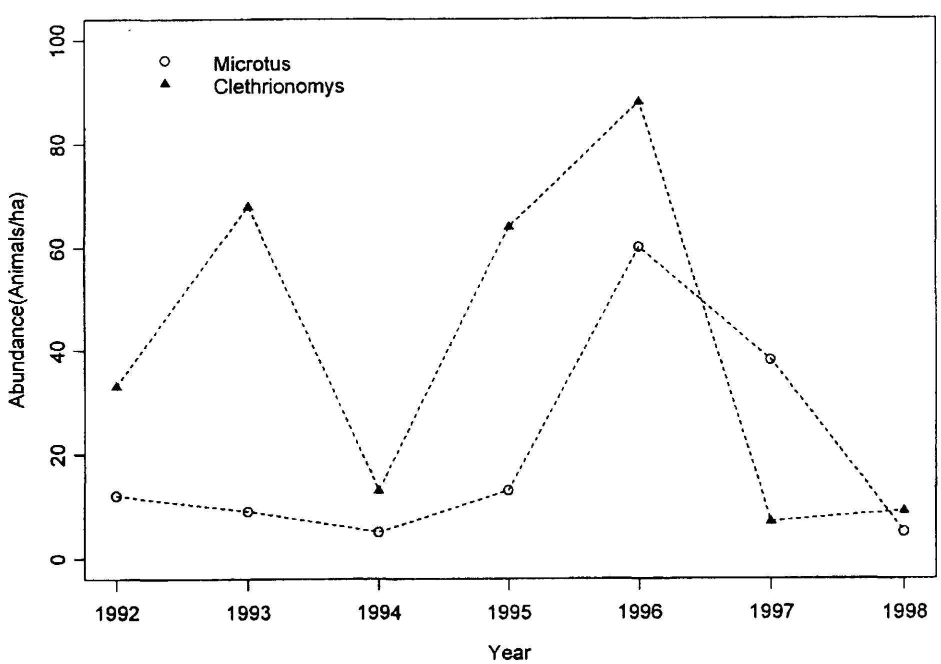

Figure 2.—1992-1998 fall abundance estimates (animals/ha) for *Microtus* and *Clethrionomys* on RF1 plot, Rock Creek, Denali National Park and Preserve, Alaska.

Table 3.—Correlation (r) of avian, vegetation, and weather variables with estimated *Microtus* and *Clethrionomys* abundance, 1992-1998, Rock Creek, Denali National Park and Preserve, Alaska. "Years" is the number of years of data available for each variable. P-value is for a test of the null hypothesis r=0.

		Microtus		*Clethrionomys*	
Measure	Years	r	P-value	r	P-value
WSI	7	0.83	0.02	0.56	0.19
SOI	7	0.44	0.33	–0.24	0.61
SRI	7	–0.22	0.64	–0.34	0.46
RICH (MAPS)	6	0.31	0.55	0.82	0.04
CONE	6	–0.26	0.62	–0.42	0.40
PROD 5	6	0.21	0.69	–0.25	0.62
PROD 10	6	0.86	0.03	0.49	0.32
CPUE 5	6	0.20	0.71	–0.74	0.10
CPUE 10	6	0.12	0.82	–0.62	0.19
RICH (Pt. Cnt.)	5	0.31	0.62	0.21	0.74
FO 5	5	–0.34	0.58	–0.61	0.27
FO 10	5	–0.35	0.57	–0.43	0.47
SEED	4	–0.07	0.93	–0.75	0.25
CROW	4	0.74	0.26	–0.12	0.88
BLUE	4	0.85	0.15	0.08	0.92
CRAN	4	0.62	0.38	0.66	0.34
BERRIES	4	0.81	0.19	0.08	0.92

factors that individually have little correlation with abundance may together go far in explaining causal mechanisms.

With our current sample sizes of 4 to 7 years, we may not yet have the power to detect relationships. We ran power simulations to determine how many more years of data might be required to detect significant univariate relationships, given the levels of variation observed thus far. With a true correlation of 0.5 and sample sizes from 4 to 7, power to detect a significant relationship at the 0.05 level ranges from less than 0.1 to 0.2. To attain power of 0.8, we need a sample size of around 10 when the true correlation is 0.8 and a sample size of around 30 when the true correlation is 0.5. Thus, for even highly correlated variables, we need to continue collecting data for another few years before we can determine whether these seemingly nonsignificant relationships are truly nonsignificant or the result of small sample sizes.

The correlation of WSI with *Microtus* abundance may have biological significance. This relationship provides the beginning of a conceptual model against which future monitoring data can be compared (i.e., cold winters with little snow may impact *Microtus* populations). Having an expected value against which annual monitoring data can be compared helps build our understanding, and at the same time, makes us more diligent about exercising the data on a regular basis. Both are important ingredients for success in long-term monitoring programs.

Our synthesis efforts for understanding passerine dynamics are clearly just beginning. The issue is complicated by the dual monitoring efforts of point count transects (Paton 1996) and MAPS constant-effort mist nets (DeSante 1997) as well as the proliferation of species monitored. Avian population dynamics are additionally confounded with migratory patterns over varying distances. Given the differences in correlations between migratory bird guilds, we suggest future analyses be done with similar groupings. With only local data as covariates, we may ultimately only be able to understand factors affecting year-round residents of Denali National Park and Preserve.

This exploratory integration exercise with the Rock Creek small mammal, avian, weather and vegetation data sets demonstrates the challenges in using the monitoring program to provide information that improves our understanding of ecosystems. Clearly, much longer term and more extensive data will be necessary to reveal the true nature of the ecological relationships. Maintaining a data collection program such as this can be difficult when it takes so long to reveal trends or relationships.

The lack of probability-based sampling procedures in Rock Creek is an important limitation, because we cannot

Table 4.—Correlation (r) of avian, vegetation, and weather variables with frequency of observation for 10 avian species in 5 migratory guilds, 1993-1997, Rock Creek, Denali National Park and Preserve, Alaska. P-value is in parentheses.

Measure	Residents	Irruptive migrants	Short-distance	Long-distance	Neararctic migrants
WSI	–0.07 (0.92)	–0.41 (0.50)	0.29 (0.63)	–0.46 (0.44)	0.17 (0.78)
SOI	0.72 (0.17)	–0.20 (0.75)	0.07 (0.92)	–0.42 (0.48)	0.19 (0.76)
SRI	–0.76 (0.13)	–0.69 (0.20)	0.59 (0.29)	0.75 (0.14)	0.68 (0.21)
RICH (MAPS)	0.17 (0.79)	0.40 (0.51)	0.12 (0.84)	–0.27 (0.66)	–0.14 (0.82)
CONE	0.85 (0.07)	0.46 (0.43)	–0.31 (0.61)	–0.02 (0.98)	–0.15 (0.81)
PROD 5	–0.59 (0.30)	–0.90 (0.04)	0.87 (0.06)	0.45 (0.45)	0.88 (0.05)
PROD 10	0.12 (0.85)	–0.37 (0.54)	0.20 (0.75)	–0.56 (0.33)	0.12 (0.85)
CPUE 5	0.61 (0.27)	–0.21 (0.73)	–0.11 (0.86)	–0.05 (0.94)	0.18 (0.77)
CPUE 10	0.50 (0.39)	–0.09 (0.89)	–0.42 (0.48)	–0.15 (0.80)	–0.12 (0.85)
RICH (Pt. Cnt.)	0.87 (0.06)	0.64 (0.24)	–0.82 (0.09)	–0.71 (0.18)	–0.75 (0.15)
FO 5	–0.35 (0.56)	–0.55 (0.34)	0.92 (0.03)	0.87 (0.05)	0.96 (0.01)
FO 10	–0.08 (0.90)	–0.22 (0.73)	0.85 (0.07)	0.81 (0.10)	0.83 (0.08)
SEED	–0.16 (0.84)	–0.63 (0.37)	0.97 (0.03)	0.73 (0.27)	0.98 (0.02)
CROW	0.90 (0.10)	–0.01 (0.99)	–0.62 (0.38)	–0.73 (0.27)	–0.42 (0.58)
BLUE	0.86 (0.14)	0.15 (0.85)	–0.65 (0.35)	–0.85 (0.15)	–0.51 (0.49)
CRAN	0.14 (0.86)	0.87 (0.13)	–0.84 (0.16)	–0.93 (0.07)	–0.95 (0.05)
BERRIES	0.82 (0.18)	0.21 (0.79)	–0.72 (0.28)	–0.86 (0.14)	–0.58 (0.42)

Table 5.—Correlation (r) of avian, vegetation, and weather variables with productivity for 10 avian species in 5 migratory guilds, 1992-1997, Rock Creek, Denali National Park and Preserve, Alaska. P-value is in parentheses.

Measure	Residents	Irruptive migrants	Short-distance	Long-distance	Neararctic migrants
WSI	0.82 (0.05)	0.38 (0.46)	–0.54 (0.27)	0.70 (0.12)	0.77 (0.07)
SOI	0.37 (0.47)	–0.40 (0.43)	–0.10 (0.85)	–0.20 (0.71)	0.35 (0.50)
SRI	–0.20 (0.70)	0.18 (0.73)	0.18 (0.73)	0.05 (0.92)	–0.39 (0.45)
RICH (MAPS)	0.17 (0.75)	0.40 (0.44)	–0.03 (0.96)	0.43 (0.39)	0.27 (0.60)
CONE	–0.38 (0.46)	–0.70 (0.12)	0.32 (0.54)	–0.63 (0.18)	–0.33 (0.52)
PROD 5	0.27 (0.61)	0.19 (0.72)	–0.07 (0.90)	0.41 (0.42)	0.04 (0.94)
PROD 10	0.78 (0.07)	0.69 (0.13)	–0.37 (0.47)	0.45 (0.37)	0.79 (0.06)
CPUE 5	0.06 (0.92)	–0.16 (0.76)	0.26 (0.62)	–0.76 (0.08)	0.05(0.93)
CPUE 10	0.06 (0.91)	–0.03 (0.95)	0.13 (0.81)	–0.72 (0.11)	0.10 (0.85)
RICH (Pt. Cnt.)	0.16 (0.80)	–0.13 (0.84)	–0.07 (0.91)	–0.45 (0.45)	0.39 (0.52)
FO 5	–0.40 (0.51)	0.19 (0.75)	0.59 (0.30)	–0.17 (0.78)	–0.59 (0.29)
FO 10	–0.52 (0.37)	0.49 (0.40)	0.79 (0.11)	–0.30 (0.63)	–0.63 (0.25)
SEED	–0.20 (0.80)	0.42 (0.58)	0.53 (0.47)	–0.22 (0.78)	–0.39 (0.61)
CROW	0.69 (0.31)	–0.33 (0.67)	–0.35 (0.65)	–0.38 (0.62)	0.70 (0.30)
BLUE	0.82 (0.18)	–0.23 (0.77)	–0.50 (0.50)	–0.19 (0.81)	0.83 (0.17)
CRAN	0.84 (0.16)	–0.22 (0.78)	–0.99 (0.01)	0.54 (0.46)	0.86 (0.14)
BERRIES	0.81 (0.19)	–0.30 (0.70)	–0.55 (0.45)	–0.18 (0.82)	0.83 (0.17)

make inferences to the rest of the park. To monitor resources in a park the size of Denali, the intensive effort in Rock Creek must be balanced by more extensive, probability-based sampling, and by use of such tools as remote sensing. In the next phase of the program's development, we plan to explore cost-effective sampling designs that include the whole park.

Two lessons about monitoring program development emerge from the Denali experience thus far. The first is to clearly define the roles of the managers, investigators, and technicians involved in the monitoring program and develop good lines of communication. The second lesson is to not be too hurried.

From the beginning, the Denali LTEM program involved a mix of personnel. The participants represented different scientific disciplines. They hailed from different parts of the NPS organizational structure, from outside the NPS, and from different parts of Alaska and other states. The roles and responsibilities of each participant were not clearly defined. Without day-to-day contact between the participants, communication about the program and its direction was difficult. By their nature, ecological monitoring programs involve a variety of participants. Recognizing from the outset that monitoring programs are a team effort will help engender success. Teamwork and communications must be budgeted for and integrated into the program in the same way as data management and quality assurance/quality control.

The drawback of being too rushed at the beginning of a program is the second lesson from Denali. The Denali LTEM program was born seemingly overnight. The time between approval of the proposal and the beginning of work was compressed to months. There was no interim period of attribute selection, study plan development, or review to refine the ideas in the proposal. This rush to the field had

Table 6.—Correlation (r) of avian, vegetation, and weather variables with catch per unit effort for 10 avian species in 5 migratory guilds, 1992-1997, Rock Creek, Denali National Park and Preserve, Alaska. P-value is in parentheses.

Measure	Residents	Irruptive migrants	Short-distance	Long-distance	Neararctic migrants
WSI	0.35 (0.49)	0.06 (0.91)	–0.04 (0.94)	0.16 (0.76)	0.00 (1.00)
SOI	–0.34 (0.51)	0.52 (0.29)	0.40 (0.43)	0.20 (0.71)	–0.13 (0.81)
SRI	0.36 (0.48)	–0.06 (0.91)	–0.85 (0.03)	–0.73 (0.10)	–0.32 (0.53)
RICH (MAPS)	–0.23 (0.65)	–0.46 (0.35)	0.44 (0.38)	0.59 (0.22)	0.36 (0.48)
CONE	–0.62 (0.19)	0.21 (0.69)	0.47 (0.35)	0.28 (0.59)	–0.12 (0.83)
PROD 5	0.35 (0.50)	–0.01 (0.99)	–0.74 (0.09)	–0.46 (0.36)	–0.43 (0.39)
PROD 10	0.25 (0.64)	0.27 (0.60)	0.10 (0.85)	–0.14 (0.80)	0.36 (0.49)
CPUE 5	–0.36 (0.48)	0.89 (0.02)	0.26 (0.62)	–0.55 (0.25)	0.15 (0.78)
CPUE 10	–0.13 (0.81)	0.87 (0.02)	0.21 (0.70)	–0.62 (0.19)	0.26 (0.61)
RICH (Pt. Cnt.)	–0.36 (0.55)	0.48 (0.41)	0.88 (0.05)	0.34 (0.58)	0.79 (0.11)
FO 5	–0.25 (0.69)	–0.11 (0.86)	–0.52 (0.37)	–0.67 (0.22)	–0.38 (0.53)
FO 10	–0.58 (0.30)	–0.20 (0.75)	–0.16 (0.80)	–0.42 (0.48)	0.01 (0.99)
SEED	–0.32 (0.68)	0.29 (0.71)	–0.37 (0.63)	–0.83 (0.17)	–0.27 (0.73)
CROW	–0.11 (0.89)	0.93 (0.07)	0.87 (0.13)	–0.11 (0.89)	0.77 (0.23)
BLUE	0.00 (1.00)	0.84 (0.16)	0.90 (0.10)	0.09 (0.91)	0.75 (0.25)
CRAN	0.76 (0.24)	0.16 (0.84)	0.37 (0.63)	0.68 (0.32)	0.05 (0.95)
BERRIES	0.08 (0.92)	0.83 (0.17)	0.85 (0.15)	0.09 (0.91)	0.69 (0.31)

important consequences. The goals and objectives for the program were not solidified and documented. Reviews by statisticians and potential data users did not occur. Important choices were made, such as selection of watersheds as the sample unit and selection of Rock Creek as the primary study site.

The consequences of using the watershed approach were not fully recognized until the program had been underway for a few years. Watersheds are attractive study areas for a number of purposes, but especially for studies of ecosystem processes (Slaughter et al. 1995). Understanding ecosystem processes is one goal of the Denali LTEM program, but the program also intends to provide information for management decision-making. The watershed design is unlikely to provide the park with that type of information. Thus, the park must now reconsider its allocation of monitoring effort to address this other important need. The Denali experience reinforces the importance of clearly envisioning intended data uses before any data are collected and carefully matching the design to the objectives (Overton and Stehman 1995, Soballe 1997, Whitfield 1988, Ward et al. 1986).

Acknowledgments

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Literature Cited

DeSante, D.F., K.M. Burton, J.F. Saracco, and B.L. Walker. 1995. Productivity indices and survival rate estimates from MAPS, a continent-wide programme of constant-effort mist-netting in North America. Journal of Applied Statistics 22:935-947.

DeSante, D.F. 1997. Design of the MAPS program: an introduction and description of the experimental design of the Monitoring Avian Productivity and Survivorship (MAPS) program in national parks, with special reference to Denali National Park and Preserve. Unpublished report, Institute for Bird Populations. 26 pp.

Hayes, F.E. 1995. Definitions for migrant birds: what is a Neotropical migrant? Auk 112:521-523.

Marchand, P.J. 1982. An index for evaluating the temperature stability of a subnivean environment. Journal of Wildlife Management 46(2):518-520.

Noon, B.R., T.A. Spies, and M.G. Raphael. 1998. Conceptual basis for designing an effectiveness monitoring program. Chapter 2 *In*: The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan.

Overton, W.S. and S.V. Stehman. 1995. Design implications of anticipated data uses for comprehensive environmental monitoring programmes. Environmental and Ecological Statistics 2:287-303.

Paton, P.W.C. and T.H. Pogson. 1996. Relative abundance, migration strategy, and habitat use of birds breeding in Denali National Park, Alaska. Canadian Field-Naturalist 110(4):599-606.

Paton, P.W.C. 1996. Landbird monitoring handbook. Unpublished report, Denali National Park and Preserve. 42 pp.

Peale, M., R. Kavanaugh, D. Taylor, and C. Slaughter. 1993. Proceedings of the Chena Hot Springs Workshop, January 24-27, 1989, Fairbanks, Alaska. Strategies for sustained monitoring in arctic and subarctic National Park Service Units and Reserved Areas. Natural Resources Report NPS/AR/NRR-93/20. National Park Service, Alaska Regional Office, Anchorage, AK. 82 pp.

Rexstad, E.A. 1994. Detecting differences in wildlife populations in space and time. Transactions 59th North American Wildlife. and Natural Resources Conference: 219-228.

Slaughter, C.W., V.Y.E. Glotov, L.A. Viereck, and V.M. Mikhailov. 1995. Boreal forest catchments: research sites for global change at high latitudes. Water, Air and Soil Pollution 82:351-361.

Soballe, D.M. 1998. Successful water quality monitoring: the right combination of intent, measurement, interpretation, and a cooperating ecosystem. Journal of Lake and Reservoir Management 14(1):10-20.

Thorsteinson, L.K. and D.L. Taylor. 1997. A watershed approach to ecosystem monitoring in Denali National Park and Preserve, Alaska. Journal of the American Water Resources Association 33(4):795-810.

Ward, R.C., J.C. Loftis, and G.B. McBride. 1986. The "data-rich but information-poor" syndrome in water quality monitoring. Environmental Management 10(3):291-297.

Whitfield, P.H. 1988. Goals and data collection designs for water quality monitoring. Water Resources Bulletin 24(4):775-780.

A Monitoring System for Research Natural Areas in the Northeastern and Midwestern United States[1]

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Abstract—Research Natural Areas (RNAs) are designated by the USDA Forest Service to protect ecosystems that are representative of the region or contain unique or distinctive flora or fauna. Because RNAs can serve as benchmark ecosystems, a long-term monitoring system was developed to assess a wide range of ecosystem attributes and processes. Monitoring within the study area is stratified by Ecological Landtypes (ELT), which are units that integrate soils, landform, and vegetation. Plots are located systematically within each ELT. Subplots within plots are used to assess live trees, snags, logs, and tip-up mounds, vegetative structure, understory vegetation, ground cover, and soils. Observations also are collected at the plot level, e.g., topographic characteristics, and at the ELT level, e.g., gap transects, wetlands, and surveys of presence of flora and fauna. Manuals were developed to guide planning, data collection, and analysis. This system was designed to be comprehensive and integrated and should have wide applicability for monitoring natural areas and lands managed for other objectives, as well as for ecosystem management research.

Resumen—Las areas naturales de investigación (RNAs) están diseñadas por el servicio forestal de estados unidos para proteger ecosistemas representativos de la región o que contienen especies de flora y fauna únicas. Tomando en cuenta que los RNAs puede servir como ecosistemas de referencia, los autores desarrollaron un sistema de monitoreo a largo plazo para evaluar una gama amplia de atributos y procesos del ecosistema. El monitoreo es estratificado por tipos ecológicos de tierras (ELT), las cuales integran unidades de suelo, paisaje y vegetación. Las parcelas de muestreo están ubicadas sistemáticamente dentro de cada ELT. Se establecieron submuestras dentro de las parcelas de muestreo para evaluar árboles vivos, tocones, leñas y ramajes; estructura de la vegetación; sotobosque; cobertura del suelo y suelos. A nivel de parcela de muestreo se evaluaron características topográficas y a nivel de elt se evaluó la presencia de flora y fauna. Se han desarrollado manuales para colección de los datos y análisis. Este sistema integrado, debería tener amplia aplicación para monitoreo de áreas naturales protegidas y tierras manejadas para otros objetivos, así como para la investigación de manejo de ecosistemas.

Managing National Forests and other public lands has become increasingly complex due to increasing demand for products from this valuable resource and calls for greater participation by the public in decisions affecting it. As a result, we need a better understanding of the land and how it changes over time. Resource monitoring helps ensure that the responses to management practices are within the expected range of effects and can be sustained.

Sound management of ecosystems requires a knowledge of the effects of natural- and human-caused change. Repeated observations over time can separate natural effects from human ones, and distinguish effective management practices from less effective or harmful ones. The ability to gather this type of information is at the core of land stewardship and ecosystem management.

Resource monitoring has been conducted for many years on various ecosystem components. Sustainable harvests of forests have been monitored with timber surveys. Wildlife has been monitored on project areas, e.g., bird censuses. Often, ecosystem components are monitored without consideration of the ecosystem as a whole, and monitoring often is conducted independently-even on the same area. Because few conclusions can be drawn with respect to interactions between and among resources, a comprehensive, integrated system of monitoring is needed.

The USDA Forest Service is required to monitor the effects of its actions over time as mandated by the National Forest Management Act and the National Environmental Policy Act. One way to separate the effects of natural and human influences is to compare the results of various ecosystem management practices against similar ecosystems on a Research Natural Area (RNA) managed to maintain natural processes without removing physical resources. This study was initiated on RNAs in the Eastern Region of the USDA Forest Service to assess ecosystem status, change, and differences among various management practices. The monitoring program was designed to be comprehensive, integrated across ecosystem components, and applicable to forests and related ecosystems in the Northeastern and Midwestern United States.

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Approach

A team of researchers, National Forest System specialists, and cooperators was formed to develop an integrated monitoring system. The team decided on a comprehensive monitoring program that:

- integrates key ecosystem components
- crosses many spatial scales
- provides for different temporal scales
- is comprehensive and well documented
- is simple and efficient.

This monitoring program is one of many initial efforts to address the need. Little is known about what constitutes the best ecosystem indicators, the most cost-effective sampling and plot designs are, or the best method for analyzing the results to provide information upon which to base management decisions. However, research is being conducted on these problems, and experience is accumulating. Monitoring for management purposes provides an opportunity for researchers to collaborate with resource managers to develop an effective monitoring system.

The team developed a sampling design and a field guide that were field tested in three areas within the region. The methods were refined and the resulting monitoring program was written in draft form as a three-volume set: Overview and Planning Guide (Tyrrell and others 1999), A Catalog of Field Methods (Smith and others 1999), and Field Data Recorder Use and Programming (Scott 1999). While the sampling and plot designs chosen are applicable to many ecosystems, they are optimal for none. Much information is provided to the planner, but much is left to be decided, for example, which attributes to include, frequency of observation, and number of plots. The planning guide does provide some guidance on making those decisions.

Monitoring Program

An effective monitoring program must be developed by first setting the monitoring objectives. The following steps draw heavily from "Vegetation monitoring in a management context", an unpublished guide developed in 1995 by The Nature Conservancy in cooperation with the Forest Service:

1. Set broad objectives.
2. Set time and cost constraints.
3. Assemble and evaluate existing data.
4. Set specific objectives.
5. Select attributes.
6. Select sampling and plot designs.
7. Plan field work.
8. Train personnel.
9. Collect data.
10. Enter and store data.
11. Assess and interpret data.
12. Evaluate objectives and monitoring program.
13. Decide on future management.

This process provides feedback on both the monitoring plan and the original management plan. The monitoring system itself must be evaluated to ensure that it is providing the appropriate kind of information at the appropriate level of detail. If it is not, the program must be modified and monitoring continued. If the management objectives are met, no change is required. If they are not met, the management activities must be modified to meet the objectives or the objectives must be modified.

Attributes

When selecting attributes, a number of factors should be included. The key factor should be the attribute's ability to answer the questions (specific objectives). As a means of helping the planner identify attributes, we arranged them in two ways—by spatial scale and broad resource category. For spatial scale, attributes are listed in groups based on whether the attributes are to be measured at the Study Area level, the ELT level, or the Plot level. We also grouped the attributes into five resource categories: general characteristics of the study area, plants, animals, water, and physical environment. Each of these was then divided into subcategories (Table 1).

This monitoring system is admittedly strongest for plants—this is a function of the objectives of the team, the history of resource surveys, and the nature of the resource component. For example, methods for developing population statistics for streams and watersheds need work. Finally, this list is meant to be used as catalog from which to choose based on the objectives and type of monitoring being conducted. Similarly, not all components of the design would be used in most applications. However, guidance is given on the priority of each attribute: important (core), costly, and special studies only.

Design

When developing a sampling design, the basic building block was assumed to be the ELT within a study area; thus, the ELT was chosen to stratify the study area. ELTs are defined based on soils, landform, rock type, geomorphic process and plant associations and are 10's to 100's of hectares in size (Avers and others 1993). A simple grid system is recommended to cover the ELT at a rate based on the target sample size (Fig. 1). The Canopy Gap Survey and surveys of herbs and small mammals using pitfall traps or drift fences are conducted along the grid lines connecting plots, because these phenomena are assumed to operate at the ELT scale. Bird Surveys are conducted at plot locations to relate the results with local habitat information. Plant information is collected on a plot with nested subplots (Fig. 2). The Overstory plot is large at 0.125-ha (20-m) radius to sample enough trees to classify the plot and to use in modeling relationships between resource components. However, a smaller plot can be used if population estimates are the primary focus. Four Understory (3-m radius) and four Vegetative Structure (5-m radius) subplots are located in the off-cardinal directions within the Overstory plot. Four Ground Layer (1 m^2) subplots surround each Understory subplot. A soil pit is dug just outside the Overstory plot. Because ecosystems are so complex, we made the design flexible enough to easily add new attributes.

Table 1.—Five resource categories, their components, and examples of their attributes.

General Characteristics of the Study Area:
- Location Attributes, such as Stand and Plot Number
- Measurement Attributes, such as UTM coordinates, and Measurement Date
- Ownership and Land-use History

Plants:
- Canopy Gaps, such as transect length, gap length, gap width
- Floristic Survey of the ELT, including species and abundance class
- Ground Layer, such as percent cover by herbaceous species, rock, and leaf litter
- Shrubs and Vines, such as species and cover or counts by basal diameter class
- Tree Regeneration, such as species, seedling height class, and sapling diameter
- Vegetative Structure, such as percent occupancy by life form by height class
- Overstory, such as species, diameter, distance, and azimuth
  - Live Trees, such as crown class and damage
  - Snag Trees, such as fragmentation class and height class
  - Logs, such as length, diameter, and decay class
  - Tip-Up Mounds, such as length and width
  - Site Index, such as species, total height, and age

Fauna:
- Bird Surveys, such as counts by species and sex
- Reptile, Amphibian, and Small Mammal Surveys, such as counts by species

Water:
- Lake Survey, such as lake area, depth, turbidity, pH, and temperature
- Stream Survey, such as stream order, channel sinuosity, and bed material
- Wetland Survey, such as seasonality and soil inundation

Physical Environment:
- Climate, such as mean annual temperature and precipitation
- Deposition Chemistry, such as pH, nitrates, and sulfates
- Soil Profile, such as soil horizon depths, textures, and colors
- Landform, such as slope, aspect, elevation, and terrain position

Data Collection

The Northeastern Region of the USDA Forest Service purchased TMDR data recorders and APG++ software from Sprengnether Instruments for use on all of its National Forests. APG++ is an application generator, that is, it is used on a desktop PC to develop data collection forms, database, and error checks which are then downloaded to the data recorders for data collection. The data are then uploaded as text files for processing. Applications for this monitoring program were developed for the full list of resource components described here except water and deposition chemistry. The Field Data Recorder Use and Programming volume describes how to alter the software for specific applications. However, because the applications generator was not available in time, data recorders were not used as part of the field test.

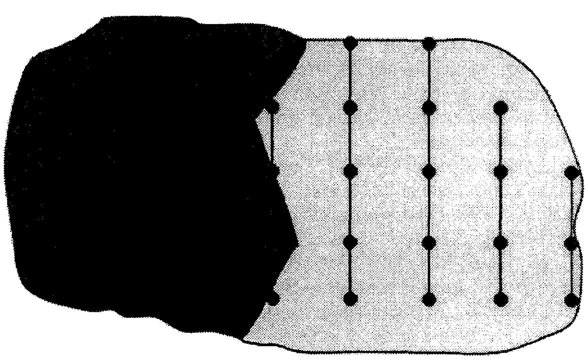

Figure 1.—Grid of plot locations and grid lines for Canopy Gap Survey across two Ecological Landtypes within a study area.

Field Test

During the summer of 1994, a field test of the monitoring program was conducted in RNAs and actively managed areas on three National Forests-one each in Illinois, West Virginia, and Wisconsin. Much was learned regarding the clarity of instructions, field logistics, and the time and cost involved in collecting the data. The manual was then revised and the remaining information was included in the planning guide. All attributes were tested except water and deposition chemistry.

Planning Guide

On the basis of the revised manual and field experience, we developed a planning guide. The target audience for the guide is the survey planner, though portions of the field guide are written for field crews. The planner works with the land manager to identify the objectives. He or she then develops the survey design, selects the attributes, and is responsible for training, data collection, analysis, and reporting. The planning guide describes:

Monitoring objectives
Types of monitoring
Resource components and attributes

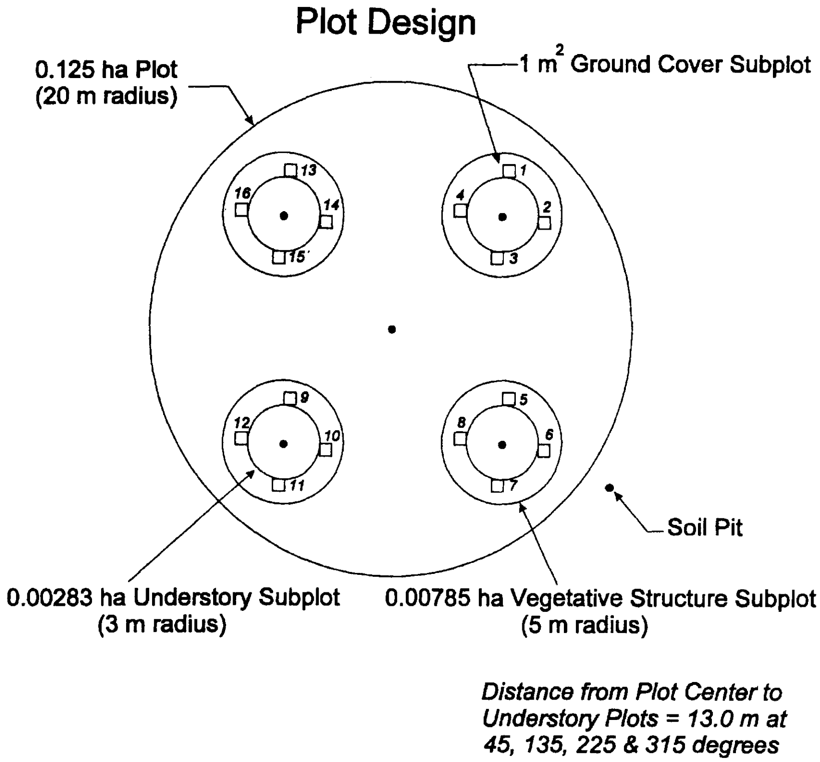

Figure 2.—Plot cluster design for vegetative and soils data.

Monitoring steps to follow
Case studies
Time and cost information from case studies
Bibliography
Glossary

With access to the Catalog of Field Methods and the Field Data Recorder Use and Programming guide, the survey planner should have much of the guidance needed to plan and conduct the monitoring program required to meet management objectives.

Summary

This program was designed for monitoring portions of National Forests in the Northeastern United States but is general enough to be applicable elsewhere. The design and list of attributes is long so that survey planners can choose the components and attributes that meet their needs. By measuring the core set of attributes, the monitoring program also can provide a means for ensuring consistency between different locations within an organization or between agencies. They may not always choose to measure the same set of additional attributes, but when they do, they are measured according to the same standards.

The three-volume set will be a useful starting point for survey planners to design and implement monitoring. The field guide alone is a rich resource for planners. The use of the data collection software is not integral to the monitoring program, but we recommend the use of field data recorders because they provide an opportunity to edit data in the field where changes are best made.

Acknowledgments

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Literature Cited

Avers, Peter E., Cleland, David T.; McNab, W. Henry; Jensen, Mark E.; Bailey, Robert G.; King, Thomas; Goudey, Charles B.; Russell, Walter E. 1993. National hierarchial framework of ecological units. Washington, DC: U.S. Department of Agriculture, Forest Service. 20 p.

Scott, Charles T. 1999. Planning and field method options for ecosystem monitoring: Volume III-Field data recorder use and programming. Gen. Tech. Rep. NC- St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. In press.

Smith, Marie Louise; Tyrrell, Lucy E.; Scott, Charles T.; Parker, Linda; Funk, David T.; DeMeo, Thomas E.; Shimp, Beth; Brakke, Marella. 1999. Planning and field method options for ecosystem monitoring: Volume II-A catalog of field methods. Gen. Tech. Rep. NC- St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. In press.

Tyrrell, Lucy E.; Funk, David T.; Scott, Charles T.; Smith, Marie Louise; Parker, Linda; DeMeo, Thomas E.; Brakke, Marella; Shimp, Beth. 1999. Planning and field method options for ecosystem monitoring: Volume I-Overview and planning guide. Gen. Tech. Rep. NC- St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. In press.

Biogeoclimatic Ecosystem Classification—a Natural System for Ecosystem-Based Land Management[1]

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Abstract—This paper puts forward the thesis that, in order to produce useful ecological inventory approaches that satisfy the requirement for integration at different scales and between different ecosystem components, the integration of ecosystem properties must occur as a fundamental component of the map units, i.e., as a part of the classification system. Other ecosystem components can be related to the integrated ecosystem classification following delineation of the basic ecosystem units. This presentation demonstrates this approach using Biogeoclimatic Ecosystem Classification (Pojar et al. 1987) concepts in three watersheds in coastal British Columbia.

The approach of the Biogeoclimatic Ecosystem Classification is to utilize phyto-sociological concepts to interpret and classify ecosystems. Plant community-derived ecosystem classes are then related to physical environmental components based on detailed field descriptions of site and soil properties. In this way the integration of the complex of environmental factors is interpreted for three fundamental properties—climate, soil moisture, and soil nutrients. Using this approach, biologically-significant boundaries in regional and local ecological gradients can be identified and used to link the classification to the landscape. The same approach is used to derive classes for ecosystem succession with the site classification. In British Columbia, regional (Biogeoclimatic Zones, Subzones, and Variants), local (Site Associations, Site Series and Site Types), and chronological (Seral Associations) scale ecosystems have been classified within a hierarchical framework. The result is a natural (taxonomic) classification that can be interpreted for a wide range of purposes, including wildlife capability and suitability, forest productivity (site index), forest health, soil conservation, riparian management, and biodiversity inventory.

This presentation demonstrates the Biogeoclimatic Ecosystem Classification approach to ecosystem inventory by reporting on the Greater Vancouver Regional District Ecosystem Inventory presently being carried out in three 20,000 ha watersheds that provide drinking water to the city of Vancouver, Canada. The project has been ongoing for about 5 years, and has involved a team of scientists including a hydrologist, terrain scientist, ecologist, forest inventory specialist, forest health specialist, and forest fire specialist. Complete, inter-related inventories of these watersheds have been completed and maps will show interpretations derived from the different ecosystem components. The inventory is linked to a landscape model, which as a number of inter-related components, including sediment recruitment and delivery, landslides and soil erosion, forest succession, forest pests, and forest fire hazard. The model is being used in conjunction with the ecological inventory to compare the impacts on water quality and biodiversity of three different management options over a 200 year planning horizon. The model and inventory is used to compare, for the three management approaches, water quality impacts (changes in annual fine sediment delivery to the reservoir) of potential watershed disturbances, including a large fire and a major insect outbreak. Future work involves determining the applicability of the model for deriving global warming effects, and the long term impacts of air pollution on water quality and ecosystem resources.

Resumen—Este artículo sostiene la tesis que para producir inventarios ecológicos útiles que satisfagan los requerimientos para la integración a diferentes escalas y entre diferentes componentes de los ecosistemas, la integración de las propiedades de los ecosistemas debe ocurrir como un componente fundamental de las unidades mapeadas, es decir, como una parte del sistema de clasificación. Otros componentes del ecosistema pueden ser relacionados como un sistema de clasificación integrado, siguiendo la delineación de las unidades básicas del ecosistema. La presentación demuestra este enfoque usando los conceptos de la clasificación biogeoclimática de los ecosistemas (Pojar et al. 1987) En tres cuencas de la costa de Columbia Británica.

Este enfoque utiliza conceptos fitosociológicos para interpretar y clasificar los ecosistemas. Las comunidades vegetales clasificadas se relacionan a los componentes ambientales físicos basados en descripciones detalladas de campo. En esta forma la integración del complejo ambiental se interpreta por tres propiedades fundamentales: clima, humedad del suelo y nutrientes del suelo. Usando este enfoque los limites biológicamente significativos en gradientes ecológicos regionales o locales pueden ser identificados y usados para la clasificación del paisaje. El mismo enfoque se utiliza para derivar clases sucesionales con la clasificación de sitios. Las escalas del ecosistema han sido clasificado de manera jerárquica en Columbia Británica: regionales (zonas y subzonas biogeoclimáticas), locales (asociaciones de sitio, series de sitio y tipos de sitio) y cronologías (asociaciones serales).

El resultado es una clasificación natural (taxonómica) que puede ser interpretada para una amplia gama de propósitos, incluyendo capacidad de vida silvestre y sostenibilidad, productividad forestal (índice de sitio), salud del bosque, conservación del suelo, manejo de áreas riparias e inventarios de biodiversidad.

Esta presentación demuestra el enfoque de la clasificación biogeoclimática de los ecosistemas al inventario de los ecosistemas del mayor distrito regional de Vancouver, llevándose a cabo en tres cuencas que abarcan 20 000 ha, las cuales proporcionan agua potable a la ciudad de vancouver. El proyecto ha sido continuado por aproximadamente 5 años, y ha involucrado un equipo de científicos incluyendo un hidrólogo, un edafologo, un ecólogo, un especialista de inventarios forestales, un patólogo forestal y un especialista en incendios forestales. Inventarios completos de estas cuencas han

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sido mapeados y mostrarán las interpretaciones derivadas de los diferentes componentes de los ecosistemas. El inventario esta ligado a un modelo del paisaje, el cual tiene un número de componentes inter-relacionados, incluyendo reclutamiento de sedimentos, erosión del suelo, sucesión forestal, plagas forestales e incendios forestales. El modelo está siendo usado en conjunción con el inventario ecológico para comparar los impactos de la calidad del agua y la biodiversidad de tres diferentes opciones de manejo sobre un horizonte de planeación de 200 años.

Sustainable land management requires an ecosystem-based system for ecosystem inventory, for describing ecosystem processes, and for developing effective management approaches that account for a wide range of extractive and non-extractive values. A fundamental prerequisite for a useful ecosystem-based land management system should be its ability to integrate physiography, surficial materials, soils, vegetation and animal ecosystem components in a meaningful manner that identifies important ecosystem processes. This report shows how the Biogeoclimatic Ecosystem Classification achieves these objectives.

BEC is an ecosystem-based land management system that has been developed over the last 50 years in British Columbia, and has been used for a range of resource applications. This report outlines the historical development of BEC, explains the theory and methods employed by the system, describes Terrestrial Ecosystem Mapping, and reviews applications of BEC. The report emphasizes that the unique value of BEC is its ability to provide ecosystem integration as an integral component of the classification approach. BEC links physiographic and biological ecosystem components and integrates them to provide a powerful tool for ecosystem-based land management.

Development of Biogeoclimatic Ecosystem Classification

Biogeoclimatic Ecosystem Classification (BEC) is a system of classification developed and widely used by land managers in British Columbia, Canada. The scientific foundations of BEC are grounded in the research of Vladamir Krajina and his graduate students at the University of British Columbia. Between 1949 and 1975 Dr. Krajina and his students carried out the original descriptions of forest ecosystems across the diverse physiographic and climatic regions of British Columbia. In 1975 the approach was adopted by the British Columbia Forest Service, and, between 1975 and 1985, what had been a principally academic system was translated into operational methodologies that are now applied by technical and professional land managers across the province. These are described in a series of regional ecosystem guides that specifically describe all subzones and site series in each of British Columbia's six administrative forest regions.

Overview of the System

Biogeoclimatic Ecosystem Classification (BEC) is described as a natural, wholistic ecosystem classification approach. BEC is a natural system because classification is based on the essential properties that characterize ecosystems – climate, soil moisture and soil nutrients. This is in contrast to interpretative classifications that classify landscape units for particular purposes, such as for interpreting forest productivity or wildlife habitat attributes for a particular animal species. Because it is a natural classification system, it is very useful for developing a range of interpretations, all of which will have a basis in an integrated ecosystem classification.

BEC is an wholistic system because it uses interpretations of plant indicator species distributions to integrate the complex of environmental factors that interact at a range of scales to produce a complex mosaic of ecosystems across the landscape. More specifically, phytosociological analysis of plant communities in specific kinds of ecosystems is used as a bioindicator to produce specific interpretations of climate, soil moisture, and soil nutrients. BEC uses phytosociological principles to identify biologically-meaningful segments of the landscape at three levels – regional, local, and chronological (Table 1).

The Regional Level

Regional ecosystems are biogeoclimatic zones, subzones and variants, and represent geographic areas with relatively uniform regional climates. The classification of biogeoclimatic subzones is determined by phytosociological analysis of mature plant communities on zonal sites. Zonal sites are characterized by having a moderate slope without a significant aspect effect, have medium-textured, moderate to deep soils without a high component of coarse fragments, and are medium in terms of the availability of moisture and nutrients. Sites with these characteristics are expected to provide the best bioindication of regional climatic effects, and differences revealed by phytosociological analysis of mature and old forest plant communities on zonal sites are interpreted to reflect biologically significant segments of the regional climatic gradients.

The Local Level

The local ecosystem level identifies site series, site associations, and site types to provide a classification of ecologically-equivalent sites within regional climates, i.e., within biogeoclimatic subzones and variants. As for the regional level, the classification of site series at the local level is developed using phytosociological analysis of mature and old forest plant communities to identify biologically-significant segments of mesoscale soil moisture and soil nutrient gradients. The site series classified within a subzone or variant are organized on an edatopic grid with relative soil moisture regime (0-8) on the Y axis, and relative soil nutrient regime (very poor, poor, medium, rich, and very rich) on the X axis. In this way the site series for a sampled ecosystem can be determined regardless of successional stage of the ecosystem using site quality analysis (see Site Description and Identification), which identifies soil moisture-soil nutrient regime combinations.

Site series may occur on a range of landforms and landscape positions, but the effect of compensating factors will result in ecological equivalence, as expressed by membership in the same plant association in the mature and old forest successional stage. For example, a site with coarse soils and constant seepage at the base of a long slope may be identified as having the same site quality as a level site with fine textured soils and fluctuating water table. These two sites, although morphologically distinct, would be included in the same site series, but identified as unique site types. Thus site series are divided into site types to account for differences in site morphological features.

The ecological equivalence of site series implies a similar vegetation potential within classification units. Thus it is expected that, for a given site series, similar plant communities will develop over time as forest succession proceeds. As a result, the site series classification provides a meaningful ecological template for describing and predicting ecosystem succession (see The Chronological Level).

Another important aspect of the site series classification is that ecosystems included within the same site series will have similar productivity. This is well demonstrated by the close correlation that has been demonstrated between site series and the site index of the commercial tree species (FRBC/MOF 1997). This correlation is presently being used to adjust growth and yield estimates for operational tenures in British Columbia. The close correlation between site series and site index suggests that the site series classification of BEC is successful in dividing the landscape into ecologically equivalent segments.

The Chronological Level

The third level of classification in BEC is the chronological level and, in general, very little work has been carried out for this component of the classification. Klinka et al. (1987) demonstrated the application of the approach for successional forest ecosystems in Coastal British Columbia. Seral associations of seral deciduous ecosystems in north western British Columbia were described by Oikos (1998e). Seral associations are classified by phytosociological analysis of seral ecosystems along forest successional chronosequences.

Stand structural stages (Table 2) describe ecologically-significant changes in stand structural characteristics along the continuum of stand development from stand initiation to old forest, following the general approach proposed by Hamilton (1988) and Oliver and Larson (1990). Stand structural stages are not defined floristically, as are other BEC classification units, but are intended to classify the main stand development processes that occur over the course of forest succession. Two stand structural stages will often incorporate a single seral association, especially during the middle stages of stand development.

Table 1.—Overview of the three levels of the Biogeoclimatic Ecosystem Classification system, showing approach to classification, ecosystem identification, and ecosystem mapping.

Level	Objective	Classification	Identification	Mapping
Regional	classification of regional climates	*Subzones* are delineated by vegetation classification of mature ecosystems on zonal sites[1]; subzones are agglomerated into *Zones*, and divided into *Variants.*	Subzones are identified by the evaluation of those plant indicator species that identify the zonal plant association in mature zonal ecosystems.	Subzone boundaries are mapped based on ground evaluations that describe and compare climatic indicator species in mature zonal ecosystems along climatic gradients.
Local	classification of ecologically equivalent sites within regional climates	*Site Series* are delineated by vegetation classification of mature ecosystems on azonal sites[2]. A site series is a group of sites within a regional climate (subzone or variant) with a similar vegetation potential. Site series are agglomerated into *Site Associations* where they occur in different subzones, and divided into *Site Types* where they differ in landform and/or physical characteristics within subzones.	Site series are identified through *site quality analysis*. This involves two parallel evaluations: an interpretation of plant indicator species and an evaluation of site and soil factors. These two evaluations are compared to evaluate site quality and determine site series.	Site series mapping is the core of ecosystem mapping and is carried out on air photos by inferring site series from an integrationof surficial materials, geomorphic processes, meso-scale slope position, and vegetation characteristics.
Chronological	classification of successional ecosystems within site series	*Seral Associations* are delineated by vegetation classification of successional ecosystems along a chronosequence. Seral associations usually include more than one structural stage (see Table 2).	Seral associations are identified by the evaluation of those plant indicator species that identify the seral association.	Mapping is carried out as a component of ecosystem mapping by evaluating plant community characteristics for a site series polygon.

[1]zonal sites are a subset of mesic sites, and are characterized by having a moderate slope without a significant aspect effect, medium textured, deep soils without a high component of coarse fragments; in mountainous areas they are located in middle mesoslope positions,

[2]azonal sites include all sites not defines as zonal

Table 2a.—Stand structural stages used in Terrestrial Ecosystem Mapping (RIC 1998) to describe changes in stand characteristics along the forest successional continuum.

		Stand Structural Stages
Code	**Structural Stage**	**Definition**
1	Non-vegetated Sparse	Initial stages in primary or secondary succession. Little or no residual vegetation except for bryophytes and lichens. <20 years since disturbance for normal forest succession; may be prolonged (50-100 yrs+) where there is little or no soil development.
1a	Non-vegetated	less than 5% total cover of vegetation;
1b	Sparse	less than 10% cover of vascular plants;
1c	Bryoid	bryophyte and lichen dominated communities >50% cover; shrub and herb cover <20%; tree cover <10%.
2	Herb	Early successional stage or self maintained structure due to environmental conditions or disturbance (e.g., avalanche tracks, wetlands and grasslands); dominated by herbaceous vegetation. Tree cover <10%, shrub cover <20; time since disturbance <20 yrs for normal forest succession. Includes 2a forb-dominated, 2b graminoid dominated, 2c aquatic, 2d dwarf shrubs.
3	Shrub	Early successional stage or disclimax / climax communities dominated by shrubby vegetation <10 m tall. Seedlings and advance regeneration may be abundant. Tree cover <10%, shrub cover >25%. Time since disturbance <20 yrs for normal forest succession.
3a	Low Shrub	Shrubby vegetation <2 m tall.
3b	Tall Shrub	Shrubby vegetation 2-10 m tall.
4	Pole / Sapling	Trees >10 m tall, have overtopped shrub and herb layers and stands are typically dense; younger stands are vigorous, older pole-sapling stages composed of dense, stagnated stands (<100 yrs) are included in this stage. This stage persists until self-thinning and canopy differentiation becomes evident. Time since last disturbance < yrs for normal forest succession.
5	Young Forest	Self-thinning has become evident and the forest canopy has begun differentiation into distinct layers (dominant, main canopy, and overtopped). 40-80 yrs since last disturbance.
6	Mature Forest	Trees established after the last disturbance have matured, a second cycle of shade tolerant trees may have become established: understories become well developed as the canopy opens up. 80-140 yrs since last disturbance.
7	Old Forest	Old, structurally complex stands comprised mainly of shade tolerant and regenerating tree species, although older seral remnants may still dominate the upper canopy; standing snags and rotting logs on the ground are typical and understories are patchy. Time since last disturbance >140 yrs for these subzones.

Table 2b.—Modifiers used in Terrestrial Ecosystem mapping (RIC 1998) to describe variations in stand structural stages.

Code	Modifier	Definition
s	single-storied	Closed forest stand dominated by dominant and co-dominant trees; advance regeneration generally sparse.
t	two-storied	Closed forest stand dominated by distinct overstay and intermediate crown classes; suppressed crown class is lacking or <20% of all crown classes combined.
m	multistoried	Closed forest stand with all crown classes represented.
i	irregular	Forest stand with very open overstory and intermediate crown classes (totaling <30% cover), with well developed suppressed crown class; advance regeneration variable.
s	shelterwood	Forest stand with very open understory (<20% cover) with well developed suppressed crown class and/or advanced regeneration in the understory. Intermediate crown class generally absent.
v	veterans	Scattered old trees which have remained intact after a natural disturbance such as fire, but account for less then 10% cover.
r	residuals	Scattered trees of any size remaining intact after forest harvesting, but account for less than 10% cover.

Site Description and Identification

Identification of biogeoclimatic subzone, site series, and structural stage requires a field description of site, soil and vegetation characteristics of an ecosystem. Plots are 400 m^2 and are selected to represent uniform forest ecosystems, i.e., areas uniform in vegetation composition and structure, and in soil and site properties. Information recorded on site, soil and vegetation within the plot is listed in Table 3. Soil classification follows CSSC (1998). Information is recorded on an Ecosystem Field Form, and procedures and protocols to describe and record ecosystem properties is summarized

Table 3.—List of site, soil, and vegetation information collected for completing an ecosystem field plot. * indicates data collected for Ground Inspection Plots used for Terrestrial Ecosystem Mapping.

Site	Soil	Vegetation
biogeoclimatic Unit *	terrain texture *	% cover of all trees, shrubs, herbs, and mosses growing on humus; trees are estimated in 3 strata and shrubs in 2 strata; epiphytes and plants growing on other substrates may also be identified
site series *	surficial material *	
moisture regime *	terrain surface expression *	
nutrient regime *	Geomorphologic processes *	
successional stage	soil classification *	
structural stage *	humus form classification *	
site disturbance	rooting depth	
elevation *	water source	
slope *	seepage water depth*	
aspect *	drainage class	
mesoslope position *	flooding regime	
surface topography	humus form strata (hfs) depths	
exposure type	hfs fabrics	
surface substrate %	hfs structures	
UTM coordinates	hfs root size and abundance	
Forest Region	hfs consistence	
Air Photo No.	hfs structure	
Mapsheet No.	von Post decomposition	
	mineral soil (ms) horizon/layer	
	ms depths	
	ms textures	
	ms coarse fragment %s	
	ms roots	
	comments on mottling, clay films, effervescence, horizon porosity	
	soil profile diagram	
Notes	notes as required	

in BCMOELP/BCMOF (1998). Data from field forms are entered into VENUS (1998) software for tabulation, synthesis, and analysis as required.

Assessments of site quality, i.e., of soil moisture and nutrient regime, is based on two separate lines of evidence – site and soil properties, and plant indicator analysis. Combinations of site and soil factors are combined in keys to interpret soil moisture and nutrient regime. For example, soil texture, depth and coarse fragment content, as well as mesoslope position and the presence of a water table or mottling are the most important indicators of soil moisture regime. Humus form classification (Green et al 1993), soil texture, colour and coarse fragment lithology are the main indicators of soil nutrient regime. Soil moisture and nutrient regime can also be assessed from indicator plant analysis (Krajina and Klinka 1985) when sites are not overly disturbed. Even in early successional communities, many plants that remain from the previous disturbance, and those that colonize the sites following disturbance will have indicator value for climate, soil moisture, or soil nutrients. To make a final determination of site quality the two lines of evidence are compared and site series determined. Codes are also available for describing whether the site represents the central concept of the site series or whether it is transitional to an adjacent site series.

Terrestrial Ecosystem Mapping

Recently in British Columbia there has been an increased emphasis on ecosystem mapping, primarily to meet the requirements of the recently enacted Forest Practices Code Act. Standards and protocols for Terrestrial Ecosystem Mapping (TEM) have recently been developed and refined, and are summarized in RIC (1998).

TEM involves the interpretation and integration of landform, physiographic and vegetation features from stereoscopic aerial photographs to delineate biogeoclimatic subzone/variant and site series boundaries. In the first step, landforms and surficial materials are defined using the approach of bioterrain mapping (Howes and Kenk 1997). Terrestrial ecosystems within these units are then outlined based on site series (soil moisture and soil nutrient regimes), and stand structural stage. Ecosystem polygons are seldom uniform in these features because of the scale of variation in ecosystems across the landscape, in relation to the scale of mapping. For this reason many ecosystem polygons are 'complex' in that up to 3 different site series-stand structural stage combinations may be recognized in a polygon. The percentage cover of each of these components is estimated and recorded in the ecosystem attribute data base for all polygons. The ecosystem attribute data base provides the basis for an ecological inventory that can be displayed in whatever GIS formats are required. Digital protocols and a data dictionary for terrain and ecosystem data bases are described in RIC (1998).

Within the last few years, millions of hectares of operational forest tenures in British Columbia have had TEM completed, mostly at a scale of 1:20,000 or 1:50,000. Most TEM for operational applications has been carried out at scale of 1;20,000 using 1:15,000 air photographs. Polygon density varies between 1,200 and 1,800 polygons per 1:20,000 map sheet. Minimum polygon area on 1:20,000 map sheets is 1 ha and mean polygon size is between 8 and 12 ha.

The TEM approach integrates physical and biotic ecosystem components into a landscape summary that provides a comprehensive inventory of ecosystem resources within the area mapped. Underlying the ecosystem map is a map of bioterrain that describes physiographic processes and surficial materials, and which can be used to develop interpretations for terrain and soil management. The ecosystem map can be used to develop interpretative maps for forest, wildlife, and biodiversity management. Bioterrain linework is coincident with ecosystem linework in the TEM product so that information from the two layers of information can be interpreted together. This integration provides a comprehensive tool for ecosystem based land management because it provides a direct link between the physical processes that determine many ecosystem properties, and the biotic components of the ecosystems mapped.

Interpretations from BEC Units and TEM

It was stated above that BEC is a natural ecosystem classification system from which interpretations can be derived, as required by the land manager. TEM provides a method for developing useful ecosystem maps that integrate the physiographic and biologic components of the landscape. Taken together a wide range of ecosystem-based interpretations are possible.

BEC was originally applied to the objectives of industrial forest management and the first interpretations were developed to assist the forest manager. The six regional BEC guides contain, for the different site series, site index estimates for the major tree species, predictions of the composition and intensity of the post-harvesting brush complex, growth limiting factors, and regeneration considerations such as tree species selection, slash burning guidelines, and site preparation recommendations. More recently stocking requirements have been adjusted to account for ecosystem factors. Klinka et al. (199?) provided a comprehensive evaluation of silvicultural systems applicable to the different site series.

Wildlife habitat capability and suitability rankings are probably the most common set of interpretations presently developed from TEM products. Algorithms for habitat suitability are based on a knowledge of present ecosystem characteristics, while habitat capability models are based on knowledge of how these habitat values will change with ecosystem succession. Forage potential estimates can also be reliably connected to site series and stand structural stage combinations.

In British Columbia the Conservation Data Centre has identified over 200 ecosystems it considers to be rare or endangered, and have used the site series concept to describe these special ecosystems. Following a coarse filter approach to biodiversity conservation, it is now being proposed that these ecosystems be protected from harvesting or other development. BEC and TEM are well suited to identifying and mapping these sites (Oikos 1998a,b), and for developing reliable strategies that do not threaten the ecological processes that maintain them (Oikos 1998a,c). TEM products provide an inventory of rare ecosystems in the area mapped. BEC concepts of ecological process are also important for developing effective management approaches for rare plant and animal species (Oikos 1998d).

BEC is also usefully applied to management and restoration of riparian ecosystems. Site series classifications of riparian ecosystems provide a framework for understanding ecosystem processes such as flooding duration and frequency, natural successional processes, the impacts of the disturbance, and feasible restoration approaches (McLennan and Johnson 1997).

BEC/TEM products provide an ecologically relevant template for developing landscape level models and for integrating additional landscape information. This is well demonstrated by GVRD Watershed Group (1998), where a forest succession model was developed that predicted forest changes over the next 200 years. The forest succession submodel was included as a component of a watershed level model and was integrated with hydrologic (sediment delivery), terrain stability, fire hazard, and forest pest hazard submodels. The watershed model is being used by watershed managers to compare the impacts to water quality and biodiversity from three potential watershed management approaches, from a large fire, and form a large forest insect outbreak. The effectiveness of the BEC system in this application is its direct link between biological and physiographic landscape components, and its ability to predict plant community composition in a forest succession model that uses biogeoclimatic sites series as a base polygon unit.

Although BEC and TEM were developed using forested ecosystems in British Columbia, the approach is applicable to other temperate forest, grassland, and alpine/arctic ecosystems. Oikos (1996) demonstrated the transferability of BEC and TEM concepts to assess potential impacts of a mining project in the central arctic. Site series specific to the project area were described, mapped, and interpreted for a range of applications including rare plant communities, grizzly bear forage potential, spring and fall caribou foraging, air quality impact indicator values, and summer and winter trafficability rankings.

In that the BEC system is a natural classification, many other interpretations are also possible. Examples include rangeland and wetland management, suburban/rural land development, recreation planning, stakeholder analysis, and environmental impact analysis. In all cases BEC provides an ecosystem basis for sustainable land management and development.

Summary and Conclusions

The Biogeoclimatic Ecosystem Classification System, together with Terrestrial Ecosystem Mapping, provides a powerful tool for ecosystem-based land and landscape management. This effectiveness is based in a number of important aspects of the system.

1. BEC is wholistic in that it uses floristic analysis and plant indicator species analysis to interpret the complex of environmental factors that determine ecosystem characteristics. This analysis and integration of environmental factors reduces ecosystem complexity by relating ecosystem properties to three major variables—regional climate, soil moisture, and soil nutrients.

2. The concept of ecological equivalence means that site series are identified that have the same vegetation potential and ecosystem productivity. This provides a very useful template for predicting forest successional development and growth and yield estimates.

3. A range of ecological information is collected in the course of sample plot analysis and this data provides a comprehensive ecological inventory for developing interpretative algorithms. Additional information not listed in Table 3 can also be collected in sample plots as required.

4. As a component of site diagnosis, the ecosystem processes that determine ecosystem productivity and other characteristics are assessed and recorded. Ecosystem–based land management requires an understanding of these ecosystem processes in order to develop effective and sustainable policies.

As a result of these fundamental components of the system, BEC has the potential to provide solutions to a range of land management issues, including certification of industrial forest operations, biodiversity conservation, riparian area management and restoration, management of ecosystems and their processes in parks, wilderness and other conservation areas, and management of municipal water supply areas. The success of BEC in all of these applications is a result of the integration of ecosystem components that is inherent in the classification units themselves. This kind of wholistic, natural system is mandatory for developing ecosystem-based, sustainable land management policies.

References

CSSC. 1998. The Canadian System of Soil Classification. 3rd Ed. Soil Classification Working Group, Research Branch, Agriculture Agri-Food Canada. Ottawa, Ontario.

BCMOELP/BCMOF. 1998. Field manual for describing terrestrial ecosystems. Land Management Handbook No. 25. B.C. Ministry of Environment, ands and Parks and B.C. Ministry of Forests. Victoria, B.B. ISSN 0229-1622.

FRBC/MOF. 1997. Site index estimates by site series for coniferous tree species in British Columbia. Special Publication Forest Renewal British Columbia and B.C. Ministry of Forests. Victoria, British Columbia.

Green, R., R.L. Trowbridge, and K. Klinka. 1993. Towards a taxonomic classification of humus forms. Supplement to Forest Science, Vol. 39, No. 1. Washington, D.C.

GVRD Watershed Group. 1998. GVRD Watersheds Ecological Inventory – Appendix Report. Contract report to the GVRD Watershed Management Department. Contributing companies are Acres International Ltd., B.A. Blackwell and Assoc. Ltd., J.M. Ryder and Associates Ltd., Oikos Ecological Services Ltd., Northwest Hydraulics Ltd., Pherotech Inc., and Timberline Forest Resources Consultants Ltd. Vancouver, B.C.

Hamilton, E. 1988. A system for the classification of seral ecosystems within the Biogeoclimatic Ecosystem Classification. First Approx. Research Report RR87004-HQ. B.C. Ministry of Forests, Victoria, B.C.

Howes, D.E., and E. Kenk (eds.) 1997. Terrain classification system for British Columbia. Version 2. MOE Manual 10. B.C. Ministry of Environment, Lands and Parks. Victoria, B.C.

Krajina, V.J., and K. Klinka. 1985. Indicator plants of British Columbia. University of British Columbia Press. Vancouver, B.C.

McLennan, D.S., and T. Johnson. 1997. Riparian Assessment and Prescription Procedures (RAPP). Field Guide. Contract Report to Watershed Restoration Program, B.C. Ministry of Environment. Lands and Parks, Vancouver, B.C.

Mitchell, W.R., R.N. Green, G.D. Hope, and K. Klinka. 1989. Methods for biogeoclimatic ecosystem mapping. Internal Report of the Ministry of Forests Research Program, RR 89002-KL, B.C. Ministry of Forests, Victoria, B.C.

MOE/MOF. 1996. Biodiversity Guidebook. Forest Practices Code of British Columbia Act. Ministry of Environment, Lands and Parks-Ministry of Forests, Victoria, B.C. ISBN 0-7726-2619-7.

Oikos 1996. Classification, mapping, and interpretations of arctic ecosystems in the Lac de Gras Area, Northwest Territories, Canada. Contract report by Oikos Ecological Services Ltd. to Diamet Diamonds Ltd., Yellowknife, NWT, Canada.

Oikos 1998a. Mapping of rare ecosystems in British Columbia. Contract report by Oikos Ecological Services Ltd. to the Conservation Data Centre, B.C. Ministry of Environment, Lands and Parks. Victoria, B.C.

Oikos 1998b. Methods for the identification of rare ecosystems in British Columbia. Field Guide. Contract report by Oikos Ecological Services Ltd. to the Conservation Data Centre, B.C. Ministry of Environment, Lands and Parks. Victoria, B.C.

Oikos 1998c. Conservation strategies for a rare ICHmc2 ecosystem. Contract report by Oikos Ecological Services Ltd. to Kispiox Forest District, B.C. Ministry of Forests, Hazelton, B.C.

Oikos 1998d. Ecosystem mapping and conservation recommendations for Hotsprings Island, Gwaii Haanas National Park Reserve. Contract report by Oikos Ecological Services Ltd. to Parks Canada, Queen Charlotte City, B.C.

Oikos 1998e. Preliminary classification of seral deciduous ecosystems in the SBSdk, SBSmc2 and ICHmc2 in north-western British Columbia. Contract report by Oikos Ecological Services Ltd. to British Columbia Forest Service, Prince Rupert Forest Region. Smithers, British Columbia.

Oliver, C.D., and B.C. Larson. 1990. Forest stand dynamics. McGraw-Hill, New York, N.Y.

Pojar, J., K. Klinka, and D.V. Miedinger. 1987. Biogeoclimatic ecosystem classification in British Columbia. For. Ecol. Manage. 22:119-154.

RIC 1998. Standards for Terrestrial Ecosystems Mapping in British Columbia. Resources Inventory Committee, Terrestrial Ecosystems Task Force, Ecosystems Working Group. B.C. Ministry of Environment, Lands and Parks and B.C. Ministry of Forests, Victoria, B.C.

Subject IV

New Approaches to Integrated Inventory and Monitoring of Forest Ecosystem Resources

Forest Productivity and Diversity: Using Ecological Theory and Landscape Models to Guide Sustainable Forest Management[1]

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Abstract—Sustainable forest management requires maintaining or increasing ecosystem productivity, while preserving or restoring natural levels of biodiversity. Application of general concepts from ecological theory, along with use of mechanistic, landscape-based computer models, can contribute to the successful achievement of both of these objectives.

Ecological theories based on the energetics and dynamics of populations can be used to predict the general distribution of individual species, the diversity of different types of species, ecosystem process rates and pool sizes, and patterns of spatial and temporal heterogeneity over a broad range of environmental conditions. This approach requires subdivision of total biodiversity into "functional types" of organisms, primarily because different types of organisms respond very differently to the spatial and temporal variation of environmental conditions on landscapes. The diversity of species of the same functional type (particularly among plants) tends to be highest at relatively low levels of net primary productivity, while the total number of different functional types (particularly among animals) tends to be highest at high levels of productivity (e.g., site index or potential net primary productivity). In general, the diversity of animals at higher trophic levels (e.g., predators) reaches its maximum at much higher levels of productivity than the diversity of lower trophic levels (e.g., plants). This means that a single environment cannot support high diversity of all types of organisms.

Within the framework of the general patterns described above, the distributions, population dynamics, and diversity of organisms in specific regions can be predicted more precisely using a combination of computer simulation models and GIS data based on satellite information and ground surveys. Biophysical models that use information on soil properties, climate, and hydrology have been developed to predict how the abundance and spatial distribution of various plants and animals. These models can be used to predict the patterns of forest type and structure that develop in response to variation in productivity and disturbance across complex landscapes, as well as species diversity and the distribution and population fluctuations of threatened species in specific regions.

The dual constraints of cost and logistics mean that only a small subset of ecological properties and processes can be monitored on any landscape, and this monitoring can only be carried out at a few locations that represent a very small proportion of the total landscape. Given these limitations, how can ecological monitoring programs provide the largest amount of interpretable information for a given expenditure of funds?

Ecological theory can contribute to more effective monitoring and management of forest ecosystems by predicting the general types and patterns of biodiversity responses that are most likely under specific conditions, so resources can be focused on the most critical ecosystem properties and processes. Theory can also provide qualitative predictions of how specific ecosystems properties, such as species diversity, are expected to change in response to natural variability in environmental conditions, as well as to specific management actions, such changes in harvest schedule or grazing regime. Predictions of expected responses are essential for guiding adaptive management, for interpretation of changes detected by long-term monitoring, and for improving early detection of potentially undesirable changes.

Landscape models allow the application of theoretical predictions to specific landscapes by providing quantitative estimates of the spatial and temporal variation of the environmental conditions (soil moisture, nutrients, temperature, streamflow, etc.) that influence the patterns of growth and survival of organisms on each particular landscape. These dynamic landscape models go far beyond typical habitat suitability models to predict how population size should change over time, as well as changes in the spatial distribution of the population. Dynamic landscape models allow more effective management and monitoring by predicting the specific patterns of response that should be expected on a specific landscape under specific conditions, so monitoring results can be quickly interpreted as either consistent or inconsistent with expected changes.

Classification of Landscapes for Planning Monitoring Programs

At a coarse level, it is obvious that forests require different monitoring methods than grasslands or wetlands. However, even within forests (or within grasslands or wetlands) there is sufficient variation in environmental conditions that a single "monitoring model" is not appropriate for all forests. Planning a monitoring program requires information on the expected spatial and temporal variability in critical ecosystem properties, as well some information on expected directions of change in response to natural environmental fluctuations or specific management actions.

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Even within a particular biome or ecoregion, landscapes and waterscapes vary sufficiently in major properties that a "one-size-fits-all" monitoring program or ecosystem model will not work, and could lead to serious errors in ecological assessments and natural resource management. Some of the most likely errors relate to predicted changes in species diversity, and the size and distribution of specific populations.

Universal Properties of Landscapes

All landscapes, no matter how large or small in area, include spatial variation in two essential attributes: 1) the disturbance regime (as characterized by disturbance type, frequency, intensity, and timing); and 2) the rate of biomass production (the potential primary productivity of plants and/or the potential productivity of animals). In addition to local heterogeneity in these two attributes, there are major regional differences in disturbance regime and productivity, as well as global patterns that results from differences in soils, topography, rainfall, and temperature.

These two landscape properties, disturbance regime and potential productivity, provide a framework for classifying landscapes. These factors influence a wide range of ecosystem properties that are directly related to forest management and biodiversity conservation. This framework, originally described as the "dynamic equilibrium model" of species diversity (Huston 1979, 1994), allows prediction of the balance between competitive exclusion (which reduces diversity under some conditions) and conditions that slow or interrupt the process of competitive exclusion. According to this model, species diversity can be reduced by either competitive exclusion under conditions of high potential productivity, or by mortality and the failure of populations to recover from mortality under conditions of high disturbance frequence/intensity or low productivity (Fig. 1). The basic "hump-backed" (unimodal) pattern of species diversity in relation to potential productivity that is predicted by this model is found in a wide variety of plant communities (Grime 1973, 1979; Huston 1979, 1980, 1994) (Fig. 2).

The two axes of this landscape classification can be quantified using a variety of sources of information. Direct measurements of site index or potential net primary productivity will not be available in most situations. However, a number of environmental factors that are correlated with NPP (such as climate, soil nutrient availability, soil moisture conditions) are available at a wide range of spatial resolutions for areas ranging from single watersheds to all of North America. Maps of soil types and topography can be combined with climatic data to predict variation in factors related to forest productivity at resolutions as fine as a few meters (e.g., Garten et al. 1994; Huston and Fontaine 1994). Appropriate analyses of remote sensing data can contribute to mapping of spatial and temporal patterns of primary productivity, and can potentially be used to identify the effects (frequency, intensity, extent) of many types of natural and anthropogenic disturbances that alter vegetation structure.

The Four Primary Landscape Types

The dynamic equilibrium model (Huston 1979, 1994) predicts the variation in spatial heterogeneity of vegetation

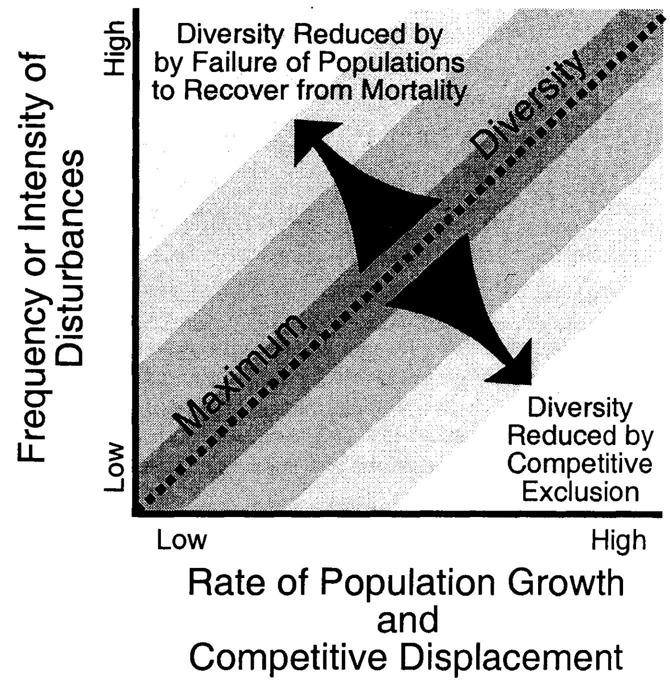

Figure 1.— Interactive effects of mortality-causing disturbances and productivity (rate of population growth and recovery) on the survival of populations of competitors. In addition to the reduction of diversity caused by failure of populations to survive under conditions of high frequency of disturbances and low productivity, diversity can also be reduced by competitive exclusion under high productivity conditions where mortality-causing disturbances are infrequent. Diversity is predicted to be highest where these two processes cancel each other out, which is illustrated along the diagonal line between low rates of population growth and low disturbances frequencies in the lower left corner, and high rates of population growth and high disturbance frequencies in the upper right (from Huston 1994, based on Huston 1979).

structure and diversity that results from an interaction between disturbances that cause mortality (e.g., formation of disturbed patches) and the rate at which populations and ecosystem processes recover from the disturbances (e.g., population growth rates and the rate of successional change) (Fig. 3).

Although significant spatial heterogeneity exists on almost all landscapes, the broad consistency in regional patterns of climate, geology, and soils (e.g., biomes or ecoregions), allows the classification of landscapes on the basis of factors related to productivity and disturbance for spatial areas ranging from the entire earth (e.g., the Holdridge Lifezone Systems, Holdridge, 1947) to single watersheds (e.g., Garten et al. 1994; British Columbia Ministry of Forests 1990).

The four extreme combinations of disturbance and productivity described below represent four very different types of environments that have different dynamics of species diversity and require different approaches for natural resource monitoring and management. Although these landscape types represent the extremes of productivity and disturbance dynamics, they clearly intergrade along the natural continua of productivity and disturbance regimes.

High Productivity - Low Disturbance Landscapes— This combination of conditions is the one that is most

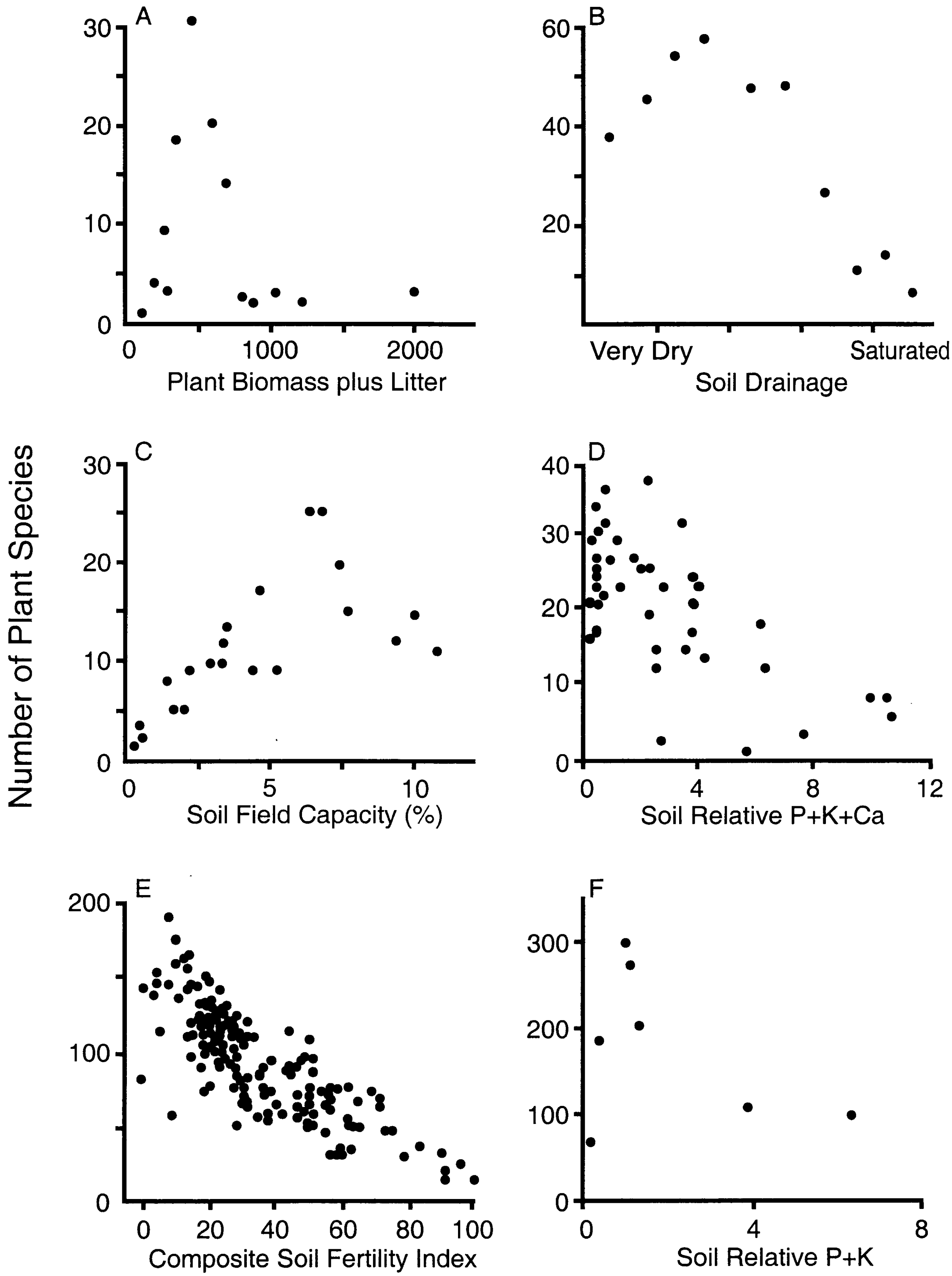

Figure 2. — Patterns of plant species diversity in relation to factors related to potential productivity in different vegetation types. (A) - (C) are oldfields and grasslands, values are number of plant species per square meter; (D) - (F) are tropical forests, values are number of tree species per 0.1 ha, number of vascular plants per 0.1 ha, and number of tree species per ha, respectively. Note that in all cases the number of plants species declines at the highest levels of fertility or other factors correlated with productivity, while the maximum number of species is found at intermediate to low levels of the same factors (from Huston, 1993, 1994).

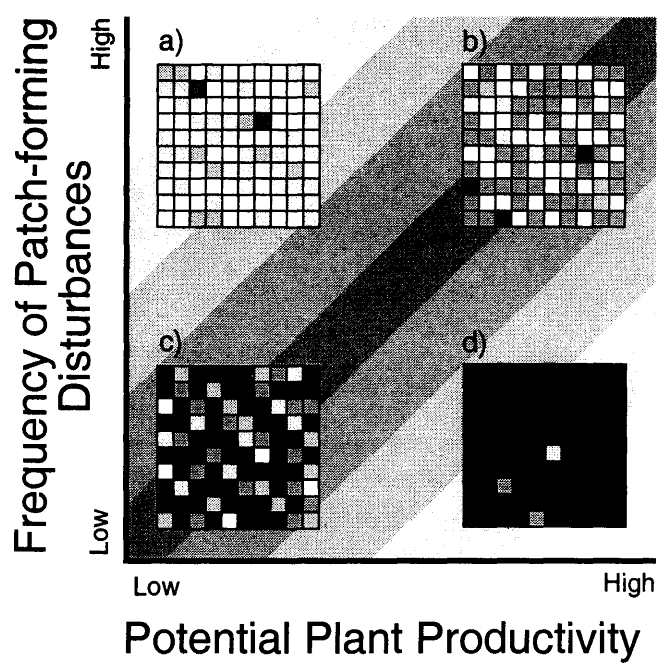

Figure 3.— Landscape heterogeneity patterns generated by the interaction of mortality-causing disturbances and the rate of population recovery. These patterns are those expected to result from the dynamic equilibrium between disturbance and recovery for the combinations represented by the four quadrants of the figure. Intensity of shading indicates standing plant biomass, and is not linearly correlated with species diversity. See discussion in text. (from Huston 1994, based on Huston 1979).

favorable for human uses and for many components of biodiversity. Unfortunately, this type of landscape has been pre-empted for human agricultural use around the world (Huston, 1993) and is one of the most endangered landscape types from the perspective of conservation and ecosystem services. Human activities typically shift this type of landscape into the high productivity - high disturbance category (see next section), with a very different set of processes and issues.

In the absence of human impacts, the combination of high productivity and low disturbance frequency and/or intensity allows most of the landscape to be covered with mature, high biomass communities. The rapid recovery of high levels of biomass following disturbance results in a relatively uniform landscape, where most of the spatial heteogeneity is caused by underlying topographic and geological variation, rather than by processes such as patch formation and succession. While scattered patches of mature forest can be found by chance even on landscapes with relatively high disturbance frequencies, on low disturbance landscapes, these mature, high biomass conditions dominate over the entire landscape (Fig. 3d).

Mature, "old-growth" forest in productive regions is typically low in tree diversity, and low in spatial heterogeneity. The classic examples of this type of landscape are the coastal evergreen forests of the Pacific Northwest of North America. Other examples might include bottomland hardwoods or certain swamp forests in the Southeastern United States. Low tree species diversity (and diversity of other types of plants as well) over a range of spatial scales in these systems is typically not overcome by the presence of early successional or "pioneer" species.

Low tree diversity may lead to a relatively low diversity of animals that are highly specialized or host-specific. However, the overall high productivity of the environment can support a high diversity of animals, particularly at higher trophic levels, including detritivores and decomposers, as well as predators (Lattin, 1990; Huston 1994). Population densities of animals can be quite high as a result of the high primary productivity.

Aquatic systems in productive environments are also likely to be highly productive, either as a result of algal growth supported by high nutrient and light availability, or high levels of organic matter input from the terrestrial system. Under these conditions, the diversity and productivity of aquatic invertebrates and fish may be quite high, particularly in streams, which typically have higher disturbance frequencies and intensities than lakes. High productivity in aquatic systems can also be caused by anthropogenic eutrophication, which often leads to low species diversity as a result of anoxia (caused by decomposition of large amounts of organic matter), toxics from certain species of algae, and competitive exclusion, particularly among the primary producers (Schindler 1974; Proulx et al. 1996).

In productive, low-disturbance landscapes, disturbed areas are particularly important because of their relative rarity. Pioneer and early successional plant species, and animals that depend on them, are likely to be rare in these environments. Disturbed areas are particularly important because both the chemical quality of the plants and the overall net primary productivity of early successional areas are likely to be much higher than those of mature forest (in spite of much lower total biomass). The relative uniformity and high biomass of vegetation that results from high productivity and low disturbance frequencies makes these landscapes subject to rare "catastrophic" disturbances (e.g., stand-replacing fires), which may affect large areas when they occur (Wright and Bailey 1982).

Species diversity on these landscapes reflects two contrasting sets of patterns and processes. First is low diversity among competing species, as a result of competitive exclusion (Fig. 1). High productivity leads to rapid rates of individual and population growth, which accelerates the expression of competitive dominance, leading to competitive exclusion and a reduction in the number of coexisting species. This pattern only occurs among species that are potential competitors, and is most conspicuous among plants, all of which compete for the same basic resources (Grime 1973, 1979; Huston 1979, 1980, 1994; Keddy 1989; Reader and Best 1989; Guo and Berry in press). The second pattern is high diversity among species that do not compete with one another (Fig. 4). High productivity and a low frequency of disturbances allows the survival of populations that would not be able to survive under lower productivity or a high disturbance frequency (or intensity). This increase in diversity results from an increase in the number of functional types of organisms (particularly animals) with different "niches." Such functional types include different feeding guilds, different trophic levels, and many different types of specialization (e.g., McMinn and Crossley 1996).

The effects of environmental or management changes on these landscapes are predictable, and contrast dramatically between plants and animals. Any increase in disturbance

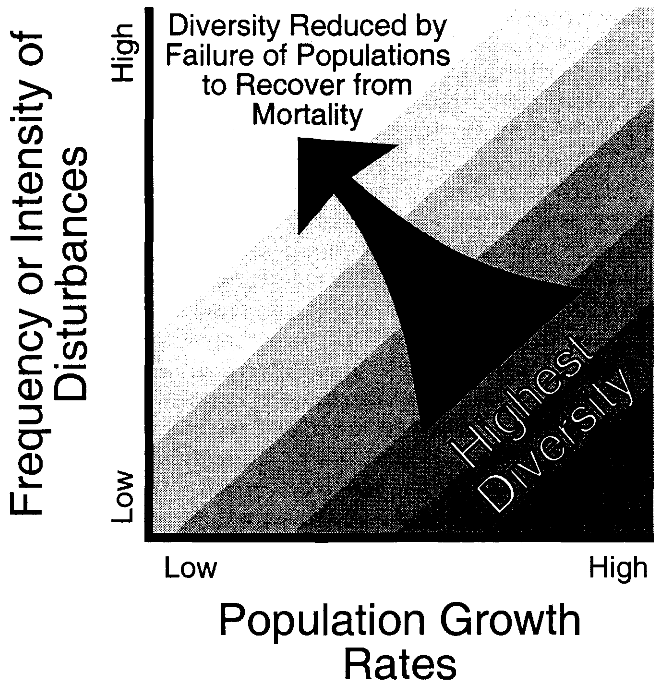

Figure 4.— Interactive effects of mortality-causing disturbances and productivity (rate of population growth and recovery) on the survival of populations of species that do not compete with one another. The highest probability of population survival, and thus the highest diversity of independent populations, is found under the favorable conditions of high productivity and low disturbance frequencies. Population survival probability, and thus total diversity of non-competing populations, decreases with increasing disturbance frequency and lower productivity (from Huston 1994).

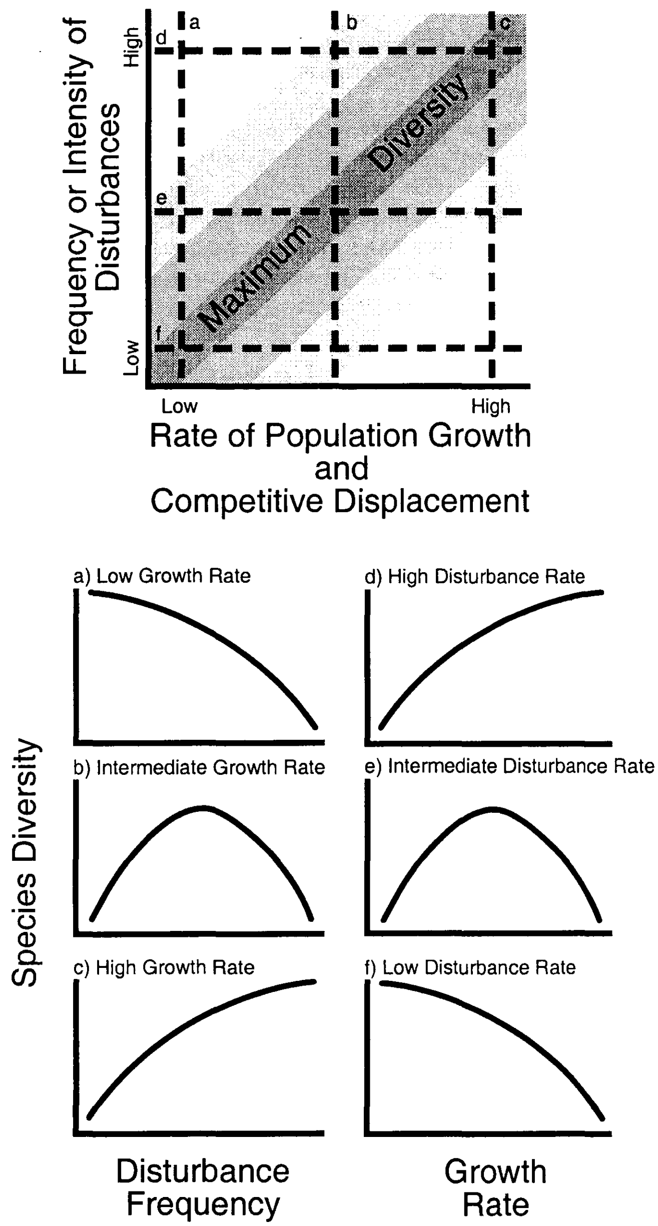

Figure 5.— Predictions of the Dynamic Equilibrium Model of species diversity. Both disturbance type and frequency, and growth rates (plant productivity, population growth rates) vary across landscapes in response to geology, topography, and climate. The effect on species diversity of a change in disturbance frequency or intensity can be reversed from one environment to another, depending on local conditions of productivity and growth rates (e.g., (a) vs. (c)). Similarly, the effect on species diversity of the same change in productivity can completely reverse, depending on the disturbance regime (e.g., (d) vs. (f)). (from Huston 1979, 1994).

frequencies or intensities, or any decrease in productivity (resulting from soil degradation or other causes) is likely to reduce animal population size and overall diversity by slowing the rate of recovery of populations from natural or anthropogenic disturbances (Fig. 4). The opposite pattern is likely to occur for the diversity of plants or any groups of organisms that compete strongly under natural conditions. Plant diversity is likely to increase in response to either an increase in disturbance frequencies (Fig. 5 c) or a decrease in productivity (Fig. 5f). Thus, in these landscapes, an increase in plant diversity is likely to indicate a change in environmental conditions in terms of both productivity and disturbance. Some types of animals (i.e., those specialized on plant species) are likely to increase in diversity in response to disturbances that increase plant diversity. However, animals that are dependent on high productivity and the absence of disturbances are likely to decline in population size and overall diversity.

Understanding the patterns of diversity on these landscapes should help resource managers to focus on the most sensitive components of the landscape or ecosystem (Hansen et al. 1991; Oliver and Larsen 1996). In addition, theoretical predictions about the expected direction of change in diversity in response to alteration of disturbance regime or productivity provide guidance that can guide forest management plans, enhance detection of changes measured by monitoring programs, and also distinguish expected from unexpected patterns.

High Productivity - High Disturbance Landscapes— This combination of conditions produces very dynamic landscapes that can be favorable for human activities as well as animal populations that can avoid or minimize the effects of the disturbances (Licht 1997). This type of landscape has also been severely altered by human activities around the world. The primary change humans impose on these landscapes is a reduction in the natural disturbance frequency and intensity, largely through the control of flooding and fires. Elimination of these disturbances dramatically alters the species diversity and spatial pattern of these landscapes (White 1979).

In the absence of human impacts, these landscapes are typically very heterogeneous with regard to species composition, diversity, and biomass. High productivity allows rapid recovery of plant biomass and animal populations following disturbances and biomass can accumulate to high levels on patches that escape disturbance for long period of time. However, biomass is typically held to moderately low levels by the frequent disturbances. The high spatial heterogeneity of these landscapes (Fig. 3b) can result from two types of processes. First, small "patchy" disturbances can produce a landscape in which there are patches of different ages, with different amounts of biomass accumulation as well as different species composition and diversity reflecting successional dynamics. Second, large disturbances can impose temporary uniformity that rapidly disappears as a result of spatial variation in productivity and the rate of recovery from the disturbances (Huston 1994). Such variation in productivity is found on all landscapes, as a result of topography and associated variation in soil nutrients, water, etc. Classic examples of this type of landscape are fire-maintained prairies and savannas, and riparian zones along streams and rivers.

In addition to high spatial heterogeneity in biomass, these landscapes can vary dramatically in species diversity and composition. The high productivity allows species diversity to be rapidly reduced by competitive exclusion in the absence of disturbances. Consequently, patterns of diversity are very sensitive to variation in disturbance regime and to variation in time since the last disturbance. In addition, the high species diversity of plants, and high landscape heterogeneity also contribute to high diversity of animals specialized on different plants and microhabitats (Huston and Gilbert 1996).

With an appropriately high disturbance frequency/intensity, plant diversity can be quite high, as it is on frequently burned (or grazed or mowed) prairies (e.g., Huston 1979, 1994; White et al. 1991; Bakker 1989; Collins et al. 1998). However, species that are slowly growing or particularly sensitive to the disturbances are typically eliminated from these landscapes or greatly reduced in abundance. The suppression or elimination of woody vegetation by fire on prairies, as well as the low tree species diversity of fire-maintained savannas in conjunction with the high diversity of herbaceous plants, are good examples of variation in the responses of different "functional types" of plants to the same disturbance regime.

The high productivity of these environments can support a high diversity of animals of various functional types, if they are not severely affected by the disturbances (Fig. 3). The high biomass and diversity of large mammals and various types of birds found on the original North American prairies and on African savannas are good examples of high animal diversity under productive conditions (Norton-Griffiths 1979).

These environments are very sensitive to changes in the disturbance regime, which often result from human intervention, but may result from natural climatic variability as well. Any reduction in disturbance frequency or intensity is likely to result in a reduction in the species diversity of some types of plants (e.g, grasses and herbs in prairies or riparian zones) and potentially an increase in the biomass and diversity of other plant types (e.g., more slowly growing woody species). Reduction in disturbance frequency or intensity can also alter the spatial heterogeneity of the landscape by allowing plant succession to proceed toward a stage with higher biomass and lower diversity (e.g., characteristics of a high productivity - low disturbance landscape). Typically, human activities have reduced disturbances in prairies, savannas, and riparian zones, leading to significant reductions in plant diversity, and major changes in the composition of the animal community in response to the changes in the structure and composition of the plants (Licht 1997). The biomass and diversity of some types animals can increase in response to reduced disturbance frequency. However, the major changes in plant diversity and composition, as well as the reduction in landscape heterogeneity, that result from decreased disturbance frequency can greatly alter the species composition of animals, and result in the reduction or elimination of many species that require the conditions produced by frequent disturbances (e.g., the recent decline of grassland bird species, REF).

Any environmental changes that result in a reduction of productivity are likely to reduce animal diversity (Fig. 4), but may actually increase plant diversity (Fig. 5e (right side of curve) or 5f). IF the disturbance frequency is not too high (Fig. 5 d). Both monitoring programs and resource management activities on high productivity - high disturbance landscapes should focus on the dynamics of spatial patterns that require disturbances for their maintenance. Many plant and animal species become rare very quickly in the absence of disturbance.

Low Productivity - Low Disturbance Landscapes—These landscapes are often misinterpreted as having high productivity because the low disturbance frequency allows large amounts of biomass to accumulate over long periods of time, even though the actual rate of accumulation is low. Most of the world's forests probably fall into this category, especially in the tropics, where many of the soils are very poor. These landscapes are not particularly favorable for agricultural activities, and tend to be very sensitive to degradation by human activities that increase disturbance frequency or reduce productivity (Uhl et al. 1997).

Low productivity - low disturbance landscapes have very high spatial heterogeneity at the scale of the dominant disturbance type (e.g., gap disturbance in forests, Fig. 3c). The low productivity results in a slow rate of recovery of biomass following disturbance, as well as a slow rate of plant succession and change in species composition. Plant diversity is typically quite high on these landscapes, as a result of two processes. First, the low productivity results in a low rate of competitive exclusion, which allows high diversity to be maintained over long periods of time in any small area. Second, the low rate of biomass accumulation produces patch-scale heteroegeneity composed of patches, all of which are going through the same slow successional sequence. At any particular time, a landscape will have patches of many different ages, with each age of patch differing in biomass, structure, and species composition. These patches of different ages add up to very high diversity at the landscape scale, and this large "species pool" further increases the diversity at the scale of individual patches. Obviously, any additional spatial heterogeneity that may result from differences in topography or soils will further increase the high plant diversity at large spatial scales on these landscapes.

The high plant diversity of these landscape often includes many rare and endemic species (Flather et al. 1994). The low productivity that reduces the rate of competitive exclusion and allows high species diversity may also contribute to reduced geneflow and higher rates of speciation (Huston 1994). The combination of (hypothesized) high speciation rates and low rates of competitive exclusion leads to high plant diversity across a wide range of spatial scales, from the local patch to large regions.

Although low productivity contributes to high plant diversity in infrequently disturbed landscapes, it can have a strong negative effect on the abundance and diversity of animals. Animal population densities tend to be low, and populations recover more slowly from disturbances than they would in a more productive environment. The size of the area (range) required to support individual animals or family groups is larger than in more productive environments. This effect is most pronounced at the highest trophic levels, and the abundance of predators is often low.

Even though the spatial density and population sizes of most animal species are low in unproductive environments, the overall diversity of animals can be quite high. This high animal diversity results primarily from species that are specialized on different plant species and on different successional stages and structural patterns of vegetation. Most of the high animal diversity of tropical forests results from this type of specialization.

The plant and animal populations on these landscapes are very sensitive to changes in either productivity or disturbance regimes. Any increase in mortality-causing disturbances is likely to result in the elimination of those populations that cannot recover between disturbances, with a consequent reduction in species diversity (Fig. 5 a). Animal species are likely to be more susceptible to local extinction from increased disturbances than plants because of the loss of available energy (for growth and reproduction) with each trophic transfer. Plant diversity can be also reduced by either an increase in productivity (e.g., resulting from fertilization or atmospheric deposition) that increases the rate of competitive exclusion (Fig. 5f), or from a decrease in productivity, which increases the probability that some populations will not recover between disturbances (Fig. 5e, left side of curve).

Critical issues on these landscapes include preventing any increase in the disturbance (mortality) rates of plants and animals beyond the low natural rates. Major changes in productivity are likely to affect both plants and animals. Any decrease in productivity is likely to decrease plant diversity and have an even greater negative effect on animal populations, and human populations as well. However, increases in productivity may actually increase animal population sizes and diversity, assuming the reduction in plant diversity is not too great. The precarious situation for most animal species in low productivity environments means that isolated "hot spots" of high productivity can be critical for the survival of many species. Monitoring and resource management should pay close attention to the rare, highly productive areas on these landscape (e.g., riparian zones, alluvial deltas, wetlands) whose importance is much greater that their area would suggest. Unfortunately, these rare productive areas are precisely where human activities are likely to be concentrated on these landscapes.

Low Productivity - High Disturbance Landscapes— These landscapes are unfavorable for plants, animals, and most human activities, except perhaps for off-road vehicle recreation. Nonetheless, the various ecosystems found under these conditions are often strikingly beautiful, and fascinating because of the remarkable adaptations evolved by plants and animals in order to survive under these conditions.

Low productivity makes recovery from disturbance slow for both plants and animals. Disturbances are often associated with climatic extremes, with mortality caused by extreme droughts, or fires following periods of favorable growth conditions and fuel accumulation (Minnich 1983; Romme and Despain 1989). Slow growth rates leads to the persistence of patterns caused by disturbances, and maximum standing biomass levels are typically very low (Fig. 3a). Both spatial and temporal variation in productivity, associated with variation in water or nutrients, have dramatic effects on the ecosystems of these landscapes. Interannual variation in rainfall often produces "boom and bust" cycles in animal and plant populations. Slight variation in soil water or nutrients associated with topography or geology can produce conspicuous spatial pattern in the structure and species composition of vegetation.

The most common diversity pattern on these landscapes is a positive relationship between productivity and small scale species diversity for both plants and animals (Fig. 5d). Productivity is rarely high enough that competitive interactions reduce plant diversity, although increases in either nutrients or water can lead to major shifts in plants species composition, with the potential loss of some species at the landscape scale (e.g., Berendse and Bobbink 1993). Much of the diversity at the landscape scale results from spatial heterogeneity associated with variation in productivity (e.g., Kerr and Packer 1997).

Areas with high resource concentrations, such as valley bottoms and riparian zones, are critical for the survival of many animal species in these environments (Pulliam 1988; Hansen and Rotella, in press). One of the greatest threats to the diversity of these landscapes is loss of these small areas of resource concentration, which should be a primary focus of both ecosystem monitoring and resource management.

Differences Between Animal and Plant Diversity Patterns

Across the range of landscape types described above, plant and animal diversity patterns are not always well correlated. Understanding plant and animal diversity patterns in ecosystems requires subdividing "biodiversity" into groups of organisms that have similar responses to the environment, as described above. The key distinction is that between groups of organisms that potentially compete with one another (among which competitive exclusion is a possibility), and groups of organisms in which the species are sufficiently different (i.e., different "niches") that competition is unlikely.

A fundamental fact of ecosystem energetics is the reduction in available energy each time one organism consumes another. Typically, 90% of the energy of the food organism is lost or respired with each transfer of energy by herbivory or predation. Consequently, the first trophic level (plants) inevitably have more energy (and ususally higher biomass) than the next trophic level (herbivores), which has more than the predators, etc. One consequence of this reduction in energy available to higher trophic levels is that the productivity and growth rates of organisms at higher trophic levels it inevitably lower than energy available at lower trophic levels (Odum 1953; Oksanen et al. 1981; Abrams 1993).

For a given level of plant productivity, the productivity of herbivores and carnivores will be significantly lower. Since plant diversity is highest at relatively low levels of productivity, the population density and overall diversity of many types of herbivores and predators is unlikely to reach its maximum under the conditions where plant diversity is highest. In fact, the diversity of increasingly higher trophic levels is most likely to be maximum at increasingly higher levels of plant productivity (Fig. 6).

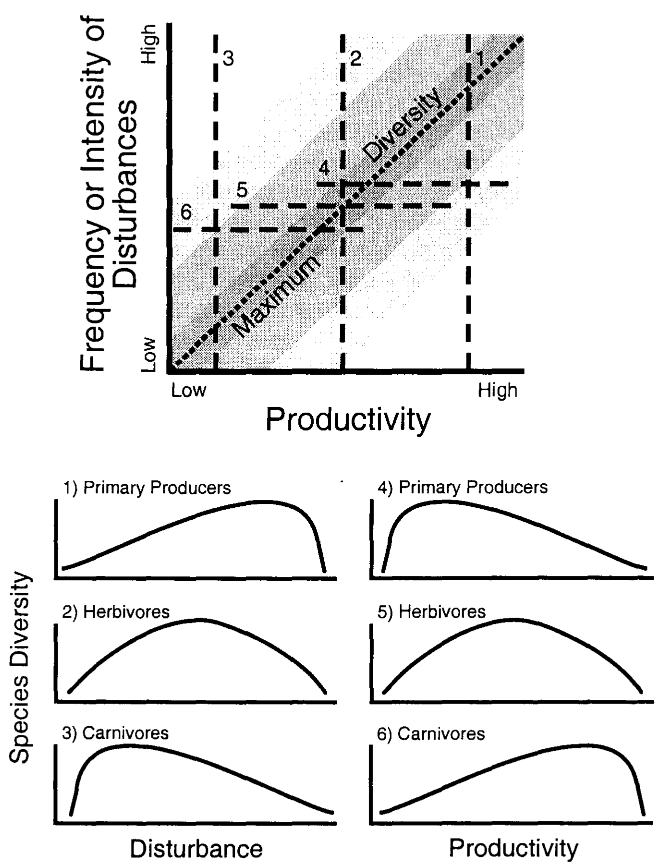

Figure 6.— Differences in conditions that lead to maximum diversity at different levels in a food web (plant, herbivore, carnivore), as a result of energy loss with each transfer between levels in the food chain. For a given level of plant productivity, there will be less energy available to support population growth of herbivores, and still less energy available to support carnivore populations. Consequently, carnivore diversity tends to be highest at high levels of productivity, while diversity among competing plants is highest at low levels of productivity. In addition, carnivore diversity tends to be more sensitive to mortality-causing disturbance than does plant diversity, with herbivores showing an intermediate response (from Huston, 1994).

Thus, it is very unlikely that high diversity of all types of organisms will occur in a single type of environment, either as a result of management efforts or natural processes. As described above, different types of organisms will reach their highest diversity under different conditions. Understanding the conditions under which various functional types of organisms reach their highest (or lowest) diversity is critical for designing and planning monitoring programs, for assessing observed responses, and for resource management planning.

Predicting Invasions of Exotic Species

Although invasions of problem-causing exotic species can occur naturally, they more commonly occur as a result of human activity. Humans increase invasions in two primary ways: 1) by transporting species long distances and across barriers that they could not naturally cross; 2) by disturbing or otherwise altering natural communities in ways that make them more easily invaded and dominated by new species.

Just as some combinations of environmental conditions tend to have higher species diversity than others, some combinations of productivity and disturbance dynamics are more easily invaded than are other combinations. Ecologists have long theorized that high diversity communities are more resistant to invasion than low diversity communities (Elton 1958; MacArthur 1972). This belief was based on the concept of ecological niches and competition for resources. It was assumed that the many species in a high diversity community would more completely utilize the environmental resources than the fewer species of a low diversity community, and make it more difficult for new species to invade. However, most patterns of invasion do not support these theoretical predictions. For example, extensive vegetation surveys in Great Plains grasslands and meadows in the Rocky Mountains (Stohlgren et al., in press) demonstrate that the highest rates of invasion of exotic species is found in the areas with the highest diversity of native species. These observations are consistent with the predictions of the Dynamic Equilibrium Model are that high diversity environments should be more invasible than low diversity environments (Fig. 7).

These invasion patterns can be understood in terms of the effect of productivity and disturbance on plant biomass or cover. When plant cover is high, as in forests or productive grasslands, rates of invasion by additional plant species are low because of intense competition, regardless of species diversity. Likewise, when plant cover is low, as a result of disturbances or low productivity, invading species can easily become established, regardless of the species diversity of the native community. The same processes that regulate species diversity, affect the survival and growth of species that are entering, or "invading," a particular habitat, regardless of whether the invading species are native or exotic.

Observations around the world indicate that low productivity habitats, such as infertile or rocky soils, are readily invaded. However, invaders of unproductive areas rarely become dominant unless they are free of natural pests or are able to escape some of the limitations on growth and survival

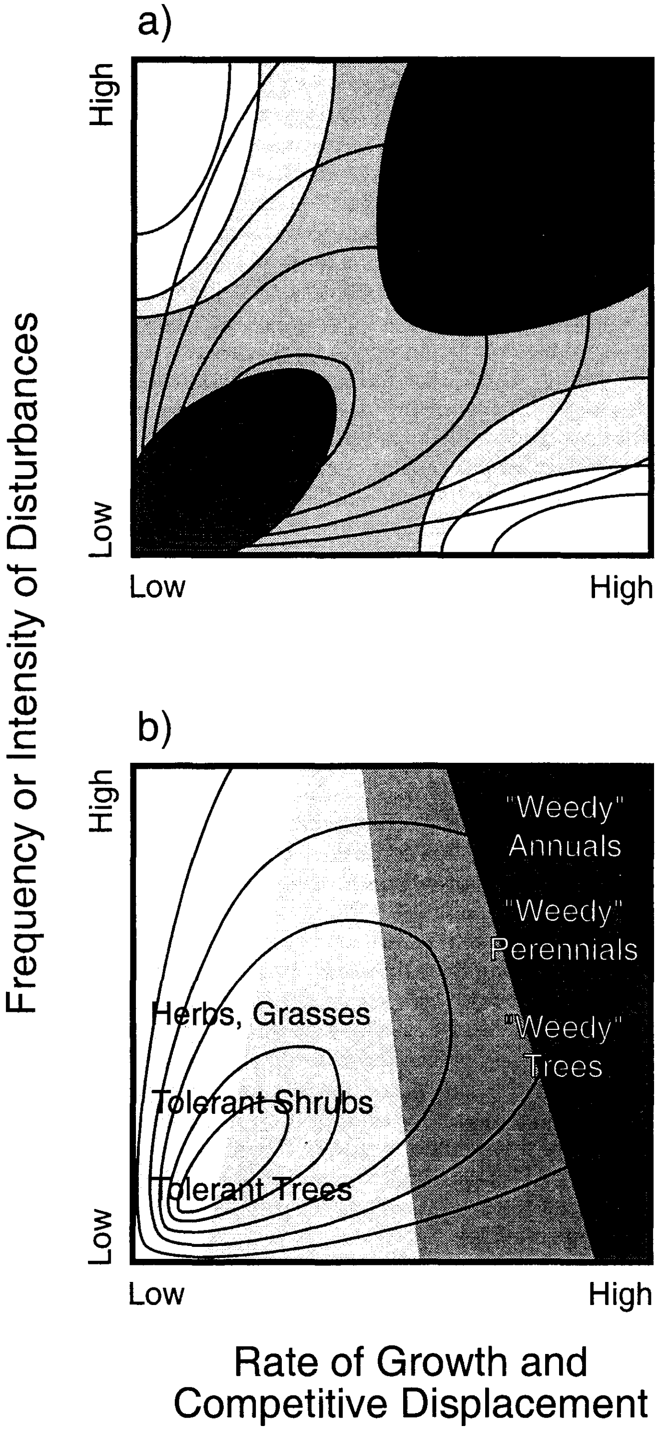

Figure 7.— Predicted community susceptibility to invasions and degree of dominance of invading species in environments classified according to disturbance and productivity (Huston 1979). A. Predicted susceptibility of communities to invasion. Darker shading indicates higher susceptibility. Note that communities with low diversity are least likely to be invaded successfully. B. Predicted life histories of successful invaders under various combinations of productivity and disturbance. Shading indicates expected dominance of a community by a successful invader. Note that if invaders alter the disturbance regime by increasing frequency or intensity, the community will shift to lower diversity and higher dominance by the invader (from Huston 1994).

(such as with deep roots to water, or nitrogen fixation, see however, Mack 1986; Billings 1990). In contrast, productive environments, which are difficult to invade (UNLESS they have been disturbed), can be dominated by successful invaders or by successful native species (Fig. 7). This pattern of susceptibility to invasion and dominance is strongest for plants and sufficiently predictable that it can provide some guidance to managers.

Although the patterns of plant invasion are fairly predictable, invasions by organisms at higher trophic levels, such as diseases, pests, and predators, are much less predictable and can have severe and rapid impacts. Epidemics such as chestnut blight, Dutch elm disease, and tracheal mites of bees, as well as the recent invasion of predators in tropical environments, can be extremely difficult or impossible to control once they are started.

Dynamic Landscape Models

The critical effect that environmental conditions have on the growth and survival of particular species, as well as on patterns of species diversity, makes environmental modeling an essential component of environmental assessment and resource management. This fact is the basic rationale for "Habitat Suitability Indices (or models)" that have been developed and used for assessment and management (Short and Williamson 1987; Short 1992). These models typically combine a number of biological and physical properties of the environment into a statistical model that is correlated with the population size of a particular species. Such models are being widely used in a variety of different applications, ranging from conservation planning to evaluation of wetland mitigations (Scott et al. 1993).

A fundamental problem with habitat suitability indices is that they are typically based on a one-time assessment of habitat conditions, even though environmental conditions in any particular habitat are constantly changing. Habitat that can support high populations densities of a particular species during certain climatic conditions, may be totally unsuitable under different climatic conditions. Likewise, the habitat with optimal conditions may shift from one part of the landscape to another as climate varies, or other environmental conditions change. Depending on the length of favorable conditions in relation to unfavorable conditions, a given species may or may not be able to maintain a viable population in an area of habitat that is, on average, suitable.

Static habitat suitability indices simply cannot predict the year-to-year variability in population sizes and reproductive rates, although this information on spatial and temporal variability is essential for planning resource management activities, and for evaluating the results of monitoring programs. One approach to overcoming this limitation is through the use of "dynamic habitat models," which are computer-based simulation models of landscapes that use climatic data together with information on topography, soils, and vegetation, to predict how habitat conditions change from year to year, or from season to season.

One application of landscape models is predicting how the pattern and properties of the habitats on a landscape will change over time as a result of natural succession, or of management activities and natural disturbances (e.g., Mladenoff and Stearns 1993; Mladenoff et al. 1994). The interaction of expanding beaver populations with forest succession and wetland formation has been modeled using this type of model (Johnston and Naiman 1990).

Landscape models that combine hydrologic models with digital models of topography (DEMs, or digital elevation models, see Beven and Moore 1993) can be used to predict both the distribution of soil moisture resulting from runoff, and the pattern of evapotranspiration, which differs from north-facing to south-facing slopes, depending on the amount of solar radiation they receive (Lin et al. 1994; Huston and Fontaine 1994). These landscape patterns of runoff and soil moisture can in turn be used to predict the distribution of plant species, variation in plant growth and productivity, and patterns of soil nitrogen availability (e.g., Garten et al., 1994), using either regressions derived from previous research, or more detailed models that simulate plant growth, forest succession, and nutrient cycling (Pastor and Post 1986, 1988; Post and Pastor 1990).

Landscape models have been developed to predict the spread of fires in specific regions (Hargrove 1994; Hargrove et al. in press), as well as to predict plant growth (net primary production or NPP) at the broad scale of continents or the entire globe (Running 1994; Korol et al. 1996). Models that predict patterns over large areas generally have much simpler representations of most processes, modeling the productivity of large blocks of forest by lumping all species into a single generic plant, rather than treating species or even individual separately as in some models.

One of the most comprehensive landscape models ever developed is the Across Trophic Level System Simulation (ATLSS), which is a group of models of many different types that is being used to help plan and evaluate the restoration of the Florida Everglades (DeAngelis et al. 1998). This "multi-model" uses the output of a detailed, mechanistic hydrologic model (the South Florida Water Management Model, South Florida Water Management District 1997) to provide daily water levels for every 2 x 2-mile portion of a large area of South Florida. The output of this biophysical model is then processed to provide higher resolution predictions of the pattern of water depth across the various vegetation types of the region. Water depth information is used in models of plant growth and fish populations to predict how deer forage and fish for wading birds varies across the region from week to week and year to year. This complex landscape model has been used to evaluate the ecological impacts of alternative water management plans (USACE 1998).

Dynamic habitat models must be customized for specific locations, using local topography, soils, climate, and other features. Consequently, these models can allow local resource managers to predict and evaluate the consequences of specific management actions, as well as to forsee the potential consequences of such disasters as fires, droughts, and pest outbreaks. With increasing computer power and better information from satellites, ecosystem mapping (BC Forest Commission 1998) and other sources, dynamic landscape models are likely to become an essential tool for resource management and planning at the large scales of national parks and forests.

Information on environmental conditions generated by dynamic landscape models can be used as input for models of plant and animal populations. One type of mechanistic model that produces predictions ranging from population dynamics to ecosystem processes is "individual-based models" (Huston et al., 1988). In these models each individual is represented separately, with parameters that indicate its size, health, age, and reproductive condition, and change through time as each individual ages, grows, moves across the landscape (if an animal), reproduces, and dies. Models of this type generally treat resource acquisition by organisms in great detail, such the feeding and growth of animals as they experience prey abundance that may vary through time or from place to place, or the light, water, and nutrient use by plants. These models have been particularly useful in dealing with organisms that vary greatly in size over their lifetime, such as fish and plants. Similar model structures have been used to look at changes in size distributions over time in both plants and fish (Huston and DeAngelis, 1987), and models of this type are being increasingly used to investigate stock management issues in fisheries (VanWinkle et al. 1993).

Forest dynamics models were among the first individual-based community models developed (Botkin et al. 1972; Shugart and West 1977, Shugart 1984). These models were originally designed to examine the effects of environmental conditions on forest structure and successional dynamics, but were quickly modified to address harvesting and other sources of mortality such as fire (Shugart and Noble 1981; Shugart et al. 1981). The great advantage of using individual-based models for forests (or any plant community) is that plants vary greatly in size as they grow from seedling to adult, and the amount of light available to any particular plant depends on how tall and how dense its neighbors are. A tall plant intercepts light and shades a small plant whether they are the same species or not. Consequently, the same type of model can be used for both single-species populations and multi-species communities (Huston et al. 1988).

Individual-based plant models can be used to predict successional dynamics under different environmental conditions or harvesting regimes (Huston and Smith 1987; Smith and Huston 1989; Shugart et al. 1981), and have been developed for a wide range of forest types, and for issues ranging from theoretical ecology to applied (Shugart 1984). Several investigators have developed spatially explicit versions of these models, in which either groups of plants (Urban 1990) or each individual plant (Busing 1991; Pacala et al. 1993) can be assigned a specific spatial location. These models can be used to look at spatial patterns that develop as a result of variation in environmental conditions (e.g., gradients or patches of soil nutrient availability, Huston and Smith 1987; Huston 1994) or processes such as tree mortality or dispersal (Smith and Urban 1988; Pacala and Deutschman 1995).

These models require information on the properties of each species that is modeled (e.g., maximum growth rate, nutrient and water responses, shade tolerance) as well as of the environmental conditions that affect tree growth (temperature, nutrients, water). Many different versions of individual-based forest succession models have been developed, and there is ongoing improvement both in model formulation and the quality of the species-specific parameters used in the models (Urban et al., 1991; Deutschman et al., in press).

Plant models can also be used to predict the dynamics of animal populations through the effect of habitat structure and food resource on animals. The effects of forest succession on the number and types of birds found in an area are well known (Ralph et al. 1991; Mills et al. 1996), and forest succession models can be used to make predictions about how the bird community will change through time in response to changing forest structure (Smith and Urban 1988; Urban and Smith 1989). Similarly, the influence of the amount and quality of food available to herbivores on the growth and population dynamics of the herbivores can be evaluated using this type of model (Pulliam and Dunning 1995; Comiskey et al. 1997; Pastor and Cohen 1997). The effects of animals on plants, as a result of herbivory or other forms of damage, can be incorporated in models that predict how forest dynamics differ in response to the presence or absence of herbivores such as deer (Pastor and Naiman 1992; Pastor et al. 1993; Mladenoff and Stearns 1993; Pastor and Cohen 1997).

Once the basic parameters for a species have been obtained from field and/or laboratory measurements of individual plants or animals, these models can be applied to many different localities, as long as each locality can be characterized in terms of the spatiotemporal variation in environmental properties and food resources important to the species. For example, models of this type typically require "GIS" information such as topography, soil properties, vegetation type, forage or prey availability, etc., as well as information or estimates of how these environmental conditions vary across the landscape and change through time (Coughenour 1991; Franklin 1995). Spatially-explicit individual-based models can be linked to dynamic biophysical models of landscape processes (see above) to develop the capability to predict how populations might respond to different combinations or patterns of environmental conditions that could occur in the future. Thus, a particular population management plan could be evaluated in terms of how the population might do under various extremes of conditions, such a prolonged droughts or cold winters.

In the models developed for the Everglades Restoration Project, spatiotemporal variation in environmental conditions related to water flow was used to compare the ecological performance of alterative water management plans (USACE, 1998). As part of this effort, a spatially-explicit individual-based model of the Florida panther was developed using physiological, growth, and behavioral information from wildlife research (Comiskey et al., 1997). Each individual panther is represented by the same basic set of equations about the energy requirements of different activities (e.g., moving, resting, nursing), but differs from other individuals because of its local environment, age, health, and interactions with neighboring panthers. Because the availability of quality food (specifically white-tailed deer) is essential for successful reproduction and growth, the Florida panther model is linked with a white-tailed deer model which uses the same type of energetic and behavioral model structure to predict the distribution and abundance of white-tailed deer in response to seasonal and interannual variation in their food availability. The deer model is linked to a vegetation model that predicts the distribution of forage of several quality classes across the South Florida landscape in response to seasonal and interannual variation in water.

Such dynamic landscape models are likely to become increasingly important for environmental assessment, planning, and resource management applications. The ability to predict how landscapes and their biotic communities change through time is invaluable for planning ecosystem monitoring and inventory programs and for interpreting data collected by these programs. Having predictions of expected changes in plant and animal populations greatly increases the capability to identify such changes (e.g. allowing use of one-tailed rather than two-tailed statistical tests) and greatly facilitates interpretation of the causes of observed changes.

Conclusion

Ecological theory has helped identify complex, but consistent, patterns in the distribution and diversity of organims. These patterns are found across all landscapes and aquatic systems, and can be classified in terms of fundamental (and quantifiable) properties of landscapes: specifically disturbance dynamics and potential productivity. A variety of sources of information, from direct field measurements to the use of satellite images, can be used to quantify the spatial and temporal patterns in disturbance and productivity at a range of spatial scales ranging from small watershed to the entire globe. Dynamic landscape models can greatly increase the spatial and temporal resolution of information on these landscape properties by interpolation based on mechanistic models of ecosystem processes.

Dynamic landscape models include hydrological and biogeochemical processes, as well as ecological processes, and can be used to translate the general predictions of ecological theory into predictions tailored to specific landscapes and time periods. The predictions of these models can contribute to planning ecosystem inventory and monitoring programs by identifying the types of species and the locations on the landscape that are most sensitive to disturbance or other environmental changes. Such models are currently under development for several different types of landscapes in North America.

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Literature Cited

Abrams, P.A. 1993. Effects of increased productivity on the abundances of trophic levels. American Naturalist 141:351-371.

Bakker, J.P. 1989. Nature management by grazing and cutting. Geobotany 14 Kluwer, Dordrecht, The Netherlands.

Berendse, F., R. Aerts, and R. Bobbink. 1993. Atmospheric nitrogen deposition and its impact on terrestrial ecosystems. In: Vos, C.C., and P. Opdam (eds.), Landscape Ecology of a Stressed Environment., pp. 103-121. Chapman and Hall, England.

Beven, K.J., and I.D. Moore (eds.). 1993. Terrain Analysis and Distributed Modeling in Hydrology. Wiley, New York.

Billings, W.D. 1990. Bromus tectorum, a biotic cause of ecosystem impoverishment in the Great Basin. In: Woodwell, G.M. (ed.), The Earth in Transition: Patterns and Processes of Biotic Impoverishment , pp. 301-322. Cambridge University Press, Cambridge.

Botkin, D.B., J.F. Janak, and J.R. Wallis. 1972. Some ecological consequences of a computer model of forest growth. Journal of Ecology 60:849-872.

British Columbia Ministry of Forests. 1990. Site classification for British Columbia—a first approximation. Victoria, British Columbia.

Busing, R.T. 1991. A spatial model of forest dynamics. Vegetatio 92:167-197.

Collins, S.L., A.K. Knapp, J.M. Briggs, J.M. Blair, and E.M. Steinauer. 1998. Modulation of diversity by grazing and mowing in native tallgrass prairie. Science 280: 745-747.

Comiskey, E.J., L.J. Gross, D.M. Fleming, M.A. Huston, O.L. Bass, H.-K. Luh, and Y. Wu. 1997. A spatially-explicit individual-based simulation model for Florida panther and white-tailed deer in the Everglades and Big Cypress landscapes. In: Jordan, D. (ed.), Proceedings of the Florida Panther Conference, pp. 494-503. U.S. Fish and Wildlife Service, Ft. Myers, FL.

Coughenour, M.B. 1991. A GIS/RS based modeling approach for a pastoral ecosystem in Kenya. In: Proceedings Resource Technology 90 - Second International Symposium on Advance Technology in Natural Resource Management, American Society of Photogrammetry and Remote Sensing, Falls Church, Bethesda, MD.

DeAngelis, D.L., L.J. Gross, M.A. Huston, W.F. Wolff, D.M. Flemming, E.J. Comiskey, and S.M. Sylvester. 1998. Landscape modeling for Everglades ecosystem restoration. Ecosystems 1: 64-75.

Deutschman, D.H., S.A. Levin, and S.W. Pacala. Error propagation in a forest succession model: The role of fine-scale heterogeneity in light. Ecology, in press.

Elton, C.S. 1958. The ecology of invasions by animals and plants. Methuen, London.

Flather, C.H., L.A. Joyce, and C.A. Bloomgarden. 1994. Species endangerment patterns in the United States. USDA General Techical Report RM-241.

Franklin, Janet. 1995. Predictive vegetation mapping: geographic modelling of biospatial patterns in relation to environmental gradients. Progress in Physical Geography 19: 474-499.

Garten, C.T., M.A. Huston, and C. Thoms. 1994. Topographic variation of soil nitrogen dynamics at Walker Branch Watershed, Tennessee. Forest Science 40:497-513.

Grime, J.P. 1973. Competitive exclusion in herbaceous vegetation. Nature 242:344-347.

Grime, J.P. 1979. Plant strategies and vegetation processes. Wiley, New York.

Guo, Q. and W.L. Berry. Species richness and productivity: dissection of the hump-shaped relationships. Ecology, in press.

Hansen, A.J., and J. Rotella. Abiotic factors. In: Hunter, M.L. (ed.), Maintaining biodiversity in forest ecosysems, pp. xx -xx. Cambridge University Press, Cambridge, Great Britain.

Hansen, A.J., T.A. Spies, F.J. Swanson, and J. L. Ohmann. 1991. Conserving biodiversity in managed forests: lessons from natural forests. BioScience 41: 382-392.

Hargrove, W.W. 1994. Using EMBYR, a large-scale probabilistic fire model, to re-create the Yellowstone Forest Lake fire. Environmental Research News, Oak Ridge National Laboratory: http://www.esd.ornl.gov/ern/embyr/embyr.html

Hargrove, W.W., R.H. Gardner, M.G. Turner, W.H. Romme, and D.G. Despain. Simulating fire patterns in heterogeneous landscapes. Ecological Modeling, in press.

Holdridge, L.R. 1947. Determination of world plant formations from simple climatic data. Science 105: 367-368.

Huston, M.A . 1979. A general hypothesis of species diversity. American Naturalist 113:81-101.

Huston, M.A. 1980. Soil nutrients and tree species richness in Costa Rican forests. Journal of Biogeography 7:147-157.

Huston, M.A . 1994. Biological diversity: The coexistence of species on changing landscapes. Cambridge University Press, Cambridge.

Huston, M.A. and D.L. DeAngelis. 1987. Size bimodality in monospecific populations: A review of potential mechanisms. American Naturalist 129: 678-707.

Huston, M.A., and L. Gilbert. 1996. Consumer diversity and secondary production. In: Orians, G., R. Dirzo, and J.H. Cushing (eds.),Biodiversity and Ecosystem Processes in Tropical Rainforests, pp. 33-47. SCOPE/Springer-Verlag.

Huston, M.A., and T.M. Smith. 1987. Plant succession: life history and competition. American Naturalist 130:168-198.

Huston, M.A., and T. Fontaine. 1994. Predicting temporal and spatial flood dynamics using a pre-calibrated model. Water Resources Bulletin, 30:651-661.

Huston, M.A., D.L. DeAngelis, and W.M. Post. 1988. New computer models unify ecological theory. BioScience 38: 682-692.

Johnston, C.A., and R.J. Naiman. 1990. Aquatic patch creation in relation to beaver population trends. Ecology 71: 1617-1621.

Keddy, P. 1989. Competition. Chapman and Hall, London.

Kerr, J.T., and L. Packer. 1997. Habitat heterogeneity as a determinant of mammal species richness in high-energy regions. Nature 385:252-254.

Korol, R.L., K.S. Milner, and S.W. Running. 1996. Testing a mechanistic model for predicting stand and tree growth. Forest Sci. 42: 139-153.

Lattin, J. D. 1990. Arthropod diversity in Northwest old-growth forests. Wings 15: 7-10.

Licht, D.S. 1997. Ecology and Economics of the Great Plains. University of Nebraska Press, Lincoln, NE. 225 pp.

Lin, D.-S., E.F. Wood, P.A. Troch, M. Mancini, and T.J. Jackson. 1994. Comparisons of remotely sensed and model-simulated soil moisture over a heterogeneous watershed. Remote Sens. Environ. 48: 159-171.

MacArthur, R.H. 1972. Geographical Ecology: Patterns in the distribution of species. Harper and Row, New York.

Mack, R. 1986. Alien plant invasion into the Intermountain West: A case history. In: Mooney, H.A., and J.A. Drake, (eds.) Ecology of Biological Invasions of North America and Hawaii., pp 191-213. New York, Springer-Verlag.

McMinn, J.W., and D.A. Crossley (eds). 1996. Biodiversity and Coarse Woody Debris in Southern Forests. USDA Forest Service, General Technical Report SE-94.

Mills, T.R., M.A. Rumble, and L.D. Flake. 1996. Evaluation of a habitat capability model for nongame birds in the Black Hills, South Dakota. Research Paper RM-RP-323, USDA Forest Service, Fort Collins, Colorado.

Minnich, R.A. 1983. Fire mosaics in southern California and northern Baja California. Science 219: 1287-1294.

Mladenoff, D.J., and F.Stearns. 1993. Eastern hemlock regeneration and browsing in the northern Great Lakes region: a re-examination and model simulation. Conservation Biology 7: 889-900.

Mladenoff, D.J., M.A. White, T.R. Crow, and J. Pastor. 1994. Applying principles of landscape design and management to integrate old-growth forest enhancement and commodity use. Conservation Biology 8:752-762.

Norton-Griffiths, M. 1979. The influence of grazing, browsing, and fire on the vegetation dynamics of the Serengeti. In: Sinclair, A.R.E., and M. Norton-Griffiths (eds.), Serengeti: The Dynamics of an Ecosystem, pp. 310-352. Univ. of Chicago Press, Chicago.

Odum, E.P. 1953. Fundamentals of Ecology. Saunders, Philadelphia.

Oksanen, L., S.D. Fretwell, J. Aruda, and P. Niemela. 1981. Exploitation ecosystems in gradients of primary productivity. American Naturalist 131: 424-444.

Oliver, C.D., and B.C.Larson. 1996. Forest Stand Dynamics, Second Edition. McGraw-Hill, New York.

Pacala, S.W., and D.H. Deutschman. 1995. Details that matter: The spatial distribution of individual trees maintains forest ecosystem function. Oikos 74: 357-365.

Pacala, S.W., C. Canham, and J. Silander. 1993. Forest models defined by field measurements. I. The design of a northeastern forest simulator. Canadian Journal of Forest Research 23: 1980-1988.

Pastor, J., and Y. Cohen. 1997. Herbivores, the functional diversity of plant species, and the cycling of nutrients in ecosystems. Theoretical Population Biology 51: 165-179.

Pastor, J., B.Dewey, R.J. Naiman, P.F. McInnes, and Y. Cohen. 1993. Moose browsing and soil fertility in the boreal forests of Isle Royal National Park. Ecology 74: 467-480.

Pastor, J., and R.J. Naiman. 1992. Selective foraging and ecosystem processes in boreal forests. American Naturalist 139:690-705.

Pastor, J. and W.M. Post. 1986. Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. Biogeochem. 2:3-17.

Pastor, J. and W.M. Post. 1988. Response of northern forests to CO2-induced climatic change: Dependence on soil water and nitrogen availabilities. Nature 334:55-58.

Post, W.M., and J. Pastor. 1990. An individual-based forest ecosystem model for projecting forest responses to nutrient cycling and climate change. In: Wensel, L.C., and G.S. Biging (eds.), Forest Simulation Systems, , pp. 61-73. University of California, Division of Agriculture and Natural Resources, Bulletin 1927.

Proulx M., F.R. Pick, A. Mazumder, P.B. Hamilton, and D.R.S. Lean. 1996. Experimental evidence for interactive impacts of human activities on lake algal species richness. Oikos 76:191-195

Pulliam, H.R. 1988. Sources, sinks, and population regulation. American Naturalist 132:652-661.

Pulliam, H.R., and J.B. Dunning. 1995. Spatially-explicit population models: current forms and future uses. Ecological Applications 5:3-11.

Ralph, C.J., P.W.C. Patton, and C.A. Taylor. 1991. Habitat association patterns of breeding birds and small mammals in Douglas-fir/hardwood stands in northwestern California and southwestern Oregon. Gen. Tech. Rep. PNW-285, USDA Forest Service, Pacific Northwest Research Station.

Reader, R.J., and B.J.Best. 1989. Variation in competition along an environmental gradient: *Hieracium floribundum* in an abandoned pasture. J. Ecol 77:673-684

Romme, W.H., and D.G. Despain 1989. Historical perspective on the Yellowstone fires of 1988. BioScience 39: 695-699.

Running, S.W. 1994. Testing forest-BGC ecosystem process simulations across a climatic gradient in Oregon. Ecological Applications 4: 238-247.

Schindler, D.W. 1974. Eutrophication and recovery in experimental lakes: implications for lake management. Science 184:897-899

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, G. Groves, H. Anderson, S. Caicco,F. D'Erchia, T.C. Edwards, J. Ulliman, and R.G. Wright. 1993. GAP analysis: a geographic approach to protection of biological diversity. Wildlife Monographs 123: 1-41.

Short, H.L. 1992. Use of the habitat linear appraisal system to inventory and monitor the structure of habitats. In: McKenzie, D.H., D.E. Hyatt, and V.J. McDonald (eds.), Ecological Indicators., pp. 961-974. Elsevier Applied Science, London.

Short, H.L., and S.C. Williamson. 1987. Evaluating the structure of habitat for wildlife. Part I. Development, testing, and application of wildlife-habitat models. U.S. Fish and Wildlife Service, Fort Collins, CO.

Shugart, H.H. 1984. A Theory of Forest Dynamics. Springer-Verlag, New York.

Shugart, H.H., and D.C. West. 1977. Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the Chestnut blight. Journal of Environmental Management 5: 161-179.

Shugart, H.H., and I.R. Noble. 1981. A computer model of succession and fire response of the high-altitude Eucalyptus forest of the Brindabella Range, Australian Capital Territory. Australian Journal of Ecology 6: 149-164.

Shugart, H.H., M.S. Hopkins, I.P Burgess, and A.T. Mortlock. 1981. The development of a succession model for subtropical rainforest and its application to assess the effect of timber harvest at Wiangarree State Forest, New South Wales. Journal of Environmental Management 11: 243-265.

Smith, T.M., and D.L. Urban. 1988. Scale and resolution of forest structural pattern. Vegetatio 74: 143-150.

Smith, T.M., and M.A. Huston 1989. A theory of the spatial and temporal dynamics of plant communities. Vegetatio 83: 49-69.

South Florida Water Management District. 1997. Documentation for the South Florida Water Management Model. Hyrologic Systems Modeling Division, SFWMD, West Palm Beach, FL.

Stohlgren T.J., D.A. Binkley, G.W. Chong, M.A. Kalkhan, L.D. Schell, K.A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and Y. Son. Exotic plant species invade hot spots of native plant diversity. Ecology, in press.

Uhl, C., P. Barreto, A. Verissimo, and E. Vidal. 1997. Natural resource management in the Brazilian Amazon: an integrated approach. BioScience 47:160-168.

Urban, D.L. 1990. A versatile model to simulate forest pattern: a user's guide to ZELIG Version 1.0. Environmental Sciences, The University of Virginia, Charlottesville.

Urban, D.L., and T.M. Smith. 1989. Microhabitat pattern and the structure of forest bird communities. American Naturalist 133: 811-829.

Urban, D.L., G.B. Bonan, T.M. Smith, and H.H. Shugart. 1991. Spatial applications of gap models. Forest Ecology and Management 42: 95-110.

U.S. Army Corps of Engineers. 1998. Central and South Florida Project Comprehensive Review Study: Overview. October 1998. USAEC, Jacksonville, FL.

VanWinkle, W., K.A. Rose, K.O. Winemiller, D.L. DeAngelis, S.W. Christensen, R.G. Otto, and B.J. Schuter. 1993. Linking life history theory, environmental setting, and individual-based modeling to compare responses of different fish species to environmental changes. Trans. Am. Fish. Soc. 122: 459-466.

White, D.L., T.A. Waldrop, and S.M. Jones. 1991. Forty years of prescribed burning on the Santee fire plots: effects on understory vegetation. In: Nodvin, S.C., and D.A. Waldrop (eds.), Fire and the Environment: Ecological and Cultural Perspectives, pp. 45-59. Southeastern Forest Experiment Station, Asheville, NC.

White, P.S. 1979. Pattern, process, and natural disturbance in vegetation. Botanical Review 45: 229-299.

Wright, H.E., and A.W. Bailey. 1982. Fire Ecology: United States and Southern Canada. Wiley, New York.

Integration of Strategic Inventory and Monitoring Programs for the Forest Lands, Wood Lands, Range Lands and Agricultural Lands of the United States[1]

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Abstract—The United States Department of Agriculture uses the Forest Inventory and Analysis (FIA) program to monitor the nation's forests and wood lands, and the National Resources Inventory (NRI) program to monitor the nation's agricultural and range lands. Although their measurement methods and sampling frames are very different, both programs are developing annual systems to better detect trends in land use and ecosystem health, evaluate effectiveness of public policies, guide sustainable development, and forecast alternative future conditions. Other federal programs use Landsat satellite data to map the nation's land cover, land use, and habitat diversity. I offer two proposals that could increase consistency and reduce cost among these federal monitoring programs. First, a national consortium would acquire Landsat data every two to five years for the entire USA, and rapidly detect abrupt changes in spectral reflectance associated with land clearing and major changes in land cover. This would provide spatial data to update existing maps of land cover and land use, and improve statistical monitoring. However, Landsat resolution is not sufficient to identify detailed categories of land use and forest cover; rather, higher-resolution sensors are necessary to significantly reduce the required amount of field data. Therefore, the second proposal is acquisition and interpretation of large-scale high-resolution aerial photography for hundreds of thousands of FIA and NRI sampling units. This ambitious enterprise might be feasible with collaboration between these two programs. They would integrate their separate photo-interpretation operations, and collocate 65-ha NRI sampling units with 1-ha FIA field plots. Each year, a 20% sub-sample of the collocated sampling units is photographed from low-elevation aircraft to detect rapid and obvious changes, while field data are gathered for a 10% sub-sample of field plots to detect slower and more subtle changes. Field data are paired with remotely sensed data, and empirical models statistically correct for measurement and classification errors in remotely sensed data. Implementation is a major enterprise that requires unprecedented partnerships among federal programs. I do not believe remote sensing will be an effective technological solution without such an enterprise. Most legislators and executive leaders are not aware of the magnitude of the logistical and institutional challenges. However, extensive coordination of remote sensing among existing federal programs could produce an efficient system to evaluate sustainability of the nation's forests and agricultural lands, and assess the health of the nation's ecosystems.

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The Forest Inventory and Analysis[1] (FIA) program in the USDA[2] Forest Service produces a baseline and long-term set of scientifically sound resource data, technology, analysis tools, and information to assess the extent, health, productivity, and sustainability of the forest and wood land ecosystems of the United States. FIA information is critically important at the national, regional and state scales to effectively deal with conservation challenges, influence patterns of capital investment, and meet needs of the forestry profession, resource managers, forest landowners, and the public.[3]

FIA uses a two-phase probability sample of 1-ha plots, which are systematically distributed over 300 million hectares of forest land in the USA. FIA uses remote sensing (i.e., photo-interpretation of high-altitude small-scale aerial photographs) to measure 3 million plots on a 1-km grid at Phase 1, and 120,500 plots are measured on a 5-km grid in the field at Phase 2. Five regional FIA programs cover the USA. At any point in time, each FIA regional program is conducting a survey in one or two states, which are typically 5- to 25-million ha in size. When a state inventory is finished, the FIA inventory begins for the next state in that region. The inventory cycle begins anew after the last state in a region is surveyed. The cycle is 8-years in the southern USA, up to 15-years in the arid interior west, and longer in Alaska.

Demand for Annual Monitoring

Although the FIA national program is among the best in the world, FIA is in a state of crisis[4,1]. Over half of all FIA information is out-of-date. Current FIA procedures and funding are sufficient for an 8- to 15-year re-measurement cycle, but users of FIA data have little confidence in data that are more than 5 years old[5,1].

An Act of Congress recently directed the Forest Service to improve its FIA program[6,1]. FIA must convert its periodic system into an annual system, in which 20% of all FIA plots in each State are measured each year. The Act further envisions new technologies, such as remote sensing, models and statistical methods that integrate data from multiple sources.

FIA recently developed a strategy to accomplish this Congressional mandate[7,1]. Implementation requires $98,920,000 per year, which is a 4-fold increase in FIA funding. The strategy primarily relies on modifications to current FIA field procedures, and about half of the increased funding supports accelerated collection of field data. However, the strategy does not assume improved efficiencies through innovative applications of remote sensing.

Objectives And Outline

My objective is a realistic portrayal of a national monitoring system for forest lands that emphasizes remote sensing and reduces reliance on expensive field data. This portrait might help the FIA program decide if a expanded remote sensing component is desirable.

Many perceive remote sensing as an inexpensive solution to the growing demand for monitoring data. However, I attempt to demonstrate that substantive use of remote sensing requires a large institutional infrastructure, which can cost tens of millions of dollars per year. Other federal programs already conduct broad remote sensing activities and share some of the same objectives with FIA. I hope to show that sharing remote sensing operations with related federal programs is in the best interests of FIA. This could reduce costs. However, it would also produce strategic monitoring data across all types of land cover, ecosystems and land uses, thus serving the objectives of many institutions for sustainable development and healthy ecosystems.

I begin listing the primary indicators of forest conditions measured by FIA. An annual system is most valuable for monitoring rapid changes in forest conditions, which I assume are caused by changes in land use, timber harvesting and regeneration, and catastrophic disturbances. Remote sensing can detect these changes, and detection accuracy increases with sensor resolution. I describe the advantages and disadvantages of different types of remote sensing for monitoring land cover and land use across the entire nation. I recommend combination of periodic change detection with Landsat data, and manual interpretation of high-resolution aerial photography for an annual sub-sample of sites. I discuss opportunities for reducing costs and sharing resources and products among several federal agencies.

Indicators of Forest Conditions

FIA produces detailed statistical tables that describe the current amount of forest and trees, and rates of change by detailed categories of forest conditions (Table 1). Classification parameters include land use and ownership, forest type and origin, productivity and stage of development, and tree stocking. Indicator parameters include forest area, number of trees, wood volume, growth, mortality and removals. The indicator parameters are estimated for permutations of many detailed classification parameters (Table 1), resulting in thousands of estimates that characterize forest condition and health.

Value of Remotely Sensed Data for Monitoring Indicators

The value of remotely sensed data depends on their correlation with these parameters and changes over time. For example, certain satellite data are well correlated with presence or absence of forest cover, but they are not well correlated with detailed categories of different forest types. Such remotely sensed data would improve the estimate for area of all forest lands, which is among the most important indicators. However, the thousands of other parameters estimated by FIA would largely rely upon expensive field data. The value of remotely sensed data also depends on their capability to detect change, and their availability during the prescribed times in the monitoring schedule.

Rates of Change in Indicators of Forest Conditions

Rapid changes in forest conditions cause the demand for annual FIA data. I assume that the most rapid changes over large geographic regions (e.g., 5- to 25-million ha.) are driven by the regional, national and global economics of the agricultural and forest product sectors, urbanization, and changes in public policy. These cause changes in land use and land cover that affect sustainability and forest health. Examples include clearing forestland for agricultural or urban uses; afforestation of agricultural lands into forestland;

Table 1.—FIA field data used for primary statistical tables[1]

Forest conditions[1] (plot-level)	No. of classes	Tree-level conditions[1]	No. of classes
Land use[2,3]	5	Tree species[4]	331
Forest type,			
broad[2,4]	29	Tree size (DBH)	5-cm classes
detailed[4]	136	Tree damage	10
Stage of stand development[2]	4	Tree quality, value	5
Stand density[2,5]	5	Tree mortality (yes, no)	2
Stand origin[2] (natural, artificial)	2	Tree removal, harvest (yes, no)	2
Land ownership	10	Wood volume	continuous
Stand age	9	Growth in wood volume	continuous
Stand productivity	7		
Area by forest condition classes	continuous		
Number of trees[2,6], wood volume[6]	continuous		
Growth[6], mortality[2,6], removals[2,6]	continuous		

[1]FIA measures many other indicators that describe landscapes, habitat, non-tree vegetation, etc.
[2]Many or most of these categories could be reliably, although imperfectly, interpreted with large-scale aerial photography. Photo-interpretation could also identify categorical degrees of tree density, volume, mortality and removals
[3]Includes timberland, other forest land, protected forest, nonforest land, and water.
[4]Any single geographic region of USA has only 20 to 40% of these national categories.
[5]Includes overstocked, fully stocked, understocked, and non-stocked.
[6]Totals are summarized by thousands of different combinations of tree and forest conditions.

land clearing, roads, utility corridors, and buildings associated with urbanization; harvesting of wood (i.e., clearcuts, partial cuts) and associated road construction; and regeneration of harvested forest areas (i.e., natural, planted). Other rapid changes at regional scales are caused by droughts, hurricanes, floods, landslides, ice storms and insect epidemics. These cause areal changes that can be detected, with varying degrees of success, by a variety of remote sensing technologies.

I further assume that other indicators within detailed categories of forest (Table 1) change more slowly. An example is the average volume and number of trees per ha by tree species and 5-cm diameter class, and their growth and mortality rates, for late-succession spruce-fir stands in protected areas of the interior-west of the USA. I make the same assumption for changes in non-tree vegetation, down woody debris, and other indicators. I further assume that many aspects of forest health is affected by the slowly changing demographics of forest populations, annual variations in weather patterns and anthropogenic stressors, such as air pollution, climate change and exotic pests. I assume these slow and ubiquitous processes are measured at regional scales (e.g., 25- to 100-million ha) through probability samples of field plots across the USA; these include the Forest Health Monitoring Program[10,3,8], which supports detailed field measurements of 4,500 forested plots on a 25-km grid, and the FIA program, which supports basic field measurements of 120,500 forested plots on a 5-km grid.

If these assumptions are approximately true, then remote sensing is better suited for frequent monitoring (e.g., 20% of plots each year) of rapid areal changes, and less frequent re-measurement of field plots (e.g., 10% of plots each year) is better suited for monitoring the slower changes in tree composition and rates of change per unit area. Remote sensing is generally less expensive than field measurements, and this strategy could reduce costs.

Remote Sensing

Remote sensing can improve annual strategic monitoring if remotely sensed data are well correlated with high-priority field data; remotely sensed data are available when needed for the monitoring design; and remotely sensed data cost less than field data or sufficiently increase statistical efficiency. For example, augmentation of field data with remote sensing can be 6 to 15 times more efficient in estimating forest area (MacLean 1963) and twice as efficient in estimating wood volume (MacLean 1972). I evaluate 5 types of remotely sensed data[11] relative to these criteria for annual monitoring at the national scale.

Low-Resolution, Broad-Swath Satellite Data

These remotely sensed data are very inexpensive and cover enormous areas (1000- to 3000-km in swath width) with a large pixel[12] size (0.25- to 1.1-km wide).[11] Sensors include AVHRR, OrbView-2[13], SPOT 4 Vegetation Sensor, and MODIS Moderate Resolution Imaging Spectrometer.

These data are suitable for continental-scale maps of forested landscapes[14], global change models and monitoring acute deforestation in dense forests[15]. These data are available nearly daily, and might replace the FIA Phase 1 aerial photography to improve statistical efficiency. However, these data have insufficient resolution to monitor most indicators of forest conditions. For example, AVHRR data can not detect presence of forest in a pixel if the proportion of forest is less than 20%.

Medium-Resolution, Medium-Swath Satellite Data

When lay-people discuss remote sensing, they frequently refer to these sorts of data. Sensors include Landsat 7, SPOT 4, the Indian Remote Sensing[17] (IRS) satellite, Radarsat, and the Sovinform Sputnik Spin-2 TK-350 camera. These data are relatively inexpensive for large areas, having a 60- to 180-km swath width, and they have a reasonably small pixel size (10 to 30-m wide)[11]. Because of its broad swath width and spectral resolution, Landsat is the most efficient for synoptic mapping of forests over very large areas, such as the entire USA.

Holmgren and Thuresson (1998) throughly review these types of satellite data for forests. With routine and standardized processing in a high-production enterprise, these data can accurately separate forest from non-forest, and reasonably identify a few broad types of forest and several levels of forest density. Landsat data can distinguish more detailed categories of forest cover with proportionally more intensive effort and customized approaches, including: masking forest from non-forest cover; specialized application to each homogeneous region; multiple dates of Landsat imagery; state-of-the-art classification algorithms; and extensive use of ancillary data in national-scale geographic information systems (Wynne and Carter, 1997; Zhiliang Zhu, personal communications). These data can identify recent clearcuts, but are less successful with partial cuts. These data can identify advanced regeneration of forests after land clearing. These data can identify urban centers, but they are less successful for identification of sparse urbanization. These synoptic data can measure size, shape and connectivity of forest patches, which are indicators of forest fragmentation and habitat suitability at landscape scales. Theses data can map broad landscape patterns and changes over time; for example, Wickham and Norton (1994) developed landscape classification system that include urbanized, residential, wetland, water, forest, clearcut and agriculture, which exist as continuous expanses, mosaics or patches. High-quality, cloud-free data are available for temperate regions each year or two. Cloud-free data are not available for much of Alaska, but Radarsat might solve this problem. Therefore, data availability is satisfactory for annual inventory and monitoring. However, there is a limit to the quality of data measured by satellites 700 km from the earth's surface.

High-Resolution, Narrow-Swath Satellite Data

These remotely sensed data are very new in the civilian sector. Their 4- to 10-km swath width and a very small pixel size (1- to 3-m wide)[11] are best suited for small areas. Sensors include Earlybird and Quickbird (EarthWatch), OrbView-3[13], Resource21, Lewis Hyperspectral Imager (TRW-NASA), Clark (CTA-NASA) and Carterra-1 (EOSAT). Depending on the sensor, 200,000 to 1,000,000 images are required to cover the entire USA. Each image requires 95 megabytes of storage, and the expected cost is $200 (Wilford, 1998).

Wynne and Carter (1997) review these types of satellite data for forests. These data have resolution, coverage and cost that are similar to high-altitude aerial photography, which are discussed in the next section. These data can[11] distinguish about a few broad types of forest in each region, several stages of stand development, clearcut and some partial cut areas, regeneration after land clearing, and concentrations of tree mortality. Photo-interpretation of these data can identify forest stands; distance to adjacent land uses, roads and non-forest cover types; many indices of forest fragmentation; and sparse urbanization in open areas or urbanization that disturbs broad areas of forest canopy. These satellite data could be acquired whenever they are needed for an annual inventory and monitoring system.

Given the cost and volume of these data, these data are not practical for wall-to-wall mapping of the entire USA. However, these data could monitor thousands of sample areas, each of which are 1-ha to 4,000-ha in size.

Small-Scale Aerial Photography

Aldrich (1979) reviews this traditional type of remote sensing. High-altitude large format (230-mm) images have resolution, coverage and cost similar to high-resolution, narrow-swath satellite data, which are described above[11]. The USGS National Aerial Photography Program[18] (NAPP) acquires 1:40,000 small-scale photography for most of the USA on roughly a 5-year cycle.

Small-scale aerial photography is widely used in many environmental monitoring programs. FIA uses NAPP photographs to improve its estimates of forest area and navigate to its field plots. The USDA Natural Resources Conservation Service uses NAPP and other small-scale imagery to photo-interpret conditions and changes on 65-ha sampling units in their National Resources Inventory[19,8] (NRI). The USGS National Wetlands Inventory[20,8] (NWI) uses NAPP photographs to map 10 categories of wetlands at 1:24,000 scale. NWI also uses NAPP images for a small sample of 1000-ha sampling units every 10 years; the purpose is regional statistics for status and trends of wetlands in the USA. The USDA National Agricultural Statistics Service[21] (NASS) uses NAPP photographs to delineate 250-ha primary sampling units and classify each unit as cultivated crop land, land used for livestock production, urban land, or other land uses. NASS then uses interviews with farmers and land managers to collect information about crops, operator households, animals, environmental factors, etc.

NAPP photography has several shortcomings for annual inventory and monitoring. The volume of 230-mm photographs is immense, requiring 350,000 images to cover the USA. The NWI[20] and NASS[21] programs require 20 years to map the entire USA with NAPP imagery. Sampling of NAPP imagery can speed this process for statistical estimation, and sampling is used by the FIA[1], NRI[19] and NWI programs. Annual monitoring requires a representative sample of photographs each year for each state; however, image acquisition[18] covers each state once every 5 years. High-resolution, narrow-swath satellite data, which were discussed in the previous section, could overcome his latter problem.

Custom 1:40,000 small-scale 35-mm aerial photography could be acquired for sampling units up to 100-ha in size. The schedule for image acquisition could match specifications for annual inventory and monitoring. However, higher-resolution 1:12,000 scale 70-mm aerial photography could be acquired at approximately the same cost for 100-ha sampling units.

Medium- and Large-scale Aerial Photography And Videography

Aldrich (1979) reviews this type of aerial photography. Photo-interpreters could reliably identify[11] most of the forest cover conditions in Table 1. Measurements might include 5 to 10 broad types of forest; 5 stages of stand development; 3 stand density classes; clearcut and partial cut areas; regeneration success; stand origin (natural, artificial); 3 to 5 severity levels for tree mortality; wildland-urban interface; indicators of forest fragmentation and urbanization; and stand size, shape and edge metrics. However, these photo-interpretations would include measurement error that requires statistical calibration with accurate field data.

70-mm 1:15,000-scale stereo photography could cover 100-ha primary sampling units, and 230-mm 1:8,000 photography could cover units up to 400-ha in size. Land use and forest stand boundaries could be mapped over the entire primary sampling unit. Mapped stands could be classified into many of the categorical variables in Table 1 (e.g., forest type), while other parameters (e.g., stand height) could be photo-interpreted at random points within the primary sampling unit. The schedule for image acquisition could match specifications for annual inventory and monitoring.

Multi-stage Monitoring Design

Based on cost, resolution, coverage and scheduling, I propose a combination of two types of remotely sensed data to augment field data in annual monitoring. First, a time-series of Landsat data would cover the entire USA. The Landsat data would replace the current FIA Phase 1 photo-interpretation of low-resolution NAPP[18] aerial photography. Second, I propose a sample of medium- or high-resolution aerial photography, which would provide considerable information at a fraction of the cost of FIA field data. I describe programs to implement these two types of remote sensing for annual monitoring in the next sections. This would create a multi-stage design, with a census of Landsat pixel data at Stage 1, the sample of high-resolution aerial photography at Stage 2, and traditional FIA field plots at Stage 3.

A National Program to Map Changes in Land Cover

Multi-temporal Landsat satellite data can detect abrupt changes in spectral reflectance at the scale of a few adjacent 30-m pixels. These changes are often caused by clearcutting, land clearing and catastrophic disturbances to forest cover. These changes are rare across most landscapes, and general sample surveys, like FIA, are not well suited to monitor rarities. In addition, satellite data provide detailed spatial data that are important to land managers but missing from statistical surveys like FIA.

Numerous National Forests and state governments use Landsat data to map land cover for large sub-regions of the USA. However, only two federal programs map land cover for the entire USA. The USGS[22] Multi-Resolution Land Characteristics (MRLC) Program[23,24] maps 3 forest categories, 3 urban categories, 3 wood land categories, 3 agricultural categories, and 21 other categories of land use and cover. The USGS GAP Analysis Program[25] maps critical habitats to help conserve biological diversity. The minimum map unit is 100-ha, and the classification system uses 18 categories[26] of forest for the entire USA. The MRLC program began in 1995 with an annual budget[8] of $10,000,000. The GAP program began in 1994 with an annual budget[8] of $3,600,000. These programs use sophisticated methods that stretch the limits of satellite data for immense regions. Success requires considerable input of energy, and neither program has completed mapping the entire USA. These programs plan to update maps for changes in land cover, but updates are not funded.

I propose[27] an additional national program that uses Landsat data on a 2- to 5-year cycle to map abrupt changes in land and forest cover. This program would fully utilize all 540 Landsat scenes[8] that cover the USA. The intent is a relatively inexpensive process to update costly maps of land cover and land use. MRLC, GAP, NWI[20], National Forests and state agencies could use the maps of change to modify their older thematic maps. The proposal provides a time-series of Landsat data to these programs for their additional use, such as major revisions to land cover maps on a 10-year cycle. FIA could use updated MRLC and GAP maps to replace photo-interpretation of its 3 million Phase 1 photo-plots to improve statistical estimates for current extent of forest land. FIA could further improve statistical estimates of changes in forest cover with these maps of change. Similarly, NRI could use updated Landsat data as ancillary measurements to improve its estimates of changes in land use and extent of agricultural and range lands. Photo-interpretation of Landsat images could identify changes in extent and distribution of broad types of landscapes patterns, such as urban, residential, wetland, water, forest, clearcut and agriculture (Wickham and Norton 1994).

Unfortunately, Landsat data might not significantly reduce the need for frequent field measurements in an annual FIA system. Landsat satellite data cannot accurately discriminate the detailed composition of forests. If forest composition changes through moderate disturbances and land management (e.g., drought, tree diseases, partial cutting, or shifts in land ownership and management objectives), then FIA must have sufficient field data to measure the new conditions. Also, some abrupt spectral changes in Landsat are caused by artifacts that are not changes in forest condition, and the characterization of changed areas requires new FIA field data. I believe that satellite data alone are not sufficient to fundamentally improve efficiency of an annual FIA system, and higher-resolution remotely sensed data are also necessary to improve the efficiency of field data.

A National Sampling Program With High-resolution Imagery

Photo-interpretation of high-resolution aerial images can accurately distinguish among many detailed forest conditions. Since these images contain substantially more information than Landsat data, high-resolution aerial images have greater potential to reduce expense of an annual FIA system. The measurement cost of an FIA plot by a 2-person field crew is 4 times greater than the cost for acquisition of custom high-resolution aerial images and photo-interpretation[11].

Only two federal programs[28] monitor changes in land cover over the entire USA with a sample of aerial imagery. The National Resources Inventory[19] (NRI) makes extensive use of available NAPP[18] and small-format aerial photography for 300,000 primary sampling units (PSUs) in the USA. Most sampling units are 65-ha in size, with a sampling intensity of 1% to 4% of the land area. However, the quality of NRI data is limited by the quality and scheduling of aerial photography, all of which originate with other federal programs. The NRI has been conducted once every 5 years, but NRI is changing to an annual system, much like FIA. The annual budget for NRI is $8,500,000[8]. The National Wetlands[20] Inventory employs a sparse sample of small-scale NAPP photography for their status and trends estimates. This is a small part of their overall mapping program, which has an annual budget of $7,750,000 per year[8].

I propose a national program that specifically acquires an annual sample of high-resolution aerial images to monitor land use, land cover and change. This national program could be a cost-sharing partnership between FIA and NRI. The sample sites would include 300,000 65-ha NRI PSUs, and another 320,000 new 65-ha PSUs would be established to cover existing 1-ha FIA field plots[29]. To reduce cost, new 65-ha plots might be established over 1-ha FIA field plots in forest and woodland landscapes, while new 1-ha FIA field plots would be established within existing 65-ha NRI PSUs in agricultural and range landscapes.

Each year, the proposed national program would procure 1:8,000 230-mm photography or similar high-resolution remotely sensed data for 20% of the 65-ha PSUs. An interpreter would delineate and classify different land uses, land cover and forest stands in each PSU. Points within the PSU would be interpreted for more detailed measurements of forest composition. As each PSU is re-imaged over time, photo-interpreters would measure changes between dates.

One point within the 65-ha PSU would be a 1-ha FIA field plot, while other points could be measured in the field by NRI crews. Goebel et al. 1998 report results from a pilot study in Oregon that tested integration of NRI and FIA field procedures. This partnership would expand monitoring well beyond forest and wood lands to cover all land uses and land cover in the USA.

Technical and Institutional Considerations— Acquisition and interpretation of custom aerial photography for 300,000 NRI PSUs and 320,000 FIA PSUs requires a large infrastructure and budget. Even if 20% of these PSUs were sampled each year with aerial photography, this infrastructure would dwarf that required for interpretation of 540 Landsat scenes every 2- to 5-years. We need strategies that would incrementally build this infrastructure, reduce the number of PSUs, and reduce cost of other components of the NRI and FIA programs.

Separate NRI and FIA sampling frames could converge into a single sampling frame through sampling with partial replacement. Some existing NRI PSUs would be abandoned and replaced with new 65-ha PSUs that cover existing 1-ha FIA field plots. This strategy is most appealing in landscapes dominated by forest lands. Likewise, new FIA field plots could be established within existing NRI PSUs, and old FIA field plots abandoned, in agricultural landscapes. This process might span 5 to 10 years. A sub-sample the FIA plots might be photographed during early years. For example, 12,000 Forest Health Monitoring[10] plots[29] are a 4% sub-sample of the FIA sampling frame. Additional PSUs could be added each year thereafter.

High-resolution imagery could reduce the total number of field plots needed to achieve data quality standards. For example, the proposed sample imagery captures considerable information about forest composition and changes over the entire 65-ha PSU. The area within the 65-ha PSUs is about 2.00% of the landscape, while only 0.03% of the landscape is within the same number of 1-ha FIA plots. Also, the larger PSUs would be more efficient for rare types of land cover and change, and linear features, such as riparian areas, roads, utility corridors, and windbreaks.

High-resolution imagery could reduce the frequency that FIA plots must be re-measured by field crews. Remote sensing could accurately identify field plots that are undisturbed, and models could predict the current conditions on these plots based on old field measurements. Photogrammetric methods at Stage 3 sampling points could measure tree mortality and changes in individual tree heights and crown sizes on FIA plots as correlates to wood growth and indicators of model accuracy.

Photo-interpretation of high-resolution imagery might replace field measurements of remote or inaccessible plots, and compensate for missing data from FIA plots that are too hazardous for field measurement or to which access is denied by private landowners[30]. High-resolution imagery could accurately monitor FIA field plots that were non-forest but could change into forest; this is very important for monitoring afforestation. High-resolution imagery could identify FIA plots with small slivers of forest, which is very important to accurately estimate forest extent as FIA converts to mapped plots.

High-resolution aerial imagery of 65-ha sampling units might provide opportunities to measure other indicators of forest condition. For example, the spatial scale of a 1-ha FIA field plot might be too confined to measure many components of habitat, but the 65-ha size might be sufficient. Photo-interpretations of 65-ha units would provide training and labeling sites, which are essential for processing satellite data.

Soft-copy digital techniques could improve efficiency of capturing photo-interpreted data. This includes registration of field plots to imagery, digitization of polygon boundaries and planimetry, photogrammetric measurements of tree heights and crown diameters, and entry of resulting measurements into the FIA data base. Digital images could be filed and managed with modern information management software.

Statistical Estimation—Although remotely sensed data could reduce cost of data acquisition in an annual monitoring system, statistical combination of diverse types of monitoring data is complex. The multivariate composite estimator could combine time-series of field data, model predictions, and multiple types of remotely sensed data, while models for measurement and prediction errors help quantify the quality of the resulting information. Statistical calibration models for each photo-interpreter could be developed with historical imagery and field data. Results of complex statistical estimators might be stored as expansion factors to simplify analyses. Diagnostic statistics would detect biased calibration and prediction models. The statistical simplicity of the remote sensing component could be protected from fluctuations in budgets by changing the pace of field data collection.

Summary

The demand for more current monitoring data is clear and compelling. Acceleration of traditional FIA field procedures would satisfy this demand, but this requires an unprecedented increase in funding[7,1]. Remote sensing could reduce costs by augmenting field data with synoptic satellite data and sampling with higher-resolution aerial photography. The National Academy of Sciences (1974, cited in Aldrich 1979) recommended this exact same approach 25 years ago.

However, effective use of remote sensing requires an unprecedented institutional infrastructure that can acquire and process hundreds of Landsat scenes and tens of thousands of aerial photographs each year. Legislators and administrators need to understand the scope of this infrastructure when comparing remote sensing to historical technologies. Unless the information needed from inventory and monitoring is dramatically reduced, remote sensing is not a cheap solution to expensive monitoring requirements. However, a strong partnership among the Forest Inventory and Analysis Program[1], the National Resources Inventory Program[19] and mapping programs in the US Geological Survey[20,23,25,22] could produce more cost-effective results with remote sensing. This partnership could produce the world's premier system to monitor trends in forest lands, agricultural lands, range lands, wood lands and land use to evaluate effectiveness of public policies and guide sustainable development.

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Literature Cited

Aldrich, Robert C. 1979. Remote sensing of wildland resources: A state-of-the-art review. USDA Forest Service. Gen. Tech. Rep. RM-71, 56 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Goebel, J. Jeffery, Hans T. Schreuder, Carol House, Paul H. Geissler, Anthony R. Olsen, and William R. Williams. 1998. Integrating Surveys of Terrestrial Natural Resources: The Oregon Demonstration Project. Inventory and Monitoring Institute Report No. 2. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 20 p.

Holmgren, Peter, and Thomas Thuresson. 1998. Satellite remote sensing for forestry planning—a review. Scandinavian Journal of Forest Research 13:90-110.

MacLean, Collin D. 1963. Improving forest inventory area statistics through supplementary photo interpretation. Journal of Forestry 61:512-516.

MacLean, Collin D. 1972. Improving inventory volume estimates by double sampling on aerial photographs. Journal of Forestry 70:739-740.

National Academy of Sciences. 1974. Remote sensing for resource and environmental surveys: a progress review. Comm. Remote Sensing Programs Earth Resour. Surv., Comm. Nat. Resour. Natl. Res. Council, Washington, D.C.

Wickham, James D. and Douglas J. Norton. 1994. Mapping and analyzing landscape patterns. Landscape Ecology 9:7-23.

Wilford, John Noble. 1998. Revolutions in mapping. National Geographic 193(2):6-39.

Wynne, Randolph H. and Duane B. Carter. 1997. Will remote sensing live up to its promise for forest management? Journal of Forestry, 95(10):23-26.

Footnotes

[1]FIA, Forest Inventory and Analysis Program, http://www.srsfia.usfa.msstate.edu/wo/wofia.htm

[2]USDA, United States Department of Agriculture, http://www.usda.gov/

[3]Citation from National Association of State Foresters, which regularly acknowledges FIA as its highest priority for USDA Forest Service research. http://www.stateforesters.org/

[4]Second Blue Ribbon Pannel on Forest Inventory and Analysis, 1998, which included national leaders from the full forestry community in the USA, including federal and state agencies, industry, academia, environmental organizations, and other user groups.

[5]Conclusion from the First Blue Ribbon Panel on FIA, 1993.

[6]PL 105-185, Agricultural Research, Extension, and Education Reform Act of 1998, 253(c), http://frwebgate.access.gpo.gov/cgi-bin/useftp.cgi?IPaddress=waisback,access.gpo.gov&filename=publ185.105&directory=/diskb/wais/data/105_cong_public_laws

[7]Draft Strategic Plan for PL 105-185, Section 253(c), August, 1998.

[8]National Environmental Monitoring Initiative, http://www.epa.gov/cludygxb/sites.html

[9]FIA Database Retrieval System, http://www.srsfia.usfs.msstate.edu/scripts/ew.htm

[10]FHM, Forest Health Monitoring Program, http://willow.ncfes.umn.edu/fhm/fhm_hp.htm

[11]Remote sensing for annual forest monitoring, http://www.fs.fed.us/ne/rsb/farm4.html

[12]Pixel stands for "picture element." It is the smallest spatial unit in a digital image, and is an indicator of resolution to be resolved, most features require a cluster of similar pixels.

[13]Orbital Imaging Corporation, http://www.orbimage.com/

[14]AVHRR map of forest types in USA, http://www.srsfia.usfs.msstate.edu/rpa/rpa93.htm

[15]NASA, http://www.mtpe.hq.nasa.gov/EC, Joint Research Centre http://www.mtv.sai.jrc.it/USGS, http://edcwww.cr.usgs.gov/landdaac/1KM/1kmhomepage.html

[16]FIA Remote Sensing Band, http://www.fs.fed.us/ne/rsb/remote.html

[17]IRS, Indian Space Research Organization, http://www.isro.org/

[18]NAPP, National Aerial Photography Program, http://edcwww.cr.usgs.gov/Webglis/glisbin/guide.pl/glis/hyper/guide/napp/

[19]NRI, National Resources Inventory, http://www.nhq.nrcs.usda.gov/NRI/intro.html

[20]NWI, National Wetlands Inventory, http://www.nwi.fws.gov/

[21]NASS, National Agricultural Statistics Service, http://www2.hqnet.usda.gov/nass/

[22]USGS, Geological Survey, US Department of Interior, http://www.usgs.gov/

[23]NAPP, Multi-Resolution Land Characteristics Interagency Consortium, http://www.epa.gov/mrlcpage/index.html

[24]NALC, North American Landscape Characterization project provides early 1990's Landsat data, http://edcwww.cr.usgs.gov/landdaac/pathfinder/pathpage.html

[25]GAP, USGS Geographic Approach to Planning for Biological Diversity program, http://www.gap.uidaho.edu/gap/

[26]Only a fraction of the national forest types exist in each region within the USA.

[27]Dr. William Befort, Minnesota Department of Natural Resources originally suggested a national Landsat program to identify changes in land cover.

[28]In addition, FIA uses 3-million Phase 1 photo-plots over the entire USA to improve statistical accuracy. However. FIA photo-plots are not permanent, and are not directly used to monitor changes in land cover.

[29]Includes both forested and non-forest FIA or FHM plots.

[30]For decades, FIA and NRI have gained access to field plots through voluntary consent from private landowners. However, this is a sensitive public issue. Aerial photography of the same plots is less sensitive, but is not immune from similar controversy.

A Strategic Plan for Forest Inventory and Monitoring in the United States[1]

Andrew J. R. Gillespie[2]

Abstract—This paper describes how the U.S. Forest Service would implement an annual forest inventory system which would collect a wider array of data on 20 percent of all plots in every State every year, with reports for each State produced at 5-year intervals. This program would be responsible for conducting consistent, strategic level forest inventory on all forest lands of the United States, including National Forest lands. This paper is an abbreviated version of the complete Strategic Plan submitted to Congress. The complete plan is available on the internet at http://www.srsfia.usfs.msstate.edu/wo/library.htm.

Objective

The objective of this strategic plan is to describe how the USDA Forest Service, Research and Development program will satisfy the forest inventory requirements stated in Section 253(c) of the Agricultural Research, Extension, and Education Reform Act of 1998, and recommendations of the Second Blue Ribbon Panel on the Forest Inventory and Analysis (FIA) Program. These requirements and recommendations call for annual measurement of 20 percent of all plots on all forest land in all States, with a nationally consistent, core set of measurements and analytical products, and production of State reports every 5 years. For the purposes of this strategic plan, the word "inventory" refers to strategic-level, grid-based, forest inventory systems which yield meaningful information at the multi-county, State, and larger scales. The plan does not address the local-scale inventories, such as timber stand exams, or data collection that are part of planning or monitoring specific National Forest projects.

The new legislation also requires an analysis of forest health information in each State report. Currently, forest health monitoring only occurs in 26 States. To fully integrate forest health monitoring data and analyses with forest inventory data and analyses and to do so at the lowest cost, this strategic plan integrates the FIA program and the detection monitoring phase of Forest Health Monitoring (FHM) program) on all public and private lands and expands the FHM program to cover all 50 States. This plan refers to the integrated program as the Forest Inventory and Monitoring (FIM) program.

The legislative direction to remeasure 20 percent of all plots every year will require a significant expansion of the existing FIA and FHM programs. To achieve the accuracy standards sought by users of FIA information, the program uses a two-phase stratified sampling system. Phase 1 consists of interpreting information from remotely sensed imagery. Phase 2 consists of sending field crews out to a sub-set of the Phase 1 points to validate the information obtained from interpreting the imagery and to collect additional, more detailed, data to determine the productivity and health condition of the forests. The accuracy standards endorsed by FIA and FHM customers require a Phase 1 sampling grid of over 3 million forested grid points across the United States (approximately 1 for every 240 acres of the 748 million acres of forest land in the United States) and sending field crews to visit 120,500 of those grid points during Phase 2. Measuring 20 percent of the plots each year implies interpreting imagery on 600,000 grid points per year and field crew visits to 24,100 grid points per year. Current funding levels enable us to interpret imagery on about 270,000 points and to visit about 11,000 points per year. Clearly the legislative mandate and Second Blue Ribbon Panel recommendations envision a major program expansion. This strategic plan describes the most cost-effective ways of meeting the legislative mandate within an FIM framework consistent with customer desires outlined in the Second Blue Ribbon Panel Report on FIA.

Vision

The Forest Service, in cooperation with our partners, delivers current, consistent, and credible information about the status and condition of all of America's forests. We summarize and report the most current information about forest health and productivity in each State every 5 years. We collect and analyze a consistent core set of ecological data on all forests so that comparable information and trends exist for all regions and ownership categories. In each region, we collect additional data beyond the core set and tailor analyses to address specific regional and local issues. Consequently, our information and trends are important indicators of the conservation status and sustainable management of America's forests.

We use the latest technologies to acquire data through remote sensing and field activities. We use experts from universities and elsewhere to augment our research and analytical capabilities and to help us develop new inventory and monitoring techniques. We use rigorous quality assurance procedures to verify the accuracy of our estimates and validate our analytical results. Consequently, State, Federal, and international agencies, industries, environmental organizations, private landowners and consultants can rely on the credibility of our information to make critical land management, policy, and investment decisions.

Our partners are an integral part of our forest inventory and monitoring activities. Without their contributions of

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personnel and funding and their continued support, this vision cannot be attained.

Present Situation

The Forest Service has systematically collected information on the status and condition of America's forests through a variety of programs for some 70 years. During most of this period the emphasis was on measuring forest product supplies at the State level. The FIA program divided the United States into regions and used a State-by-State cyclic approach within each region, completing fieldwork and reports for one State at a time. National Forests have been left free to implement their own local inventory systems. Over the past 20 years, differences emerged among regions in data definitions, measurement standards, analysis and compilation approaches, and information management practices. This resulted in a collection of regional inventory systems with limited consistency for drawing conclusions at the national level and for making comparisons among regions. More consistency is now needed to better serve customers' needs for comparable information across regions.

In 1967, the Forest Service set a target of conducting inventories on an 8 year cycle in the South and 10 years in the rest of the United States. This target was attained in 1983-84, but the cycle length increased in the late 1980's due to changes in costs and appropriations. In 1992, the First Blue Ribbon Panel on FIA, a collection of 30 different customers, recommended shortening the cycle length to 5 years throughout the United States. They concluded that America's forests were changing faster than could be captured with the longer cycle. Unfortunately, cycles lengthened further in the mid-1990's because of reductions in funding and staffing. In recent years the inventory cycle has been 8+ years in the South, 13+ years in the North, and 15+ years in the West. Despite the recent changes in funding and staffing, FIA research and development efforts have borne fruit. On each plot, the FIA program today collects 20 percent more data than in the 1980's with 10 percent less funding (constant dollars).

In FY 1999, $23.1 million was appropriated for the FIA program to conduct inventories of forested land outside of the National Forest System (NFS). There is no specific appropriation for strategic forest inventory or forest health monitoring within National Forests. In some parts of the United States, NFS personnel collect strategic inventory data following their own protocols. Elsewhere, NFS offices contract with FIA field units to collect data following standard FIA protocols. In FY 1998, NFS provided $3.3 million to Stations for data collection on NFS lands. The decision on which approach to use for NFS lands is at the discretion of the Regional Forester. Occasionally, competing priorities for NFS inventory and monitoring funding prevent collecting FIA data on NFS lands.

Customer Needs

Key customer groups include:

- State and National Forest policy decision makers
- State foresters
- Industry and consultants
- Environmental organizations
- Forest Service officials
- Researchers
- Journalists
- Interested private citizens

Taken together, the legislative mandate from Section 253 and recommendations of the Second Blue Ribbon Panel, identify the following needs:

- Data collected annually, analyzed promptly, and used to produce individual State Reports every 5 years
- Consistent core data and analyses across political and administrative boundaries and different land ownerships
- Current information that is consistent with historical information
- Data sets and analytical results that include a wide array of forest ecosystem parameters that address the health status and condition of the forests in addition to traditional productivity measures
- Data that can be post stratified and analyzed in numerous ways
- Data that are readily available in elemental, summarized, and analyzed forms, targeted at different audiences
- Data that are reliable and credible because data quality attributes are fully documented
- Analyses and interpretations of trends in the data, including making projections that look ahead 20 years

This strategic plan describes how the Forest Service intends to achieve its vision for conducting strategic forest inventories by moving from the present situation to satisfy the new legislative mandate and customers' information needs.

Proposed Program to Meet Legislative and Customer Requirements

Coverage

The legislative mandate calls for a single inventory program to cover all forested lands in the United States, regardless of ownership or availability for forest harvesting. This plan includes all forest land in the lower 48 States plus Alaska, Hawaii, Puerto Rico, the U.S. Virgin Islands, the Northern Mariana Islands, the Trust Territory of the Pacific Islands, and the territories and possessions of the United States. It covers all public and private forest land including reserved areas, wildernesses, national parks, and defense installations, as well as National Forests.

Although we acknowledge the importance of grasslands and urban ecosystems, this strategic plan is focused on non-urban, tree-dominated ecosystems. Given the narrow focus of the legislation, we do not feel it is appropriate to include in this plan major new initiatives to seize the lead in addressing inventory of grasslands and urban trees. We intend to continue to collaborate with partners to address inventory and monitoring for grassland and urban tree populations. We do have some ideas and ongoing pilot projects on these topics, and would be pleased to share them with interested parties.

Sampling Intensity

The legislative mandate requires measurement of 20 percent of the plots in each State each year, except where lesser sample intensities are agreed to by the State Forester. After consultation with the State Foresters and other local partners, we propose to sample Alaska, Hawaii, and other island territories at a reduced rate, making better use of remote sensing to address local issues of concern.

Visiting 20 percent of all plots in a State will undoubtedly provide a high level of information, but at a high cost. We believe that there are less expensive alternatives which would still address the needs of customers for consistent and timely information. We would welcome an opportunity to discuss these alternatives with Congress.

The plan assumes that we will measure enough plots to achieve standard errors of area and volume estimates which are consistent with historical levels of precision. Individual States or National Forest Regions may choose to increase the sample intensity by installing additional plots, at their own expense, in order to increase the precision of inventory estimates. Those costs and outcomes are not included in this plan. However, one of the advantages of the proposed annual inventory system is that it will provide maximum flexibility to States and National Forests to engage in such intensifications on short notice in response to local concerns. Whatever sampling mix is finally decided upon will reflect the needs and desires of State Foresters as provided for in the Conferees Notes to PL 105-185.

We will superimpose a nationally uniform cell grid over our existing set of sample locations, in order to provide a uniform basis for determining the annual set of measurement plots. This will eliminate existing discrepancies in the sample intensity between States and regions, and will provide a standard frame for integrating FIA and FHM and for linking the integrated program's other data sources such as satellite imagery, spatial models, and other existing surveys that occur at different scales.

Core Variables

The proposed inventory program includes a nationally consistent set of core measurements, collected on a standard ground plot, with data managed, processed, analyzed, and reported in a uniform fashion. The core set of measures will address inventory and forest health monitoring objectives. The set includes ecological variables not previously collected consistently across all regions. Because a nationally consistent set of core variables is needed to respond to the legislative mandate and address customer information needs across scales, field units will use the national definitions and measurement protocols established for the core variables on all public and private forest land. (House Report language amplifying Section 253(c) specifically mentions that National Forest inventories contributing data to the FIM program will use the same core variables and measurement protocols as used on private lands.) Field units may also add additional measures, conduct special analyses, and prepare reports that respond to specific customer needs, such as information to support the President's Northwest Forest Plan.

Forest health data will continue to be collected from subset of plots which maintains the present level of effort in the FHM program.

Data Collection

Data are collected in a variety of ways, by permanent or temporary Federal employees; by State employees through cooperative agreements; or via contracts with non-government sources (universities, private contractors, etc.). We have experience with all these options, and in practice will use the most cost effective means of achieving the required quality level. The costs are our best estimate of the total cost of delivering the program envisioned in the legislation. Actual staffing plans are developed by each field unit, providing flexibility to take advantage of local conditions. All field data collectors will receive standardized training and will pass a standard certification test before collecting data.

Quality Assurance

We will extend our present Quality Assurance/Quality Control (QA/QC) program, which includes documentation of methods, training for data collectors, field checks of data quality, field data entry software to allow real-time error checking, peer review of analysis products, and continuous feedback to ensure that the system evolves and improves over time. The QA data and analyses will be included in publications and made available to interested users. Internal analysis of QA data will be used to adjust field procedures and to develop new methods as needed.

Information Management

We are developing a national information management system that serves both internal data management needs as well as external (public) data access needs. The information database will consist of a core set of tables, data validation procedures, algorithms, analytical and compilation procedures, and data access tools to ensure that core data are treated identically across the country. Regional-specific data will also be made available when possible. The East-wide and West-wide data bases, which currently receive approximately 1000 on-line requests per month, are precursors to the next generation information management system currently under development. The next generation system will include all the data currently in the existing systems and will allow comparisons of current trends with past trends. Appropriate parts of this system will be accessible via multiple channels including the World Wide Web and CD-ROMs.

Analysis

The FIM program will include several levels of analysis.

Annual Report—Each year, core data will be compiled into a standard set of core tables for each State which will be released in hard copy and electronic formats. Data will be compiled and released once per year, on a schedule to be determined, but in any case with no more than 6 months elapsing between the end of the measurement period and the release of the data.

The job of analyzing and compiling annual data from each State is a larger task than the traditional analytical program. Additional staff and computing capacity are needed to simultaneously produce individual State-level reports.

Periodic Reports by State—Every 5 years, a complete analytical report will be produced for each State. To make most efficient use of analysts, approximately 10 State reports will be produced annually. Each State report will document the following:

- The current status of the forest based on the last 5 years of data
- Trends in forest status and condition over the preceding 20 years, with emphasis on comparing the most recent data with data from the previous period
- Timber product output (TPO) information for the State
- Analysis and discussion of the probable forces causing the observed conditions
- Projection of the likely trends in key resource attributes over the next 20 years, under various scenarios.

The State reports will be prepared by the FIM program in collaboration with State, other Federal, academic, and other knowledgeable individuals. Given the large amount of work this will entail for each State, State reports will be completed on a rotating basis; i.e., 10 States per year—see "Schedules" section for year of first expected report by State. The analytical reports will include tabular analyses as well as spatial representation of key variables of interest.

Periodic National Report—Starting 5 years after the program begins, FIM will prepare a National Summary report which includes the same elements described above but at the regional and national scales. The FIA program has historically prepared such summaries for the Resource Planning Act (RPA) Assessment. The National Summary will be prepared either as a part of the collection of RPA Assessment reports or, if the RPA Assessment legislative mandate changes, as a separate FIM program document.

Special Studies—Over the past 20 years, a number of special studies have been conducted that relied, to some extent, on FIA and FHM data to provide regional context. Two examples are *The Southern Appalachian Assessment*, published in 1996, and *Private Forest-Land Owners of the United States*, 1994. Many of the past special studies have been sought by customers interested in multi-State or regional analysis of resource trends. Most special studies have relied heavily on the expertise of partners. This strategic plan includes only limited capacity to conduct special studies beyond the periodic reports mandated by the legislation. Any funds needed to conduct future special studies will need to be provided in addition to the funding needs outlined in Section 10.

Research and Development

Investments in research and development will focus on building practical, efficient methods to obtain and report information of interest to customers. Priority research areas include the following:

1. Trend analysis—which estimation procedures are most appropriate for analyzing trends in forest inventory and forest health monitoring data over the past 20 years?

2. Projections—using the present data as a starting point, how can likely future trends in resource status under different management and policy scenarios best be projected? What forms of collaboration with other researchers can be created to assure that FIM projections are consistent with other Forest Service; e.g., RPA projections?

3. Remote Sensing—what techniques are most appropriate for detecting and measuring changes in resource extent, status, and condition from satellite imagery and available low-altitude imagery? (Low altitude imagery is collected from instruments mounted on aircraft. It includes aerial photography, aerial videography, various types of radar, and other spectral sensors.) How can the FIM program make most efficient use of currently classified imagery and can declassified products that can be shared with partners be produced from classified imagery? What efficiencies and economies of scale can be gained from increased collaboration with the Natural Resources Conservation Service and NOAA's EROS Center?

4. Geospatial Analysis and Display Tools—what new geostatistical techniques are most appropriate for analyzing data that are accurately referenced with Global Positioning Systems (GPS)? How can geographic data layers be most effectively populated and shared with partners? What new techniques can be developed to merge FIM geospatial data with similar data on other natural resources; e.g., water resource information from the U.S. Geological Survey to gain additional information and insights about resource interrelationships?

5. Modeling—what new techniques can be developed to model changes expected over time in forests undisturbed by human, pathogenic, or atmospheric phenomena? Can the long-term effects of disturbances be modeled at the landscape scale using FIM data and do those models suggest that changes in current natural resource management strategies are needed to avoid or mitigate detrimental effects and improve sustainability? What changes in silvicultural treatment options need to be explored further to respond to disturbances? Most modeling research will be done by partners in close collaboration with FIM analysts.

These research and development needs will be addressed in several ways. We will increase the number of research and development staff in existing FIM units. We will also draw upon the capacity of other Forest Service Research & Development (R&D) units having missions allied with inventory and monitoring goals; e.g., silviculture research units. This will create a cadre of researchers and developers who are familiar with the capabilities of existing FIM systems.

Collaborative relationships with universities, industry research organizations, interest groups, and other Federal agencies will be strengthened. This will allow the Forest Service to gain increased experience in specialized areas, as well as gain access to creative scientists outside of the Forest Service. The full array of funding arrangements available to the Forest Service R&D program, such as competitively awarded contracts, cooperative research grants and agreements, and joint grant applications, will be used to foster the collaborative relationships and focus on specific FIM research and development needs.

Partnerships

Partnerships are key to establishing and implementing the Strategic Plan. Partners will help determine program direction; participate in data collection and analysis; facilitate external relationships; and conduct research and development work in support of the inventory program. State Foresters, who share responsibility for the delivery of forest information and programs to our customers, are particularly important partners who will play a direct role in program oversight and implementation. The following partnerships will be implemented within 1 year of funding this plan.

Program Direction

Input from partners is critical in making sure that the FIM program stays responsive to customer needs. The following mechanisms will be used to ensure continuous customer feedback is obtained to help guide the FIM program.

1. Each Regional FIM program will participate in at least one open "user group" meeting per year, inviting a cross section of FIM partners, cooperators, and customers to discuss program status and satisfaction. The meeting will be advertised and open to all interested parties, in compliance with the Federal Advisory Committee Act. The objective of the meetings will be to share information and seek feedback abut the status, performance, and challenges affecting the FIM program.
2. The Deputy Chief for Research & Development will seek continued interaction with the Second Blue Ribbon Panel to provide feedback on progress in implementing their recommendations and to obtain additional views. This group will serve the same purpose at the national level that the regional interactions serve. To provide links between regional user groups which may form and the Second Blue Ribbon Panel or other national user group, the Deputy Chief for R&D will encourage some customers to participate in both the regional and national groups.

Data Collection

Partners will participate in data collection where they have the capacity and interest to do so, and where they can meet quality standards at equal or lower costs. Partners can also make landowner and mill owner contacts to gain permission for plot visits or to complete timber product surveys. Partners will have the opportunity to add resources to the program to gain increased information, for example additional measurements. If Federal budgets fall short of requirements, an increased level of partner donation of in-kind services may be needed to help the FIM program meet the legislative mandate. (Currently, State partners contribute $2.328 million per year in direct cash support of the base program, in addition to significant in-kind support. The primary means is through assigning State employees to serve on field crews. An increased level of State partner participation will smooth and accelerate the transition to the annualized FIM program envisioned in the legislation and Second Blue Ribbon Panel report. Some forest industry partners also contribute employees to assist in field measurements on their properties. Increased partnerships in other FIM phases, such as the analytical phase, will also hasten the transition to the annualized system.)

Analysis

Partners will have a key role in analysis. Appropriate roles for partners include helping determine the elements, scenarios, and assumptions to be included in the analysis; providing their opinions as to the reasons for past trends, or probable assumptions for future projections; and serving as peer reviewers for draft products. Actual analysis may be completed by FIM analysts, university collaborators, or consultants; however, only analyses overseen by FIM staff will be published as FIM products.

University collaborators and consultants, as well as FIA researchers and developers, will be encouraged to publish results in peer-reviewed journals to validate the quality of their results. Peer review is necessary to assure top quality analyses, research, and development activities. They will also be encouraged to share their findings broadly afterwards through other means to assure rapid adoption and clear comprehension of the results.

Marketing, Technology Transfer, and Public Relations

Partners will use their networks to inform their local communities about ongoing FIM activities, and to make sure that knowledge of inventory reports and products reaches a variety of audiences. The FIM results may be transformed by partners into news releases, popular articles, brochures, Internet web site links, and other means that best serve audience needs.

Use of Technology

Forest Service Inventory programs are already taking advantage of advanced technology. All field crews presently use Global Positioning Systems (GPS) to document field sample locations. All crews are equipped with portable data recorders for on-site entry and checking of field data. The inventory offices routinely use Geographic Information Systems (GIS) for managing and analyzing spatial information. All inventory data will be managed and stored using a modern, off-the-shelf database management system. We already have made reports, analyses, maps, data, and analysis tools available on our Internet web sites, where usage has already grown to 1000 hits per month. We will continue to increase our activities in this area. We also have made our data available in digital form on compact disks, and we are planning enhancements such as custom tabular and geographical analysis tools.

There are several areas where we have been conducting research in the hopes of developing operational tools for inventory. These include:

- Use of commercially available satellite imagery to improve sample methods.
- Use of image analysis and spatial statistical analysis tools to produce maps and analyses of interest to customers.

Research in these areas will continue, with the objective of developing operational inventory tools and application technology. We will increase collaboration with NASA and with the Natural Resources Conservation Service (NRCS) to coordinate progress in these areas.

Organization Structure

Current Structure

The current Forest Service forest inventory and monitoring organizational structure consists of four major components:

- Five FIA units located at research Stations, responsible for forest inventories at a strategic level on all United States forest lands except National Forests (609 million acres).
- Nine inventory staffs in NFS Regions, responsible for forest inventories at both the strategic and tactical levels; e.g., for specific plans and projects on the 139 million acres of forest land that is part of the National Forest System (total NFS land ownership is 190 million acres) and for monitoring the effects of plans and projects as they are implemented on National Forests.
- Four regional Forest Health Monitoring programs led by Forest Service R&D, responsible for detection monitoring on both public and private forest in 32 States.
- One Bureau of Land Management (BLM) State Office (Oregon) that inventories 3.2 million acres of forestland. BLM land outside Oregon is inventoried by FIA units.

This organization structure has allowed each entity maximum flexibility to address local inventory needs, at the expense of maintaining consistency in inventory approaches across different administrative units. Differences in approaches have led to cases where no data are available for some National Forests. There has been some duplication of efforts, as well as inconsistency, between FIA and FHM. There does not presently exist any mechanism for making decisions to assure consistency regarding methods, standards, and definitions within FIA, or between FIA, FHM, and NFS.

Stakeholders outside the agency have two major criticisms of the current organizational structure. Although they see much funding allocated to inventory and monitoring, they are dissatisfied with the relatively small portion devoted to the strategic level FIA inventories that are their top priority. They also do not understand why the Forest Service cannot achieve more consistency in data across administrative boundaries.

New Organizational Structure

Three fundamental changes are proposed to respond to the legislative mandate and the Second Blue Ribbon Panel report recommendations to restructure Forest Service inventory and monitoring programs.

Reassign Responsibilities and Funding for Strategic Inventories on National Forests to FIM Units—The FIM program will be formally given the responsibility and the necessary resources to implement the base FIM program across National Forest lands. This change in policy and funding will allow the swift transition to annualized inventories across all land ownership categories through out the United States in a consistent fashion. In addition, FIM will collaborate with National Forests to augment the base program, as needed, to address regional or local National Forest issues, using additional National Forest resources. The budget requirements necessary to complete the proposed program on National Forest lands—$5.9 million—are included in that total. The outcome of the change will be State reports that include consistent data of the same vintage for National Forests as for private lands and analytical results and trends that are fully and directly comparable across regions and landownership categories. This change will also assure that a fully consistent set of data will exist across all ownerships at landscape and bioregional scales for use in the future rounds of National Forest land management planning. This will assure that National Forests can accurately place themselves into the appropriate regional context. Pioneering reports for the State of Utah and Utah National Forests are an early example of the outcomes anticipated.

Integrate FIA and FHM to Create FIM—The field plot portion of the FHM detection monitoring program will be merged with the FIA program to create a single program that gathers a wide array of ecological data in an efficient fashion. We will accomplish this by (1) combining the FIA and FHM samples to create a single national grid, with FHM as a subset of FIA; (2) collecting an extended suite of ecological measurements (including current FHM measurements plus additional measurements) on a subset of FIA plots each year, at no less sample intensity than the current FHM intensity; (3) maintain the FHM overlap and summer measurement window for the extended suite of measurements; and (4) consolidate management and support functions into a single program which will maintain close ties with other FHM program components (evaluation monitoring and long-term ecological monitoring). We expect that this will result in substantial savings through elimination of redundant field operations, and will allow better linkages between the data which are collected. The additional ecological information will better serve National Forest information needs, and will also respond to the Second Blue Ribbon panel recommendations.

Create an FIM Executive/Management Framework—This framework recognizes the large number of partnerships critical to successful implementation of the FIM program, as well as the decentralized organization structure of the Forest Service. At each level, the framework includes representatives of FIA and FHM programs, State Foresters (one representative for each of the northern, southern, and western State Forester groups), and representatives from the NFS and State and Private Forestry (S&PF). All members will participate fully in all discussions and decisions, and will serve as a conduit for information between FIM and their respective organizations. The outcome of this change will be improved accountability for delivery of a consistent strategic inventory and monitoring program. The framework consists of three levels.

1. FIM Transition Team—This team consists of senior executives charged with making policy decisions for the FIM program. The team will be responsible for swiftly transitioning the somewhat separated strategic inventory and monitoring components into a fully integrated forest inventory and monitoring program that is implemented through the five Research Stations with FIA field units, with oversight and guidance provided by the Washington Office. Initial team membership includes five Station Directors, three Staff Directors, and three State Foresters. (Forest Service Station Directors who oversee FIA units; Forest Service Staff Directors for Science Policy, Planning, Inventory, and Information (R&D); Ecosystem Management and Coordination (NFS); and Forest Health Management (S&PF); and State Foresters from Northern, Southern, and Western regions.) The team derives it authority to make national policies for strategic inventories from the Deputy Chief for R&D. The FIM transition team will represent the agency in an annual program review, as requested by the Second Blue Ribbon panel.

The team will operate by consensus in creating the policies needed to facilitate the swift transition to an integrated FIM program. Where the team cannot reach consensus on policies, it forwards recommendations to the Deputy Chief for R&D for decision. Close consultative relationships are maintained with Deputy Chiefs for NFS and S&PF to assure support for policy decisions.

2. Program Management Team—This team consists of managers responsible for the day-to-day operation of the FIM program. Team members include FIA unit program managers; national program managers for FIA, FHM, and NFS; three State representatives; and three NFS representatives (east, interior west, west coast). State and NSF members should be management level employees with responsibility for inventory programs at the State or Regional level. This team meets regularly to make tactical decisions regarding implementation of the core FIM program, and to share information about other ongoing activities.

3. Technical Bands—These bands consist of technical staff who make recommendations regarding program operations such as field methods, analysis algorithms, information management systems. These groups meet as needed to do staff work in response to requests from the Management team. Each Technical Band will include members from FIA and FHM units, three State representatives, and three NFS members. Band members should be individuals with advanced technical skills in some area relevant to the particular topic area for the given band. University and interest group experts are consulted as needed for participation or peer review.

Additional Staff

The core of the FIM program staff will come from existing FIA and FHM staff. In order to meet the legislative mandate, additional staff will be needed in a number of areas. The number of additional staff needed will be determined partly by the level of sampling which is funded and partly by the level of staff support contributed by FIM partners. In addition to needing more people to deliver an expanded program, new skills will also be needed to take advantage of recent advances in technology; e.g., remote sensing imagery. Some of these skills can be acquired by training existing employees. Other skills will need to be acquired by hiring new staff.

The Forest Service has extensive experience leading research and development programs involving partnerships with universities. The additional analyses required by customers will be accomplished most effectively if the talents of Forest Service researchers outside of existing FIA and FHM units are combined with the talents of university faculty, graduate students and other partners.

The use of contractors to assist in the various aspects of the FIM program is being evaluated. In recent years, commercial forestry consultants and contractors have conducted some inventory field work for National Forests, Stations, and States. FIA units have also used contractors to provide specialized services; e.g., aircraft support and pack animals. Where contractors are more cost-efficient and can meet the same quality and timeliness standards as Forest Service crews, they will be used.

National Centers

While much of the FIM work will still be done in existing Station work units, there exist significant opportunities for increasing cost effectiveness through concentrating expertise to perform tasks serving the national program as a whole. We will create several National Service Centers to provide research, development, and applications tools and services for all the regional FIM units. Potential service centers include:

1. Information Management Service Center. This group will consist of experts in database design, and management, computer programming, and Internet applications. They will lead the development of national information management systems, including data recorder programs, data handling systems, core analysis algorithms, and data access tools. We will build on existing capabilities presently located in Starkville, Mississippi and Las Vegas, Nevada.

All FIM data will also be made available to the Natural Resource Information System (NRIS), presently under development for managing data on National Forests. The NRIS is being developed to operate at multiple scales, from individual National Forests to State-wide. The NRIS will ultimately include all FIM information and metadata including core data and quality assurance data, at whatever spatial scale is supported by NFS for the area. The FIM participation in NRIS is key to improving the linkage between NFS inventory data collected at sub-forest scales and GFIM data gathered at forest and larger scales. Together, the FIM national database and NRIS regional/forest databases will seerve an extremely broad set of customers for inventory and monitoring data.

2. Forest Ownership Project. We propose to institutionalize the periodic national landowner surveys, conducting such surveys once every 10 years. The work will be handled by one of the FIM units (presently Northeastern Station). The next ownership study should be published by 2005.

Coordination and Integration

Integration With Other Agency Reporting Activities

The Forest Service 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 proposed inventory program is that it contains sufficient scope of data to enable us to respond to new data needs as they arise.

Resource Planning Act (RPA) Assessment—This Assessment is done on a 5 year cycle, with mandatory reporting to Congress at 10-year intervals. The FIA provides the historic and current forest inventory data used to describe current resource status and provide the basis for future projections for the RPA analyses. The FIM Program will continue to provide information and analyses covering all lands covered by FIM, at the cycle needed, as well as to expand the scope of data available to include a core set of ecological attributes at the national level.

Chief's "Annual State of the Forest" Address—It has been proposed that the Chief of the Forest Service issue an annual "State of the Forest" report to describe progress and challenges facing the Nation's forests. The FIM Program will provide the statistical information necessary to prepare such an address.

National Environmental Status and Trends Report (NESTR)—This report is being developed for the White House Office of Science and Technology Policy by the John Heinz III Center for Science, Economics, and the Environment. Over 75 percent of the data for the forestry part of the report comes from the FIM program.

International Reporting—The FIM will respond to all requests for national estimates of status, condition, and trends, in America's forests. Examples include the United Nations' Temperate and Boreal Forest Resource Assessment and the Criteria and Indicators for Conservation and Sustainable Management of Temperate and Boreal Forest (The Montreal Process). Where international information needs exist that assume different data protocols, FIM analysts and partners will adjust United States data; e.g., volumes that include bark and different merchantability standards to satisfy the needs.

The Forest Inventory and Monitoring Program is not being designed specifically to respond to all of the Montreal Process criteria and indicators. However, many of the criteria and indicators will be addressed by the proposed inventory program, at a scale of State-level or larger.

Coordination With Other Federal and State Partners

FIA units are already using Global Positioning Systems (GPS) for field operations. The Forest Service has an agreement with the Department of Defense to use GPS receivers which take advantage of special frequencies to provide enhanced coverage and accuracy in obtaining locations. We will continue to coordinate with the Departments of Defense and Energy to improve our capabilities in this area.

We will continue our working relationship with NASA through participation in the Global Observation Earth Satellite (GOES) working group which is looking at new ways to characterize land cover, including forest cover, on a frequent basis. We also collaborate with U.S. Geological Survey (USGS) in several research and development projects, such as the North America Land Classification project.

We are engaged with other Federal natural resource agencies including the National Park Service (NPS), BLM, USGS, and NRCS on a variety of initiatives such as:

- An existing Memorandum of Understanding with NPS for data collection on NPS lands.
- Existing arrangements with the BLM for data collection on BLM lands.
- Participation in joint projects with BLM and NRCS in Oregon, Colorado, and the Delaware Bay area. These projects are looking at ways of combining inventory procedures in areas of common interest including forest and rangelands.
- Pilot project with NRCS looking at ways to eliminate interagency disagreements regarding forest and range resource estimates.
- Collaboration with NRCS and BLM on a rangeland health monitoring initiative.
- Continued participation in and collaboration with the Gap Analysis Program (GAP).
- Partnerships with the U.S. Global Change Research Program to improve estimates of biomass and carbon relations in United States forests.

Every State forestry agency is consulted as a routine part of conducting forest inventory. As we move to a continuous annual inventory system, these contacts will occur more frequently as part of the partnerships and relationships described previously.

The NFS regions enjoy a unique relationship with FIM. The FIM data provide the essential landscape-level context for National Forest planning. Having consistent and comparable data for private lands adjacent to National Forests in vitally important for regional assessments and for implementing ecosystem management. Like other partners, NFS managers may choose to enhance the FIM sample by adding additional sample locations or measurements to meet additional information needs. The FIM provides a nationally consistent framework of data for National Forests which can be aggregated upwards for regional or national NFS reporting, avoiding the present problems with data which are incompatible across some regional or National Forest boundaries.

Compliance With Privacy Act of 1974

Private landowners are essential partners for the FIM program. Without a landowner's permission, the FIM program cannot collect data on private land. To protect the privacy of participating private landowners, the FIM program keeps confidential the exact latitude and longitude of FIM field sample locations and never links the identity of participating private landowners to plot data. These policies are long-standing and consistent with the Privacy Act of 1974. Further, exact plot coordinates are not included in data bases released outside of the FIM program.

Measuring Success and Establishing Accountability

Measuring and monitoring the success of the FIM program is critical both to making continuous improvements as well as maintaining accountability with our customers and Congress. Formal program accountability flows through the line: from Deputy Chief for R&D to Station/Staff Directors, and then from Station Directors to local FIM program staff, or from Staff Directors to national program staff. The Deputy Chief for R&D is the accountable officer for FIM program delivery. Washington Office Staff roles include ensuring programmatic and fiscal accountability.

A variety of program monitoring approaches are necessary to make available the information needed to measure success and establish accountability. The following types of program monitoring perspectives will be used:

1. Implementation monitoring—have we done what we said we would do? Examples of criteria include: (1) Did we measure the planned number of plots by State by year? (2) Did we produce databases and reports by the planned deadlines? (3) Did we develop the internal systems that we promised, within budget? (4) Did we achieve our quality assurance objectives?

2. Effectiveness monitoring—is our work having the desired effect? Examples of criteria include: (1) What do our user groups think about the quality, usefulness, timing of our products? (2) What do user groups think of the consistency, compatibility, and credibility of our results? (3) How many and what kinds of customers are we serving? Are we answering their questions? (4) What key management and policy decisions are being influenced by our data?

3. Validation monitoring—are our methods, approaches, and techniques scientifically defensible? This is most readily obtained through scientific peer review.

4. Fiscal accountability—How efficiently are appropriated funds and contributions from partners utilized to deliver the FIM program?

Program success will be evaluated continuously and reported via an annual business report, similar to a corporate annual report. It will serve as the annual Government Performance and Results Act report for the FIM program and will describe:

- Past year activities, products, outputs (success in implementation).
- Past year accomplishments, outcomes, and impacts (success in effectiveness).
- Results of any program peer reviews conducted in the past year (success in validation).
- Major changes expected in the coming year.
- A basic financial accounting balance statement (income, expenses).
- A basic statement of staffing resources (people involved, Forest Service and other).

External accountability will be augmented by annual meetings of national and local users groups, where the annual business report will be presented and discussed.

Two types of internal Forest Service reviews will be performed. Formal Technical Assistance Visits (TAVs) will be limited to the Research Work Unit Description revision process for FIM field units. These will be focused on research and development aspects of the FIM unit. Less formal 'Directors Reviews' will take place, as needed. These will be sponsored jointly by the Transition Team to cover details relating to unit operations.

Transition Schedules

Tables 1 and 2 outline a 5 year transition plan for moving from the present system to an annual system in all parts of the country. Table 1 shows the year of implementation for each State, and Table 2 shows the first year that a report is expected. Note that the initial reports are not always scheduled exactly 5 years after the initiation of fieldwork, due to the need to balance the reporting workload over a 5 year cycle. Subsequent reports for a given State will follow the initial report at 5 year intervals. This schedule is based on the FY 1999 appropriation level and assumes that increased funding becomes available.

Staffing Resources Required

To deliver an FIM program that measures 20 percent of all plots in all States annually will require an estimated 840 full time equivalents (FTE's) each year. This figure covers all phases of the program including preparation work, field work, information management, analysis, reporting, technique research, and management and overhead. This compares with the present program staff size of approximately 420 FTE's (including Federal and State cooperators), indicating a need for 420 new FTE's. More detailed information regarding the number of staff by position and grade level is available on request.

Staffing plans for each region were developed by regional FIA managers in consultation with Station Directors and program partners and reflect the actual conditions of each region. Variation will exist across regions due to the different approaches best suited to each region.

It is not necessary that all of these new positions be Federal employees. State personnel assigned full time to FIM work, or contractors or other cooperators, may contribute the effort needed to implement the program.

Financial Resources Required

To deliver an FIM program that measures 20 percent of all plots in all States annually will require a total budget of $82,089,000 in 1999 dollars, with inflation increases of approximately 3 percent per year. Note that failure to adjust annually for inflation will inevitably lead to erosion in program delivery.

This figure covers all phases of the program, including salaries for all program staff, and the cost of equipment, travel, publications, overhead, and miscellaneous items.

Table 1.—Initiation of annual inventory systems, States by year. All States to be initiated by 2003.

Region	1999	2000	2001	2002	2003
Northeast	ME	NY, OH	CT, MA, RI, NH, VT	NJ	DE, MD, WV, PA
North Central	MN, IA, MO, IN, WI	ND, SD, NE, KS, IL	MI		
South[1]	TN, TX, KY, AR	NC, MS, OK	FL, PR		
Interior West			NV, UT, AZ	ID, NM, NV, WY	MT, CO
West Coast	HI	WA, CA, Int AK	OR, Coast AK		

[1]Southern States of GA, AL, VA, SC, LA will already be implemented in 1998.

Table 2.—Initiation of 5-year reports by State. Each State will have reports at 5 year intervals beginning in the year shown.

Region	2003	2004	2005	2006	2007	2008
Northeast		ME	NY, OH	CT, MA, RI	NH, VT, NJ	DE, MD, WV, PA
North Central		MN, MO	IN, WI, IA,	ND, SD	NB, KS	IL, MI
South	GA, AL	VA, SC,	LA, TN	TX, KY,PR	NC, MS, AR	OK, FL
Interior West		NV, AZ	NM, UT	CO, WY	MT	ID
West Coast		HI	WA, CA, Int AK	OR, Coast AK		

This compares with the present available funds of $37,185,000 drawn from existing Forest Service and State contributions. This indicates a need for $44,904,000 in new funds to come from Federal and State sources. In addition, we estimate initial start up costs of approximately $9,508,000 over 5 years for purchases of new equipment needed to increase our current capability. More detailed information regarding the cost by item and region is available on request.

Budgets for each region were developed by regional FIA managers based on staffing plans and reflect the actual conditions in each region. Costs vary among regions due to the nature of the resource and the different approaches best suited to each region. For example, severe topography and lower road densities in the Interior West make costs higher there than in the South because a crew may require 2 days to measure each plot. In addition, severe winter conditions in the high-elevation west and northeast preclude crews from working in winter months when mountains become inaccessible. This requires us to either relocate work crews to warmer areas or to lay crews off and rehire/retrain crews after winter, both of which add to costs.

Although we attempted to ascertain how much States were willing to contribute to achieve this goal, most States are reluctant to commit to a figure until they see what Congress offers first. Many States feel that this level of strategic forest inventory is a Federal responsibility, and so are not willing to commit cash resources to share the cost of the inventory. Other States who are willing to contribute resources are only willing to do so if they get something "extra," above and beyond the base program offered to non-contributing States.

We believe that a Federally funded base program of less than 20 percent of plots per State would be acceptable to our partners provided they have the opportunity to contribute resources needed to make up the difference. We would welcome a request from Congress to discuss these options further, because we believe this might reduce the total program cost by up to 30 percent while still addressing the concerns and interests of State Foresters and other partners and customers.

Characterizing Forest Fragmentation and Vulnerability Based on Patch Characteristics[1]

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Abstract—Loss and fragmentation of natural forests due to human activities represents one of the greatest threats to global biodiversity and the sustainability of the biosphere. Although we are aware of declines in natural forests, we lack comprehensive knowledge of the extent and magnitude of forest loss and fragmentation. Moreover, we lack methodology to assess the vulnerability of forests to human activities. This paper highlights a simple 2-step method to assess forest fragmentation and vulnerability due to human activities over a range of scales. The method is demonstrated in tropical forest zones of Central America, South America, and Africa, using 1-km global land cover data.

The shrinking and fragmentation of intact forests has become a major environmental concern worldwide (Turner et al. 1990; Groom and Schumaker 1993; Houghton 1994; Imhoff 1994; Ojima et al. 1994). These two factors have and continue to contribute to the loss of important forest resources and associated ecological services, including timber production (Franklin 1992), forest plant and animal diversity (Van Dorp and Opdam 1987; Bierregaard et al. 1992; Whitmore and Sayer 1992; Stouffer and Bierregaard 1995; Jullien and Thiollay 1996; Metzger 1997), and the processes of water interception, infiltration, and runoff that determine the magnitude of flooding, water storage, and the quality of drinking water (Peterjohn and Correll 1984; Saunders et al. 1991; Franklin 1992).

Shrinking and fragmentation of forests results primarily from human activities that convert natural land cover to anthropogenic uses, including agriculture, urban, and residential uses (Zipperer 1993; Ojima et al. 1994). As an area is developed, continuous forest stands are divided into smaller and smaller patches, and the proportion of individual forest patch edges juxtaposed to anthropogenic land cover increases until the patches are fully imbedded in a sea of human land use. Small patches that become imbedded within a sea of human land use are the most likely to be lost, or to become sufficiently small and/or isolated enough such that they no longer support an array of interior forests species. Unless checked by biophysical (e.g., slopes or geology), economic (e.g., a downturn in the economy) , or social (e.g., preservation land) constraints, forests adjacent to developing areas continue to shrink in size, become more fragmented, and eventually are lost (Zipperer 1993).

By analyzing the size ranges of individual patches, the spatial pattern in the range of sizes, and the types of edges surrounding individual patches, it is possible to see fragmentation events and evaluate relative vulnerabilities of individual patches from composite images of land cover. Moreover, new digital coverages of land cover and advances in Geographic Information Systems (GIS) and other computer tools permit analysis of land cover pattern and forest fragmentation over relatively large areas (Jones et al. 1997; Riitters et al. 1997).

We developed a 2-step analysis process that uses a relatively simple set of landscape pattern statistics to evaluate the status of forest loss, fragmentation, and threats due to human use. We also developed a simple index of forest patch vulnerability based on patch sizes and edge characteristics. These indicators can be calculated and interpreted from a wide range of remote sensing imagery in a GIS. We demonstrate the application of these indicators and a vulnerability index in tropical zones of Central America, South America, and Africa using 1-km land cover databases distributed by the U.S. Geological Survey's EROS Data Center.

Methods

A set of three continental images of land cover were obtained from the U.S. Geological Survey through the Global Land Cover Characteristics (GLCC) project and converted to Arc/Info GRID format. These data have a nominal one-kilometer spatial resolution, and were derived from satellite imagery (Advanced Very High Resolution Radiometer or AVHRR) from the time period of April 1992 to March 1993. We used the 17-class land cover grid (International Geosphere Biosphere Program, Lambert equal-area projection) for Central America (on the North American coverage), South America, and Africa (Belward and Loveland 1995).

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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To identify forest land cover, and to determine if forest land cover was adjacent to or divided by natural non-forest land cover, or anthropogenic land cover, we reclassified the 17 land cover classes into three classes (forest, anthropogenic, and non-forest natural, Table 1).

We used a two-step process to assess tropical forest fragmentation on three different continents; an initial step at the continental-scale to identify areas where forest fragmentation might be occurring, and a second step to evaluate the extent and nature of forest fragmentation and risk to individual forest patches in those areas identified in the first step.

The first step involved converting the 3-class land cover grid into individual patches using the Regiongroup command in GRID. This command grouped cells with the same land cover class into patches with unique values. Cells may be connected in any direction (including diagonals). Figure 1 provides an example for South America. We then identified three areas, one in central America (southern Honduras), one in South America (central Amazon), and one in Africa (southeastern Ivory Coast and southwest Ghana), where large block tropical rain forests have been fragmented into smaller patches by human land uses. We also used this process to identify an area in South America where little fragmentation was evident (control).

We zoomed into the smaller, subarea within each continent by clipping them out of the larger continental grids in Arc/Info GIS. Grided versions of patches for each of the three areas were then converted into polygons. Using the relationship between arc and polygon topologies, the proportion of adjacent land cover was calculated for each forest polygon.

The proportion of anthropogenic/forest edge was calculated as: anthropogenic edge / (anthropogenic edge + natural edge) x 100. We included the entire area of all patches located at the edges of the study areas rather than artificially cutting them off. This reduced the impact of the study area boundary on the patch statistics. For example, a patch of several hundred cells might have been clipped so that only a few patches were in the study area. In this case, the edge values (and area) for the entire patch were used in the calculations. Shorelines of rivers, bays, and oceans were counted as natural edge (Figure 1).

Table 1.—Classification of the 17 IGBP land cover classes into forest, natural non-forest, and anthropogenic land cover

IGBP class	New classification
Evergreen needleleaf forest	Forest
Evergreen broadleaf forest	Forest
Deciduous needleleef forest	Forest
Deciduous broadleaf forest	Forest
Mixed forest	Forest
Closed shrublands	Non-forest natural
Open shrublands	Non-forest natural
Woody savannas	Non-forest natural
Savannas	Non-forest natural
Grasslands	Non-forest natural
Permanent wetlands	Non-forest natural
Croplands	Anthropogenic
Urban and built-up	Anthropogenic
Cropland/natural mosaic	Anthropogenic
Snow and ice	Non-forest natural
Barren or sparsely vegetated	Non-forest natural
Water bodies	Non-forest natural

Quintiles were calculated for the edge values, with anthropogenic edge proportions of 20% and less being classified as 1 (least risk) to proportions of over 80% which were classified as 5, or highest risk.

Patch area was also split into categories on the assumption that large patches are at lower risk than small patches, even if they have a high proportion of anthropogenic edge. Patches of 3 pixels (300 Hectares) or less were classified as 3, or highest risk, patches between 3 and 300 pixels were classified as 2, and patches over 300 pixels were classified as 1.

An index was generated by multiplying the values for area and edge. The resulting index values ranged from 1 to 15, and were displayed in 5 colors. Darker green represents the lowest risk, values 1-3, light green shows values 4-6, yellow 7-9, pink 10-12, and red 13-15 (greatest risk, see Figure 2). Natural land cover was displayed as light blue, and anthropogenic use as black. It is possible to evaluate and display forest vulnerability across an entire continent and then zoom into areas of interest. Figure 3 illustrates how one can zoom into the central Amazon Basin from an entire view of South America.

Results

Identification of individual forest patches through the GRID Regiongroup command permits an initial screen of forest fragmentation across an entire continent. Figure 1 illustrates how one can use the continental-scale forest patch map as an initial screen to find areas that might be undergoing significant forest loss and fragmentation. The example provided in Figure 1 is of South America and it clearly shows significant patterns of forest loss and fragmentation in the central Amazon. A similar method was used to screen areas of significant forest fragmentation in Central America and Africa. As a result of this screening, central Amazonia of South America, the southern Honduras area of Central America and the southeast area of the Ivory Coast and southwest Ghana of Africa were selected for the second level of analysis.

Comparison of patch characteristics for forested areas in the central Amazon, southern Honduras, and southeast Ivory Coast/southwest Ghana show that the three areas differ in terms of forest/human spatial pattern and risk. All three of these areas contain tropical forests whose loss and fragmentation due to human activities is of primary concern. Figure 4 illustrates the spatial distribution of forest patches by degree of risk (five quintiles or levels of risk). As expected, based on our methods, forest patches at greatest risk were small and fully imbedded within anthropogenic land cover (Figure 4). Forest patches classified as moderate-high and moderate risk varied in size from a 5 or 6 pixels up to 35-40 pixels, and have from approximately 50% to 100% of their edges adjacent to anthropogenic cover (Figure 4). Larger forest patches that fell into moderate-high and moderate risk classes tended to be fully imbedded within anthropogenic cover whereas smaller patches in these two classes tended to have a lower percentage of edge adjacent to anthropogenic cover (Figure 4). Forest patches in the two lowest risk classes tended to be large (>50 pixels) and had a

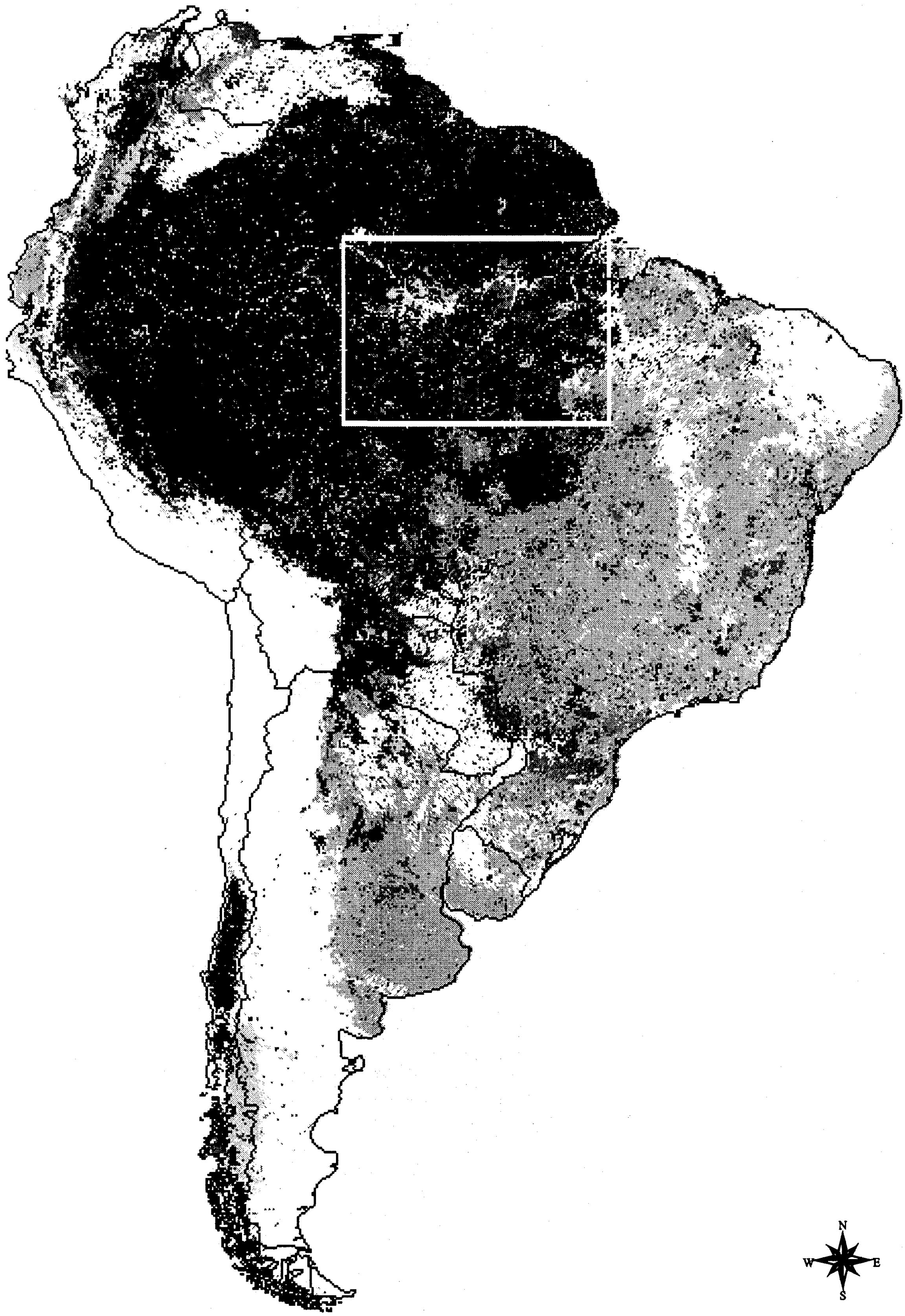

Figure 1.—Individual patches at the continent scale and the Amazonia study area boundary.

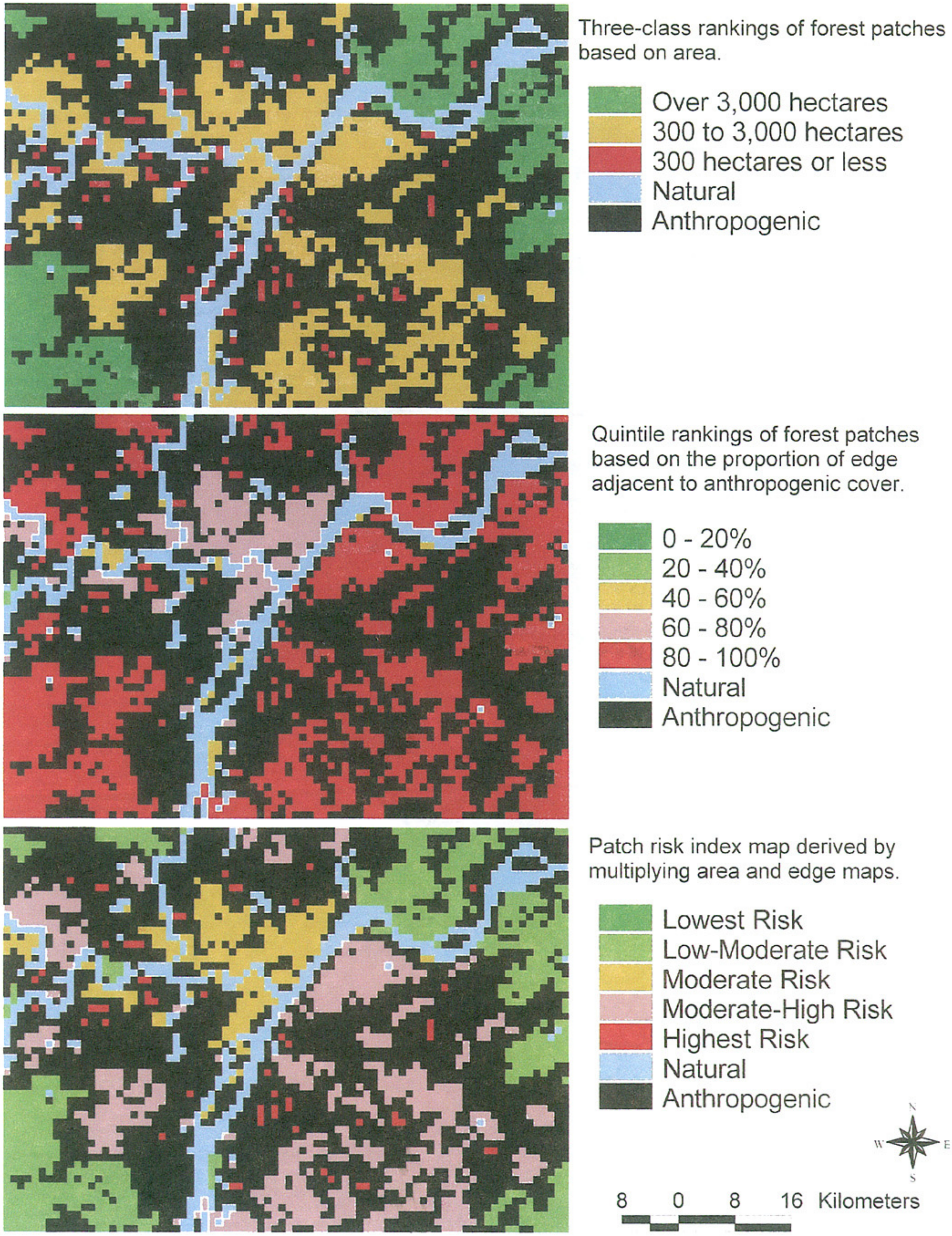

Figure 2.—Combining landscape themes to evaluate forest vulnerability in Central Amazonia.

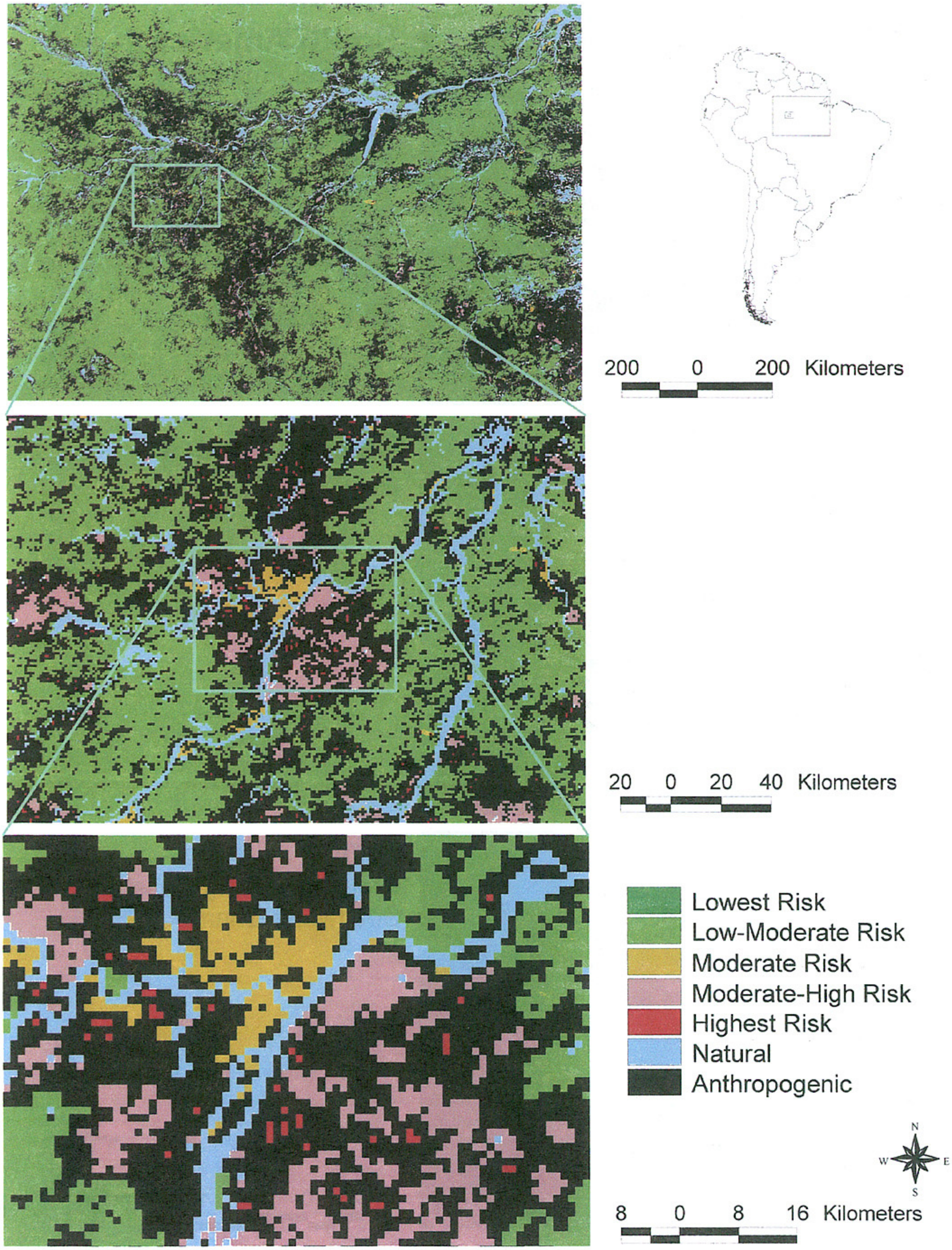

Figure 3.—Forest patch vulnerability in Central Amazonia at three scales.

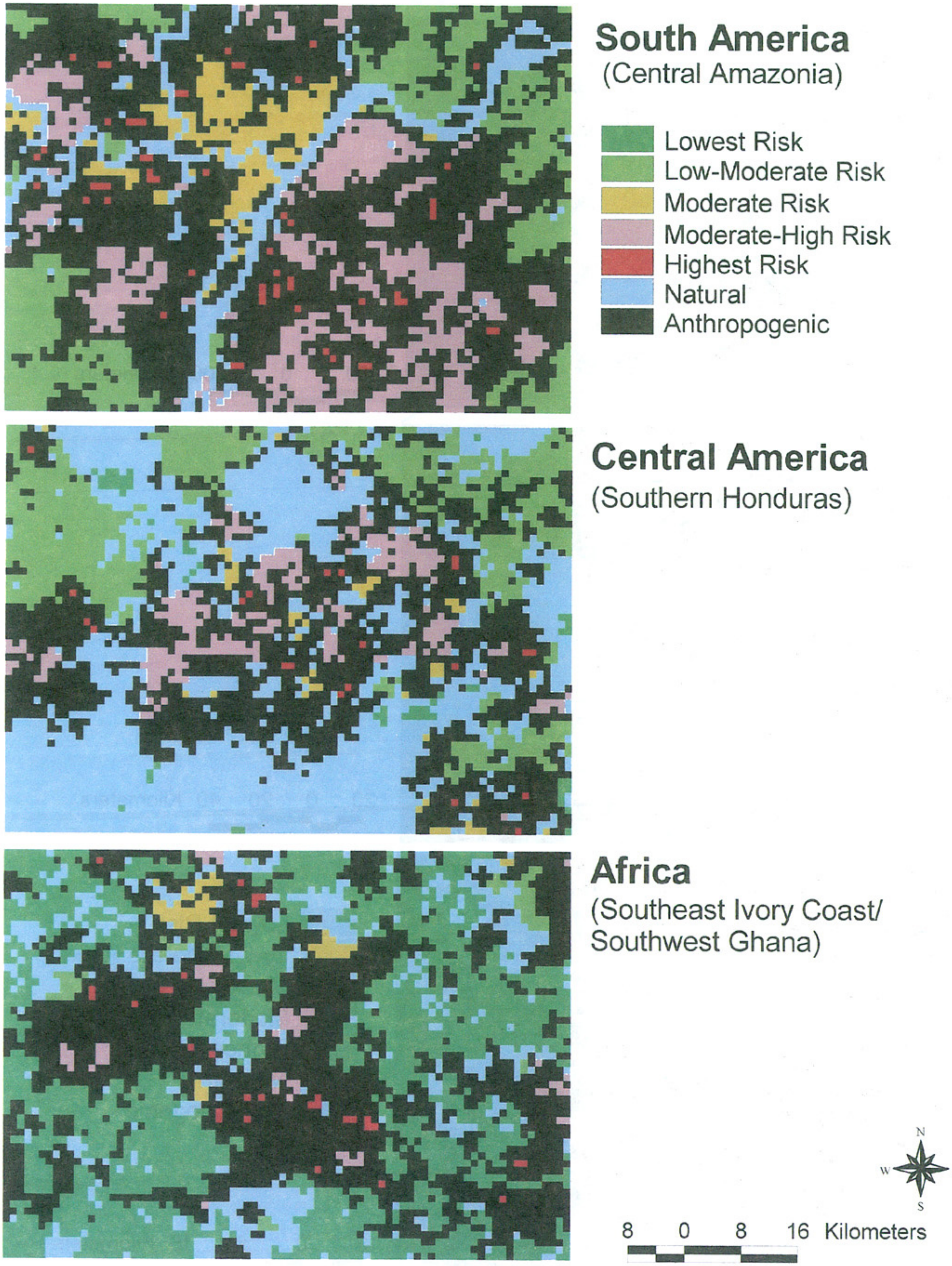

Figure 4.—Forest patch vulnerability in three tropical zones of the world.

significant proportion of their edges adjacent to natural nonforest land cover, such as woodland savannah (Figure 4).

Of the three areas, forest patches in the central Amazon had the highest average risk score (Table 2). It also had a relatively high proportion of its forest patches in the maximum risk class, as did the African site (Table 2). Figure 4 also shows that the Amazon site has the greatest amount of anthropogenic cover of the three sites and has a large number of forest patches fully imbedded within anthropogenic cover. The central American site had the lowest percentage of forest patches in the maximum risk category and adjacent to anthropogenic cover, but it had a higher average patch risk score than the African site (Table 2). All three areas had a considerably higher percentage of forest patches in the high risk category than the relatively undisturbed site (Table 2). Based on average risk scores of forest patches, one could conclude that forest patches in the central Amazon are at greatest risk, followed by the southern Honduras, and the African site. However, the African site had a greater number of high risk forest patches than did the southern Honduras site (Table 2).

Discussion

The two-step analysis process highlighted in this paper provides a way to evaluate forest fragmentation across entire continents, and to evaluate the extent and nature of fragmentation in specific areas. Moreover, the approach evaluates the relative risk of forest loss and fragmentation based a simple index of forest patch size and the percentage of an individual patch edge that is adjacent to anthropogenic cover. This assumes that areas with numerous small forest patches imbedded in a sea of anthropogenic cover are more likely to be undergoing rapid forest fragmentation and forest loss than larger forest patches imbedded within natural land cover (patches that are naturally fragmented). Based on patterns of deforestation reported in other studies (Zipperer 1993), this assumption seems reasonable. Unlike more traditional remote sensing methods that evaluate forest loss from a set of imagery obtained over a range of dates (Tucker et al. 1984; Iverson et al. 1989; Hall et al. 1991; Vogelmann 1994; Jones et al. 1997), our method provides a way to evaluate ongoing fragmentation from a single land cover product, such as the global 1-km land cover database produced by the U.S. Geological Survey's EROS Data Center.

Because of costs associated with data collection and processing at continental scales, geographic "targeting" approaches, such as that highlighted in this paper, are needed to assess forest resource conditions over large areas at multiple scales. Jones et al. (1997) used landscape data to evaluate watershed conditions at a regional scale, and to target those areas that potentially needed additional evaluation. Using a regional scale land-cover database, Wickham et al. (1998) ranked watersheds relative to their potential for forest restoration and increased connectivity.

The approach can be applied to land cover data at varying scales, including land cover derived from satellites, as well as aerial photography. However, because the scale of the imagery can affect index value for a given area (see Lillesand and Kiefer 1994), comparisons among areas should be limited to a single scale of imagery.

This paper makes no attempt to analyze the consequences of forest patch vulnerability on ecological resources or associated processes. To do so would require the application of ecological, biological, and hydrological process models, depending upon the ecological resource of concern. For example, one could evaluate the consequences of losing high risk forest patches on biota through the use of metapopulation and biogeography process models (Whitcomb et al. 1981; Fahrig and Merriam 1985; Schumaker 1996; Keitt et al. 1997). Similarly, watershed models are needed to assess the consequences of forest patch loss on water quality.

The vulnerability index applied in this paper could be improved by adding thematic data layers on slope and elevation and protected areas. For example, some forest patches with high amounts of anthropogenic edge might be less likely to be developed because they are on areas with steep slopes and hence are unsuitable for development, or because they are protected by law. Cost grids of these additional characteristics could be calculated in a GIS and incorporated into the index. For example, forests in protected areas would have risk values at or near zero because these sites are not likely to be developed. Similarly, forests on steep slopes would have lower scores than forests in relatively flat areas. The threshold for slopes (the point at which development probably would drop substantially) could be determined from existing patterns of development. Additionally, it may be possible to improve the index by separating internal from external edge, since the former represents an internal erosion of forest patches and the later a peripheral erosion (Zipperer 1993).

Finally, it may be possible to improve the initial screening process of each continent by applying a spatially filtering approach (Riitters et al. 1997). For the purpose of this study, we located the three study sites by visually inspecting patch maps for the three continents. However, fragmented forests

Table 2.—Comparison of forest patch statistics and risk for central Amazonia (CA), southern Honduras (SH), southeast Ivory Coast/southwest Ghana (IC), and a relatively undisturbed forest area in the Amazon (CN). Maximum risk patches were those with index values between 13 and 15 (see Methods section).

Area	Number forest patches/ total number patches	Average forest patch area	Average anthro edge	Forest patches at maximum risk	Average index value of patches[1]
		km²	------- *percent*	------	
SH	84/210	13.87	64.25	19.05	3.09
CA	94/164	17.86	85.56	35.11	2.51
IC	57/220	34.60	79.00	35.09	1.25
CN	2/109	2111.5	4.72	0.0	1.00

[1]Weighted by area.

are difficult to see at the continental scale because the image is relatively fine-scaled (see Figure 1). The spatial filtering approach utilizes a "windowing" concept which can be implemented in a GIS. One sets the window size based on the scale at which wants to analyze fragmentation. For example, a window of 100 x 100 pixels would analyze forest patch characteristics on area of 10,000 km^2 around each pixel (assuming a one Km pixel). The window starts from the top left part of the land cover patch map and moves one pixel at a time until it reaches the bottom right pixel in the grid. Next, one could calculate the average patch size or edge to area ratio or number of patches in the window. The result would be a new map of average patch size or edge to area ratios for forest patches in the window. The new map would result in a better visualization of forest fragmentation across each continent, and a way to target areas for more detailed analysis. The same spatial filtering approach could be used to display forest patch risk at a continental scale.

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Literature Cited

Belward, A.S. and T. Loveland. 1995. The IGBP-DIS 1km land cover project: remote sensing inaction. Pp. 1099-1106, *in* Proceedings, 21st Annual Conference of the Remote Sensing Society, Southampton, United Kingdom.

Bierregaard, R.O., T.E. Lovejoy, V. Kapos, A.A. dos Santos, and R.W. Hutchings. 1992. The biological dynamics of tropical rain forest fragmentation. Bioscience 42:859-866.

Fahrig, L, and G. Merriam. 1985. Habitat patch connectivity and populations survival. Ecology 66:1762-1768.

Franklin, J. F. 1992. Scientific basis for new perspectives in forests and streams. Pp. 25-72, *in* R. J. Naiman (ed.) Watershed Management. Springer-Verlag, NY.

Groom, M.J., and N. Schumaker. 1993. Evaluating landscape change: patterns of worldwide deforestation and local fragmentation. Pp. 24-44, *in* P.M. Kareiva, J.G. Kingsolver, and R.B Huey (eds.), Biotic interactions and global change. Sinauer, Sunderland, Massachusetts, USA.

Hall, F.G., D.B. Botkin, D.E. Strebel, K.D. Woods, and S.J. Goetz. 1991. Large-scale patterns of forest secession as determined by remote sensing. Ecology 72:628-640.

Houghton, R.A. 1994. The worldwide extent of land-use change. BioScience 44:305-313.

Imhoff, M.L. 1994. Mapping human impacts on the global biosphere. Bioscience 44:598.

Iverson, L.R., R.L. Graham, and E.A. Cook. 1989. Applications of satellite remote sensing to forest ecosystems. Landscape Ecology 3:131-143.

Jones, K.B., K.H. Riitters, J.D. Wickham, R.D. Tankersley, Jr., R.V. O'Neill, D.J. Chaloud,

E.R. Smith, and A.C. Neale. 1997. An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas. EPA/600/R-97/130.

Jullien, M., and J.M. Thiollay. 1996. Effects of rain forest disturbance and fragmentation: comparative changes of the raptor community along natural and human-made gradients in French Guiana. J. Biogeogr. 23:7-25.

Keitt, T.H., D.L. Urban, and B.T. Milne. 1997. Detecting critical scales in fragmented landscapes. Conserv. Ecol. 1(1):1-20.

Lillisand, T.M., and R.W. Kiefer (eds). 1994. Remote sensing and image interpretation. John Wiley and Son, Inc., 750 pp.

Metzger, J.P. 1997. Relationships between landscape structure and tree species diversity in tropical forests of southeast Brazil. Landscape and Urban Pl. 37:29-35.

Ojima, D.S., K.A. Galvin, and B.L. Turner II. 1994. The global impact of land-use change. BioScience 44:300-304.

Peterjohn, W. T. and D. L. Correll 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65:1466-1475.

Riitters, K.H., R.V. O'Neill, and K.B. Jones. 1997. Assessing habitat suitability at multiple scales: a landscape-level approach. Biological Conservation 81:191-202

Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conserv. Biol. 5:18-32.

Schumaker, N. H. 1996. Using landscape indices to predict habitat connectivity. Ecology 77:1210-1225.

Stouffer, P.C., and R.O. Bierregaard. 1995. Effects of forest fragmentation on understory hummingbirds in Amazonia Brazil. Conserv. Biol. 9:1085-1094.

Townshend, J.R.G., C.O. Justice, and V. Kalb. 1987. Characterization and classification of South American land cover types using satellite data. Int. J. Rem. Sens. 8:1189-1207.

Tucker, C.J., B. Holben, and T.E. Goff. 1984. Intensive forest clearing in Rondonia, Brazil, as detected by satellite remote sensing. Rem. Sens. Env. 15:225-261.

Turner, B.L., II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyers (eds.). 1990. The earth as transformed by human action. Cambridge Univ. Press, Cambridge, UK.

Van Dorp, D., and P.F.M. Opdam. 1987. Effects of patch size, isolation and regional abundance on forest bird communities. Landscape Ecol. 1:59-73.

Vogelmann, J.E. 1994. Assessment of forest fragmentation in southern New England using remote sensing and geographic information systems technology. Conserv. Biol. 9:439-449.

Whitcomb, R.F., J.F. Lynch, M.K. Klimkiewicz, C.S. Robbins, B.L. Whitcomb, and D. Bystrak. 1981. Effects of forests fragmentation on avifauna of the eastern deciduous forest. Pp. 125-206, *in* R.L. Burgess and D.M. Sharpe (eds.), Forest island dynamics in man-dominated landscapes. Springer-Verlag, New York, New York. USA.

Whitmore, T.C., and J.A. Sayer (eds.). 1992. Tropical deforestation and species extinction. Chapman and Hall, London.

Wickham, J.D., K.B. Jones, K.H. Riitters, T. Wade, and R.V. O'Neill. 1998. Transitions in forest fragmentation: implications for restoration opportunities at regional scales. Landscape Ecology, in press.

Zipperer, W.C. 1993. Deforestation patterns and their effects on forest patches. Landscape Ecol. 8:177-184.

Ecological Quality Assurance Principles[1]

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Abstract—The application of sound quality assurance principles and protocols is essential to inventorying and monitoring of forest ecosystem resources because of the complexity, breadth and inherent variability of the data collected, the long term nature of monitoring and the numerous agency and individual participants involved. The paper focuses on the basic elements of a comprehensive ecological quality assurance plan that are amenable to adoption by Canada, the United States and Mexico. The concept of quality management systems, including the employment of data quality objectives is reviewed in terms of their applicability to ecological monitoring. Quality assurance for field biological measurements is stressed since past emphasis has mainly been on laboratory based chemical assays. Total management commitment, adequate training and complete documentation are the key to effective quality management. Development of basic quality assurance principles that are acceptable to the three countries will help establish a philosophy of 'continuous improvement' in North American ecological forest monitoring that can be built on and refined with time.

Today's concern for sustainable development and global environmental conservation is focusing attention on the need for sound ecological monitoring. For meaningful integration and interpretation, ecological data must be of known and adequate quality. The data must reflect the true ecological conditions and be suitable for the resolution of defined issues. Only by collecting and using data of known quality can we be sure that data from different sources are comparable and that spatial and temporal trends can be assessed statistically. In the past, data have often been collected with little attention given to the quality of the measurements or data generated for one program have been used for another with no consideration given to any limitations that might have been put on the original data. It has been said that no number is significant and worthy of being recorded without an estimate of its uncertainty. Decision makers need to know the uncertainty to determine the potential risk for making an inappropriate decision. It is generally not possible to determine data quality after the study is over.

Ecological monitoring of forest ecosystems involves the integration and assessment of physical, chemical and biological data from air, water, land and biota. Quality assurance practices for laboratory based and some field based measurements have been well developed over the last decade with the availability of national interlaboratory comparison programs and laboratory accreditation programs. As well as requiring laboratories to meet specific performance requirements, these programs raise the overall awareness for quality assurance throughout measurement programs. Unfortunately, many of the types of measurements used for monitoring forest ecosystems do not lend themselves to the same rigorous quality assurance practices. Determination of forest health, for example, does not involve the measurement of specific quantitative parameters but rather an estimation of more subjective quantities such as tree density, tree growth, canopy density and overall tree health. The introduction of satellite surveillance in some programs as a replacement for, or to supplement, detailed ground observations introduces yet another level of complexity and uncertainty into the measurement process.

The purpose of the Quality Assurance Workshop is to review some of the techniques that are currently being used to monitor the health of forest ecosystems, to estimate the level of quality required in the data and to identify appropriate quality assurance. Speakers will be describing current forest monitoring practices at different scales from small plots to large regions along with some of the quality assurance practices that are being employed. The concluding panel session will provide an opportunity to discuss some of the next steps that can be taken by Mexico, the United States and Canada towards implementation of a North American quality assurance program.

Quality Assurance Principles

According to Taylor, 1987, data quality assurance is defined as a system of activities whose purpose is to provide assurance that data meet defined standards of quality with a stated level of confidence. Data quality control is the system of activities whose purpose is to control quality of data so that it meets the needs of the user and data quality assessment is the overall system of activities whose purpose is to provide assurance that quality control is being done effectively. Quality assessment involves a continuing evaluation of performance through the use of round-robin intercomparison studies and/or other appropriate audits. While these definitions were originally intended for more traditional laboratory measurement programs, they are equally applicable in general terms to more complex ecological monitoring programs.

All monitoring programs must address quality issues starting with the purpose and design of the program through the various measurement steps, design and use of the data system to data interpretation and archiving. Firstly, the data must be of adequate quality to meet the predefined needs of the program. Data Quality Objectives (DQOs) must be established that define the maximum degree of uncertainty that can be tolerated in the data to meet the program requirements. Appropriate statistical techniques can then be applied to determine the required frequency of sampling

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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and spatial distribution of sampling locations. Field observation techniques and sampling techniques can then be chosen with sufficient checks for reproducibility and representativeness to meet the DQOs. Laboratory analytical techniques can be chosen with due consideration to required precision and accuracy of the measurements: use of a laboratory accredited to ISO/IEC Guide 25 (1990) would be an asset. The data management system must be adequate for the program. It must be reliable, secure, have sufficient capacity, incorporate appropriate data validation checks and have sufficient capability to address the requirements of the program, e.g. determination of spatial and temporal trends.

Quality Management

Quality management is defined in ISO 9000 (1987) as the overall management function that determines and implements quality policy throughout an organization. It must instill an awareness and a concept of 'continual improvement' to everyone involved in a program. It is the driving force for quality. While the ISO 9000 series standard was originally intended for a production facility, many of the same principles can be advantageously applied to organizations responsible for conducting monitoring programs and even research facilities. It is important to note that quality management includes strategic planning, allocation of resources and other systematic activities for quality, such as quality planning, operations and evaluations.

Quality management is usually promulgated throughout an organization using a 'quality system' which is defined (ISO 9000, 1987) as, the organizational structure, responsibilities, procedures, processes and resources for implementing quality management. In the interest of efficiency and effectiveness, the quality system should only be as comprehensive as needed to meet the quality objective(s). The quality system ensures that adequate space and facilities are available within the organization to conduct the monitoring program, that a quality culture exists throughout the organization, that qualified staff are available and that an appropriate training plan is in place to continually upgrade skills, that all procedures are thoroughly documented, that all equipment is well maintained and regularly calibrated and that a system of internal and external audits are in place to verify the data generated. Documentation must be available to ensure that each and every piece of information is completely traceable. The quality system provides the infrastructure for sound and traceable monitoring.

Quality Control

Quality control for the more traditional monitoring that involves sampling and laboratory analysis consists of an ongoing systematic set of documented procedures carried out for each of the operations of the monitoring program (site selection, field sampling, laboratory analysis and data management). Quality control must ensure that samples are representative and reproducible, that analytical measurements meet prescribed reproducibility and accuracy and that information management system is reliable, complete, has internal checks and contains all necessary quality control information or meta data. A more detailed list of quality control elements is provided in Table 1. Quality control provides a continuous daily check on the performance and capability of each operator and operation in the measurement process but can only reflect the performance of each activity in isolation. The intrinsic nature of quality control does not allow a comparison of sampling and laboratory procedures between different operators or between different organizations contributing data to a given monitoring program.

Quality Assessment

Quality assessment is a form of external audit and provides verification that the quality control program is effective and, in addition, provides a comparability between different operators within the program. Quality assessment usually takes the form of co-locating samplers between different networks and the analysis of interlaboratory comparison samples by different analysts and different laboratories. The value of co-located samplers in precipitation monitoring networks has been discussed by Vet et al, (1989). Interlaboratory samples usually consist of well homogenized performance samples or certified reference samples. Such comparisons should be conducted a minimum of twice yearly and preferably quarterly. Most laboratory accreditation programs include regular performance testing but one should always check to determine whether those samples are appropriate for the particular monitoring program. Timely feedback from external audits is invaluable for diagnosing subtle problems which cannot be identified through internal quality control.

Monitoring Forest Ecosystems

Much of the material presented above has been developed over the past two decades predominantly for traditional chemical and in some cases biological monitoring of water quality. While many of these same practices can be applied to monitoring of forest ecosystems, ecological monitoring involves measurements that are not so clearly defined. Chemical analysis of vegetative and soil samples is much less advanced than chemical analysis of water or sediment samples plus there is the natural variability to consider

Table 1.—Elements of laboratory quality control.

Sample tracking	Analytical quality control
Log-in (LIMS)	Selection of method
Sample type	Method validation (performance)
Sample history	Instrument maintenance logs
Determinant of interest	Instrument performance
Methods	Calibration checks
Detection limits	Control charts
Tolerance limits	Blanks, splits, blinds and replicate samples
Special requirements	Surrogates
	Data validation
	Criteria for reporting low level data
	Review of raw data
	Internal checks (LIMS)

which is inherent in any biological matrix. Some estimate of overall tree health has to be an essential component of forest health assessment. This requires selection of appropriate indicators of tree health which tend to be more observational and subjective in nature.

Kirkland (1992) identified four basic classes of ecological indicators: response indicators; stressor indicators; exposure indicators and habitat indicators, each of these will tell us something different about the ecological condition. These four types of indicators are further defined in Table 2. The list of possible indicators for ecological health assessment is almost endless and selection of the most appropriate indicators will have a profound impact on the value of the monitoring program. By way of an example, the 1998 biannual State of the Lakes workshop held in Buffalo, New York, October 1998 focused on the selection on appropriate indicator species for monitoring the health of the Great Lakes. Initially a list of some 800 possible indicators were identified. Using a peer review process the number was reduced to something more manageable and then the task of the workshop participants was to identify a short list of the most meaningful indicators. This was obviously quite a challenge. An essential complement to the careful selection of appropriate indicator species is the planning for associated data quality. How does a degree of quality associated with one indicator relate to that of another? Indicators of forest health usually include parameters such as tree species and density, tree size, crown condition, amount of dieback, foliage density, wildlife damage as well as foliage and soil chemistry. Other more specialized indicators may be used for more specific monitoring requirements.

Assessments of forest health usually require monitoring to be carried out at different scales from very detailed monitoring of small plots to broader scale regional monitoring and even, in some cases to very large scale monitoring of entire areas using satellite imagery. Since it is desirable to be able to relate data from one scale to that of another, the quality must be defined in such a way as to allow meaningful comparisons to be made. In the case of remote satellite imagery, it has been very difficult to relate the reflected optical signal to a specific ecological condition and to assess the degree of certainty of observed variations.

Table 2.—Types of ecological indicators (Kirkland 1992).

Response indicator:	A characteristic of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community or ecosystem level of organization.
Stressor indicator:	A characteristic measured to quantify a natural process, an environmental hazard or a management action that affects changes in exposure and habitat.
Exposure indicator:	A characteristic of the environment measured to provide evidence of the occurrence or magnitude of a response indicator's contact with a chemical or biological stressor.
Habitat indicator:	A physical, chemical or biological attribute measured to characterize conditions necessary to support an organism population or community in the absence of pollutants.

Palmer et al. (1998) described and compared two quality assurance programs for the United States Forest Health Monitoring, FHM, program. The FHM program is a U.S. wide program, initiated in 1990, to monitor, assess and report on the status and trends of forest ecosystem health. The measurements were largely observational in nature, including measurements such as species, distance apart, tree history, diameter at breast height, tree condition, crown density, crown dieback, foliage transparency, crown diameter, etc. The quality assurance programs were based on established data quality objectives derived from specified data acceptance criteria. Detailed measurement procedures were documented for the field crews who were then thoroughly trained and periodically audited by reference crews. The two quality assurance programs were, a) the reference crew system in which special field crews visited routine plots and b) the reference plots system in which field crews and reference crews selected a small number of reference plots for use as a standard. The overall objective of the comparison study was to quantitatively compare the reference crew and the reference plot measurements in terms of quality control, quality assessment and cost. Several different types of measurements were included involving varying degree of objectivity. For example, tree species measurement is determined by identification of natural species, diameter at breast height is a direct measurement using a tape measure while crown condition and size involve ocular estimates. Measurements were selected from indicators of site condition, tree growth and regeneration and tree crown condition.

A quantitative comparison of the two approaches was determined by comparing the value for any given measurement by a field crew with the same measurement by a reference crew to obtain an estimate of '% correct' where '% correct' is defined as being within the tolerances of the measurement quality objectives (MQOs). The MQOs also specified how often the tolerances must be met. Both systems had their advantages and in most cases the results from the two systems agreed quite closely. Table 3 taken from the report by Palmer et al. shows the percentage of plots that met the measurement quality objectives for the two re-measurement systems. The greatest differences between the two approaches were in the measurement of tree species and crown diameter. The measurement of crown diameter is understandable since it is an ocular estimate of crown size made from a distance whereas tree species measurement involves identification of natural species which one would expect to be reasonably straight forward. It should be noted that the quality objectives for these two parameters were quite stringent which may have contributed to the apparent differences. For both these types of measurements it would appear that the 'reference crew' approach was less reliable than the 'reference plot' approach. More difficulty was experienced by the crews in the measurement of saplings than for more mature species.

The authors reported that the programs resulted in an overall improvement in data quality by providing rapid feedback to the field crews on quality related issues. This was particularly valuable during training and early season auditing when the field crews did not have a lot of experience. It was also useful throughout the season to verify that more experienced crews retained consistency in their measurements. Each of the two approaches offer theoretical and

Table 3.—Percentage of plots achieving quality objectives for two quality control systems (Palmer et al. 1998).

Parameter	MQO[1]	Plots within DQO[2] (Plot system)	Plots within DQO[2] (Crew system)
		percent	
Species	90%	92	77
Hor. distance	90%+-1ft	92	100
Azimuth	90%+-10	100	100
Tree history	95% Agree	100	100
DBH	90%+-1	8	0
DBH check	85% Agree	75	84
Condition class	90% Agree	83	93
Crown class	85% Agree	33	38
Crown ratio	90%+-10	67	69
Crown density	90%+-10	50	45
Crown dieback	90%+-10	100	92
Foliage transparency	90%+-10	100	100
Crown diameter (max)	90%+-5 ft	100	93
Crown diameter (90)	90%+-5 ft	100	77
Arith. average diameter	90%+-5 ft	100	93

[1]Management quality objectives.
[2]Data quality objectives.

practical advantages for assessing data quality. The reference crew system has the advantage that the field crews do not know which sites will be revisited whereas with the reference plot system the field crews know which are the reference plots and may tend to give these special attention.

These programs were also used to assess precision, accuracy, bias and representativeness while the overall measurement error could be calculated from the bias and precision estimates. Calculation of a mean parameter for describing forest health is not very informative about the state of the forest without some indication (probability) as to whether the real state of health is anywhere close to the mean value. Sophisticated statistical software are of limited value if the raw data are of unknown precision and bias. Theoretically the reference plot approach should be preferable for estimating precision, bias and accuracy. These can be calculated based on one set of data on reference plots since all crews measure the same plots. Any differences in results can be attributed to measurement errors.

Conclusion

While quality assurance requirements for forest health or ecological monitoring may appear different from those used for traditional chemical or biological monitoring, in many cases it is the same principles that apply. A good quality management system can be flexible enough to accommodate the special requirements of ecological monitoring. The establishment of data quality objectives, thorough documentation of all study plans and procedures, adequate and ongoing training, good quality control, a good data management system and external audits should allow measurement errors to be quantified so that overall data variability can be estimated. Managers of large scale ecological and forest health monitoring programs are starting to include elements of quality assurance into their programs but there is still much progress to be made before ecological data of known quality are commonplace. The application of uniform quality assurance principles in Canada, the United States and Mexico will ensure that data throughout North America will be credible and comparable. Regular symposia bringing scientists from the three countries together to discuss monitoring issues should go a long way towards fulfilling this aim.

Literature Cited

ISO. 1987. Quality management and quality assurance standards—guidelines for selection and use. International Standards Organization 9000 Series. Paris, France.

ISO/IEC. 1990. General requirements for the competence of calibration and testing laboratories. International Standards Organization Guide 25 (3rd edition). Paris, France.

Kirkland, L. 1992. EMAP on the Great Lakes quality assurance program planning: Current EPA thoughts and issues. Proceedings of the 5th ecological quality assurance workshop, USEPA. Environment Canada, Ontario Ministry of Environment, NWRI, Burlington, Ontario, L7R 4A6, Canada.

Palmer, C. J.; Cline, S. P.; Cassell, D.; Heravi, N.; McLain, W. 1998. Comparison of two quality assurance re-measurement systems for forest health monitoring—results of 1994 Colorado pilot. Unpublished report, University of Nevada. Report to the Forest Health Monitoring Program, USDA Forest Service, Research Triangle Park, North Carolina.

Taylor, J. K. 1987. Quality assurance of chemical measurements. Lewis Publishers, Chelsea, MI 48118, U.S.A.

Vet, R. J.; Sirois, A.; Lamb, D.; Artrz, R. 1989. Intercomparison of precipitation chemistry data obtained using CAPMoN and NADP/NTN Protocols. NOAA Technical Memorandum ERL ARL-174, Air Resources Laboratory, Silver Springs, MD, U.S.A.

Towards Harmonization for Monitoring Key Forest Variables in Europe Using Earth Observation Data[1]

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Abstract—The Member States of the European Union established the European Forest Information and Communication (EFICS) Program in 1989 with the aim to improve forest information in Europe and to facilitate the availability of the information. In 1994 the Space Applications Institute of the European Commission set up the Forest Information from Remote Sensing (FIRS) Project in order to support EFICS by developing methods for deriving forest information from earth observation data, principally mapped, geo-referenced information but also statistical data. Two studies carried out in the frame of these two activities clearly revealed the need for harmonization of the nomenclature and the definitions and methods used for assessing the forest variables within the Pan-European area.

As mapped forest information is lacking for most of Europe it has been considered practical to combine the provision of harmonized key variables with the development of methods for, eventually, providing the information in geo-referenced mapped format as derived from remotely sensed data. The use of earth observation data furthermore provides a continuous monitoring capability of some of the key variables which can be assessed by remote sensing at an acceptable degree of precision and accuracy. Therefore, several development studies on application of remote sensing for Pan-European forest monitoring have been launched, e.g. forest area, species composition, structural diversity and change. These development studies are being supported by research projects under the so-called Framework Program of the European Commission.

The member states of the European Union (EU) have not agreed upon a common forestry policy. Wood products were not among the commodities included in the original treaty, and forestry as such has not been included in the EU common agricultural policy (CAP). However, the European nongovernmental and governmental forest organizations have expressed their need for close cooperation, not least due to the fact that EUROSTAT, (the statistical office of the EU), is obliged to collect reliable statistics on the EU forest sector. Thus, the Standing Forestry Committee (SFC), an advisory body to the European Commission (EC) was established in 1989. The SFC, assisted by the Working Party on Forestry Statistics under the Agricultural Statistics Committee of EUROSTAT, is the main player in EU forestry matters. Major decisions can only be taken by the Council, the assembly of EU ministers responsible for forestry in their respective countries.

In 1989 the SFC had the so-called EFICS (European Forest Information and Communication System) regulation approved by the Council. The EFICS regulation requests the EC to provide a frame for collecting, coordinating and processing data concerning the forestry sector and its development. The EFICS is planned to take account of existing data, and in particular statistics compiled by EUROSTAT. It will make use of information available in the Member States, and in particular data contained in national forest inventories and any other relevant databases accessible at community and international level. But, still it is the SFC that has the mandate to decide on both the actual content and the implementation. The EFICS regulation has been extended until the year 2002.

Concurrently with the preparation of the EFICS regulation the Joint Research Centre (JRC) of the EC initialized and implemented a European program (the European Collaborative Program for the use of high resolution Second Generation Earth Observation Satellites in the Management of the Less Favoured Areas) ECP. The ECP had the main objective to test the applicability of remotely sensed data in local management, e.g. land use planning and forestry, and to assist local users in the application of earth observation (EO) data for their own specific purposes (Folving and Megier, 1992). The idea was to create a link between practical local management and a centralized information system.

The ECP clearly revealed wide interest from the forestry community in using remotely sensed data in daily management. Via the ECP it became evident that the main obstacles for using EO data were found in the cost of the data and the lack of cheap, user friendly software. Due to the principle of subsidiarity the program was stopped in 1992, and the development of methods for application of remotely sensed data for local forest management was suspended accordingly.

In 1994, the FIRS (Forest Information from Remote Sensing) Project was launched in support to EFICS. The idea was to utilize the results from the ECP to implement the practical application of EO data in the monitoring of European forest areas (Kennedy et. al., 1994).

The main objective of the FIRS Project is to contribute to the development of a unified European forest information system (i.e., EFICS), by developing methods for providing both sectorial (i.e. production- related) and environmental (i.e. ecology-related) forest information in the form of both

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statistical and mapped data – with emphasis on mapped data (Folving et. al., 1995; Kennedy et. al., 1995). The methods are based on the application of EO data and GIS techniques.

Three basic inputs had to be created before the actual method development and their applications at a Pan-European scale could be fully embarked upon. Firstly, regionalization of the Pan-European area into major forest ecosystems had to be produced because it was foreseen that the methods had to be adjusted to "local" forest characteristics. This work was finished in 1995 and the results have been published (e.g., SAI, 1995) and are illustrated on the WWW (http://www.jrc.sai.egeo.firs). Secondly, a system of nomenclature had to be defined which could be applied to the Pan-European area using EO data. This work was finished in 1996 (Köhl and Päivinen, 1996) and is available at the same UTL address given above. Thirdly, a network of common test areas had to be selected, and so-called 'ground truth' for each site had to be provided. Due to a number of constraints, not least costs and the lack of harmonized information, such a network could not be established per se. It was therefore decided that test areas, and the data from these would be compiled in an ongoing manner through the various sub-projects or application modules of the FIRS Project.

Three major applications modules will be described in §3. Studies on nomenclature are dealt with in the next section which will also looks at new requirements in the EU for forest monitoring, in terms of the development of the Common Agricultural Policy (CAP). Section 4 presents the very preliminary work being done to address the challenges for the newest environmental trend in requiring sustainable development, preservation and enhancement of bio-diversity.

Harmonization of Nomenclature and Information Priorities

For many years organizations like EUROSTAT and UN-FAO (United Nations - Food and Agriculture Organization) have compiled and published statistics on forests and forest products. This statistical information is based on national statistics. However, recent international conventions such as the Convention on Biological Diversity, the Ministerial Conference on the Protection of Forests in Europe require new types of information and new data to be collected.

When the FIRS Project was launched, high priority was given to studies dealing with the definition of the European user needs concerning forestry and how the existing variations in assessment methods, nomenclature and definitions could be dealt with. The aim was to provide a proposal for a common nomenclature to be used for the EO data applications. The first study was very much directed towards spatial, geo-referenced information.

In parallel, the EFICS Program launched a more general study on the same theme, but which was not restricted to the application of EO data. The study reviewed the majority of NFI systems currently in existence in Europe. The results are published in - European Commission, 1997.

The FIRS Project's Nomenclature Study

This study was carried out by a working group lead by the EFI (European Forest Institute) and the Swiss Federal Institute for Forest, Snow and Landscape Research (Köhl and Päivinen, 1996). Three main "user" groups were asked which forest attributes were of most interest to them, and then to rank these attributes according to importance. The result is summarized in Table 1. Although, as expected, most attributes are common to the three user groups, as expected, their priorities are somewhat complementary. 'Forest area' is ranked as a high priority by all groups, 'bio-diversity' and 'landscape-related' attributes are ranked very low by foresters engaged in forest productivity. Foresters mainly working with environmental protection and landscape management, however, put little emphasize on productivity information.

Interestingly, several of the attributes requested are not included in many existing National Forests Inventories. This is especially true for many of the newly requested environmental attributes. Some of these parameters are, however, available from other sources or organizations, such as information on soil and water.

The last column in Table 1 reveals that several attributes need to be harmonized because currently no common nomenclature or assessment method exists in Europe. This is somewhat worrying as it also clearly indicates that international statistics compiled from national statistics may not always produce comparable data.

The feasibility of using EO data (from high, medium and low-resolution sensors), for assessing the attributes at various scales was also investigated. The outcome, summarized in Table 2, shows that high resolution EO data are potentially very important for assessing and mapping forest attributes but that data from instruments with medium to low spatial resolution are of little interest in European forestry.

The feasibility of using EO data for forestry was also discussed in working groups set up as part of two international workshops initiated by the FIRS Project. One in Joensuu, Finland, (Kennedy et. al., 1995) and one in Vienna, Austria, (Kennedy, 1997). The groups discussed and evaluated the potential of using remote sensing for the assessment of key forest attributes. On the first occasion the group was also asked to evaluate the potential for using remote sensing operationally for mapping of the forest attributes at the European scale (Table 3).

The interesting point is that foresters in academic research have rather low expectations of the application of EO data, whereas foresters dealing with practical inventory problems seem to have larger expectations of remote sensing technology (Tables 1 and 2). It is also interesting to note that there has been very little change in expectations of academic foresters over a 2-year period. However, the launch of several SAR (Synthetic Aperture Radar) instruments seems to have created at least a small improvement in the expectation towards the use of microwave data in this field.

The EFICS Information Needs Assessment

In 1996, the European Commission decided to launch a detailed study on information needs, data acquisition methods etc., in Europe to support the EFICS. The European Forest Institute led the consortium carrying out the work. The Study is unique in providing a full overview, and comparison of forest surveys and inventory systems in 22 European countries (European Commission, 1997b).

Again the difference in priorities between "production" foresters and "environment" foresters is evident. The ranking of attributes in Table 4 has been carried out using questionnaires. A total of 500 questionnaires were sent out, a little less than half, 43%, were returned. The organizations or persons contacted were asked to list and rank the 15 most important attributes. The rankings of 'important' and 'very important' are used for the total ranking in shown in Table 4. The study revealed slight differences in regional interests in Europe. Northern European countries seem to be a little more interested in forest volume and in costs, whilst in central Europe the protection function of the forests seem to be of greater concern, than in the other parts of Europe. Northern European countries are unique in listing timber quality, the Atlantic countries in afforestation and central Europe in woody biomass, recreation and non-wood goods.

In general, forest area (83% of the replies) and tree-species composition (79%) are the most important attributes, followed by protection functions (77%) and nature conservation area, volume of annual increment and cut (76%) and, finally, the attribute biological richness (75%) and diversity (7%). Growing stock volume (71%) and Health (69% of the replies) are also considered of high interest.

Putting the Nomenclature System Into Use

The interest of having a common nomenclature and common assessment methods is not just due to the need for comparable statistical information. It is also linked to needs created by the Common Agricultural Policy of the EU, and to a strong political need for rural development, especially in the so-called less favoured areas. The less favoured areas of the EU are of course defined in economic terms, but, more often than not they correspond to the mountainous and hilly regions, and are frequently characterized by forested or other wooded land. Such areas are also the most important sources for fresh water.

Table 1.—The rankings of the forest attributes according to the FIRS Project's information needs assessment.

Attributes	Ranks for information groups			Need for harmonization
	Production	Environment	Land use	
Land cover (type, density etc.)	5	2	1	required
Actual forest area	1	3	1	required
Other wooded area	12	3	3	required
Potential forest area[1]	6	6	7	
Stand structure (Species composition, layers, density.)	2	3	6	required
Age	4	9	12	
Diameter	2	12	15	
Height	2	8	14	minor
Quality	2	11	10	required
Health	3	2	8	existing
Defoliation	8	2	11	
Damage (fire, storm, ins., diseases, game, pollution)	4	2	5	required
Volume	1	13	13	required
Assortments	3	13	13	
Timber value	3	12	9	
Woody biomass[1]	11	6	11	required
Herb biomass[1]	13	4	12	
Growth/Increment	3	7	8	
Drain/removals	3	7	14	required
Soil types[1]	5	3	2	
Site factors	4	5	6	minor
Vegetation types	10	1	5	required
Topography	9	4	2	required
Climate[1]	8	6	5	
Productivity	3	10	8	
Regeneration	6	7	14	
Stand history	10	7	9	
Ownership	7	7	5	
Management objective	4	3	3	
Value of protected infrastructure[1]	-	-	-	
Water resources[1]	9	2	5	required
Protection status[1]	8	1	2	required
Naturalness[1]	14	1	6	
Threats to species diversity[1]	13	1	9	
Environmental impact[1]	9	1	4	required
Non-wood goods and services[1]	9	4	6	
Scenic beauty[1]	16	2	4	

[1]Attributes not assessed by most of the national forest resource assessments.
1 highest rank – 5 lowest rank.

Rural development and a Common Agricultural Policy are synonymous with the payment of subsidies. Within the EU, this means subsidies for taking land out of agricultural production, subsidies for afforestation on these so-called set aside land, and subsidies to the farmer until the point in time when the newly forested areas provide an income. Harmonization at the European level is therefore a necessity to aid the implementation of tools to control the expenditure of the subsidies which are allocated and implemented on the basis of 'local' or regional conditions.

The most recent EC regulation on the Common Agricultural Policy and Rural Development is not yet available.

Table 2—Feasibility of using Earth Observation data at various resolutions.

	Nomenclature		Feasibility		
Attribute	Ha	Definition	High	Medium	Low
Forest area	0.5	Forest cover 21 – 100 %	Yes	No	No
	1		Yes	?	No
	10		Yes	Yes	No
	100		Yes	Yes	?
Other wooded land	0.5	Open forest, forest cover 5 – 20 %,	Yes	No	No
	1	species able to grow >7m	Yes	?	No
	10		Yes	Yes	No
	100		Yes	Yes	?
Land cover	0.5	Open forest, forest cover 5 – 20 %,	Yes	No	No
	1	shrubland 21 – 100 %	Yes	?	No
	10		Yes	Yes	No
	100		Yes	Yes	?
Stand structure	0.5	Crown density in 5 % classes	Yes	No	No
	1	Crown density in 20 % classes	Yes	?	No
	10	Crown density in 40 % classes	Yes	Yes	No
	100	Crown density in 40 % classes	Yes	Yes	No
Vegetation type	0.5	Species spp.	Yes	?	No
	1		Yes	?	No
	10		Yes	Yes	No
	100		Yes	Yes	No
Diameter	Tree	Stand mean diameter,	No	No	No
	stand	1.3 m diameter	?	?	No
Height	Tree	Height of single tree,	Yes	No	No
	stand	Mean height in 5 m classes	Yes	?	No
Volume	0.5	Above ground volume of standing trees	Yes	No	No
	1	50 cubic meter pr ha classes	Yes	No	No
	10		Yes	?	No
	100		Yes	Yes	No
Woody biomass	0.5	Dry weight of woody plants	Yes	No	No
	1	50 t pr ha classes	Yes	No	No
	10		Yes	?	No
	100		Yes	Yes	No
Drain/removals	0.5	Over bark volume of trees	Yes	No	No
	1	In 50 cubic meter pr ha classes	Yes	?	No
	10		Yes	?	No
	100		Yes	Yes	No
Damage	0.5	Two classes:	Yes	Yes	No
	1	>50 cubic meter pr ha	Yes	?	No
	10	no damage	Yes	?	No
	100		Yes	Yes	No
Health	tree	Crown thinning characteristics like: shape and color	Yes	No	No
Increment	0.5	Increment between two	Yes	No	No
	1	successive assessments	Yes	No	No
	10	50 cubic meter pr ha pr 5 years	Yes	?	No
	100		Yes	Yes	No
Topography	0.5	Elevation in 100 m classes,	?	No	No
	1	Aspects in 8 categories and slope in 10% classes, Relies in plane, convex and concave	?	?	No
Spatial patch arrangement	0.5	Dominance, contagion, fractal dimension etc.	Yes	No	No
	1		Yes	?	No
	10		Yes	Yes	No
	100		Yes	Yes	No

Table 3.—Potential of Remote Sensing for mapping forest attributes.

Attribute	Potential of using EO-data[1] Optical data 1994	Optical data 1996	Active microwave data 1994	Active microwave data 1996	Operationality[2]
Forest / non-forest	2	2	4	3	1
Coniferous / broad-leaved	2	2	4	4	1
Broad-leaved genus	4	4	4	4	3
Coniferous genus	3	3	4	4	2
Biomass and volume	3	3	4	4	2
Closure	2	2	4	4	2
Stage of forest development	3	3	4	3	2
Spatial diversity - fragmentation	2	2	4	3	3
Hydrological conditions	4	4	3	3	3
Infrastructure	3	3	4	4	2
Topography	1	1	2	2	2
Drastic & rapid changes	1	1	4	3	2
Slow & gradual changes	2	2	4	3	3

[1]Potential: 1 = very high; 2 = high; 3 = moderate; 4 = poor.
[2]Operationality (at a European scale): 1 = operational; 2 = semi-operational; 3 = research.

What is well known however, is that the conventions on bio-diversity and sustainable development of forests in the context of rural landscape will be included. This means that there will be a need for much stronger links between the forestry sector and the environmental organizations on the requirements for maintenance of ecological values. These links will undoubtedly benefit from having a harmonized set of definitions when dealing with the forest ecosystems.

As a consequence, in order to incorporate these shifts in policy, the FIRS Project was partly re-focussed at the beginning of 1997 (E.C., 1997). The aim is to accommodate, as far as possible, the new requirements, and to integrate the new needs emerging from EU regulations. The key attributes needed by environmentalists and ecologists had to be incorporated and more efforts are being placed on the mapping and monitoring forests rather than on statistics. Six attributes were selected as prime foci of the FIRS Project. These are, in order of present priority: 1) forest area; 2) other wooded land; 3) structure and composition; 4) volume, biomass and fuel; 5) bio-diversity; and, 6) environmental indicators. Special emphasis should be given to change in these attributes. Some of the major on-going projects dealing with the provision of information on these attributes at the European level are described in §3.

One result of adopting these new developments has been that new challenges come to the surface. There is an urgent need for example, to be able to assess the precision and accuracy of spatial data, and to study Europe, less as a continent of countless administrative divisions, as is done for the more traditional statistical reporting, but more as a geographic entity divided into facets governed both by natural environmental features and socio-economic activities. There is a shift therefore, to utilize natural watersheds in order to allow holistic approaches to studying and understanding entire forest ecosystems and their functions.

On-Going Projects

The research and development (R&D) activities being coordinated, monitored and undertaken within the FIRS Project are outlined in Table 5. Only a small part of the R/D is carried out in-house as the policy of the EC is to involve the Member State institutions as much as possible. The contracted R&D is competitive and to a large extent being financed by other EC services which have specific interests in the results or methods developed. The FIRS Project is also engaged in third party work and participates in Share Cost Actions, whereby studies are selected and 50% funded by the EC. The FIRS Project also assists the Directorate General in the coordination of the forest R&D projects which include components utilizing remote sensing techniques. Two major projects, a "Pilot study in the field of monitoring forested areas" and the "Forest Monitoring in Europe using Remote Sensing (FMERS) Project" deal with assessing the forest attributes identified as priority variables in Europe. These are mapping forest and other wooded land the identification and monitoring of criteria and indicators of structural bio-diversity and biomass estimation.

A project entitled "An AVHRR-based probability map" aims at the provision of a tool for probabilistic mapping of forest areas in Europe using statistics from EUROSTAT. The project with *Regione dell'Umbria* is a support study to the Share Cost Action entitled MARIE-F (Monitoring and Assessment of Resources in Europe – Forest) in which the FIRS project is a partner. All these projects supply input for the in-house R&D (primarily software development and modelling), and assist in providing the necessary background information for the definition of new R&D actions.

Changes in Forest Lands

The objective of the project "Pilot study in the fields of monitoring forested areas" is to develop standardized methods for using remotely sensed data and GIS techniques for the provision of statistical and mapped data on European forest resources. The developments are based on existing experiences and will provide cost-effective tools, for long term monitoring of the structural bio-diversity and major changes of the forested areas of Europe.

Table 4.—The final ranking of the most important attributes

Attribute	Total	Government/ forestry and agriculture	Government/ environment	State forest organization	Industry	Private forest owners	Nature conservation/ environmental organization	Research
	222	49	12	18	27	10	23	49
Decrease of forest land	1	2	1	3	8	4	5	2
Forest land	2	4	5	1	11	4	8	1
Increase of forest land	3	4	5	1	8	4	8	3
Tree species composition	4	6	5	9	5	1	5	6
Protective function and natural conservation	5	1	1	3			1	3
Volume of annual cut	6	8		3	1	1		3
Volume of annual increment	7	10		3	2	1		6
Biological richness and diversity	8	6	1	3			1	10
Changes in growing stock volume	9			9	5	4		6
Protection function	10	2		9			5	
Health condition/ vitality of standing trees	11	10	11				11	10
Growing stock/ stem volume	11	8			5	9		13
Transfer of 'exploitable forest' to other use	13	13	11		14	9		
Exploitable forest	14				4	9		
Age class distribution	15	13	11	9	13	4		
Plantations	16				8			
Silvicultural treatment	17			9		9		
Ownership	18	12				9		
Timber quality/ assortments	19			3	2			
Forest damage (excluding fire)	19						11	
Woody biomass	21							10
Productivity/ site quality	22			9				6
Recreation/ nwgs	23		1				11	
Wildlife habitat	24		5				1	
Potential land for afforestation	25							
Vegetation type	26		5					13
Other wooded land	27		11					
Volume of mortality (natural losses)	28				12			
"Naturalness"	29		5				4	
Changes in above-ground biomass	30							
Total biomass	31							
Recreation/ forest area	32		11					
Landscape/ scenic beauty	33		11				8	
Stand structure (density, layers)	33							
Accessibility	35							
Forest damage by fire	36						11	
Soil	36							

Table 5.—The major studies of the FIRS project.

Activities within the FIRS project		
Contracted R&D projects	**Financed by**	**Consortium**
Pilot study in the field of monitoring forested areas	Directorate General VI, Agriculture, fisheries and forestry	GAF mbH, Germany, JOANNEUM Research, Austria, IVL, Sweden Agence M.T.D.A., France University of Freiburg, Germany
FMERS—1 Forest mapping	CEO Project	VTT Automation, Finland CESBIO, France European Forest Institute, Finland SCOT Conseil, France University of Bologna, Italy (+ nine associates)
FMERS—2 Bio-mass assessment	CEO Project	SSC, Sweden METLA, Finalnd SLU, Sweden ISA, Portugal
AVHRR Forest Probability Map	EGEO	VTT, Finland
MARIE-F- Regione dell'Umbria	EGEO	Regione dell'Umbria Forest Department, Italy
Share cost projects and third party work		
MARIE-F	DG XII—Share cost action	EARS, Holland FIRS, Joint Research Centre, University of Freiburg, Germany METLA, Finland University of Leicester, England CEMAGREF/ENGREF, France
Evaluation of RS data for classifying and mapping the forests of Ireland	Irish Department of Agriculture, Food and Forestry	Coillte Teoranta, Ireland FIRS, Joint Research Centre NRSC, England
Coordination and technical assistence in support to other services of the European Commission		

The study consists of two parts: 1) **Forest monitoring:** The objective here, is to develop and demonstrate a system to identify significant changes in forest cover. The major focus will be on the detection of changes that differ from the normal vegetative succession of the ecosystems. Such changes are for example, related to growth conditions, cuttings and damage. The system will be as independent from ground data as possible. The performance of the system will be based on optical satellite data, and facilitate both large and small-scale monitoring capabilities. 2) **Structural diversity**: The aim of this component is to define, develop and test a system for monitoring the structural diversity of forested areas. Pilot studies are being carried out in the main forest ecosystem regions of Europe. The system will be based on high and medium spatial resolution satellite data, and will be able to discriminate forest patches and classify them according to content and shape. The system is linked to the change detection system developed in the first part of the project.

Forest Monitoring in Europe (FMERS-1) Study

The FMERS project has two parts. Part 1 focuses on the applications of medium spatial resolution EO data for large area forest mapping. Part 2 is a research and development study to evaluate EO data for assessing the above-ground woody biomass of forest and other wooded land in Europe.

The main objectives of the forest area mapping component of the FMERS project are: 1) to investigate the utility of medium spatial resolution satellite data for forest monitoring at a European scale; and 2) to complement the forest data already being collected by the national forest inventories using more traditional methods.

The project will develop and implement methods for using both optical and microwave remotely sensed data for the provision of standardized geo-referenced information (i.e., location, size and composition of forested and other wooded land) and for the provision of statistical information (i.e., area estimates) describing the forests and other wooded lands in Europe. The first part of the study developed the methodology and tested the applicability of the developed method in test sites located in the major forest eco-regions of Europe (Häme et.al., 1998). The second part is focusing on two large study regions, one comprising the Atlantic and Mediterranean forest types, the other the boreal and central-western European temperate forest regions. The aim is to evaluate and quantify the differences both in technical and financial terms between using medium and high spatial resolution satellite data for mapping, and for deriving area estimates of the main forest categories and their composition (groups of main species) of both forest and other wooded land. It is also the aim to clearly identify the potential and limitations of these satellite data to complement the more traditional methods, and to investigate the portability of the methods to the entire continent of Europe for up-dating on a 3 to 5-year basis.

Forest Monitoring in Europe (FMERS-2) Study

The objective of this study is to evaluate remotely sensed data for assessing the above-ground woody biomass, (and volume where feasible), of forest and other wooded land of Europe. The study will develop models which can be used with remotely sensed data and calibrated using ground information, for deriving estimates of above-ground woody biomass for large regions. A boreal and an Atlantic-Mediterranean test-area have been selected to test the approach. In both test areas the model and approach will be investigated at three different pixel resolutions. These are:- I) very high (less than 10 m pixel); II) high (less that 100 m pixel), and III) medium (between 100 and 300m pixel). The very high resolution data will be simulated from air photographs. The analyses of the method-performance in the test areas will be used to evaluate the possibilities of utilizing the approach at a European level.

MARIE-F Study

The FIRS project is a partner in the project's team, but, has at the same time contracted a supporting study to one of the regional forestry authorizations in Italy. The objectives of the study are:- 1) to investigate and develop an objective satellite-based methodology for inventory monitoring of forest timber and forest vitality in Europe using a Forest Light Interaction Model (FLIM) developed by the leading partner at EARS in Holland, and 2) to evaluate the potential of the model to provide uniform and comparable forest baseline data and statistics, for larger areas and at lover costs, in support to national and European forest strategies. The Regione dell'Umbria Forest Department assists the FIRS Project in assessing and evaluating the performance and utility of the outputs from the model once applied to forest land in Umbria.

Evaluation of Remote Sensing Data for Ireland

The in-house developed software package, SILVICS, (McCormick, 1998; McCormick and Folving, 1998) which has been developed under the FIRS project has been improved and adapted to large scale real application within the frame of a third party contract from the Irish Department on Agriculture, Food and Forestry. SILVICS is a user-friendly software package, which runs on most computer platforms, and which provides advanced techniques for the geometric and radiometric correction, structural and statistical analysis, and classification of multispectral satellite imagery. The software is being implemented as part of a national forest inventory in Ireland.

Figure 1 shows the forest classification of a Landsat TM imagery of an Irish test site. The Landsat TM data was classified into eight forest classes, in three main steps: 1) Prior to classification, a standard clustering algorithm (Isodata) was applied to the imagery. Each of the resulting clusters was then assigned a land cover category, based on a subjective visual comparison with available ground information. 2) The "raw" spectral samples (signatures) for each forest class of interest were then "purified", by using the clusters from step 1 to filter out pixels belonging to non-forest categories or to other forest classes. 3) The purified signatures from step 2 were then divided into two independent data-sets. The first set of purified signatures was used to train the four SILVICS classification algorithms, and to classify the image. The second set of purified signatures was then used to assess classification accuracy.

A comparison of the classification accuracies for the four SILVICS image classification algorithms is shown in Table 6. As can be seen the mahalanobis distance and maximum likelihood algorithms gave the highest classification accuracies. It is important to note that the high classification accuracies shown in Table 6 are due to the subjective interpretation of image clusters, which were used to purify the raw signatures (as described in steps 1 and 2 above). Thus, the classification accuracies in Table 6 primarily illustrate the relative performances of the four classification algorithms. An assessment of the true classification accuracy should be determined by ground surveying.

Summary And Outlook

Other studies on the application of remote sensing in forestry have been partly, or in total, financed by the EC under the EU Fourth Framework Programme. These Projects are more directed towards primary research than the ones under the FIRS Project, described above. However, results and methods which can be directly, or at least easily implemented and used for practical purposes will be included in the so-called 'toolbox' being developed for linking the application of EO data into the EFICS. Figure 2 shows this toolbox concept: EFICS will link users with National Forest Inventory data from the Member States, and with metadata bases, Global Forest Networks etc. Most of the data being supplied to the potential user in this way will be statistical and will be enumerated for various statistical units, regions, forest districts and so on. The projects under FIRS and the Share Cost Action projects will contribute to the toolbox assisting the users to retrieve, and to combine information from EO data with statistical information for their various needs. Publicly available software like the SILVICS package

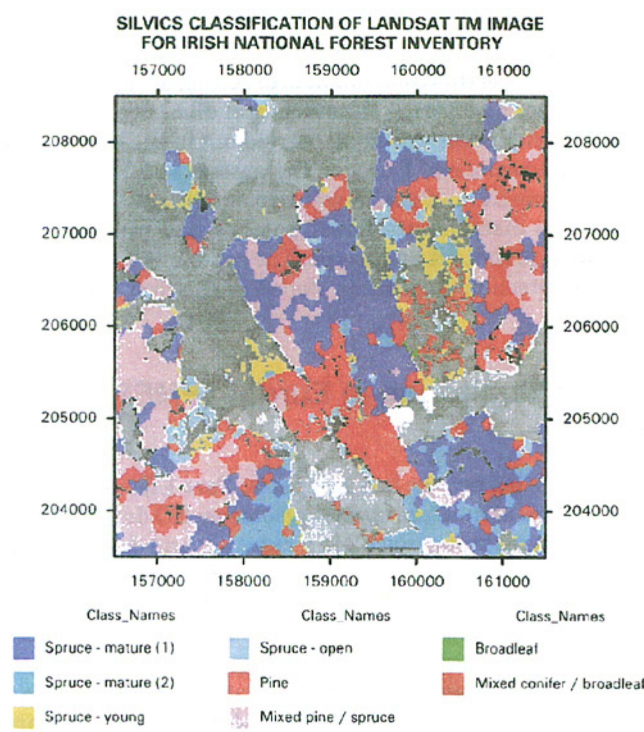

Figure 1.—Map from one of the Irish test sites.

Table 6.—Relative accuracies of SILVICS classification methods.

	Classification accuracy for four selected algorithms (%)			
Forest class	Minimum distance	Mahalanobis distance	Maximum likelihood	Neural network
Spruce–mature (1)	92.5	95.4	93.9	97.6
Spruce–mature (2)	88.1	94.7	94.7	90.5
Spruce–young	97.3	89.8	91.3	87.4
Spruce–open	66.5	84.7	83.0	76.5
Pine	87.9	94.7	89.1	91.5
Mixed pine/spruce	90.5	85.7	93.9	90.2
Broadleaf	95.2	93.6	94.8	95.2
Mixed conifer/broadleaf	86.4	92.5	89.3	91.8
Overall accuracy (%)	87.6	91.3	91.0	89.8

will constitute an important part of the toolbox, but the most important part will consist a of common nomenclature and definitions providing comparable information.

The main requirements are presently to develop modules for assessing the diversity of the forest cover. The EU commitments towards international conventions, such as the Helsinki Process (Finnish Ministry of Agriculture and Forestry, 1993) has shifted the priority away from pure production related indicators towards environmental indicators. This, together with the increasing needs for mapped information for global, regional and national modeling and especially the needs from physical planning, have influenced the priorities of the work program for the next 4 year period.

The forest diversity module follows the outline in figure 3 (McCormick and Folving, 1998). The compositional elements are being supplied through the FMERS Project and the structure and change elements are supplied from the "pilot study in the field of monitoring forested areas". The basic techniques consist of standard image processing procedures, but the processing methods and the nomenclature and, eventually, the verification will follow the findings in the mentioned supporting studies.

As environmental issues are slowly becoming more and more important for the forestry sector, and as this new trend is closely linked to environmental planning and modeling, the challenge for National Forest Inventories are twofold: Firstly, the new bio-diversity indicators and indicators on sustainable development have to be defined. Secondly, spatial data sets need to be prepared as it is not sufficient to know the magnitude of some forest variable or indicators, but, more – it is necessary to know exactly where to find the type, its locations, shape and extension. Forest areas are becoming important as environmental and socio-economic buffers. The FIRS project is accordingly being changed to meet these new challenges. The Project is being merged with activities dealing with watershed management.

The next Framework period will thus be concentrated on the development of criteria and indicators for assessing and monitoring forest diversity at the landscape scale, and on the development of new forest-vegetation typologies and vegetation abundance descriptions suited for run-off and erosion modeling, and for general watershed management.

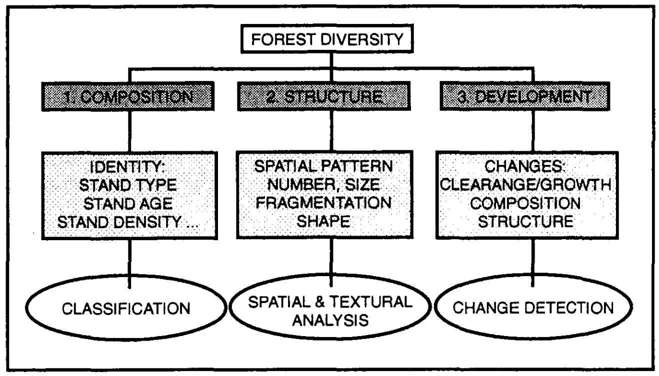

Figure 3.—The forest diversity components of the toolbox being developed under the FIRS project in support to the European Forest Information and Communication System.

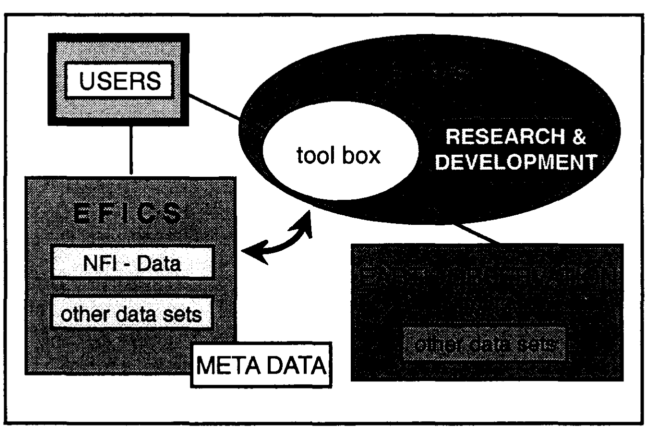

Figure 2.—The "toolbox" concept of the FIRS project. The Project is assisting EFICS in providing the necessary methods for extracting relevant forest information from EO data

References

European Commission. 1997. FIRS Status Report, October 1997. Space Applications Institute, Joint Research Centre of the European Commission. Special reports. S.P.I.97.94.

European Commission. 1997. Study on European Forestry Information and Communication System. Reports on forestry inventory and survey systems. Luxembourg: Office for Official Publications of the European Communities.

Finnish Ministry of Agriculture and Forestry. 1993. The Resolutions and the General Declarations of the Second Minesterial Conference of the Protection of Forests in Europe. Conference on the Protection of Forest in Europe, 16-17 June, 1993, Helsinki.

Folving, S. and Megier, J. 1992. Remote sensing applied in management of the Less Favoured Areas and landscape ecological mapping – experiences from the JRC Collaborative Programme. Proceedings UNESCO MAB Seminar: "Changes in agricultural systems: driving factors, effects on landscapes and ecological patterns. Caen, Normandy, September 9-11, 1991.

Folving, S., P. Kennedy and N. McCormick (1995) EC Initiatives on European Forest Ecosystems Mapping and Forest Statistics. In: Proceedings to the 14th EARSeL Symposium on 'Sensors and Environmental Applications of Remote Sensing', Chalmers University of Technology, Göteborg, Sweden, 6-8 June, 1994.

Häme, T. Andersson, K., Lohi, A; Köhl, M; Päivinen, R; JeanJean, H; Spence, I; LeToan, T; Quegan, S; Estreguil, C; Folving, S. and Kennedy, P. 1998. Validated forest variable maps and estimates across Europe using multi-resolution satellite data: Results of the first phase of the FMERS study p.705-708. In Proceedings to: 27th International Symposium on Remote Sensing of the Environment, 'Information for Sustainability', Tromso, Norway 8-12th June 1998.

Kennedy, P. J. (Ed.) 1997. Application of remote sensing in European forest monitoring. Proceedings, Workshop, Vienna, Austria, 14-16 October, 1996. EUR 17685.

Kennedy, P. J., Folving, S. and McCormick, N. (1994) An introduction to the FIRS Project. In: Proceedings to International Conference on Satellite Technology and GIS for Mediterranean Forest Mapping and Fire Management', Aristotle University, Thessaloniki, Greece, 4-6, November 1993.

Kennedy, P., S. Folving and N. McCormick (1995) European Forest Ecosystems Mapping and Forest Statistics: The FIRS Project. In: Proceedings to International Workshop on 'Designing a System of Nomenclature for European Forest Mapping', European Forest Institute, Joensuu, Finland, 13-15 June 1994. EUR 16113.

Kennedy, P. J., Päivinen, R. and Raihuvua, L. /Eds. 1995. Designing a system of nomenclature for European forest mapping. Proceedings, Workshop, Joensuu, Finland, 13-15 June 1994. EUR 16113.

Köhl, M and Päivinen, R. 1996. Definition of a system of nomenclature for mapping European forests and for compiling a Pan-European forest information system. Space Application Institute, Ispra, EUR 16416 EN.

McCormick, N. 1998. An integrated system for mapping European forestsusing medium- and high-resolution satellite imagery: the SILVICSsoftware. Joint Research Centre, European Commission. EUR Report.(In preparation).

McCormick, N. and S. Folving. 1998. Monitoring European forestbiodiversity at regional scales using satellite remote sensing.In: Assessment of Biodiversity for Improved Forest Planning. Bachmann,P., M. Kohl, R. Paivinen (editors). Kluwer Academic Publishers,Dordrecht, The Netherlands.

SAI Special Publications. 1995. Regionalization and stratification of European forest eco-systems. EC JRC Space Applications Institute Special Publications, S.PI 95.44.

Assessment of Rangeland Health and Resource Condition Through Ecological Classification and Predictive Vegetation Modeling[1]

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Abstract—Ecological classifications of potential and existing vegetation patterns are of particular importance to assessments of ecosystem health for at least two reasons: 1) they provide a useful framework for summarizing resource information from disparate sources, and 2) they can be mapped across large areas by using techniques that integrate remote sensing, geographic information systems, and ecological modeling. In this paper, we describe methods for mapping potential and existing vegetation in rangeland environments based on previous research conducted within a mixed grass prairie ecosystem of western North Dakota, U.S.A. We also illustrate how the intersection of these thematic layers can be used to derive indices of rangeland health and resource condition. Two examples are provided—total biomass production and year-long cattle forage production.

Most assessments of rangeland health within the United States rely on measures of current landscape conditions (e.g., vegetation and soil properties) collected from field plots in a random, grid-based sampling design (Burkart et al. 1994; National Research Council 1986; USDA 1993; Woudenberg and Farrenkopf 1995). Interpretation of such data is complicated, however, because: 1) the attributes collected for field plots often vary between inventory programs; 2) methods for extrapolating plot data across large areas are seldom developed; and 3) "natural" reference conditions cannot be established readily from plot data.

Ecological classifications of potential and existing vegetation environments provide a useful framework for summarizing resource information from disparate sources (Jensen et al. 1991; Host et al. 1996; Scott and Jennings 1998), and they can be mapped across large areas by means of remote sensing, geographic information systems, and ecological modeling technologies (Franklin 1995). Such maps facilitate rapid and cost-effective assessments of ecosystem health because they provide a basis for describing current conditions, "natural" baseline reference conditions, and potential resource values.

The primary objective of this paper is to describe how two fundamental ecological map themes, potential and existing vegetation, can be intersected to create novel information and indices useful for monitoring rangeland resource conditions and health. We present derived maps of rangeland health indices that demonstrate how a spatially explicit use of ecological classifications can be more informative than variables derived from traditional, site-based techniques. This paper synthesizes previous research on biophysical modeling of potential vegetation patterns (Jensen et al. 1998a), use of satellite imagery and potential vegetation to map existing vegetation patterns (Winne et al. 1998), and the assessment of rangeland health based on ecological classifications (Jensen et al. 1998b).

Study Area

This study was conducted within the Little Missouri National Grasslands (LMNG) of western North Dakota (Fig. 1), an area of approximately 809,380 ha that is managed primarily by the USDA, Forest Service, Custer National Forest, for cattle grazing, oil and gas leasing, wildlife habitat, and recreation. Terrain is diverse, and vegetation patterns are characteristic of the mixed grass prairie region of the Northern Great Plains (Bailey 1995). Dominant plant species include western wheatgrass (*Agropyron smithii*), green needlegrass (*Stipa viridula*), needle and thread grass (*Stipa comata*), blue grama (*Bouteloua gracilis*) and threadleaf sedge (*Carex filifolia*). Various broadleaf and coniferous trees and shrubs are found on steep north slopes, in narrow drainages and draws, and in wide valleys along streams and rivers. The initial list of potential vegetation types considered for biophysical modeling in this study included six grassland, six shrubland, and six woodland habitat types (Table 1). Further details can be found in Jensen et al. (1998a).

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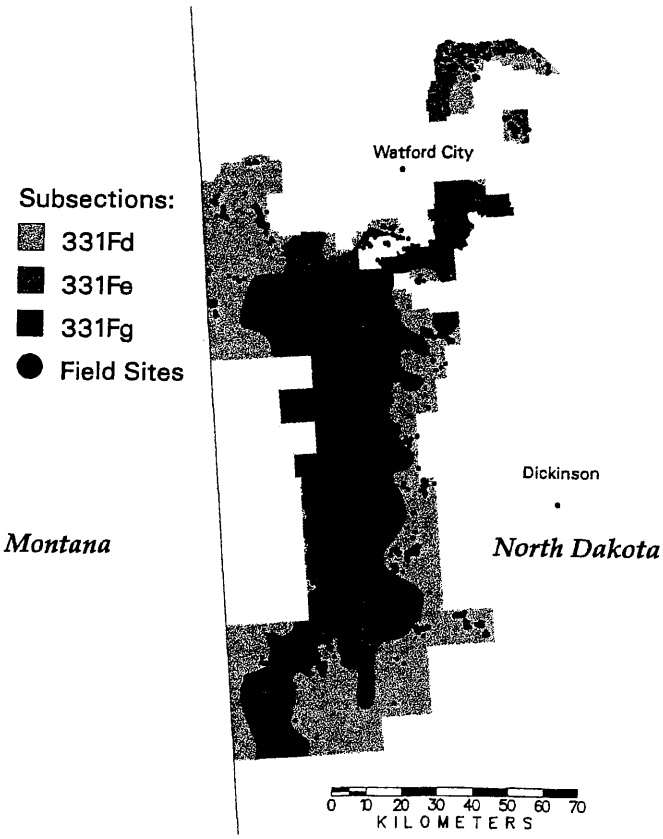

Figure 1.— Generalized display of the field plots used in describing known habitat type locations within the Little Missouri National Grasslands, stratified by geoclimatic subsections.

Methods

Potential vegetation was mapped according to habitat type, where a given combination of diagnostic plant species (e.g., *Agropyron smithii / Stipa viridula*) represents a unique environment for management (see Daubenmire 1968; Pfister et al. 1977). Existing vegetation was mapped by land cover type (e.g., low cover grasslands); additional analyses were conducted at the more detailed level of dominance types, which are defined by the dominant plant species within specified layers of vegetation at a site (e.g., Idaho fescue/ bluebunch wheatgrass).

Characterization of Field Plots

A total of 2,617 field plots were collected by Custer National Forest personnel between 1987-1996 for a variety of objectives, including resource inventories, development of habitat type and seral plant community classifications, and ground-truth sampling for mapping land cover. Although sampling designs differed, all plots were collected according to standardized procedures outlined in the Ecological Inventory and Analysis Guide of the USDA, Forest Service, Northern Region (USDA-FS 1988). Field plots were 0.18 ha in size and were located without preconceived bias (Mueller-Dombois and Ellenberg 1974) on representative habitat types and dominance types across the landscape. Data collected at each plot included: general environmental characteristics (e.g., slope, aspect, elevation, geology, landform, landform position), production by lifeform, canopy cover by lifeform, ground cover, canopy cover and plant height by species, and

Table 1.—Listing of the 18 primary habitat types (potential vegetation environments) identified within the Little Missouri National Grasslands. This list reflects a synthesis of habitat types as described by Hirsh and Baker (1984), Girard et al. (1989), Hansen et al. (1984), and Jensen et al. (1992). Habitat types denoted with an (x) are those identified in the final discriminant analysis of potential vegetation environments stratified by lifeform (grasslands, shrublands, woodlands) and subsection.

Habitat Type	Missouri Plateau	Missouri Breaks	Little Missouri Badlands
Grassland Habitat Types			
Agropyron smithii_Stipa comata	X	X	X
Agropyron smithii_Stipa viridula	X	X	X
Agropyron smithii_Stipa viridula-Bouteloua gracilis	X		X
Andropogon scoparius-Carex filifoilia			
Calamovilfa longifolia-Carex			
Stipa comata-Carex filifolia	X	X	X
Shrubland Habitat Types			
Artemisia cana-Agropyron smithii	X	X	X
Artemisia tridentata wyomingensis-Agropyron smithii	X		X
Juniperus horizontalis-Andopogon scoparius	X	X	X
Rhus aromatica-Agropyron spicatum			X
Rhus aromatica-Muhlenbergia cuspidata	X	X	X
Sarcobatus vermiculatus-Agropyron smithii			
Woodland Habitat Types			
Fraxinus pennyslvanica-Prunus virginiana			X
Fraxinus pennsylvanica-Symphoricarpos occidentalis	X		X
Fraxinus pennsylvanica/Ulmus americana-Prunus virginiana	X	X	
Juniperus scopulorum-Oryzopsis micrantha	X		X
Populus deltoides-Juniperus scopulorum (CT)			X
Quercus macrocarpa-Prunus viriginiana	X	X	

geographic location (latitude, longitude). For 1296 plots, habitat types were determined based on floristic and abiotic characteristics following an hierarchical dichotomous key developed for the study area by Jensen et al. (1992); existing vegetation was assessed for all 2617 plots and assigned to one of 94 land cover types (Redmond et al. 1997).

Mapping Potential Vegetation

A map of potential vegetation (habitat type) was developed by: 1) delineating appropriate biophysical strata for modeling; 2) developing rule sets through multivariate statistical analysis to predict potential vegetation for all appropriate strata; and 3) extrapolating these rule sets to create a continuous map of habitat types at 30 m resolution (Jensen et al.. 1998a).

First, each field plot was assigned nine climatic (Waltman *et al.* 1997), six topographic, and seven spectral variables (Table 2) using ARC/INFO Geographic Information System (GIS) software; these were then used as predictor variables for modeling potential vegetation. To facilitate development of predictive rule sets, plot data then were stratified by geoclimatic subsection (Fig. 1; Nesser et al. 1997), and by lifeform of existing vegetation (i.e., grasslands, shrublands, and woodlands) as mapped previously for the study area (Redmond et al. 1997). Nine groups resulted; Table 1 outlines the habitat types modeled within each one.

For each group, stepwise multivariate analysis of variance test (MANOVA) was used to determine which variables (Table 2) best predicted the habitat types associated with each field plot. Variables that significantly ($P<0.01$) reduced Wilks' Lambda in the above stepwise MANOVA analysis were then used to compute Fisher canonical discriminant functions for predicting habitat types in each stratum. Again for each group, classification accuracy was assessed using a jackknife procedure (Norusis 1985). Using the Fisher functions, predicted habitat types were mapped at 30 m resolution.

Table 2.—List of raster based biophysical environment predictor variables used in potential vegetation modeling.

Variable symbol	Variable name
Climatic variables	
CST_AMDX	Annual moisture surplus/deficient (mm)
CST_BIO5	Biological window (days) at 5 °C
CST_BIO8	Biological window (days) at 8 °C
CST_FFPX	Frost-free period (days)
CST_GDD	Growing degree days at 10 °C
CST_MAAT	Mean annual air temperature (°C)
CST_MSDX	Mean summer moisture deficient (mm)
CST_PET	Potential evapo-transpiration (mm)
CST_SRPG	Soil ratings for plant growth
Topographic variables	
TSI	Terrain shape index
Ele	Elevation (m)
Flat	No solar aspect class (slopes < 5%)
High	High solar aspect class (aspect 135°- 315° and slopes > 5%)
Low	Low solar aspect class (aspect 316° - 134° and slopes > 5%)
Slp	Slope (%)
Satellite imagery variables	
MNDVI	Modified normalized vegetation index
TM1	Landsat thematic mapper band 1 (blue, 0.45 - 0.52 μm)
TM2	Landsat thematic mapper band 2 (green, 0.52 - 0.60 μm)
TM3	Landsat thematic mapper band 3 (red, 0.63 - 0.69 μm)
TM4	Landsat thematic mapper band 4 (NIR, 0.76 - 0.90 μm)
TM5	Landsat thematic mapper band 5 (MIR1, 1.55 - 1.74 μm)
TM6	Landsat thematic mapper band 6 (thermal, 10.4 - 12.5 μm)
TM7	Landsat thematic mapper band 7 (MIR2, 2.08 - 2.35 μm)

Mapping Existing Vegetation

Existing vegetation was mapped in two general stages (Winne et al. 1998): polygons first were delineated through an image segmentation process, then a land cover label was assigned to each polygon through supervised classification (Table 3). The entire process relied on several sources of digital data, including potential vegetation, ground-truth data, and two Landsat Thematic Mapper (TM) images. Further details about the land cover mapping process can be found in Winne et al. (1998).

Because maps of existing vegetation derived from satellite imagery do not always meet the needs of research and management, we explored refinement of the land cover classification to better match the needs of potential users. Working with the field plots that were used to drive the classification, we stratified four grassland cover types by

Table 3.—Procedure for classifying existing vegetation and land cover (Winne et al. 1998).

Delineate polygons

- Unsupervised classification of Landsat TM data, seeding the first loop with potential vegetation, to create *unsupervised classification image*.
- Principal components analysis of Landsat TM data, and subsequent textural filter: Create *first principal component image* and apply a filter to create *structure image.*
- Aggregate pixels into polygons of specified minimum mapping unit: Using the *structure image* as a mask, run sequential MERGE programs to create *merged image* from *unsupervised classification image.*

Label polygons

- Convert *merged image* to ARC/INFO GRID format: Identify individual polygons in *gridfile*; for each, add attributes to use in supervised classification (mean values for all TM bands, elevation, aspect, and slope).
- Supervised classification of polygons in *gridfile*: Assign cover type labels to unsampled polygons based on attribute similarity with polygons sampled by field plots (n = 2617).
- Stratify existing vegetation by potential vegetation to create an additional set of labels.

potential vegetation, then compared the types before and after stratification (Winne et al. 1998).

Rangeland Health and Condition Ratings

To construct ratings of resource condition and ecological integrity, 1296 field plots were summarized according to site, soil, and vegetation attributes for selected ecological classification groupings. Resource value ratings, such as forage production, hiding cover, structural cover, and fire behavior, then were calculated for each plot from vegetation measurements (Jensen et al. 1998a). Summary tables were constructed from the plot data for each of three classification schemes—potential vegetation, existing vegetation, and existing vegetation stratified by potential vegetation (hereinafter termed "refined existing vegetation"). For each of the potential vegetation types, summaries of potential natural communities (or late seral vegetation expressions) were constructed. In a similar manner, summary tables were constructed for each existing vegetation type. Association of the known habitat type membership for each field plot with its predicted cover type facilitated development of a more refined classification of existing vegetation. This process increased the number of existing vegetation classes from 26 to approximately 150, and greatly improved the ability to display differences in resource condition and ecological integrity across the study area (Winne et al. 1998). Landtype association polygons (1:100,000 scale) were used as a base for generalizing both potential and refined existing vegetation patterns, as well as their associated ecological classification information (Jensen et al. 1998c).

Results and Discussion

Potential Vegetation Map

Figure 2a illustrates the map of predicted habitat types at 30 m resolution for a small portion (13,287 ha) of the study area ≤ the Bullion Butte 7.5' quadrangle. Seventeen habitat types were mapped in this area (including water and nonvegetated lands). Grassland habitat types were well distributed and formed the landscape matrix, occupying 65% of the quadrangle. Shrubland habitat types were predicted to occur on about 14% of the quad, and often were associated with more dissected topography. Woodland habitat types covered about 12% of the area, and were found primarily in draws and riparian areas.

For the entire study area, accuracy of the habitat map was relatively high (Jensen et al. 1998a) as compared to other studies using similar discriminant analysis procedures (Franklin et al. 1989, Franklin and Wilson 1991, Jensen et al. 1990, Lowell 1991). Predictions of habitat types based on biophysical environment variables (Table 2) were consistently more accurate within woodlands (70-100%) as opposed to shrublands (62-100%) and grasslands (54-77%) across all three subsections of the LMNG. Accuracy values also varied by subsection; across all three lifeforms, accuracy was highest in the Missouri Breaks, followed by the Missouri Plateau and the Little Missouri Badlands subsections.

Although a 30 m resolution habitat type map (Fig. 2a) can provide a valuable base map for land use planning (Jensen 1991, Jensen et al. 1998c), management does not usually occur at such a fine resolution. Thus, it is often necessary or desirable to generalize this fine-scale information to make it more effective for land use planning. In Figure 3, we illustrate how this can be done by associating the 30 m habitat type data for the entire LMNG with broad-scale ecological units (landtype associations).

Existing Vegetation Map

Within the study area, 382,121 patches were mapped; each was assigned one of 32 land cover types (Table 4). Mean thematic accuracy of the cover type map was assessed at 74.4%, as compared to about 60% for an earlier map that did not incorporate potential vegetation (Winne et al. 1998). Nearly half (48%) of the study area was mapped as grasslands; shrublands and woodlands covered 19% and 11% of the area, respectively. Also, a noteworthy proportion (19%) of the area was mapped as agricultural lands. Figure 2b illustrates land cover within the Bullion Butte quadrangle, where 28 of the 32 cover types were mapped. Within Bullion Butte, distributions were generally similar to those for potential vegetation, but patches were smaller and landscape patterns more fragmented. As with potential vegetation, grasslands dominated the Bullion Butte landscape, occupying 60% of the area, followed by shrublands at 22%, woodlands at 8%, and agricultural lands at 4%.

Looking at numbers of patches, nearly all (96%) were mapped as natural vegetation cover (i.e., not urban, agriculture, water or cloud cover types); in terms of area, however, natural vegetation comprised only 80% of the study area. Mean patch size for all types was 4.07 ha, but areas of urban, agriculture, water, and clouds tended to occur in substantially larger patches than the natural vegetation cover types ($\bar{x}$ = 19.3 ha vs 3.4 ha, respectively). This points to the importance of maintaining relatively fine-scale data when natural land cover patterns are of interest: our ability to draw such distinctions between natural vegetation cover and anthropogenic/unvegetated types suggests that in the move from pixels to polygons, we have not lost the ability to describe patterns of ecological importance.

Although capturing pattern is critical, adequately detailed classification of vegetation types is equally important. When plots assigned to four grassland cover types were stratified by potential vegetation, the resulting 13 plot groupings appeared to have more narrowly defined environmental ranges than the original four (Jensen et al. 1998b). In general, for the 13 types, between-class variability in composition of dominance types was reduced as compared to the between-class variability in composition for the original four grassland cover types. The refinements obtained through stratification offered potential improvements to interpretations of current vegetative conditions; for example, differences in graminoid production were apparent between the 13 grassland types, but not the original four (Winne et al. 1998b). Thus, we suggest that existing and potential vegetation should be considered in concert when describing a landscape. To date, however, our stratification has been plot-based. Although taking the next step and spatially stratifying existing vegetation by potential vegetation is a simple GIS operation, interpreting the stratified map is not

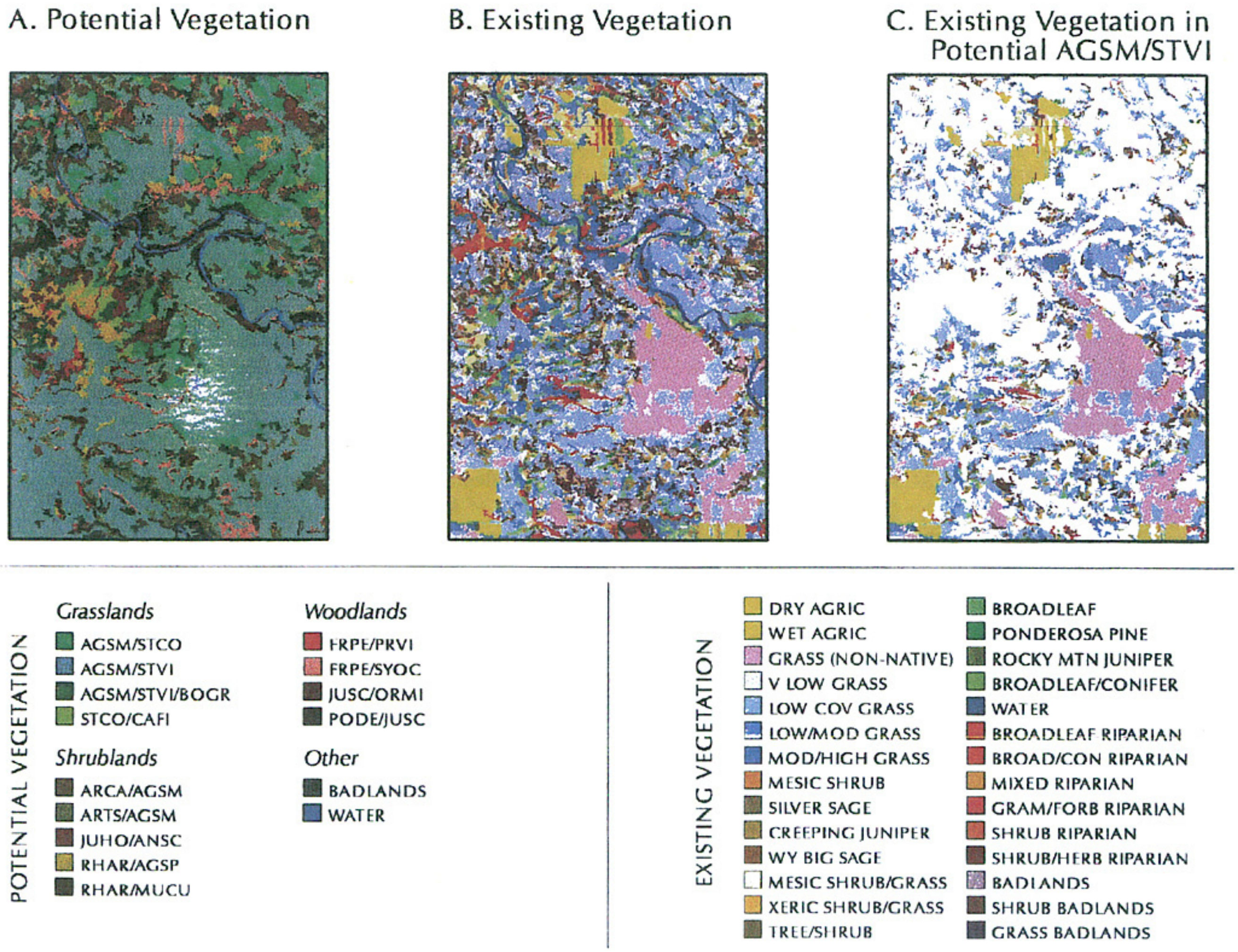

Figure 2.— For the Bullion Butte 7.5' quadrangle, illustration of a) potential vegetation (habitat type); b) existing vegetation (cover type); c) existing vegetation for the *Agropyron smithii/Stipa viridula* habitat type (AGSM/STVI), which occupies 56% of the quadrangle.

necessarily straightforward. Nonetheless, some interesting patterns emerge. For example, the *Agropyron smithii / Stipa viridula* habitat type, which occupies 56% of Bullion Butte quadrangle (Fig. 2c), has largely been converted to agricultural lands and non-native grasses. If conservation of this grassland habitat type were a priority, a map of existing vegetation within the type (as shown) could be used to identify potential locations for reserves and to otherwise direct management decisions.

Rangeland Health and Ecological Integrity

In a more detailed study, Jensen et al. (1998c) derived three indices of ecological health and integrity, along with three resource value ratings, which suggested some departure from reference conditions in the LMNG, particularly for shrublands (ecological integrity) and woodlands (resource value). Rather than repeat these here, we will illustrate the process for two types of index ratings, ecological integrity and resource value, and present one example for each. We reiterate that, in practice, multiple measures are critical for accurate and reliable interpretations.

Ecological Integrity Ratings—Indicators of rangeland ecological integrity or sustainability are commonly based on those features (or measurable surrogates) that directly relate to the long-term soil productivity and plant demographics at a site (National Research Council 1994). For this example, we chose total biomass production as a measure of ecological integrity and a surrogate for long-term soil productivity (Fig. 4).

Interpretation of ecological integrity ratings is influenced by the level of generalization used to display such relations. For example, summarized at a broad level (i.e., across all lifeforms), and based on total biomass production alone, the ecological integrity of the study area does not appear to be at risk: current conditions are similar to reference conditions. This interpretation is not surprising because the grassland settings of the LMNG are likely to drive overall impressions; they represent a majority of the area, and grassland soils are highly resilient to herbivory (Jensen et al. 1992). Shrublands and woodlands, however, which are relatively limited in spatial extent, are selectively utilized by livestock such that their ecological integrity may not be adequately represented in a generalization of lifeforms by landform setting.

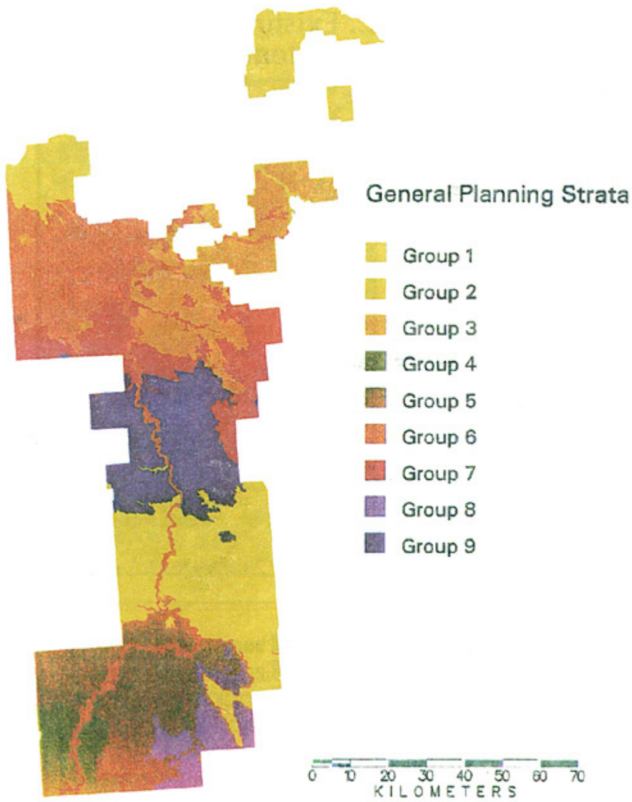

Figure 3.— Generalized potential vegetation settings of the Little Missouri National Grasslands appropriate to regional and subregional scale ecological assessments and land use planning activities.

Viewed by lifeform (Fig. 4), shrubland settings display the largest departure from reference conditions, followed by grasslands and woodlands. Woodlands, with their high proportion of woody biomass, might be expected to align most closely with reference conditions. The fact that shrubland settings consistently show the lowest ecological integrity relative to undisturbed reference conditions suggests that current (or past) grazing systems might have had an impact on the long-term sustainability or resilience of these systems. This interpretation, however, needs to be tested by additional field sampling; we offer it only as an example of how one might interpret this rating of ecological integrity.

Class ratings like the one presented in Figure 4 also can be used as efficient starting points for stratified, random sampling designs to support subsequent field assessments of ecological indicators (e.g., soil compaction, erosion, plant vigor). For example, because changes in total biomass production are probably correlated with other ecological indicators, the four classes displayed for total biomass production in shrublands could be used as an initial stratification for more detailed ecological condition assessments of shrubland health. Random selection of landtype association polygons by these strata in subsequent field sampling could reduce the number of samples required, because between-polygon variability with respect to ecological indicators may be reduced. Stratified, random sampling designs have proven effective in other ecological assessment efforts (Austin and Heylingers 1989, 1991; Bourgeron et al. 1994, Engelking et al. 1994), and should be considered for future assessments of rangeland health.

Resource Value Ratings—Ratings of resource value are commonly used in rangeland health assessments (National Research Council 1994, RISC 1983) to describe the value of current vegetative conditions for various resource uses. Calculation of these ratings is made by contrasting the current vegetative properties of a potential vegetation environment to those for a desired plant community for that environment. In this study, we used the potential natural community (or late seral dominance type) as the desired plant community for a habitat type in calculating resource value; in most cases, these dominance types possess the highest value for a variety of resource uses (Jensen et al. 1992).

We selected year-long cattle forage production as an example of a resource value condition rating for the study area (Fig. 5). This was calculated for each landtype association polygon based on a proportioning of individual plant species production values by a forage preference value rule set. When summarized across all lifeforms, year-long cattle forage production is highly similar to reference conditions (Fig. 5). When individual lifeforms are examined, however, woodlands show rather large departures from reference conditions, and grasslands closely follow reference conditions. We assume that two reasons are responsible for the fairly high similarity to reference conditions for most grassland environments in the LMNG: 1) as mentioned before, grassland soils in the study area are highly resilient to herbivory; and 2) numerous crested wheatgrass (*Agropyron cristatum*) seedings have been established across the study area, and these have high value for year-long cattle forage production. Because grasslands are widely distributed in the LMNG, they dominate the overall picture in terms of year-long cattle forage production, such that without stratification, the low values in woodland settings would not have been apparent. Furthermore, if interpretations were based solely on total biomass production, woodlands might appear to be in the best ecological health of the three lifeform settings. Simply considering another rating can dramatically alter interpretations; again, we emphasize the need to consider multiple measures of ecological integrity and resource value.

Management Implications

Accurate maps of both potential and existing vegetation are required if the ecological classification approach described herein is to be used effectively in future studies. With this in mind, we offer three recommendations to readers contemplating the use of these methods. First, the techniques used to produce each map—discriminant analysis for potential vegetation, and image segmentation coupled with supervised classification for existing vegetation—are data-hungry, and require large numbers of field plots if they are to produce satisfactory results. Second, consideration of scale is a critical aspect of the mapping process. To successfully map vegetation patterns of interest, the characteristic range of landscape patch sizes to be mapped must match

Table 4.—Total number of patches, mean patch size (ha), and total area (ha) mapped for land cover types in the study area, shown as edgematched from two classified Landsat TM scenes (Winne et al. 1998).

	Cover type	# Patches	Patch size	Total area
1100	Urban or developed lands	10	62.93	629
2010	Agriculture-dry	7,474	20.05	149,843
2020	Agriculture-wet	6,912	20.05	138,557
3111	Non-native grass	12,021	4.73	56,891
3130	Very low cover grasslands	22,530	2.11	47,498
3140	Low cover grasslands	49,305	7.13	351,515
3150	Low/moderate cover grasslands	49,075	3.87	189,824
3160	Moderate/high cover grasslands	24,085	2.68	64,629
3210	Mixed mesic shrubs	11,670	2.49	29,007
3309	Silver sage	3,319	2.22	7,370
3313	Creeping juniper	9,151	2.06	18,886
3352	Wyoming big sagebrush steppe	4,499	1.86	8,381
3510	Mesic shrub-grassland complex	34,880	2.83	98,835
3520	Xeric shrub-grassland complex	4,824	1.99	9,579
3530	Tree/shrub complex	7,949	2.09	16,620
4140	Mixed species broadleaf forest	15,336	4.77	73,223
4205	Limber pine	109	1.39	151
4206	Ponderosa pine	532	1.90	1,010
4214	Rocky mountain juniper	8,099	1.96	15,902
4300	Mixed broadleaf/conifer forest	3,084	2.12	6,539
5000	Water	1,643	13.07	21,480
6120	Broadleaf riparian	11,986	3.99	47,803
6130	Mixed broadleaf/conifer riparian	1,358	1.89	2,561
6140	Mixed forest/non-forest riparian	533	1.99	1,061
6210	Graminoid/forb dominated riparian	11,121	2.56	28,428
6310	Shrub dominated riparian	9,580	2.34	22,423
6400	Mixed shrub/herbaceous riparian	12,522	2.15	26,906
7600	Badlands	19,697	1.57	30,876
7601	Shrub badlands	34,642	2.31	79,872
7602	Grass badlands	4,061	1.60	6,491
9800	Clouds	47	10.44	491
9900	Cloud shadow	67	11.76	788
	Total		4.07	1,554,068

reasonably with the grain size of the predictor variables used in modeling. When possible, the variables considered for inclusion in a predictive vegetation model should be tested at multiple spatial scales to determine the most appropriate grain size. For example, climate interpolation models (Thornton et al. 1997, Waltman et al. 1997) can be run at 30 m, 90 m, and 1 km resolution to assess the spatial scale at which different climatic attributes influence the pattern of interest. Also with regard to scale, limiting the extent of the area dealt with at one time may be of use; by stratifying a study area into more homogeneous environments, performance can be greatly improved. Third, to facilitate direct testing of assumed relations between biophysical variables and vegetation patterns, gradient-oriented field sampling (Austin et al. 1994, Austin and Heylingers 1991, Bourgeron et al. 1994) should be incorporated in plot selection.

Finally, land managers and conservationists are often faced with difficult decisions to resolve issues of conflicting land use. This is especially true in rangeland settings where the pattern of land ownership is complex, and where there may be strong economic pressures to fully utilize resources on both private and public lands. The ecological classification approach described herein presents several advantages over grid-based site level methods traditionally used to monitor land use and condition on public lands:

- Results are spatially explicit and can be continuously mapped in a standardized manner over mixed ownerships and large geographic areas.
- Existing field data, often collected for different purposes and by different agencies, can be standardized and utilized, thereby saving time and money associated with collecting additional field data.
- Multiple indices can be easily derived and mapped, which, in turn, can facilitate more thorough and reliable evaluations of ecosystem conditions, compared to ones based on just one or two indicators of limited reliability.

For these reasons, we believe this approach deserves wider application for assessing ecosystem health and integrity in other landscapes.

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Literature Cited

Austin, M.P.; Heylingers, P.C. 1991. New approach to vegetation survey design: gradsect sampling. In: Margules, C.R.; Austin, M.P., eds. Nature conservation: cost effective biological surveys and data analysis. Melbourne, Australia: CSIRO: 31-36.

Figure 4.—Total biomass production class ratings for the Little Missouri National Grasslands, expressed as the percent difference between current and reference conditions.

Austin, M.P.; Smith, T.M. 1989. A new model for the continuum concept. Vegetatio. 83: 35-47.
Austin, M.P.; Nicholis, A.O.; Doherty, M.D.; Meyers, J.A. 1994. Determining species response functions to an environmental gradient by means of a beta-function. Journal of Vegetation Science. 5: 215-228.
Bailey, R.G.; Jensen, M.E.; Cleland, D.T.; Bourgeron, P.S. 1994. Design and use of ecological mapping units. In: Jensen, M.E.; Bourgeron, P.S., eds. Ecosystem management: principles and applications: eastside forest ecosystem health assessment. Gen. Tech. Rep. PNW-318. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 2: 101-112.
Bailey, Robert G. 1995. Description of the ecoregions of the United States 2d ed. rev. and expanded (1st ed. 1980). Misc. Publ. No. 1391 (rev.). U.S. Department of Agriculture, Forest Service, Washington, DC. 108p. with separate map at 1:7,500,000.
Burkart, M.R.; Oberle, S.L.; Hewitt, M.J.; Pickus, J. 1994. A framework for regional agroecosystems characterization using the National Resources Inventory. Journal of Environmental Quality. 23(5):866-874.
Cleland, D.T.; Avers, P.E.; McNab, W.H. [and others]. 1997. National hierarchical framework of ecological units. In: Boyce, Mark S.; Haney, Alan, eds. Ecosystem management: applications for sustainable forest and wildlife resources. Yale University Press, New Haven and London: 181-200.
Daubenmire, R. 1968. Plant communities, a textbook of plant synecology. Harper and Row Publishers, New York. 300 p.
DiBenedetto, Jeff P. 1998. Hierarchical relations of ecological classification and mapping systems within mixed grass prairie. Montana State University, Bozeman, MT. M.S. thesis.
Engelking, L.D.; Humphries, H.C.; Reid, M.S.; DeVelice, R.L.; Muldavin, E.H.; Bourgeron, P.S. 1994. Regional conservation strategies: assessing the value of conservation areas at regional scales. In: Jensen, M.E.; Bourgeron, P.S., eds. Volume II: Ecosystem management: principles and applications. Gen. Tech. Rep. PNW-GTR-318. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR: 208-224.
Franklin, Janet. 1995. Predictive vegetation mapping: geographic modelling of biospatial patterns in relation to environmental gradients. Progress in Physical Geography. 19(4): 474-499.
Franklin, S.E.; Peddle, D.R.; Moulton, J.E. 1989. Spectral/ geomorphometric discrimination and mapping of terrain: a study in Gros Morne National Park. Canadian Journal of Remote Sensing. 15: 28-42.
Franklin, S.E.; Wilson, B.A. 1991. Vegetation mapping and change detection using SPOT MLA and LANDSAT imagery in Kluane National Park. Canadian Journal of Remote Sensing. 17: 2-17.

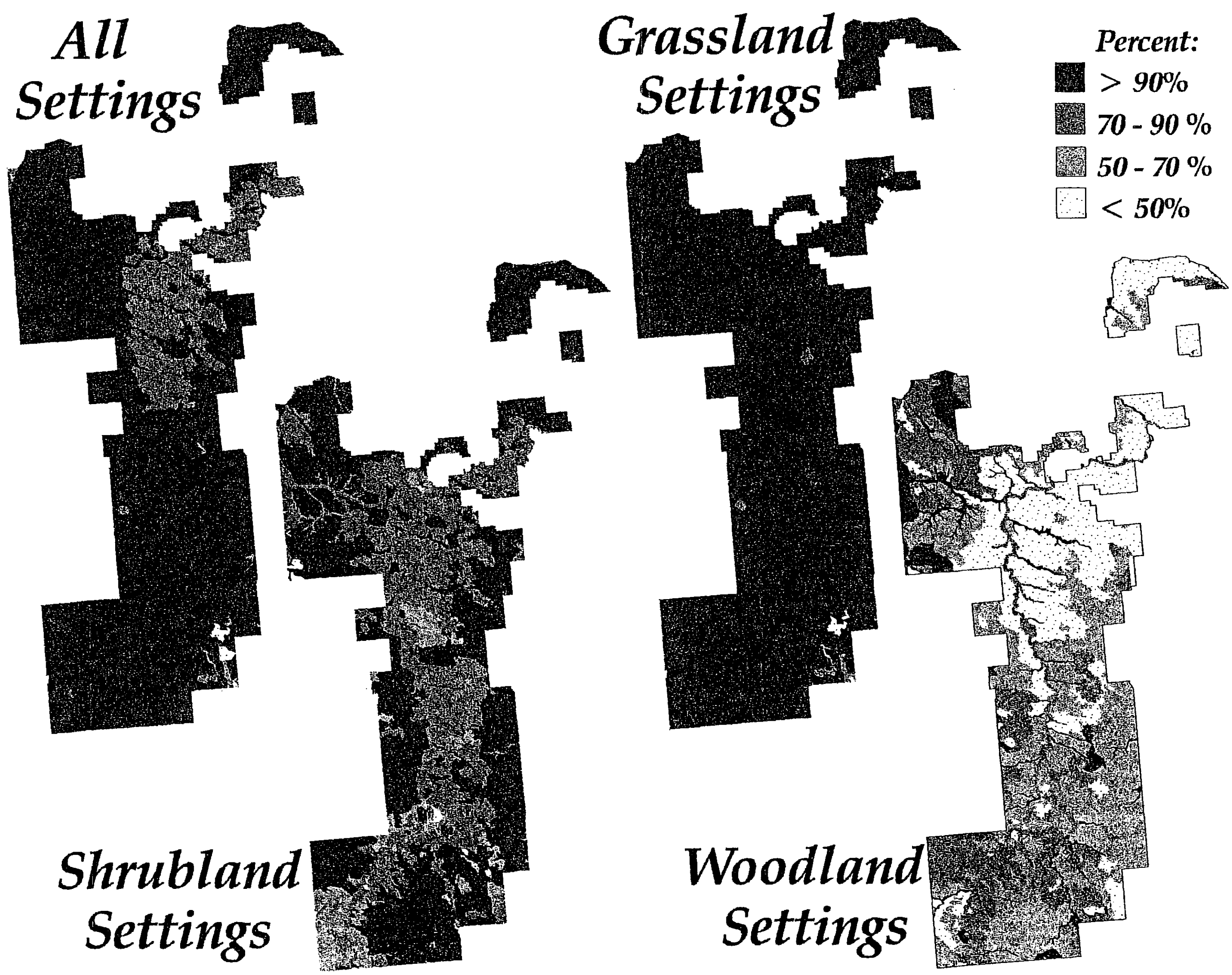


Figure 5.— Year-long cattle forage production for the Little Missouri National Grasslands, expressed as the percent difference between current and reference conditions.

Gauch, H.G. 1982. Multivariate analysis in community ecology. Cambridge University Press, New York.

Girard, M.M.; Geotz, H.; Bjugstad, A.J. 1989. Native woodland habitat types of southwestern North Dakota. Res. Pap. 281. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Exp. Sta., Fort Collins, CO. 36 p.

Hansen, P.L.; Hoffman, G.R.; Bjugstad, A.J. 1984. The vegetation of Theodore Roosevelt National Park, North Dakota: a habitat type classification. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, CO. 35 p.

Hirsh, K.J.; Baker, W.T. 1984. Classification of grasslands and shrublands in southwestern North Dakota. In: Proceedings, North Dakota Academy of Science; April 1984. Grand Forks, North Dakota. The Academy. Vol. 38. 82 p.

Host, G.E.; Polzer, P.L.; Mladenoff, D.J.; White, M.A.; Crow, T.R. 1996. A quantitative approach to developing regional ecosystem classifications. Ecological Applications 6: 608-618.

Hutchinson, C.F. 1982. Techniques for combining LANDSAT and ancillary data for digital classification improvement. Photogrammetric Engineering and Remote Sensing. 48: 123-130.

Jensen, M.E.; Simonson, G.H.; Dosskey, M. 1990. Correlation between soils and sagebrush-dominated plant communities of northeastern Nevada. Soil Science Society of America Journal. 54: 902-910.

Jensen, Mark E.; McNicoll, Cecilia H.; Prather, Martin. 1991. Application of ecological classification to environmental effects analysis. J. of Env. Qual. 20: 24-30.

Jensen, M.E.; DiBenedetto, J.D.; Heisner, F. 1992. An ecological classification for the Little Missouri National Grasslands. Missoula, MT: U.S. Department of Agriculture, Northern Region

Jensen, M.E.; Hann, W.; Keane, R. E. [and others]. 1994. ECODATA—a multiresource database and analysis system for ecosystem description and evaluation. In: Jensen, M.E.; Bourgeron, P.S., eds. Volume II: Ecosystem management: principles and applications. Gen. Tech. Rep. PNW-GTR-318. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR: 192-205.

Jensen, Mark E.; Bourgeron, Patrick; Everett, Richard; Goodman, Iris. 1996. Ecosystem management: a landscape ecology perspective. Journal of the American Water Resources Association. 32: 203-216.

Jensen, Mark; Goodman, Iris; Brewer, Ken. [and others]. 1997. Biophysical environments of the basin. In: Quigley, Thomas M.; Arbelbide, Sylvia J., tech. eds. An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins: Volume 1. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 335 p.

Jensen, Mark E.; BiBenedetto, Jeff P.; Bourgeron, Patrick S.; Brewer, C. Kenneth. 1998a. [In review]. Biophysical modeling of rangeland potential vegetation at a landscape scale. Journal of Ecosystem Health.

Jensen, Mark E.; Redmond, Roland L.; Goodman, Iris A.; Sobecki, Terrence; Bourgeron, Patrick S. 1998b. [In review]. Use of ecological classifications in the assessment of rangeland health. Journal of Ecosystem Health.

Jensen, M.E.; Crespi, M.; Lessard, G. 1998c. A national framework for integrated ecological assessments. In: Cordel, H. Ken; Bergstrom, John C., eds. Integrating social sciences with ecosystem management: human dimensions in assessment policy and management. Sagamore Press, Champaign "Urbana," IL.

Keane, R.E.; Jensen, M.E.; Hann, W.J. 1990. Ecodata and Ecopac: analytical tools for integrated resource management. The Compiler. 8(3): 24-37.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society, Special Publication No. 36. 116 p.

Lowell, K.E. 1991. Utilizing discriminant function analysis with a geographical information system to model ecological succession spatially. International Journal of Geographic Information Systems. 5: 175-191.

Meidinger, D.; Pojar, J. 1991. Ecosystems of British Columbia. Spec. Rep. Series 6. Victoria, BC: Research Branch, Ministry of Forests.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York. 547 p.

National Research Council. 1986. Soil conservation: assessing the National Resources Inventory. Committee on Conservation Needs and Opportunities, Board on Agriculture, National Research Council. National Academy Press, Washington, DC.

National Research Council. 1994. Rangeland health: new methods to classify, inventory, and monitor rangelands. National Academy Press, Washington, DC. 182 p.

Nesser, John A.; Ford, Gary L.; Maynard, C. Lee; Page-Dumroese, Deborah, S. 1997. Ecological units of the Northern Region: subsections. Gen. Tech. Rep. INT-GTR-369. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT. 88 p.

Norusis, M.J. 1985. Statistical package for the social sciences. SPSS, Inc., Chicago, IL.

Pfister, R.D.; Kovalchick, B.L.; Waide, J.B.; Presby, R.C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Exp. Sta., Ogden, UT. 174 p.

Redmond, R.L.; Winne, J.C.; Tady, T.P.; Thornton, M.; Troutwine, J.; Ma, Z. 1997. Existing vegetation and land cover of the Little Missouri, Grand River, and Sheyenne National Grasslands. Final Report, Contract #53-034304-000012, submitted to U.S. Department of Agriculture, Forest Service, Northern Regional Office. Montana Cooperative Wildlife Research Unit, The University of Montana, Missoula. 174 p.

RISC. 1983. Guidelines and terminology of range inventories and monitoring. Report of Range Inventory Standardization Committee. Denver, CO: Soc. Range Manage. 28 p.

Scott, J.M.; Jennings, M.D. 1998. Large-area mapping of biodiversity. Annals of the Missouri Botanical Garden. 85: 34-47.

Soil Survey Staff. 1975. Soil Taxonomy. U.S. Department of Agriculture, Hand. 436, U.S. Gov. Print. Office, Washington, DC.

Thornton, P.E.; Running, S.W.; White, Michael A. 1997. Generating surfaces of daily meteorological variables over large regions of complex terrain. Journal of Hydrology. 190: 214-251.

U.S. Department of Agriculture, Forest Service. 1988. Ecosystem classification handbook, chapter 4 - ecodata sampling methods. Northern Region, Missoula, MT.

U.S. Department of Agriculture, Forest Service. 1991. Ecological classification. In: Ecological classification and inventory handbook, FSH 2090.11. Washington, DC.

U.S. Department of Agriculture. 1993. Soil survey manual. USDA Handbook No. 18. U.S. Government Printing Office, Washington, DC.

U.S. Department of Agriculture, Soil Conservation Service. 1976. National range handbook. Washington, DC.

U.S. Department of Interior, Bureau of Land Management. 1984. National range handbook. Washington, DC.

Waltman, W.J.; Ciolkosz, E.J.; Mausbach, M.D. [and others]. 1997. Soil climate regimes of Pennsylvania. The Pennsylvania State Univ. Agric. Exp. Sta. Bull. No. 873. University Park, PA.

Whitman, W.C. 1978. Analysis of grassland vegetation on selected key areas in southwestern North Dakota. A Report on a Project of the North Dakota Regional Environmental Assessment Program Contract No. 7-01-2. Department of Botany, North Dakota State University, Fargo, ND. 199 p.

Winne, J. Chris; Redmond, Roland L.; Jensen, Mark E.; Hart, Melissa M.; DiBenedetto, Jeff P.; Goodman, Iris A. [In review]. Integrating satellite imagery and potential vegetation to delineate pattern and map existing vegetation in a mixed grass prairie ecosystem. Journal of Ecosystem Health.

Woudenberg, S.W.; Farrenkopf, T.O. 1995. The Westwide forest inventory data base: user's manual. Gen. Tech. Rep. INT-GTR-317. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT. 67 p.

Zonneveld, I.S. 1989. The land unit—a fundamental concept in landscape ecology, and its applications. In: Landscape Ecology. The Hague, Netherlands: SPB Academic Publishing. 3(2): 67-89.

Primer Inventario Nacional de Bosques Nativos[1]

Carlos Merenson[2]
Celina L. Montenegro[3]

Abstract—The area of native forests of Argentina is considered between 35 and 45 million hectares, although its commercial potential is of approximately 15 million hectares. At present the country lacks the necessary information for the design and development of political to achieve conservation and sustainable use of its native forest resources. It is necessary and a high priority to have reliable information, to which will contribute, as a fundamental tool, the realization of the country first National Forest Inventory of Native Forest.

The National Forest Inventory has been implemented, in the flame of the Native Forests and Protected Areas Project, which is an operation agreed with the International Bank of Reconstruction and Development (BIRF) whose executioner is the Secretary of Natural Resources and Sustainable Development (SRNyDS) of the Presidency of the Nation through Loan no. 4085-AR. It will include the native forests of the following fitogeographic regions: Parque Chaqueño; SelvaTucumano-Boliviana; Selva Misionera Bosques Andino-Patagónicos; and Monte y Espinal. The methodology will be on the basis of the following approaches and objectives:

To obtain the situation, delimitation and extension of the different forest types and to generate thematic maps to scale 1:250.000 using LANDSAT5/TM optic images, and in case of faulty information it will be supplemented with SPOT1 and SPOT2 optic images and radar images (RADARSAT).

- To assess forest parameters required for estimate of timber volumes, through the installation of a National Network for sampling.
- To include indicators for Global Evaluation of Forest Resources 2000 (FAO), in forest maps about distribution and condition of the native forests.
- To implement the most uniform sampling design to achieve the same precision level in all fitogeographic regions (error estimate of 10% on the volumes calculated at a probability level of more than 85%).
- To establish a National Network for permanent sampling, that is up to date.
- To establish a Forest Evaluation National System.

Componente A—Generación y Diseminación de Investigación e Información.

Subcomponente—Inventario Nacional de Bosques Nativos y Areas Protegidas y Manejo de la Correspondiente Base de Datos.

Antecedentes

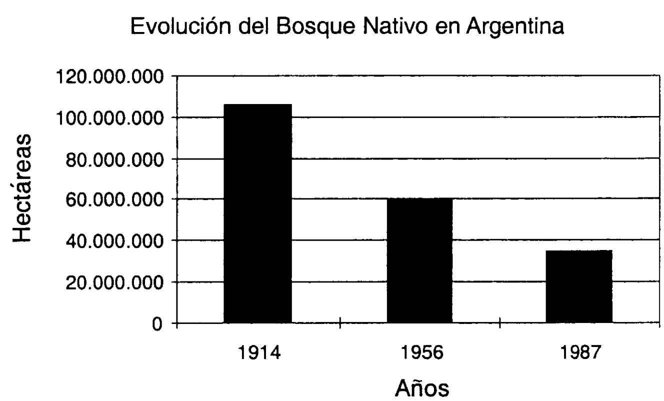
El Proyecto Bosques Nativos y Areas Protegidas es una operación acordada con el BIRF, cuyo ejecutor es la Secretaría de Recursos Naturales y Desarrollo Sustentable de la Presidencia de la Nación.

Para la realización del inventario se ha contratado un consorcio, de acuerdo a los procedimientos que establece el Convenio de Préstamo N° 4085-AR.

Jus{ 'cación

El área boscosa de la Argentina se estima entre 35 y 45 millones de hectáreas y su potencial comercial se estima en aproximadamente 15 millones de hectáreas.

El gráfico nos muestra que en **75 años** la **Reducción** fue de aproximadamente el **66%**, de continuar esta tendencia el **Punto de Extinción** para las diferentes regiones forestales sería el siguiente:



	Punto de Extinción en años	Punto de Extinción al año
Selva Misionera	20	2006-2009
Monte Occidental	38	2024-2027
Selva Tucumano Boliviana	67	2053-2056
Parque Chaqueño	79	2065-2069
Bosque Andino Patagónico	154	2140-2143

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Según criterios técnicos internacionalmente aceptados cuando la proporción de la superficie boscosa de un país, en relación a su superficie territorial, desciende del 25%, deben esperarse hechos negativos, y por debajo del 20%, pueden llegar a producir lesiones graves al medio ecológico.

El País carece de un inventario de Bosques Nativos que permita evaluar las amenazas ambientales sobre los mismos - incluyendo sus implicancias económicas y sociales - y brindar información sobre la cual basar el análisis de las opciones políticas. Sin esta información resulta aventurado desarrollar planes realistas y obtener el concenso político para lograr manejar los recursos naturales en forma sostenible y generar beneficios a toda la comunidad.

Se dispondrá entonces de información confiable sobre el recurso, que permita organizar el uso sustentable del mismo y programar eficientemente esquemas de incentivos para la restauración y conservación forestal.

Objetivos Generales

- Obtener información básica de los recursos forestales nativos del país para la formulación de políticas forestales.
- Crear y mantener actualizada una base de datos de dichos recursos forestales.
- Reforzar la capacidad operativa de la SRNyDS para el manejo de la base de datos.

Los propósitos básicos de esta acción son:

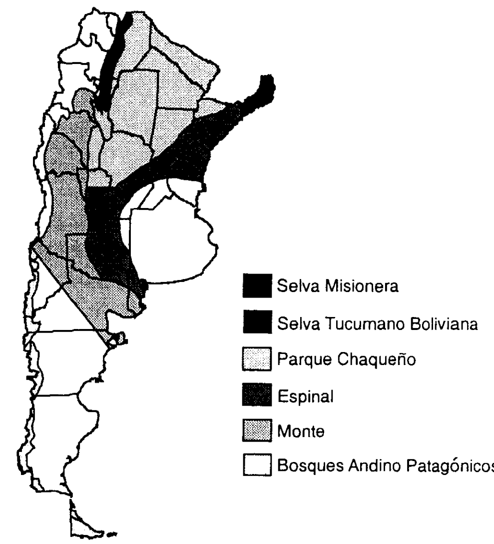
1. Proporcionar información actualizada de los bosques nativos que satisfaga la demanda de tipo estadístico del país y del Mercosur.
2. Constituir una base de datos de fácil acceso y manejo para asistir a la planificación y gestión de los bosques nativos, a escala nacional y provincial.
3. Contribuir a dar cumplimiento a las obligaciones emergentes de los convenios suscriptos por el país en el ámbito de las Naciones Unidas relacionados con la evaluación de los recursos forestales.

Objetivos Específicos

- Obtener información confiable sobre la ubicación, extensión y estado de los bosques.
- Proporcionar información estadística adecuada a los requerimientos de la demanda.
- Crear una base de datos que constituya el Sistema Nacional de Evaluación Forestal
- Proporcionar el marco de referencia a fin de disponer de un sistema de evaluación y monitoreo permanente.
- Aportar las herramientas para una futura política de restauración y conservación de las masas nativas.
- Fortalecer la competencia de la SRNyDS (DRFN) para almacenar, analizar, recuperar, publicar datos e información confiable del bosque nativo.

Regionalización

Regiones del Inventario Nacional de Bosques Nativos



Secretaria de Recursos Naturales y Desarrollo Sustentable

Orden de Prioridad Asignada por Región

Prioridad 1	Parque Chaqueño
	Selva Misionera
	Selva Tucumano Boliviana
Prioridad 2	Bosque Andino Patagónico
Prioridad 3	Monte y Espinal

Datos

En la realización del inventario nacional de bosques nativos se consideró un error del 10% con una probabilidad del 85%, para el volumen calculado a nivel país. Duración del inventario: 36 meses.

Productos Esperados

- Cartografía en formato digital y papel que indique ubicación y límites de los tipos forestales con su estratificación, e identifique las áreas protegidas.
- Superficie de los distintos tipos forestales nativos, discriminando las áreas protegidas.
- Manual de operaciones del inventario.
- Número de árboles por hectárea.
- Area basal por hectárea.
- Volumen por hectárea.
- Distribución de diámetros, por especie y/o grupos de especies.
- Indicadores de regeneración de las especies de interés.
- Indicadores de biodiversidad por región fitogeográfica; del estado de la cobertura vegetal, estado de volumen

existente y estado de áreas forestales dentro de áreas protegidas.

- Instalación de hardware y software para procesamiento digital de imágenes; e implementación de un sistema de información geográfica y su base de datos asociada.
- Publicación de los resultados del inventario forestal nacional.

Conclusiones

El Inventario Forestal Nacional suministrará un diagnóstico real de la situación de los recursos; a partir de allí se podrá formular o revisar la política que permita cumplir con las competencias nacionales sobre el mismo tales como: conservación, restauración, ordenación y manejo sustentable de las masas boscosas nativas. De esta manera el bosque y su biodiversidad cumplirán mejor sus funciones:

Socioeconómicas—el bosque como sistema sustentable de producción y fuente de trabajo tanto en las industrias como en el comercio maderero y no maderero.

Ecológica—el bosque como espacio vital de la flora y la fauna, como fuente de conservación de la biodiversidad.

Protectora—el bosque como moderador hídrico, fijador de suelos, regulador de la atmósfera.

Recreativa—el bosque como lugar de esparcimiento de la población.

Criteria and Indicators of Sustainable Forest Management: the Canadian Initiative[1]

J. Peter Hall[2]

Abstract—In 1993, the Canadian Council of Forest Ministers embarked on an initiative to define, measure, and report on the forest values Canadians want to sustain. This initiative, through multidisciplinary participation resulted in 6 criteria of sustainable forest management. Each criterion has several elements to it. Each element is associated wit one or more indicators that may be used to track progress towards sustainability. Currently the Canadian Forest Service is coordinating the development of a major progress report on these criteria and indicators. This report is slated for release in the year 2000. In doing this major year 2000 assessment of the entire suite of indicators close attention is placed on the near term viability of reporting via these indicators. Can they be routinely monitored? How are monitoring needs being changed to address certain indicators? And which indicators are simply not viable to measure and monitor in the near term? Throughout this exercise, a close relationship has been cultivated with the international Montreal Process for Criteria and Indicators of Sustainable Forest Management of temperate and boreal countries.

Forests are a major consideration in global discussions on sustainable development. Canada accounts for 10% of the world's forest land and almost 20% of global trade in forest products, therefore, decisions and actions with regard to sustainability can have a major impact on global economic, social and environmental systems.

The issue and concept of sustainable development have been popularized globally by the Brundtland Commission's report, "Our Common Future." Sustainable development is defined as "economic development that meets the needs of the present generation without compromising the ability of the future generations to meet their own needs." The concept has greatest application in biological systems; particularly forestry and agriculture. Since the tabling of the Brundtland report, sustainable development has captured the imagination of the public as well as of policymakers at local, national and international levels. Sustainable development is a desirable objective for all individuals, institutions, economic sectors, societies and indeed for the global community at large. The term has stimulated much world wide discussion at the conceptual level, and efforts are now being made to apply it (Maini 1990). The issue has emerged from a growing international realization that current levels of resource use and international inequities were leading to potentially devastating consequences. Sustainable development is a term reflecting human and societal values and needs, and not a term intrinsic to forest ecosystems themselves. It is therefore necessary to identify and define these values before a structure to assess sustainability can be put in place by governments or other institutions.

The role of forests in the biodiversity and climate change conventions negotiated in association with the UNCED process reflect the importance of sustainable forest management. The increasing commitment to environmental stewardship also reflects the view that the environment, including its natural resources, is not an asset inherited from the past but one held in trust for future generations. Consequently, forest-related activities must maintain the productive and renewal capacities of forest ecosystems while protecting a variety of non-timber forest values; aesthetics, wildlife and fisheries habitats, watersheds, and cultural values. Sustainability is supported by a knowledge of the condition of forest ecosystems, and the ability to understand this enables the implementation of adaptive forest management methods. This process then enables policymakers to implement programs to detect the symptoms of damage to forest ecosystems and take appropriate action (Hall and Addison 1990). This paper describes the assessment of sustainability in Canada using two systems of Criteria and Indicators (C&I) for the sustainable management of forests.

Canadian Processes for Assessing Sustainable Development

A formal integration of science and policy develops from necessity. Forest-related issues are growing in number and complexity, while the means to deal with them is declining as both private and public sectors are struggling to reduce expenditures. Furthermore, many global forest issues either have their genesis in scientific discovery or require scientific knowledge or new technologies for their resolution. Policy involves defining the issues for the forest sector, determining what additional knowledge is needed, and bringing together the best information and resources to design programs to address issues (Ottens 1997).

Strong links exist between international developments and science because many global forest policy issues are science-driven; climate change, ozone depletion, changes in biodiversity, sustainable forest management, trans-boundary air pollution all have their origin in science. To a large extent, however, it is not until these issues are perceived by the public as dangers to health, safety, and market competitiveness or access that they become issues of public policy. As a consequence these policy issues require science-based solutions, especially if regulation and legislation are the outcomes of the policy resolutions.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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A framework of criteria and indicators of sustainable forest management is being implemented in many countries as they move from the general goal of sustainable yields to the broader concept of sustainable development. There is a need to define the key elements or values to be sustained, and within each of these criteria, measurable indicators to demonstrate progress toward specific objectives (Anonymous 1995a). This can then provide a focal point for domestic policy development and program orientation, and a common language by which to discuss concepts of sustainable development nationally and internationally.

The Canadian Process

In 1993, the Canadian Council of Forest Ministers (CCFM) embarked on an initiative to define, measure and report on the forest values Canadians want to sustain and enhance. With the support of technical and scientific advisors, the CCFM consulted extensively with officials and scientists from the federal, provincial and territorial governments, as well as with experts from the academic community, industry, non-governmental organizations, the Aboriginal community and various other interest groups (Anonymous 1995b). The results were reflected in "Defining Sustainable Forest Management: A Canadian Approach to Criteria and Indicators" published in March 1995. The development of these C&I termed here, the *Canadian Process*, is an important step in meeting Canada's domestic commitments on sustainable forest management. This commitment to sustainability is supported by a National Forest Strategy endorsed in March 1992 by federal, provincial and territorial governments and by other interested groups including industry, Aboriginal peoples and environmental associations.

Over the years, governments have been rethinking their forest policies to better reflect the principles of sustainable management. Activities range from revising forest legislation to take into account a wide array of forest values, to developing programs that involve the public in ecosystem management plans and resource strategies.

The C&I are intended to provide a common understanding and scientific definition of sustainable forest management. Together they serve as a framework for describing and measuring the state of our forests, for implementing adaptive forest management, and assessing progress toward sustainability. The information is needed to shape forest management policies and to focus research on areas where we need to improve our technology and knowledge. The C&I framework reflects an approach to forest management based on the recognition that forests ecosystems provide a wide range of environmental, economic and social benefits to Canadians and that sustainable forest management demands an informed and participatory public, as well as the best available information and knowledge.

The six sustainable forest management criteria that have been identified include traditional concepts, such as timber values, but go beyond economics to encompass—among others—environmental, social and Aboriginal values (Table 1). Each criterion is subdivided into a number of indicators; a total of 83 have been established to help track progress in achieving sustainable development by balancing environmental, economic and social objectives. No single criterion or indicators is a measure of sustainability on its own, but together they can highlight trends or changes in the status of forests and forest management over time.

Soon after the release of the C&I framework, the CCFM created a task force to report on Canada's ability to measure the various indicators. This task force included representatives from the federal, provincial and territorial governments. Teams of experts and a technical committee representing many forest interests drafted a preliminary on the C&I using data collected from a wide range of sources. The report was then reviewed and approved by the cooperators and contributors (Anonymous 1997a).

Montreal Process

The group known as the Montreal Process Criteria and Indicators for the Conservation and Sustainable Management of Temperate and boreal forests was established following the endorsement of a statement of political commitment known as the "Santiago Declaration." The Montreal Process consists of a set of seven criteria and 67 indicators applicable to temperate and boreal forests for use by respective policymakers at the national level. The Montreal Process Working Group includes: Argentina, Australia, Canada, Chile, China, Japan, Republic of Korea, Mexico, New Zealand, the Russian Federation, the United States of America and Uruguay. These countries cover five continents and together represent 90% of the world's temperate and boreal forests and 60% of all forests. Extensive areas of tropical forests are also included in many of these countries. The countries account for 45% of world trade in wood and wood products and 35% of the world's population (Anonymous 1997b).

Table 1.—Criteria of Canadian and Montreal Processes

Canadian Process (CCFM)	Montreal Process
Conservation of Biological diversity	Conservation of Biological Diversity
Maintenance and Enhancement of Ecosystem Condition and Productivity	Maintenance of Productive Capacity of Forest Ecosystems
Conservation of Soil and Water Resources	Maintenance of Forest Ecosystem Health and Vitality
Forest Ecosystem Contributions to Global Ecological Cycles	Conservation and Maintenance of Soil and Water Resources
Multiple Benefits of Forests to Society	Maintenance of Forest Contribution to Global Carbon Cycles
Accepting Society's Responsibility for Sustainable Development	Maintenance and Enhancement of Long-term Multiple Socioeconomic
Benefits to Meet the Needs of Societies	
	Legal, Institutional and Economic Framework for Forest Conservation and sustainable Management

The seven criteria included in the Montreal Process framework are each defined by indicators to measure progress toward the values defined as sustainable for each of the Criteria (Anonymous 1995a). Six of the criteria and indicators describe forest conditions, attributes, functions or benefits, and strongly resemble the goals, concepts and conditions in the Canadian Process.

The Criteria determined for the two systems reflect similar values desired from forests of the approaches used to assess sustainability (Table 1). The individual elements and indicators differ between the processes, but there is about an 80% overlap. The seventh Criterion in the Montreal Process is a description of institutional factors to enable reporting, and the implementation of sustainable forest management in the various countries (Anonymous 1995a).

Issues Emerging from the C&I Process

The reports completed to date introduce forest ecosystems and forest management in Canada, explaining the area of forest covered, and identify forest-management characteristics affecting sustainability. The C&I are considered in the context of providing information on trends in the status of forests and related values over time, and are based on monitoring programs currently in place. Much of the data required for national reporting are provided through current information systems; other data and methods for reporting need to be developed or improved. Some indicators are expected to evolve as new data, techniques, or research results become available. Where there are currently no reasonable quantitative measures; qualitative or descriptive indicators are used to describe the relationship of indicators to sustainability, or an ability to report on the indicator.

In order to be effective on an international level, C&I must be compatible with similar international processes, while providing detail and precision on national values. National circumstances differ in economic development, patterns of land ownership, population, forms of social and political organization, and expectations of how forests should contribute or relate to society. C&I facilitate international reporting, and provide the framework for international agreements while reflecting national differences in characteristics and descriptions of forests. One result of this reporting process has been the emergence of a number of forest management issues that will influence forest science and forest ecosystem management in the future.

National System of Forest Classification

In Canada, as in most countries, there are systems in place to classify forest and other terrestrial ecosystems. These have been developed for various purposes of land/resource management and have proven generally useful, but tend to be regional in coverage and based on different goals and methods. The need for a national system soon became evident as a result of C&I reporting. The development of a system of classification of the *Forest Ecosystems of Canada* represents a natural extension of ecological land classification work conducted over past decades by federal and provincial agencies. This has been identified as a priority in the National Forest Strategy particularly to improve reporting capability. A baseline description of Canada's forest composition will be established that will provide a fundamental tool for assessing impacts and trends resulting from timber and fire management practices, changes in atmospheric and climatic properties, and introduction of exotic pests and diseases. These plot data could also supplement information from a network of permanent forest inventory plots being currently developed as a component of a new national forest inventory. An important objective of the classification of forest ecosystems is to describe the most common forest ecosystems of Canada and their associated site conditions across climatic gradients. Such a standard ecological framework based primarily on existing vegetation structure and species composition will be suitable for the reporting and assessment of the C&I processes.

It is expected that the project will be a cooperative undertaking among the CFS, provincial and territorial governments, and universities. In order to provide a framework for the discussion of sustainable forest management the concept of *forest type* based on a forest ecosystem classification is used. Ideally, forest type can be expanded beyond tree species groupings to a concept forest ecosystem mapping. At the point at which ecosystems are mapped, the forest type mapping becomes a highly effective tracking of the distribution and abundance of ecosystems and hence, their diversity (Anonymous 1998). Changes in the diversity of ecosystems allows some ability to estimate the potential changes in availability of habitat for species and hence to estimate potential changes in species diversity. Using forest type as a surrogate for ecosystem diversity, for example, relies on the ability to track or predict changes in the nature, extent and distribution of aggregated forest types at national or regional scales. Some benchmark record or historical record of forest type must be used against which to measure the degree of change and repeated measures over time can then indicate expansion, contraction, loss and creation of forest types. The interpretation of changes in the distribution and abundance of forest types can be used as a signal that changes may be occurring in species and genetic diversity of forests. The concept of forest type is basic to the description of many aspects of the condition of forest ecosystems.

National System of Forest Inventory

Canada has had a national forest inventory for several decades based upon the aggregation of the provincial and territorial inventories. These inventories have served the purposes of timber management, a primary responsibility of resource management in provincial governments. In recent decades as forests have become recognized as more than a resource base with many values of importance; the need for a different approach to forest inventory has become apparent. From a national perspective current inventories suffer from a variety of designs, they cannot track change over time, and they do not report on new values, particularly those of socioeconomic significance, non fibre values, etc. Consequently, systems in place for many decades are no longer sufficient to answer current and projected demands.

At the same time, the timber management demands have not disappeared, but rather increased because of the need to maintain the resource base in the face of the many demands on it. Consequently, forest management agencies in Canada are in the process of developing a new plot-based inventory, designed to report over time, a range of values for use in reporting for a number of national initiatives, of which C&I are prominent ones. It is expected that a newly designed inventory can assist materially in reporting on approximately one-third of indicators in both process. Other national reporting requirements are centered on biodiversity, ecosystem preservation and global change, all of which are to be addressed by a new national forest inventory.

Range of Historic Variation & Baseline

It is necessary to understand the changing nature of forests, to identify when change is induced by human intervention, and how this change affects sustainability. When disturbances and stress remain at levels within the range of natural variation and the biological components and processes of the forest are maintained, then forest health will also be maintained since forest ecosystems are inherently dynamic and adapted to stress. Since it is extremely difficult to manage for all species individually, it is necessary to maintain the processes that species have evolved with and are now dependent on. Stresses beyond the limits of tolerance can thus be expected to adversely affect sustainability (Anonymous 1998).

The impacts of forest management activities might create conditions in forests beyond the limits of tolerance of species. Prevention of the introduction of exotic insects and diseases into forests that might cause extensive damage in the absence of natural controls is a key part of sustainable forest management. Air pollution is another anthropogenic stress that is known to impact negatively on forest sustainability.

Several indicators in both processes use the concept of areas of forest affected by agents beyond the range of historic variation. It is difficult to define all the interrelationships and needs of species or processes within an ecosystem, but recognition of historic disturbance regimes and habitat conditions is necessary to provide a framework for interpreting current data and information.

The issue for C&I is to determine what baselines against which assessments can be made. In many areas these are lacking in whole or in part, and new ones must be used. New assumptions must be made against which to compare results from past assessments, and interpretations made for the future. Reporting on C&I will use a mixture of new and old baselines and this will complicate our application of adaptive forest management.

Information Sources

This first C&I report described our present ability to measure the forest values that Canadians want to sustain and enhance. Generally speaking, the most current data available describe timber management because values such as forest type and age, and the incidence of natural and human disturbances have been measured and monitored for many years. Economic indicators, such as employment trends in the forest sector and the value of timber exports, are also reported at the national level. Some indicators, such as the carbon budget, which is measured through computer models, also can be reported on nationally.

In other areas, national and/or quantitative data do not exist. Currently, efforts are underway to determine means of addressing the lack of information on such topics as biodiversity at the genetic level and measures of soil and water quality. Existing data describe the range of disturbances occurring in forests that reflect past, rather than current, practices. This indicates the need for development and monitoring of new indicators.

There are also gaps in data for some socioeconomic indicators. We are presently unable to provide national economic analyses of non-timber values such as the recreational subsistence and Aboriginal use of forests; nor can we fully report on the in-depth public involvement at various levels in planning and monitoring forest practices. Qualitative descriptions or case studies are used to provide some level of understanding of the status of indicators that lack data.

There has been considerable progress in developing measures of Canada's achievements in sustainable forest management, but more work remains to be done. Future efforts will focus on maintaining and expanding current databases, developing methodologies to collect data for such areas as the social elements of sustainability, and improving our understanding of forest ecosystems. The framework will be updated to include indicators that provide a comprehensive picture of the sustainability of our forests and that can be reported on nationally.

Reporting on both processes currently use data from national and regional databases, from published scientific literature and reviews of many subject areas. National government databases include those in Natural Resources Canada, Canadian Forest Service, *Compendium of Canadian Forestry Statistics, Canada's Forest Inventory*, and the Canadian Centre for Geomatics, *Canadian Road Networks Database*. Databases from Environment Canada, and other national cooperating agencies are also widely used. Also included in this category are the periodic assessments of the state of forest research and forest conditions in Canada and abroad (Hall et al. 1998).

Data are compiled from geographic information systems and remote sensing from satellite imagery. For example, a change in the net area of forest available for timber production that can be obtained from satellite imagery, will be directly correlated with the availability of timber and other forest products. Sources of information often include results from operational research studies which may be site-specific, thus limiting their applicability on a national scale.

Many indicators in one of the processes have an equivalent counterpart, or combination of counterparts in the other framework. Information or data developed to report on one process can therefore be used to report on the other process, so the level of effort required to modify and present information for the two processes is low. In some cases, indicators have a comparable indicator, or combination of indicators, in the other. Information required for one can then be drawn, in part or in whole, from data or information developed for the other. The level of effort required to modify and present indicator results is then somewhat greater. Finally, there are a few indicators that are unique to one of the processes. The information may exist but in any case the level of effort required to modify and present information for one report could be considerable. These issues of data management and the knowledge infrastructure required to do assessments are major issues for governments, and are being addressed through modern knowledge infrastructure methods.

Assessing Sustainability

As data are analyzed and synthesized, and used to assess sustainability in C&I reporting, forest managers begin to look at forests differently. We are beginning to realize, as the scientific community realized many decades ago, that everything is related to everything else. This is a new paradigm emerging for forest managers and policymakers.

The impacts and stresses on forests are a combination of natural and anthropogenic factors; of insects, diseases, fire, harvesting, pollution, land use changes all of which act together. The impacts of these stresses also change in time and space. At the same time our level of knowledge is insufficient to take the action necessary to ensure sustainable forest management indicating continued need for research and monitoring. Natural impacts should not affect sustainability, as defined by not beyond the natural limits of variability, but since it is difficult to define this baseline, or often to recognize it, our ability to 'manage' forests is consequently compromised.

Conclusions

Northern and temperate forests are generally adapted to damage by insects, diseases or weather events, and hence few adverse effects on sustainability are expected. Forest ecosystems are less well adapted to human-caused stresses such as air pollution or global warming and exposure to these adversely affect sustainability. Similarly, combinations of harvesting plus these stresses cause ecosystems to react in a manner different from completely natural conditions. However, since humans and their activities are part of these ecosystems, it is necessary to account for all activities and ensure that ecosystem needs are not compromised. Continuous assessments as described in criteria and indicators enable the forest manager and the policymaker to take remedial action in the face of environmental stress and so ensure the goals of sustainable forest management.

The boreal and temperate forest countries of which Canada is a major one, are being required to attain sustainable development to satisfy a combination of national and international commitments. As a result of these international agreements, protocols and commercial obligations a series of Criteria and Indicators for sustainable forest management have been established and reported on. The basis for the implementation of sustainable development policies is an awareness of what is going on in our forests, and maintaining an ability to report intelligently on changes in our forests. Forests because of their vast areas, limited populations, lack of accessibility have a number of characteristics that make them particularly challenging to manage. At the same time the new requirements for reporting have resulted in new indicators and in new ways of expressing them. Canada participates in two systems of Criteria and Indicators to measure progress in sustainable forest management.

Literature Cited

Anonymous 1995a. Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. The Montreal Process, Canadian Forest Service, Ottawa 27 p.

Anonymous 1995b. Defining Sustainable Forest Management—A Canadian Approach to Criteria and Indicators, Canadian Council of Forest Ministers, Ottawa. 22 p.

Anonymous 1997a. Criteria and Indicators of Sustainable Forest Management in Canada. Technical Report. Canadian Forest Service, Ottawa, 137 p.

Anonymous 1997b. Canada's report on the Montreal Process Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. Canadian Forest Service, Ottawa, Canada (DRAFT) 139 p.

Anonymous 1998. Montreal Process report of the Technical Advisory Comm., June, 1998, 51 p.

Hall, J. Peter and Paul A. Addison. 1990. Response to air pollution: ARNEWS assesses the health of Canada's forests. Inform. Rep. DPC-X-34. 42 p.

Hall, P., W. Bowers, H. Hirvonen, G, Hogan, N. Foster, I. Morrison, K. Percy, R. Cox, and P. Arp, 1998. Effects of Acidic Deposition on Canada's Forests. Inform. Rep. ST-X-15, Science Branch, Canadian Forest Service, Ottawa, Canada, 23 p.

Maini, J.S. 1990. Sustainable Development and the Canadian Forest Sector, The Forest. Chron. Vol:66-4, Aug. 1990. pp. 346-349.

Ottens, H. 1997. Science and Technology Networks: Policy Framework, Science Branch, CFS Unpublished report. 56 p.

The CIFOR Criteria and Indicators Research Program[1]

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Abstract—The paper provides an overview over a four-year international research program to develop criteria and indicators for sustainable forest management at the forest management unit level led by the Center for International Forestry Research (CIFOR). It outlines the scope of the research, the methods used and the most important results obtained so far. The paper focuses on the development of three of the key C&I Tools that the project aims to deliver, the CIFOR Generic C&I Template, the Basic Assessment Guide (BAG) for social sustainability and the Criteria and Indicators Modification and Adaptation Tool (CIMAT). It discusses the utility of these tools with respect to developing locally relevant and scientifically sound criteria and indicators at the forest management unit level. The paper also explores the relevance and utility of such C&I to the development of cost-effective feedback and monitoring arrangements in the context of the complex ecological and social systems of forests in the humid tropics. It concludes that criteria and indicators can play a useful role in facilitating improvements to forest management through the development of such monitoring arrangements, thereby catalyzing the development of adaptive co-management systems in tropical forests.

Forest managers are faced with two fundamental problems: conceptualising and operationalising sustainability (Moffat 1994) in the context of forest management, while at the same time dealing adequately with the complex and dynamic ecological, social and economic systems involved. Zadeh (1973) has pointed out that there is an inverse relationship between the complexity of systems and our ability to make precise and yet significant statements about their behaviour. This is because uncertainty is an inherent quality of complex systems.

In order to deal effectively with the complexity inherent in forested ecosystems there is need to follow an adaptive management philosophy that embraces the attributes of persistence, change and unpredictability (Holling and Meffe, 1996). This means that management will need to continuously challenge and evaluate its own hypotheses, following thereby a course of iterative improvement. It is within this context that the development of criteria and indicators for sustainable forest management (C&I) must take place. Criteria and indicators are tools that can be used to conceptualise, communicate, evaluate and implement sustainable forest management. As tools for monitoring and feedback they can contribute to the management of complexity through iterative improvement in an adaptive management environment.

The development of appropriate criteria and indicators for sustainable forest management has been high on the international forests agenda for some years now. The first suggestions in this regard were made by the International Tropical Timber Organization (ITTO, 1992). The need for criteria and indicators was also emphasized during the United Nations Conference on Environment and Development (UNCED) in Rio in 1992 and reiterated more recently during the meeting of the Intergovernmental Panel on Forests (IPF 1997). Currently there are about nine intergovernmental (in the broadest sense) initiatives on developing criteria and indicators for the regional and national levels (Granholm et al. 1996) and very many more initiatives at the Forest Management Unit (FMU) or Sub-national level (Prabhu and Tan 1996). Most of the latter have developed in response either to certification of forest management or within the framework of ITTO's Target 2000 objective.

This paper focuses on research on criteria and indicators for sustainable forest management led by the Center for International Forestry Research (CIFOR). This research has focused on developing C&I for the forest management unit level. It is important to note that C&I may be identified at various levels: global, regional (and eco-regional), national, and local or forest management unit. Research shows that it is unlikely that a single set of criteria and indicators will apply uniformly across the globe, or that a set of criteria and indicators developed for the national level will be meaningful at the forest level (Prabhu et al. 1996, Woodley et al. 1998).

Following Prabhu et al. (1998a) criteria and indicators can be defined as:

Criterion—A standard that a thing is judged by. Criteria are the intermediate points to which the information provided by indicators can be integrated and where an interpretable assessment crystallises. Principles form the final point of integration. Criteria should be treated as reflections of knowledge, where knowledge is the accumulation of related information over a long period of time. It can be viewed as a large-scale selective combination or union of related pieces of information.

Indicator—An indicator is any variable or component of the forest ecosystem or the relevant management systems used to infer attributes of the sustainability of the resource and its utilisation. 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.

From CIFOR's perspective it is the facility of C&I to organize information most relevant to sustainable forest management in an operational, transparent, and acceptable

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manner that makes them ideal tools for the development of adaptive management systems. Fundamental to the success of adaptive management systems is that this kind of information be available to all stakeholders involved in the management process. Criteria and indicators can therefore ultimately enable and empower rational and effective decision making in forest management units.

The research carried out at CIFOR will be described in terms of the two chronological phases of the project, moving on from there to an examination of some of the key products and future steps.

The First Phase

In 1994 CIFOR set out a collaborative research program to test and develop criteria and indicators for sustainable forest management (C&I) at the FMU level. The objectives were to:

- develop a methodology to evaluate and generate C&I,
- generate a minimum number of cost-effective and reliable C&I for each test site, based on iterative and comparative field evaluations of selected sets, and
- initiate work on a system to evaluate the sustainability of forest management as a whole, based on the recommended criteria and indicators.

This research program was based on comparative field evaluation ('tests') of the leading sets of C&I in one case study each in five countries: Indonesia, Cote d'Ivoire, Brazil, Austria and Cameroon. In preparation a pre-test of methods was conducted in Germany. This work has been reported (Prabhu et al. 1996, Prabhu et al. 1998b) with the main focus being on the identification of criteria and indicators held in common between the countries in which testing took place.

The approach involved interdisciplinary teams of foresters, social scientists and ecologists, selecting and evaluating C&I from Smart Wood (Rainforest Alliance, USA), Initiative Tropenwald (ITW—Germany), and Woodmark (Responsible Forestry Standards, Soil Association, UK) on all sites. The Deskundigenwerkgroep Duurzaam Bosbeheer (DDB—the Netherlands) and the Lembaga Ekolabel Indonesia (LEI—Indonesia) sets were evaluated at all sites except Germany. In the sum 1100 C&I were tested in each of the selected countries. This process involved three phases, conceived as three separate filters. It is important to note that this was not simply a mechanical sifting process. It explicitly allowed creative inputs and modifications to criteria and indicators, provided these were also subjected to the evaluation process. A recent example of the application of this process is provided by Woodley et al. (1998), and reported in these proceedings.

To assess the C&I during field work an iterative approach was used in which nine attributes were identified as important to evaluate C&I. These attributes seek to determine whether the C&I are:

1. Summary or integrative measures,
2. closely and unambiguously related to the assessment goal,
3. adequately responsive to stress or change in the system
4. diagnostically specific,
5. appealing to users,
6. easy to detect, record and interpret (feasible),
7. precisely defined (clear),
8. produce replicable results (reliable), and
9. relevant.

Costs associated with an indicator were sought to be minimised by asking three questions:

1. **where** to place an indicator within a system in order to sum up a satisfactory amount of information on interactions,
2. **how** to define the indicator such that information is integrated meaningfully, and
3. over **what** intervals of time should this information be collected, leaving the question of defining the actual field procedures for a later phase.

To be cost-effective, indicators were to be selected in such a way that they provided information on changes at 'choke points' in the system. Such a selection of indicators would ensure that information on systems interactions prior to the 'choke point' will be reflected by changes at the choke point itself. Having selected the 'choke points', the second consideration was then to further define the indicator. Indicators could be descriptive (qualitative) or quantitative. Finally the interval of time over which information was to be integrated was considered.

Analysis of the results of the tests showed that a strong element of commonality existed among the sets of C&I proposed at the three tropical sites. The ecological indicators emerged as being more generic than the others, with roughly 70% being held in common among the tropical sites. Indicators dealing with management prescriptions cam next with 60% being held in common. The social C&I were least generic with only about 30% being held in common. This was probably due both to the weakness of the social C&I tested and the high variability of the social and value systems involved. Comparison of these results with those obtained from the test in Austria revealed that most of the criteria and indicators identified as being common to the three tropical sites were also listed in the Austrian set. This suggests that at least in closed forest formations the development of a common 'core' set of C&I is possible, however site specific elements will continue to remain important particularly for social aspects and lower levels of hierarchy, such as verifiers.

The CIFOR team also analysed the divergence in selected C&I among teams and tried to determine the reasons for such variation. Three important sources of variation were identified. The composition or nature of the sets of C&I selected for testing was the most fundamental, since they formed the pool from which team members selected the best C&I. The composition of the expert teams also proved an important influence because of individual interests and expertise among team members. In this context we are reminded by Lele and Norgaard (1996) that efforts by natural scientists to operationalise the concept of sustainability in a 'scientific' manner are "fraught with dangers because values, opinions, and social influences are an inextricable part of science, especially applied science". Finally, a series of site-specific factors, including resource ownership and access, history of forest management, forest system ecology, demography and culture, were identified as important. As a result of the research during Phase 1 a subset of principles, criteria, indicators and verifiers was identified that were common to all sites (see Prabhu et al. 1996 for details).

The Second Phase

The first phase revealed weaknesses related particularly to C&I for social sustainability and for conservation of biodiversity in managed forests. Furthermore during the first phase the CIFOR project had focused exclusively on large-scale commercial management of natural forests. It was felt that there was a need to broaden this to include community based forest management and plantation forests. Recognising that no single set of C&I was likely to be viable across the globe the aim of the second phase, which concludes in early 1999, is to deliver a tool-box for the development and application of C&I. In this approach users are presented with options and guidelines for developing criteria and indicators but are required to make their own choices regarding which assessment tools and decision making methods are appropriate for their situations. In this section we provide an overview of the research carried out during the second phase, focusing in the next section on some of its outputs.

Social C&I

During Phase I of the C&I project, the difficulty of assessing social C&I stood out clearly as a problem. Most reliable methods available to social scientists were too time consuming; and the quick ones were too "dirty". Three topics were identified as priorities, because of their ubiquity in the C&I selections and concerns of Phase I teams. These were:

- Definition of relevant stakeholders in forest management
- Intergenerational access to resources, and
- Rights and means to manage forests

The focus here was to develop methods that would allow these criteria on inter-generational access to resources and participation/co-management to be meaningfully adapted to local site conditions. At the same time this research would contribute towards improving the overall 'generic template' and exposing the causal relationships between these C&I and sustainability. The main output of tools related to social C&I are a 'social sustainability assessment kit', an improved selection of indicators and definition of verifiers where possible. The 'kit' consists of the Basic Assessment Guide (BAG), additional methods ('Grab-BAG) a scoring guide and the current best bets for social C&I.

The development of the 'kit' involved tests of 12 social science methods in two areas of Cameroon (a central area near Mbalmayo and Mt. Cameroon, to the Northwest) and of Indonesia (the P.T. Kiani Lestari area in central East Kalimantan and the Bulungan Research Forest to the north of that province) and in two sites in the state of Para in Brazil. The team worked with communities in "forest-rich" and "forest-poor" areas.

As an example of how the testing proceeded is the work on "inter-generational access to resources", an issue widely deemed important—and very difficult to assess—in sustainable forest management. Use was made of data from a methodological pre-test conducted in and around Danau Sentarum Wildlife Reserve in West Kalimantan, Indonesia. Its purpose was to contribute to the development of principles, criteria and indicators for sustainable forest management (SFM). In a paper on the topic the methods pre-tested were described, and earlier versions of the principles, criteria and indicators re-evaluated, re-ordered and scored in a dual attempt: to develop simple, inexpensive and reliable assessment methods, and to contribute to our understanding of the causal links between inter-generational access to resources and sustainable forest management.

Economics C&I

The question of suitable C&I for assessing economic impacts of forest management has been addressed through a conceptual paper by Ruitenbeek and Cartier (1998). The paper suggests that some commonly used C&I are inappropriate because they are frequently misinterpreted, are methodologically unsound, are inadequately developed, or are too costly to implement. The authors therefore offer both a 'negative list' of indicators, and a 'positive list' of recommended C&I that can address the issues and concerns raised in this paper.

Some attributes of the 'positive list' are summarized in Table 1. It reflects the broader needs to address efficiency, equity, sustainability and a precautionary stance in FMU

Table1.—Recommended Economic Principles for Sustainable Forest Management (from Ruitenbeek & Cartier 1998).

Principle	Examples of Criteria and Indicators
Forest management is socially efficient.	Efficient timber extraction methods are applied. Sustainable harvesting of non-timber forest products occurs. Management generates positive economic rent.
Intragenerational equity is enhanced.	Involvement of local population in forest management. Equitable positive rent share to all participants. Transparent allocation of concessions.
Forest estate and forest use options are maintained.	Forest migration pressure is minimized. Non-forest policies do not affect forest management. Existence of non-confiscatory land use policies.
Precautionary measures promote system resilience.	Anti-corruption measures in place. Existence of broad-based adaptive management plans. Establishment of effective buffer zones.

management. What is perhaps notable about this list is that it does not necessarily involve a lot of economic calculations relating to pricing and values: many C&I that are of economic relevance are simply physical measures.

Within the 'negative list,' they include: (i) use of internal rate of return, which is a frequently used but inaccurate measure of economic efficiency; (ii) valuation of biodiversity, carbon sequestration, and certain ecological functions that are equally well captured by a simple physical accounting of the forest biomass; and, (iii) use of complex economic indices and coefficients to characterize income distribution concerns.

In this paper the authors argue that economic criteria and indicators of sustainable forest management should reflect the dimensions of efficiency, equity and sustainability, and need to look beyond the forest stand to institutional and policy issues. If such criteria inform our decisions, we may yet end up with exploitation of the forests. It would, however, be rational exploitation; rational exploitation reflecting an enlightened self-interest that captures the broader global needs of current and future generations.

Biodiversity C&I

Biodiversity is an extraordinarily broad concept and, given the huge diversity of life in tropical forests, it is impossible to make rapid direct assessments of biodiversity in forests in anything other than a superficial manner. It is likely that there will be limited skilled human resources and time for biodiversity assessment in any system of criteria and indicators, so it is important that we design tools that do not require expert application and interpretation. A consistent result of all the (independent) expert teams during Phase 1 of the C&I research project was that none of the proposed indicators for conservation of biodiversity were adequate—either due to problems of practicability, or relevance to managers. Consequently, a process was started in 1996 to devise "new and improved" indicators, initially for genetic diversity, and later for other aspects of biodiversity. In both cases we assembled an international team of experts to a workshop to "brainstorm" ideas for indicators and "verifiers" (which are the actual measurements to be collected in the field).

As part of CIFOR's continuing efforts to develop operational C&I related to biodiversity the workshop was held in Bogor at the end of April 1997. It concluded that the approach adopted by the Genetic Resources Workshop in the preceding year (Namkoong et al. 1996), i.e. focusing on the processes that maintain biodiversity, offered the most effective basis for considering biodiversity C&I. These ideas have subsequently been field tested. The publication on the genetic indicators has been adapted following the field test (Namkoong et al. 1998). CIFOR's research on biodiversity C&I suggests that, in contrast to more traditional approaches to assessing taxonomic diversity, it may be possible to assess the effects of management practices on biodiversity by examining the state of those processes that generate or maintain biodiversity. The indicators and verifiers that were suggested examine the state of these processes. Seven indicators were proposed, supported by numerous verifiers. For each indicator, quick and easy verifiers are recommended, those designated "Primary" verifiers are used first, and more sophisticated ("Secondary") verifiers are used only if clear results are not obtained from Primary verifiers. The initial publication on biodiversity indicators (Stork et al. 1997) produced following the workshop was revised, based on the experiences in the field test. About 22 verifiers that were considered practical, relevant, and responsive to change were identified as a result of the test (Annex 1 summarises the results of the field test). Great emphasis was placed on practicability because of the project team's belief in "adaptive management", by which managers would be capable of carrying out self-assessments, with a view to modifying their practices accordingly. This implies that the data would need to be collected and interpreted by non-experts.

A key outstanding issue is how to combine information from many indicators to reach an overall decision. Another key issue is the need for research on setting baselines and thresholds. The final step in the C&I process leading towards adaptive management is to provide the forest manager(s) with a system whereby their analysis of indicators provides not only an assessment of sustainability, but also proposes possible mitigation measures. For example, a biodiversity indicator of tree size structure may be unsatisfactory—one solution might be to raise the diameter cutting limit, but this may have negative consequences on economic indicators. The appropriate mitigation measure needs to take impact on all indicators into account. This is however a proposal for future research as it goes beyond the current scope of the project.

CIFOR is also carrying out additional research on indicators related to water quality and quantity in Central Kalimantan. In an effort to develop these indicators further we are seeking to determine whether it is possible to determine spatially explicit causal links between management interactions and changes to water quality and quantity. First results suggest there may be difficulties in doing so. Should this hold true it would diminish the value of such indicators to forest managers, inasmuch as they will not be able to clearly link management interventions to these changes.

Community Based Forest Management

Research on C&I for community managed forests took place as four 'tests' of C&I in Indonesia, Cameroon and Brazil. The findings of the first pre-test in Indonesia in Tengganan suggest that systems resilience and risk management are two issues bridging socio-economic, ecological and managerial sustainability considerations. Knowledge was another issue highlighted as consequential to good management practice. The survival of highly evolved systems of natural resource management, such as those witnessed in Tengganan, was seen as closely interdependent with cultural survival. Tengganan's socio-religious organisation seemed to play a crucial role in setting management objectives and regulating forest access and interventions. Amongst the more complicated issues encountered in Tengganan was the question of identifying forest stakeholder groups, their various management objectives, the allocation of priority amongst these and how this affects the distribution of forestry associated costs and benefits. The general consensus was that these are key issues to understand how the social and ecological systems integrate. In

Tengganan, marked inequalities seemed to be inherent in the social system underpinning Sustainable Forest Management. However, the system appears to be fair according to the religious doctrine of its perpetuators.

The results of the pre-test were then fed into the methodology to be used in the three following tests in Cameroon, Indonesia and Brazil. As a result of the Cameroon test it became apparent to the researcher team note that although villagers may lack the analytical skills and knowledge used by experts to identify factors affecting the sustainability of the local situation, all members of the expert team agreed that access to local knowledge was essential to their gaining a good understanding of the local situation. Indeed, the team relied heavily on local knowledge to conduct its work.

Community participation is important for building a broad-based consensus between different forest stakeholder groups. A consensus on priority C&I, if reached with imperfect or incomplete knowledge of the knowledge and interests of certain stakeholder groups, may reinforce inequitable power balances and conceal the need for more thorough investigations. Naturally, if only some stakeholders i.e. policymakers or conservationists, participate in developing C&I then the negative implications their interests carry for other, non-participating, stakeholders, may not be fully exposed by the C&I developed. Maximizing forest peoples' participation will help clarify the trade-offs and compromises incurred through the distribution of forest-derived costs and benefits. When these are established, it becomes possible to review the 'fairness' of the distribution patterns. The second full test of C&I for CMF was carried out in Sanggau, West Kalimantan (Indonesia) and the third and last test was carried out in Para, Brazil. The final report for this research activity will be available in early 1999.

Other Research

Research is also underway on developing C&I for plantation forests. The focus of this work is on industrial scale, quick-rotation plantations in Indonesia and longer rotation teak plantations in India. A similar collaborative research program is due to commence in Brazil. Work on C&I based decision tools is the most recent of the CIFOR project's activities. The research aims to test various decision support methods that would enable resolution of contradictory information and facilitate holistic decisions. Such techniques include the Analytic Hierarchy Process, Delphi methods etc. It also aims to develop a knowledge based computer tool that enables adaptation of scientific sound C&I, to local situations using locally available expertise, and incorporating local expectations. This is the Criteria and Indicators Modification and Adaptation Tool (CIMAT) described below.

Tools from the Tool-box

The 'tool-box' under development at CIFOR will contain some nine 'tools' on completion of the second phase of the project in early 1999. Using our own experience of testing C&I as the model, our approach is to focus on developing three types of tools. The first type is the development of C&I to form a 'generic template' or starting platform. The second type would enable adaptation of the generic template to local situations. The third type facilitates application of the C&I. This is summed up in Figure 1. For the purpose of this paper only three of those tools are described briefly here.

CIFOR's Generic C&I Template

In most tropical areas the development of C&I at the FMU level (or at any other level) has either yet to begin, or is in its infancy. Faced with this situation managers charged with the development of C&I are asking how they should go about this challenging task. They will be concerned to develop C&I appropriate for their context and comparable to international efforts. The Generic C&I Template provides a comprehensive set of criteria and indicators (C & I) compiled from CIFOR's research on the testing of C & I for the sustainable management of forests as a starting point for their deliberations.

The "generic template," is not to be confused with an ideal and universally applicable set of C&I. Although using the term "generic" in the title may invoke query as to the scope

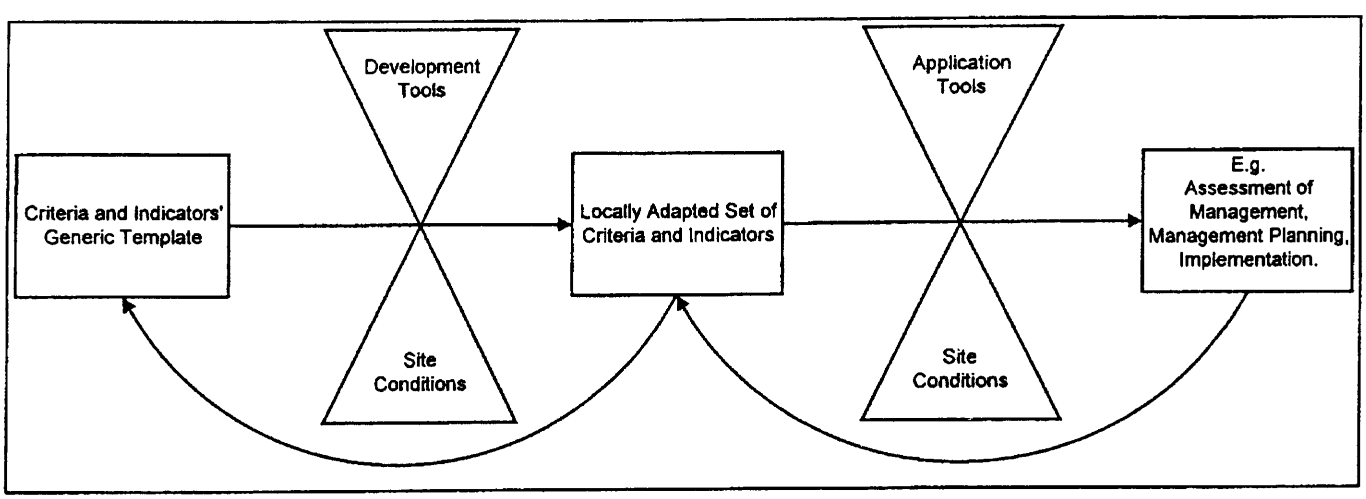

Figure 1.—Illustration of the use of the generic template and the tools for adaptation and application of C&I.

of applicability ("generic to what?"), it is envisaged that this template would be used primarily for tropical natural forests managed for commercial purposes. A generic template for tropical plantation and community-managed forests may be provided later. Hence, the C&I outlined in the template are generic relative to a specifically defined commercial-natural forest type in the humid tropical zone. However, many of the C&I in this document have also emerged in tests temperate forests in Austria and in Boise (Idaho), USA. "Generic" also implies that this C&I template can be employed by a variety of user groups. We have identified potential users to include certification bodies, government officials, donors, forest managers, project managers, and scientists.

The C&I in the Template are not intended to be used as a tool to directly assess either the sustainability of forest management practices or the performance of a particular FMU. Rather, they are intended to provide users with a "starting platform" to formulate a more locally sound set of C&I. Thus the adoption of the complete set is not mandatory. Once adapted, however, the set can be used for a variety of applications, which include the assessment of management, management planning, and implementation. The C&I set in this document are organised along two major 'axes':

1. The 'vertical' axis pertains to a hierarchical framework of principles, criteria, indicators and verifiers (P, C, I & V).
2. The 'horizontal' axis divides the C&I into four major areas of concern: policy, ecology, social, and the production of goods and services.

As an example an excerpt of C&I from the Generic Template are provided in Annex 2. This example focuses on an aspect of social sustainability.

The BAG (Basic Assessment Guide for Human Well-Being)

The BAG is designed as a manual to be used by individuals and organisations wishing to assess the sustainability of a timber operation especially in the tropics. The manual has been developed, based on results of systematic methods tests in Cameroon, Indonesia and Brazil with supplementary work in Trinidad and the United States. It assumes assessors will visit timber company base camps and villages, ask pertinent questions of people in the area, and examine available data from the company and local government offices, in addition to the methods spelt out in the BAG. The BAG focuses on certain critical social issues. It identifies the 'best bets' for social C&I as a starting point for the assessment of human well-being. Next it provides a cook-book approach to assessing human well-being in five steps:

1. identification of relevant stakeholders;
2. assessment of security of intergenerational access to resources;
3. assessment of rights and obligations to manage forests cooperatively;
4. assessment of the health of forests, forest actors and cultures; and
5. a scoring method based on a 1-10 scale, weighted by the importance of the principle.

Although this cookbook approach does not represent the ideal, it can provide useful guidance in cases where assessors are not qualified social scientists. The BAG is aimed at a person with a bachelor's degree in a natural science. For more qualified users another manual called the 'Grab-BAG' is being developed.

CIMAT (Criteria and Indicators Modification and Adaptation Tool)

The goal of this research on the Criteria and Indicators Modification and Adaptation Tool (CIMAT) is to help people to adapt the generic hierarchy of principles, criteria, indicators and verifiers to meet local expectations and conditions. Modifications to the hierarchy are required for the following reasons:

- filling specific knowledge gaps (for example, about local species important for biodiversity assessment),
- modifying indicators to local conditions (for example, to reflect local social or cultural considerations),
- adding indicators where extra information is deemed important, and
- rejecting them if they are redundant for assessment of sustainability in the local context.

An ideal computer-based tool which supports such modifications would do three things:

- Firstly, and most pragmatically, it would make the clerical job of keeping track of changes to the C&I more straightforward than it currently is, thereby increasing the efficiency of modification.
- Secondly, it would enhance the quality of modifications by encouraging people to think hard about the changes they make, encouraging them to record justifications for their changes, enabling cross-referencing of related C&I in different parts of the hierarchy and providing access to other people's experience in doing the modification task.
- Finally, and most idealistically, a computer tool would help with the evolution of C&I amongst the global community, by providing a resource for interdisciplinary teamwork and an electronic forum for sharing C&I knowledge across locations and disciplines.

CIMAT is an early and tentative step towards this ideal tool. CIMAT will be a tool for people who are developing C&I, using CIFOR's generic template as a starting point. Its development has been based upon a user needs survey. Three groups of users were identified:

- In-house and in-country experts who have been involved in the evolution of the current C&I sets.
- International C&I stakeholders.
- Assessors/certifiers.

CIMAT is not an expert system, in the sense that it will not make decisions, nor will it act as an expert guiding a user through an assessment of sustainability. It is a tool for knowledge management, rather than a decision-making system. CIMAT contains a knowledge base of C&I for sustainable forest management. This knowledge base is essentially incomplete, and contains 'hooks' upon which users can hang knowledge which is relevant to sustainability of forest management in the particular context they are interested in. CIMAT will invite the user to bring their knowledge to the system, in order to enhance and build upon the knowledge within it. The core of CIMAT will be the current knowledge base of C&I. This is the template set of C&I which users will be able to modify by bringing their own and other people's local or specialist knowledge to the system. Each criterion, indicator or verifier in the hierarchy will be an 'object', which can be changed, deleted, added or moved. It will be possible to create links between indicator objects that have things in common, or which are related in some way. Each object will remember the sequence of modifications that it undergoes, so each indicator will end up with its own 'history' of how it has been adapted to meet local conditions.

In addition, CIMAT will include knowledge about how and why the C&I objects can be modified. This knowledge will enable CIMAT to suggest possible modifications to the user, and also to encourage users to think about why they are making modifications and to provide justifications for their changes. By recording not only changes to indicators, but also some of the reasoning leading to these changes, it is hoped that CIMAT will be a useful tool for teams who are involved in the ongoing process of developing and adapting sets of C&I for local forest management.

Finally CIMAT will also include knowledge about how the C&I can be applied. In the current version of CIMAT this function will not be supported as an interactive module. It is helpful to think of a sustainability assessment as a process of argumentation, in which the user's data and the knowledge base are used in combination to provide arguments for and against an assessment of sustainable management. In this way it may be possible to be sensitive to cases where, for example, the broad sweep of an assessment points to sustainable management but a few negative indicators can provide critical counter-arguments pointing to specific areas which require attention. There exist probabilistic and quantitative approaches to handling risk, as opposed to uncertainty, which is by definition not quantifiable. However, due to the great variety of ways in which uncertainty can be introduced in a C&I assessment, it may be more informative to a user if they are provided with information about the possible sources of uncertainty in a final assessment.

Conclusions

The C&I research program at CIFOR is quite comprehensive touching as it does large scale management of natural forests, community managed forests and plantations (not reported here) on the one hand, and biodiversity C&I, social C&I and C&I based decision tools on the other. However it is not exhaustive, i.e. all aspects of sustainable forest management are not covered. Instead the focus has been on the areas where a comparative advantage is believed to exist or where little research is taking place.

CIFOR's vision for the C&I under development is that they would eventually become an integral part of the monitoring and feedback systems of forest management units. This could either be for large (industrial) scale units or for community managed forests. It is CIFOR's intention to follow-up on our research on criteria and indicators for sustainable forest management (on completion of the current Phase 2) with research on their utility and effectiveness within actual management units as key tools for enabling adaptive co-management.

"Adaptive co-management", in CIFOR's use of the phrase, involves self-improving management systems based on a conscious learning process in management; the integration or involvement of all relevant stakeholders in a self-management process; and recognition in management of the dynamism and complexity of human and natural systems touching on management Adaptive co-management (ACM), in different forms, has been emerging as a promising means of resource management with forest related, agricultural, and fisheries applications. So far, progress has been via piecemeal and disconnected initiatives, and there is little understanding of how to maximize its contribution to sustainable tropical forest management. A key aspect of ACM is the mechanism by which managers can monitor the outcomes of their interventions and so enable conscious learning. There is therefore a pressing need for a monitoring arrangement that delivers comprehensive, relevant, scientifically sound and cost-effective information regarding the sustainability of resource use to forest managers. Therefore the research will aim to move the C&I from their current form of being information targets to their integration as part of a user friendly monitoring arrangement, i.e. their use in day-today management. This should help establish standards for assessing and monitoring sustainable forestry and in evaluating the success of adaptive co-management models. Research on models of C&I based monitoring arrangements will enable bridging the gap between the definition of sustainability and its operationalisation in a complex forest environment. Furthermore such monitoring arrangement are expected to ease integration of local level information to sub-national and national levels of decision making, thus improving the information basis for policymakers.

Literature Cited

Boyle, T.J.B., Lawes, M., Manokaran, N., Prabhu, R., Ghazoul, J., Sastrapadja, S., H.-C. Thang., Dale, V., Eeley, H., Finegan, B., Soberon, J., Stork, N.E. (1998). Criteria and Indicators for Assessing the Sustainability of Forest Management: A Practical Approach to Assessment of Biodiversity. CIFOR. Bogor, Indonesia.

Granholm, H., Vahanen, T. and Sahlberg, S. (Eds.) (1996). Background document. Intergovernmental Seminar on Criteria and Indicators. Ministry of Agriculture and Forestry, Helsinki, Finland.

Holling, C.S. and Meffe, G.K., (1996). Command and control and the pathology of natural resource management. Conservation Biology 10, 328-337.

IPF Secretariat (1997): Final Report of the Intergovernmental Panel on Forests. Advance unedited text. http://www.un.org/dpcsd/dsd/ipf.htm; gopher://gopher.un.org:70/00/esc/cn17/ipf/session4/IPFIV (March 27, 1997).

ITTO (1992). ITTO Criteria for measurement of sustainable tropical forest management. ITTO Policy Development Series 3, Yokohama.

Lele, S. and Norgaard, R.B., (1996). Sustainability and the scientist's burden. Conservation Biology 10, 354-365.

Moffat, I. (1994) On Measuring Sustainable Development Indicators. International Journal of Sustainable Development and World Ecology 1, 97-109.

Namkoong, G., Boyle, T.J.B., El-Kassaby, Y., Eriksson, G., Gregorious, H.-R, Joly, H., Kremer, A., Savolainen, O., Wickneswari, R., Young, A., Zeh-Nlo., M., Prabhu, R. (1998). Criteria and Indicators for Assessing the Sustainability of Forest Management: Conservation of Genetic Diversity. CIFOR. Bogor, Indonesia.

Namkoong, G., Boyle, T.J.B., H.-R Gregorious., Joly, H., Sovalainen, O., Wickneswari, R., Young, A. (1996). Testing Criteria and Indicators for Assessing the Sustainability of Forest Management: Genetic Criteria and Indicators. CIFOR Working Paper No. 10. CIFOR. Bogor, Indonesia.

Prabhu, R., Colfer, C.J.P., Dudley, R.G. (1998a). Guidelines for Developing, Testing, and Selecting Criteria and Indicators for Sustainable Forest management. CIFOR. Bogor, Indonesia.

Prabhu, R., Colfer, C.J.P., Venkateswarlu, P., Tan, L.T., Soekmadi, R., Wollenberg, E. (1996). Testing Criteria and Indicators for the Sustainable Management of Forests: Phase I Final Report. CIFOR. Bogor, Indonesia.

Prabhu, R., Maynard, W., Eba'a Atyi, R., Colfer, C.J.P., Shepherd, G., Venkateswarlu, P., Tiayon, F. (1998b) Testing and Developing Criteria and Indicators for Sustainable Forest Management in Cameroon: The Kribi Test. Final Report. CIFOR, Bogor, Indonesia.

Prabhu, R. and Tan, L.C., (1996). Out of the woods? Assessment of sustainable forest management. In: Tan, L.C. 1996. Initiatives on Assessing Sustainability: Status and Future Directions. Summary of the open session of the Third International Project Advisory Panel (IPAP) meeting on testing criteria and indicators for sustainable management of forests, Turrialba, Costa Rica, February 29–March 1, 1996. CATIE/CIFOR Special Publication, CIFOR, Bogor, Indonesia.

Ruitenbeek, H.J. and Cartier, C., 1998. Rational exploitations: economic criteria and indicators for sustainable management of tropical forests. CIFOR Occasional Paper, Bogor, Indonesia. (In press)

Stork, N.E., Boyle, T.J.B., Dale, V., Eeley, H., Finegan, B., Lawes, M., Manokaran, N., Prabhu, R., Soberon, J. (1997). Criteria and Indicators for Assessing the Sustainability of Forest Management: Conservation of Biodiversity. CIFOR Working Paper No. 17. Cifor. Bogor, Indonesia

Woodley, S., Alward, G., Gutierrez, L.I.., Hoekstra, T., Holt, B., Livingstone, L., Loo, J., Skibicki, A., Williams, C., Wright, P. (1998). North American Test of Criteria and Indicators of Sustainable Forestry (Volume 1 & 2). Final Report.

Zadeh, L.A., (1973). Outline of a new approach to the analysis of complex systems and decision processes. IEEE Trans. Syst., Man Cyber., SMC-3, 28-44.

Tools

CIFOR (1998) The CIFOR Criteria & Indicators Generic Template. Draft.

Colfer, C.J.P., Tiani, A.M., Brocklesby, M.A., Etuge, P., Sardjono, M.A., Prabhu, R., McDougall, C., Wadley, R.L., Harwell, E., Woelfel, J., Diaw, C., Tchikangwa, B. and Guenter, M., (1998). The BAG (Basic Assessment Guide for Human Well-Being. Draft manual.

Colfer, C.J.P., Tiani, A.M., Brocklesby, M.A., Etuge, P., Sardjono, M.A., Prabhu, R., McDougall, C., Wadley, R.L., Harwell, E., Woelfel, J., Diaw, C., Tchikangwa, B. and Guenter, M., (1998). The Grab Bag: Additional Methods for Assessing Human Well-Being. Draft manual.

Annex 1: Biodiversity C&I

Practicability of verifiers. This table summarizes the conclusions of the test of biodiversity C&I held in Central Kalimantan in November 1997 (Boyle et al. 1998). Testing was carried out by a team of inventory technicians from the concessionaire on the one hand and a team of scientists and technicians on the other. The results of both teams were compared in the field before conclusions were drawn by the assembled experts.

Primary	Ease of assessment	Relevance	Response to change	Cross linkages	Account-ability	Conclusion
V1.1.1: Areal extent of each veg. Type	?	✓	✓✓	✓✓	✓✓	Accept
V 1.2.1: Number of patches per unit area	?	✓✓	?	✓✓	✓✓	Reject
V 1.2.2: Largest patch size of each veg. Type	✓	✓	✓✓	✓✓	✓✓	Accept
V 1.2.3: Area weighted patch size	✓	x	✓✓	✓✓	✓✓	Reject
V 1.2.4: Contagion	?	✓✓	?	✓✓	?	Reject
V 1.2.5: Dominance	✓✓	✓✓	✓✓	✓✓	✓✓	Accept
V 1.2.6: Fractal dimension	?	✓	✓✓	✓✓	✓✓	Reject
V 1.3.1: Av. distance among patches of same cover type	?	?	✓✓	✓✓	?	Reject
V 1.3.2: Percolation index	?	✓	✓✓	✓✓	?	Accept
V 1.4.1: Total amount of edge for each veg. Type	?	✓	✓✓	✓✓	?	Reject
V 1.4.2: Edge round largest patch	?	✓	✓✓	✓✓	?	Reject
V 2.1.1: Vertical structure.	?	✓	✓✓	✓✓	✓✓	Accept
V 2.1.2: Size class distributions.	✓	✓✓	✓✓	✓✓	✓✓	Accept
V 2.1.3: Relative abundance of leaf sizes	?	✓✓	✓	✓✓	✓✓	Reject
V2.1.4: Gap frequency/forest regeneration phase	✓	✓✓	✓	✓✓	✓✓	Accept
V 2.1.5: Canopy openness	?	✓✓	✓✓	✓✓	✓✓	Reject
V 2.2.1: Standing and fallen dead wood.	✓✓	✓✓	✓✓	✓✓	✓✓	Accept
V 2.2.2: Other structural elements	✓	✓✓	✓✓	✓✓	✓✓	Accept
V 3.1.1: Abundance of tree species in different guilds	?	✓	✓✓	✓✓	✓✓	Accept
V 3.1.2: The abundances of avian guilds	✓	✓✓	✓✓	✓✓	✓✓	Accept
V 3.2.1: Abundance of nests of social bees.	n/a	x	n/a	n/a	n/a	Reject
V 3.2.2: Fruiting success in key plant species	?	✓✓	✓✓	✓✓	✓✓	Accept
V 3.2.3: Fruiting intensity of bat-pollinated species	x	✓✓	n/a	n/a	n/a	Reject
V 3.2.4: Abundance terrestrial frugivorous mammals.	x	✓✓	n/a	n/a	n/a	Reject
V 3.3.1: Pitfall traps	✓	✓✓	✓✓	✓✓	✓✓	Accept
V 4.1.1 Species richness reported by local people	✓✓	✓✓	✓✓	✓✓	✓✓	Accept
V 4.1.2: Number of different bird calls.	✓	✓✓	✓✓	✓✓	✓✓	Reject
V 4.1.3: Numbers of large butterfly species	✓✓	✓✓	✓✓	✓✓	✓✓	Accept
V 4.1.4: Number of species in local markets.	✓	✓✓	✓✓	✓✓	✓✓	Reject
V 4.1.5: Number of leaf types in litter	✓	✓✓	✓✓	✓✓	✓✓	Accept
V 4.1.6: Lists compiled by experts.	x	✓✓	n/a	n/a	n/a	Reject
V 4.2.1: Temporal changes in species richness.	x	✓✓	n/a	n/a	n/a	Reject
V 4.2.2: Time series of mature/secondary growth species	x	✓✓	n/a	n/a	n/a	Reject
V 4.2.3 Time series of α and β diversities.	x	✓✓	n/a	n/a	n/a	Reject
V 5.1.1: Measures of the population size of selected species	x	✓✓	n/a	✓✓	n/a	Reject
V 5.1.2: Time series of relative population-size estimates	x	n/a	n/a	n/a	n/a	Reject

Primary	Ease of assessment	Relevance	Response to change	Cross linkages	Account-ability	Conclusion
V 5.2.1: Age or size structure**	x	n/a	n/a	✓✓	n/a	Reject
V 5.2.2: Life tables and their statistics.	x	n/a	n/a	n/a	n/a	Reject
V 5.3.1: Spatial structure of populations.	x	n/a	n/a	n/a	n/a	Reject
V 6.1.1: Standing and fallen dead wood.	✓✓	✓✓	✓✓	✓✓	✓✓	Reject
V 6.1.2: State of decay of all dead wood.	✓✓	✓✓	✓✓	✓✓	✓✓	Accept
V 6.1.3: Abundance of small debris.	?	✓✓	✓✓	✓✓	✓✓	Reject
V 6.1.4: Depth of litter/gradient of decomp.	✓✓	✓✓	✓✓	✓✓	✓	Accept
V 6.1.5: Abundance of imp. decomp'ers	x	✓✓	n/a	n/a	n/a	Reject
V 6.1.6: State of terrestrial leaf bags.	✓✓	✓✓	?	✓✓	✓✓	Accept
V 6.2.1: Soil conductivity and pH	✓	✓✓	?	✓✓	✓✓	Reject
V 6.2.2: Soil nutrient levels	x	✓✓	n/a	n/a	n/a	Reject
V 6.2.3: Insect herbivory	?	✓✓	✓✓	✓✓	?	Reject
V 7.1.1: Abundance/diversity of aquatic organisms	✓✓	✓	✓✓	✓✓	✓✓	Accept
V 7.1.2: Chemical composition of stream water	✓	✓	✓✓	✓✓	✓✓	Reject
V 7.1.3: State of aquatic leaf bags	✓	✓✓	✓✓	✓✓	✓✓	Accept
V 7.2.1: Stream flow	x	✓✓	n/a	n/a	n/a	Reject

Notes:

✓✓	Definitely true
✓	Probably true
?	Uncertain
x	Not true
n/a	Not assessed

Annex 2: Excerpt from the CIFOR Generic C&I Template. A 'Social' Principle with one Criterion and Related Indicators and Verifiers

P.3.	**Forest Management Maintains or Enhances Fair Intergenerational Access to Resources and Economic Benefits**
C.3.1	**Local management is effective in controlling maintenance of, and access to, the resource** Direct link to P.2 Indirect link to C.1.5; V.2.1.4.1; V.2.1.3.4
I.3.1.1	Ownership and use rights to resources (inter and intra-generational) are clear and respect preexisting claims Direct link to I.3.3.1; I.1.1.4; I.6.2.1; I.4.2.1; I.2.1.1; I.2.1.2; I.2.1.4; C.1.5 Indirect link to I.3.1.2; I.3.1.4; I.3.1.5; I.4.2.2; I.4.2.4; I.1.1.2; I.2.1.3; I.1.5.1
I.3.1.2	Rules and norms of resource use are monitored and successfully enforced Direct link to I.1.1.3; C.6.4; I.2.1.1; I.2.1.2; I.2.1.4; C.1.5 Indirect link to I.3.1.1; I.3.1.3; I.3.1.5; I.4.2.1; I.4.3.1; I.2.1.3
I.3.1.3	Means of conflict resolution function without violence Direct link to I.3.2.1; I.3.2.4; I.4.3.1; I.1.4.1 Indirect link to I.4.1.2; I.4.1.3; I.4.2.4; I.4.2.5; C.7.2
I.3.1.4	Access to forest resources is perceived locally to be fair Direct link to I.3.2.1; I.4.3.1 Indirect link to I.4.2.4; I.4.2.5; C.1.5 V.3.1.4.1 Access of small timber operators to timber concessions Indirect link to I.1.5.4 V.3.1.4.2 Access of non-timber users to non-timber forest products Indirect link to C.1.5
I.3.1.5	Local people feel secure about access to resources Direct link to I.3.3.1; I.3.3.5; I.4.2.4; I.4.2.5; I.4.3.1; I.2.1.1; I.2.1.2; I.2.1.4; I.2.1.6; I.1.1.4 Indirect link to I.3.3.2; I.4.1.1; I.4.1.2; I.4.1.3; I.6.1.1; I.2.1.3; C.1.5; I.1.5.1

Aplicación de Criterios e Indicadores en Ecosistemas de Clima Templado en México[1]

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Resumen—El gobierno mexicano en acuerdo con el grupo de trabajo llamado " El Proceso de Montreal " ha adecuado siete criterios y varios indicadores relacionados con la conservación y manejo sustentable de los bosques naturales que desarrollan en clima templado. Los criterios e indicadores proveen un común entendimiento de lo que se entiende por manejo sustentable, para cada uno de los 12 países participantes, los cuales juntos representan el 90 % de los bosques de clima templado y boreal del mundo.

Los criterios comunes son: conservación de la diversidad biológica; mantenimiento de la capacidad productiva de los ecosistemas forestales; mantenimiento de la sanidad y vitalidad de los ecosistemas forestales; conservación y mantenimiento de los recursos suelo y agua; mantenimiento de la contribución de los bosques al ciclo global del carbono; mantenimiento y mejoramiento de los múltiples beneficios socioeconómicos de largo plazo para cubrir las necesidades de las sociedades; y marco legal, institucional y económico para la conservación y el manejo sustentable de los bosques.

Los primeros seis criterios están relacionados específicamente con las condiciones, atributos y funciones del bosque, así como los valores y beneficios directos e indirectos que provee los recursos forestales. El criterio siete, se refiere a las políticas internas del Gobierno Mexicano, que facilitan la conservación y manejo sustentable del bosque.

Los criterios, son categorías de condiciones o procesos mediante los cuales puede evaluarse el manejo forestal sustentable de los bosques. Así mismo, un criterio es caracterizado por un grupo de indicadores relacionados, los cuales son monitoreados periódicamente para evaluar posibles cambios. Por otra parte, los indicadores son medidas especificas de un criterio. Variables cualitativas y cuantitativas son empleadas para medir periódicamente los cambios dentro del bosque. Así mismo, para cada indicador existen diferentes metodología para medir o cuantificar determinada variable a través del tiempo.

Consideraciones Generales de México

La República Mexicana se localiza entre los 14° 32' y 32° 43' latitud norte y 86° 42' y 118° 27' longitud oeste. La superficie total del país es de 1,967,183 km^2, de los cuales el 72% son de tierras forestales ocupados por coníferas y hojosas. Por su ubicación geográfica, México posee tres grandes ecosistemas: bosques templados, selvas y zonas áridas, lo cual le permite contar con una de las floras más ricas y variadas del mundo.

Descripción de Ecosistemas Existentes

Ecosistema templado—Dentro de este ecosistema desarrollan diferentes tipos de vegetación cuya distribución corresponde en general a la ubicación de las serranías más importantes de México: Sierra Madre Occidental, Sierra Madre del Sur, Sierra Madre Oriental, Sistema Neovolcánico, Macizo de Oaxaca, Sierra Madre de Chiapas, Sierras de Baja California entre otras. Los tipos de vegetación representativos son: bosque de pino, bosque de pino-encino, bosque de encino y bosque de otras coníferas.

El clima donde se desarrolla esta vegetación corresponde al templado subhúmedo o semi-seco, con temperatura media anual entre 10 y 20 °C, precipitación anual de 600 a 1,000 mm, concentrada de 6 a 7 meses; y en altitudes de entre 1,500 y 3,000 msnm. La gran variación en temperatura, precipitación y altitud favorece el desarrollo de las siguientes especies arbóreas: *Pinus arizonica, P. durangensis, P. pseudostrobus, P. patula, P. montezumae, P. teocote, P. tenuifolia, Abies religiosa, Cupressus lindleyii, Juniperus* spp., *Libocedrus* spp., *Quercus* spp., *Alnus* spp., *Arbutus* spp. entre otras.

La vegetación de este ecosistema constituye el pilar de la industria forestal mexicana, ya que más del 60% de las especies de pino tienen importancia comercial y el 80% de los productos forestales del país se obtienen de los bosques de pino-encino. Los bosques de clima templado frío poseen una enorme capacidad de generar beneficios sociales y económicos. Tienen un gran valor para el país por ser la fuente principal de madera, por su contribución al ciclo hidrológico y por su valor estético.

La perturbación y deforestación que se presenta en la vegetación del ecosistema templado es alarmante. Los factores más comunes que inciden en su deterioro son: Cambios en el uso del suelo por el crecimiento no planificado de los asentamientos humanos; Ampliación de la frontera agrícola sobre suelos con vegetación de bosques; Incremento de la ganadería extensiva; Explotaciones forestales no reguladas y clandestinas; Construcción de carreteras; Construcción de torres para conducción de electricidad; Construcción de oleoductos y gasoductos.

Ecosistema tropical—Dentro de este ecosistema se encuentran los tipos de vegetación que se desarrollan en los climas cálido-húmedo y cálido-subhúmedo, con lluvias en verano o en todo el año, con una precipitación generalmente mayor de 1,500 mm y temperatura media anual varía de 24

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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a 26 °C. El área de distribución del ecosistema se enmarca en las vertientes del Golfo de México, del Océano Pacífico, Istmo de Tehuantepec, norte de Chiapas y Península de Yucatán.

Las selvas altas y medianas son sin duda el tipo de vegetación más importante de este ecosistema, tanto por su diversidad en especies de flora y fauna como por su función ambiental. La clasificación de las selvas se basa en la altura de sus componentes, así como en las características de sus especies, de mantener o tirar las hojas en alguna época del año, por ejemplo: selva alta perennifolia, selva alta o mediana subcaducifolia, y selva baja caducifolia.

Algunas de las principales especies arboreas son: *Brosimum alicastrum*, *Ficus* spp., *Dialium guianense, Manilkara zapota, Bursera simarouba, Swietenia macrophylla, Andira galeottiana, Calophyllum brasiliense, Pachira aquatica, Bucida buceras, Ceiba pentandra, Croton draco, Hymenaea corbaril, Enterolobium cyclocarpum, Cedrela odorata, Licania arborea, Roseodendron donell-smithii, Hura polyandra, Piscidia piscipula, Lysiloma bahamensis, Cordia dodecandra, Alvaradoa amorphoides, Haematoxilon brasiletto, Lysiloma acapulcensis, Ceiba acuminata, Bursera excelsa, Amphilpterygium adstringens, Bursera* spp, *Ipomoea* spp.

En el pasado, grandes extensiones de la vegetación tropical resultaron severamente afectadas y disminuidas, particularmente las selvas altas y medianas perennifolias, en que grandes extensiones de éstas fueron desmontadas para destinarlas al uso agropecuario. Asimismo, los fenómenos meteorológicos como huracanes y ciclones, aunados a incendios, han perturbado a la vegetación tropical.

El bosque tropical mesófilo también ha sufrido afectaciones debido a que en muchos casos se eliminó parte de la vegetación original para establecer cultivos como café, plátano, cacao y otros. Por otra parte, se aprecia que la selva tropical subcaducifolia y caducifolia, no ha sido alterada como la selva perennifolia, debido a que en general el clima donde se desarrolla no es tan favorable para la agricultura (sequía de 5 a 7 meses en el año).

Ecosistema de zonas áridas—En general, estas áreas se distribuyen al norte del paralelo 21° 30′ entre las Sierras Madre Oriental y Occidental; comprenden parte de los estados de Querétaro, Guanajuato, Aguascalientes, Zacatecas, San Luis Potosí, Durango, Chihuahua, Nuevo León y Coahuila. Asimismo en el estado de Sonora se encuentra el Desierto Sonorense y en la Península de Baja California el desierto del mismo nombre. La precipitación pluvial es menor de 350 mm al año, con una distribución muy irregular durante la época de lluvias, donde la temperatura media anual varía entre 15 y 25 °C y una época de sequía no menor de 7 meses.

Más del 40% de la superficie del territorio nacional se encuentra comprendido dentro de las zonas áridas y semiáridas, donde existen un gran número de especies de flora y fauna susceptibles de ser aprovechadas para usos industriales, forrajeros, medicinales, comestibles, cinegéticos y de ornato. La vegetación de la zona árida incluye una gran diversidad de tipos, consecuencia de la cantidad de microambientes derivados de la alta oscilación térmica y escasa precipitación. Los tipos de vegetación más representativos del ecosistema árido y semiárido son los siguientes: mezquitales y huizachales; matorral micrófilo, cardonales y tetecheras; izotales, nopaleras y pastizales.

Las principales especies entre otras son las siguientes: *Partenium argentatum, Agave lecheguilla, Euphorbia antisyphilitica, Simmondsia chinensis, Yucca schidigera,* Prosopis spp, Atriplex canescens, Potlieria angustifolia, *Opuntia* spp, *Chilopsis linearis, Turnera difusa, Flourencia cernua, Larrea tridentata, Lippia spp, Coryphantha palida, Cephalocerus senilis* y otras cactáceas.

En cuanto al deterioro de este ecosistema se debe básicamente a los siguientes causas:

Sobre-explotación del recurso forestal; Cambio del uso del suelo por apertura de áreas agrícolas y para ganadería extensiva; Sobrepastoreo. Las regiones más afectadas son las Sierras de Baja California Norte, Desierto de San Sebastián Vizcaíno, Sierras y Llanuras de Durango, Sierras y Llanuras Occidentales, así como las Llanuras y Sierras de Querétaro e Hidalgo.

Distribución de la Propiedad

La propiedad de los suelos donde desarrollan los bosques de clima templado y las selvas en México se dan de la siguiente forma: Propiedad social 80%, Propiedad nacional 5%, Propiedad privada 15%.

Criterios e Indicadores

El Proceso de Montreal, se constituyo en Ginebra en junio de 1994 con el fin de impulsar el desarrollo de criterios e indicadores para la conservación y el manejo sustentable de los bosques templados y boreales, mismos que deberán ser aceptados y aplicados en cada país participante. Los diez países que inicialmente integraron el grupo son: Australia, Canadá, Chile, China, Corea del Sur, Los Estados Unidos de Norte América, La Federación Rusa, Japón, México y Nueva Zelandia. Posteriormente, Argentina y Uruguay se anexaron al grupo de trabajo. En conjunto, los doce países integrantes representan el 90% de los bosques de clima templado y boreal del mundo.

Se entiende como criterio a una categoría de condiciones o procesos por medio de los cuales puede evaluarse el manejo sustentable de los bosques. Por otra parte, un indicador es una medida de un aspecto de un criterio. Una variable cualitativa o cuantitativa puede ser medida o descrita periódicamente para observar tendencias en el ecosistema. Así mismo, los criterios e indicadores son herramientas que facilitan el conocimiento real de los ecosistemas al igual que las tendencias futuras de las poblaciones vegetales. Por otra parte, la aplicación de los criterios e indicadores proveerá de información necesaria a los manejadores de bosques así como a las autoridades para tomar mejores decisiones de los recursos naturales.

Los criterios que se consideran para la conservación y manejo sustentable de los bosques son: 1. Conservación de la diversidad biológica; 2. Mantenimiento de la capacidad productiva de los ecosistemas forestales; 3. Mantenimiento de la sanidad y vitalidad de los ecosistemas forestales; 4. Conservación y mantenimiento de los recursos suelo y agua; 5. Mantenimiento de la contribución de los bosques al ciclo global del carbono; 6. Mantenimiento y mejoramiento de los múltiples beneficios socioeconómicos de largo plazo para cubrir las necesidades de las sociedades; y 7. Marco legal, institucional y económico para la conservación y el manejo sustentable de los bosques.

Durante el segundo semestre de 1997, los países miembros del Proceso de Montreal presentaron el primer reporte sobre la aplicación de criterios e indicadores. Para México, Rodríguez, Vera y de la Rosa (1997) presentaron el primer acercamiento a la aplicación de criterios e indicadores en un contexto nacional. Debido a la gran diversidad geológica y topográfica existente en el ecosistema templado, se considera que la aplicación de criterios e indicadores a nivel nacional, no es representativo del ecosistema templado, por lo cual deberán de aplicarse los criterios e indicadores por regiones con características de preferencia similares.

Por lo anterior, y debido a la importancia de los criterios e indicadores para lograr un manejo sustentable de los recursos forestales, la Dirección de Desarrollo Forestal del Gobierno del Estado de Veracruz, decidió aplicarlos con el fin de establecer una base real (bench mark) de los recursos naturales y así poder cuantificar posibles cambios en el componente del ecosistema templado denominado **"Cofre de Perote"**.

Consideraciones Generales del Cofre de Perote

La región Cofre de Perote, por su geología y topografía, presenta una gran variedad de climas y tipos de suelo, configurándose varios ecosistemas, los cuales son ricos en su composición floristica. La región es constituida por 16 municipios y ocupa una superficie aproximada de 275, 700 has. Así mismo, la región ha sido dividida en tres áreas para su estudio:

1. El Parque Nacional, decretado en 1937, tiene una superficie de 11,700 hectáreas. Se ubica desde la cota de los 3,000 msnm hasta la cima de la montaña a los 4282 msnm. Dentro del parque, esta distribuidos 4 municipios, 10 comunidades y ejidos y se estima una población de 4,700 habitantes.

2. El área de cuencas de captación, ocupa la mayor superficie, con aproximadamente unas 200,000 has que conforman tres cuencas: Nautla, Carmen Oriental y La Antigua-Actopan. Se caracteriza por presentar un mosaico discontinuo de áreas forestales y cultivos agrícolas, su importancia radica en la regeneración de acuíferos y sus áreas boscosas, se estima que 1 hectárea de bosque, cosecha 6,600 m^3 de agua/año.

3. El área del Valle de Perote, el valle constituye un ejemplo clásico de la fragilidad y complejidad de los valles de montaña de zonas semiáridas, el cual tiene aproximadamente 64,000 has ubicado entre el estado de Puebla y el oeste central de Veracruz. La altitud del valle varia entre los 2200 a 2600 m. El clima es clasificado como seco con temperaturas frías. Además, en el valle, existe una considerable variación en cuanto a la intensidad de precipitación mensual, la cual se distribuye en un periodo corto, registrándose la mayor precipitación en los meses de julio y agosto. Así mismo, en el área se registran altos niveles de evaporación, creando condiciones de estrés a la vegetación existente.

Para poder desarrollar cada criterio e indicador, se consulto información generada en el área de estudio, en el documento no se mencionan metodologias, únicamente se da la información disponible para cada indicador.

Conservación de Diversidad Biológica en el Cofre de Perote

Diversidad del Ecosistema

Superficie por tipo forestal en relación a la superficie total de bosque—La superficie arbolada de la región cofre de perote es de 110 000 hectáreas. Los tipos de vegetación que se desarrollan son los siguientes: en el páramo de altura, *Pinus hartwegii*, seguido por masas puras de *Abies religiosa*. Descendiendo, se encuentra el bosque de pino constituido principalmente por *Pinus montezumae, P. teocote, P. pseudostrobus, P. ayacahuite* y *P. patula*. La siguiente formación arbórea, es la conocida como el bosque de pino-encino, formado principalmente por *Pinus teocote, P. patula, P. pseudostrobus, Quercus crassifolia, Q. lauriana* y *Arbutus xalapensis*. Finalmente, se encuentra el bosque caducifolio constituido por *Liquidambar macrophilla, Carpinus caroliliana, Ostrya virginiana, Magnolia schiedeana, Mangolia dealbata, Podocarpus reichei* y *Quercus spp*.

Superficie por tipo forestal de áreas protegidas—Dentro del parque nacional, se encuentran 11, 700 hectáreas las cuales por diversos problemas administrativos no se encuentran protegidas totalmente, se espera que al definirse los problemas administrativos se protegerá la totalidad de la superficie del parque nacional.

Fragmentación de los tipos de bosque—El 70% de los bosque de la región Cofre de Perote se encuentran fragmentados por diversa causas, entre las cuales destacan: ampliación de la frontera agrícola; construcción de caminos; aprovechamientos de controlados; ataque de plagas y enfermedades; incendios forestales intencionales.

Diversidad de Especies

Número de especies que dependen del bosque—En un estudio realizado durante cuatro años, se calculo que existen 80 familias con 600 especies, entre especies maderables y no maderables. Para el bosque de *Abies*, se cuenta con 122 especies correspondientes a 40 familias de plantas vasculares, incluyendo 6 helechos. Para el bosque de pino-encino 426 especies corresponden a 80 familias de plantas vasculares, incluyendo 26 helechos y dos licopodios. Finalmente, las especies dependientes del bosque caducifolio son 221 especies correspondientes a 87 familias de plantas vasculares incluyendo 14 helechos y un licopodio.

Especies raras, vulnerables o en peligro—La magnolia, *Magnolia dealbata*, es una especie en peligro de extinción debido principalmente a la tala. Entre las especies raras, se encuentran *Symplocos coccinea, Sphaeropteris horrida, Nephalea mexicana* y *Valerina sorbiifolia.*

Mantenimiento de la Capacidad Productiva del Ecosistema

Superficie de terrenos forestales y superficie neta de suelos forestales disponibles para la producción de madera—El área con terrenos forestales es de 206 800 has y la superficie neta para la producción de madera es de 110 000 has. Aproximadamente, 68 900 has son utilizadas con fines agrícolas y pecuarios. Unicamente 10 000 has de bosques son aprovechadas bajo programas de manejo.

Volumen total de los arboles comerciales y no comerciables—Las existencias volumétricas comerciales son de 9 millones de metros cúbicos. En cuanto a las existencias maderables no comerciales se estiman en 15 millones de metros cúbicos. Actualmente en la región del Cofre de Perote se están produciendo 61 mil metros cúbicos de madera sobre una superficie aproximada de 1,700 hectáreas.

Superficie plantada—A la fecha se han plantado 3546 has en suelos degradados con pendientes mayores al 15%. Solamente, 221 has tienen edad suficiente para calcular su volumen, de tal manera que el volumen estimado es de 16 354 m^3.

Extracción anual de productos no maderables—Anualmente se extraen en promedio 2.5 toneladas de diversos productos no maderables, entre los cuales destaca el hongo blanco y otros hongos comestibles. Es necesario indicar que no existen planes de manejo sustentable para todas las especies no maderables que provee el bosque.

Mantenimiento de la Sanidad y Vitalidad del Ecosistema

Superficie y porcentaje de bosque afectado por procesos o agentes más allá del rango de variación histórico—Los incendios son comunes en la zona forestal del Cofre de Perote, durante 1995, se incendiaron 700 has compactas. Debido a que los incendios fueron muy intensos, afectaron el vigor de los arboles, posteriormente, estos fueron atacados por descortezadores, afectando un total de 35 has. Después del segundo semestre de 1998, como consecuencia de la sequía causada por " El Niño", se registraron daños al arbolado en 2500 has, de esta superficie, 750 has fueron drásticamente afectadas.

Superficie y porcentaje de terrenos forestales sujetos a niveles de contaminación del aire—En el estado de Veracruz, se produce una cantidad importante de contaminantes atmosféricos. La planta nucleoelectrica Laguna Verde, realiza monitoreo ambiental con el fin de observar tendencias y comportamientos de los radionuclidos de origen natural o artificial. Para la región Cofre de Perote, se determino que la dosis promedio anual es de 98.2 mili Roentgen. Lo anterior, debido a que los vientos alisios transportan los radionuclidos al Cofre de Perote.

Conservación y Mantenimiento de los Recursos Suelo y Agua

Superficie y porcentaje de terrenos forestales con erosión significativa del suelo—Se cuenta con una superficie aproximada de 150 000 has de suelos forestales erosionados, lo cual representa el 72% de la superficie total de la Región Cofre de Perote. Lo anterior, debido al cambio de uso del suelo, el producir una tonelada de maíz en la zona forestal representa una perdida de 13 toneladas de suelo.

Superficie y porcentaje de terrenos forestales manejados principalmente para cumplir funciones de protección—Se cuenta con una superficie de 10 000 has arboladas las cuales están protegiendo a otros recursos. Usualmente, son áreas arboladas aledañas a los márgenes de los ríos, arroyos, terrenos gran pendiente y lagunas. Considerando la importancia de las áreas de protección, se han realizado trabajos para retener suelo y agua en una superficie de 3,066 has durante la época de precipitación, de tal manera que se han construido 1 915 469 tinas ciegas a curvas de nivel (50 cm de ancho, 50 cm de profundidad y 2.0 m de largo), 6 447 presas filtrantes.

Superficie de terrenos forestales con disminución significativa de la materia orgánica del suelo—En general los suelos forestales de la Región del Cofre de Perote, contienen en promedio 8% de materia orgánica. Exposiciones mas húmedas y menos afectadas por los incendios y pastoreo, tienen porcentajes de materia orgánica superior al 13% .

Superficie de terrenos compactados—Se ha calculado que más de 110 000 has presentan diferentes grados de compactación la cual es provocada principalmente por pisoteo de animales que pastorean indiscriminadamente en toda la región.

Mantenimiento de la Contribución de los Bosques al Ciclo Global del Carbono

A la fecha, no existe ningún trabajo especifico para estimar la biomasa total del ecosistema así como de la fijación del carbono para cada categoría de edad del bosque y balance global del carbono.

Mantenimiento y Mejoramiento de los Beneficios Socioeconómicos de Largo Plazo para Cubrir las Necesidades de la Sociedad

Producción

Valor y volumen de la producción maderable y no maderable—

Produccion	**Volumen**	**Valor ($)Mn**
Maderable	50,982 m^3rta	8,330,459
No maderable	2.5 toneladas	884,100
Astillado	4,725 toneladas	1,417,500
Total		**10,632,059**

1 dólar = 10.04 pesos mexicanos.

No se cuenta con información completa acerca de abastecimiento y consumo de madera, valor de la producción como porcentaje del producto nacional bruto y grados de reciclaje de productos forestales.

Recreación y Turismo

Superficie de terrenos forestales manejados para recreación—Aproximadamente 11 700 has las cuales corresponden al parque nacional es utilizada en actividades de recreación y turismo. Los habitantes de la Cd. de Xalapa son quienes principalmente utiliza los bosques del Cofre de Perote para recreación. Sin embargo, se tienen en forma esporádica visitantes del estado de Puebla y de la Cd de México.

Número y tipo de instalaciones disponibles para recreación—Existen cuatro centros de desarrollo ecoturistico que en promedio atienden a 12 000 personas por año. Por otra parte, 10 000 turistas por temporada acuden a realizar actividades de Rafting en ríos que sé forman en el Cofre de Perote. El alojamiento y alimentación usualmente es realizado en la Cd de Xalapa.

Inversión en el Sector Forestal

Valor de las inversiones—

Concepto	Periodo	Valor ($)Mn
Conservación del recurso forestal	1993-1998	1 680 000.00
Sanidad y manejo	1993-1997	800 000.00
Plantaciones	1993-1997	4 125 000.00
Recreación	1993-1997	1 454 000.00
Total		**8 059 000.00**

1 dólar = 10.04 pesos mexicanos.

Niveles de gasto de investigación, desarrollo, educación, extensión y uso de nuevas tecnologías—La Dirección General de Desarrollo Forestal, ha invertido $250 000 pesos en la preparación de 26 técnicos a nivel de maestría en el manejo de recursos forestales. Los técnicos trabajan en la Dirección de Desarrollo Forestal del Gobierno del Estado de Veracruz y concluirán su programa académico el próximo mes de marzo de 1999. Actualmente, los técnicos de encargan de realizar las actividades de extensión y aplicación d nuevas tecnologías y la inversión asciende a $1 000 000.00 de pesos anuales.

Empleos de la Comunidad en el Sector Forestal

Empleo directo e indirecto en el sector forestal—

Actividad	Periodo	Numero De Jornales
Empleos generados en el bosque	1994	8 300
Empleos generados en 24 industrias forestales	1996	235 283
Conservación del recurso	1993-1997	138 022
Total		**381 605**

Salarios promedio—

Actividad	Año	Salario Por Dia $ Mn
Trabajo en el bosque	1998	40.00
Trabajo en la industria forestal	1998	60.00

1 dólar = 10.04 pesos mexicanos.

Marco Legal, Institucional y Económico para la Conservación y Manejo Sustentable de los Bosques

La propiedad en México esta perfectamente definida, en las regiones forestales el tipo de tenencia dominante es la pequeña propiedad y el ejido. De acuerdo a las modificaciones del artículo 27 constitucional realizadas en 1992, se da seguridad jurídica a los ejidos y terrenos comunales. Por lo tanto, los ejidatarios y comuneros son los legítimos dueños de sus tierras, agua y otros recursos.

El 25 de septiembre de 1998, se expidió el Reglamento de la Ley Forestal, en la cual se establece el marco legal para apoyar la conservación y el manejo sustentable de los bosques por entidad federativa; de los aprovechamientos, forestación y reforestación; Así como del cambio del uso del suelo. El mismo reglamento, favorece la aplicación de recomendaciones para realizar las mejores prácticas para el manejo forestal. Por otra parte, existe un programa para el desarrollo forestal (PRODEFOR), el cual brinda apoyo económico a los dueños de los bosques. Dicho programa depende de la Secretaria del Medio Ambiente, Recursos Naturales y Pesca.

Conclusiones

1. La aplicación de criterios e indicadores propuestos por el Proceso de Montreal, son aplicables a las condiciones de la Región Cofre de Perote.
2. La implementación de criterios e indicadores en la Región Cofre de Perote, establece las bases para conservar y manejar los recursos naturales en una forma sustentable.
3. Se carece de información referente a la contribución de los bosque del Cofre de Perote al ciclo global del carbono.
4. Para muchos indicadores no se tiene información cuantitativa o cualitativa, para lo cual se trataran de implementar las metodologias pertinentes para cuatificarlos.
5. Los planes de manejo forestal existentes en México, no incluyen criterios e indicadores que garanticen un manejo sustentable. Ya que los planes actuales de manejo solo cuantifican crecimientos y existencia volumétricas del rodal o predio a ser aprovechado.

Literatura Consultada

Bello, E. l. 1991. Diagnostico socioeconómico del ejido forestal ingenio el rosario, municipio de Xico, Veracruz. Tesis de licenciatura. Universidad de Veracruz.

Dorantes, L.J. 1994. Programa de mejoramiento genético forestal en el estado de Veracruz. Publicación del Colegio Profesional de Biólogos. Universidad Veracruzana.

Gerez, F.P. 1985. Uso del suelo durante cuatrocientos años y cambio fisonómico en la zona semiárida poblano-veracruzana, México. Biotica 10(2):123-144.

Gutiérrez, C.L. 1993. Estudio biológico de una especie forestal endémica *magnolia dealbata* zucc. Tesis de maestría en ciencias. Universidad Autónoma de Nuevo León.

Hernandez, M.A. 1984. Estructura y regeneración del bosque natural de oyamel (*Abies religiosa*) en el Cofre de Perote, Ver. Tesis de licenciatura. Universidad de Veracruz.

Munguia, G.J. 1994. Caracterización agrosocioeconomica de la zona sub-humeda del valle de Perote, Ver. Tesis de licenciatura. Universidad de Veracruz.

Narave, F. H. 1985. La vegetación del Cofre de Perote, Veracruz, México. Biotica. 10(1):35-64.

Ruiz, N.F. 1994. La problemática del desarrollo forestal en el Cofre de Perote. Publicación del Colegio Profesional de Biólogos. Universidad Veracruzana.

SARH-SFFS. 1994. Inventario Nacional Forestal de México.

Silva, J.J. 1994. Monitoreo ambiental en la planta nucleoeléctrica laguna verde. Salud publica y ecología. Problemática ambiental en el estado de Vearcruz. Publicación del Colegio Profesional de Biólogos. Universidad Veracruzana.

Rodríguez, F.C., Vera, C.G. and De la Rosa V.A 1997. Mexico's first approximation report on criteria and indicators for the conservation and sustainable management of temperate forests. México.

Williams-Linera, G. 1994. El bosque de montaña: un ecosistema muy frágil. Publicación del Colegio Profesional de Biólogos. Universidad Veracruzana.

Evaluacion y Analisis de la Estructura de Ecosistemas Forestales[1]

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Resumen—La estructura de un ecosistema se define básicamente por el tipo, número, ordenamiento espacial y ordenamiento temporal de los elementos que lo constituyen. En este contexto destacan principalmente la estructura específica, dimensional y espacial de los ecosistemas. La evaluación y el monitoreo de la estructura de ecosistemas forestales debe basarse en índices cuantitativos que permitan analizar objetivamente influencias antropogénicas o procesos de sucesión natural. El objeto de este trabajo es, por tanto, analizar diversas variables cuantitativas para la descripción de los atributos estructurales del estrato arbóreo de los ecosistemas, así como un método de inventario forestal para su obtención.

Para la evaluación de la diversidad específica se discuten los índices de Shannon y el perfil específico de Pretzsch o índice A. Para la evaluación y análisis de la estructura de ecosistemas mixtos incoetáneos, se analizan índices que incluyen la distribución espacial de los atributos del arbolado. La agregación de los árboles se describe mediante el índice de ángulos de Gadow, las relaciones de vecindad entre las especies presentes se caracteriza empleando el índice de mezcla de especies de Füldner. La estructura dimensional se obtiene a través del índice de diferenciación dimensional de Füldner, considerando diferenciación diamétrica y en altura.

Para la obtención de las variables estructurales se discuten las posibilidades de aplicación del procedimiento de inventario de Füldner denominado grupos estructurales de cuatro árboles.

Abstract—The structure of an ecosystem is defined basically for the type, number, space distribution and temporary distribution of the elements that constitute it. In this context highlight mainly the specific, dimensional and space structure of the ecosystems. The evaluation and monitoring of the forest ecosystem structure should be based in quantitative indexes that allow the objective analysis of anthropogenic influences or natural succesion processes. The object of this paper is, therefore, to analyze diverse quantitative variables for the description of the structural attributes of the arboreal stratum of the ecosystem, as well as a method of forest inventory for their obtaining.

For the evaluation of the species diversity the indexes of Shanon and the species profile or index A of Pretzsch are discussed. Mainly for the assessment and analysis of the structure of mixed unevenaged ecosystems, indexes that include the spatial distribution of the tree atributes are discussed. The aggregation of the trees is described by means of the contagion index of Gadow, the relationships of neighbourhood between the species come characterize using the index of species mingling of Füldner. The dimensional structure is obtained through the index of size differentiation of Füldner, considering diameter and height differentiation.

For the obtaining of the structural the possibilities of application of the forest inventory procedure structural group of four trees of Füldner are analyzed.

El contar con información cuantitativa referida en tiempo y espacio sobre la estructura de los ecosistemas forestales, es condición básica para el análisis de este atributo desde el punto de vista dinámico. La descripción tradicional de tales ecosistemas comprende normalmente, junto a variables medibles como área basal, diámetro y alturas, una serie de variables categóricas que describen de manera cualitativa la estructura de los mismos mediante conceptos subjetivos dependientes de la persona que realiza el análisis y que, por tanto, no son reproducibles (Gadow,1993). Los cambios en la estructura de los ecosistemas por sucesión natural o influencias antropogénicas pueden de esta manera suponerse, pero no evaluarse cuantitativamente.

Una de las tareas del manejo forestal es la búsqueda de nuevos métodos de inventario y planeación de los ecosistemas forestales, particularmente en una época en que se generan múltiples discusiones sobre la conservación y fomento de la biodiversidad, a la par que se observa un incremento en la demanda de productos forestales. De particular importancia es la generación de esquemas de gestión de los recursos forestales en ecosistemas mixtos multicohortales, que representan los escenarios deseables a futuro en muchas regiones (Aguirre et al. 1998a); en tales ecosistemas deberán considerarse índices que caractericen cuantitativamente la estructura; el reto del manejo forestal consiste en obtener a partir de tales variables los nuevos indicadores de la sustentabilidad.

La estructura de un ecosistema se define básicamente por el tipo, número, ordenamiento espacial y ordenamiento temporal de los elementos que lo constituyen. En este contexto destacan principalmente la estructura de especies, la estructura espacial y la estructura dimensional de los ecosistemas (Thomasius y Schmidt 1996).

Los índices para la caracterización de la estructura de los ecosistemas permiten una mejor reproducción de la condición de los mismos en un momento determinado y de su evolución en el tiempo (Gadow 1997; Nagel,1998). Tales índices deberán considerarse adicionalmente a las variables empleadas de manera convencional (diámetro y altura media, área basal, volumen, edad, densidad, etc.), a fin de lograr una mejor descripción de los rodales.

El objetivo de este trabajo es analizar diversas variables cuantitativas para la descripción de los atributos estructurales

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del estrato arbóreo de los ecosistemas forestales, así como un método de inventario forestal para su obtención. Los niveles de descripción considerados incluyen la estructura de especies, la estructura horizontal del ecosistema y la estructura dimensional del arbolado.

Estructura de Especies

El índice de Shannon (1948) es una de las variables más empleadas para la estimación de la diversidad de especies (Gleichmar y Gerold 1998), para su determinación se emplea la fórmula:

$$H' = -\sum_{i=1}^{S} P_i \cdot \ln(P_i)$$

S = número de especies presentes
p_i = proporción de las especies $p_i = n_i / N$
n_i = número de individuos de la especie i
N = número total de individuos

Como ejemplo de la aplicación de este índice se presentan los siguientes casos de fracciones de un ecosistema con diferente composición de especies:

— 100% *Pinus pseudostrobus*; H' = 0.00
— 80% *P. pseudostrobus*, 20% *Quercus rysophylla*; H' = 0.50
— 50% *P. pseudostrobus*, 50% *Q. rysophylla*; H' = 0.69
— 70% *P. pseudostrobus*, 20% *Q. rysophylla*; 10% *Juniperus flaccida*; H' = 0.80

El valor H' incrementa conforme ocurre un mayor número de especies y la proporción de individuos de las mismas es más homogénea. H' depende por tanto no sólo del número de especies presentes en un ecosistema, sino de la frecuencia con que estén representadas.
Para la caracterización de la estructura vertical de las especies de un rodal, Pretzsch (1996) desarrolló, a partir del índice de Shannon la variable perfil de especies A, cuya fórmula es:

$$A = -\sum_{i=1}^{S} \sum_{j=1}^{Z} p_{ij} \cdot \ln(p_{ij})$$

S = Número de especies presentes
Z = Número de estratos de altura (3 en este caso)
P_{ij} = proporción de especies en las zonas de altura $p_{ij} = n_{ij}/N$
n_{ij} = número de individuos de la especie i en la zona j
N = número total de individuos

Pretzsch define tres estratos para la aplicación del índice A; el estrato I comprende sobre 80% hasta 100% de la altura máxima del rodal; el estrato II sobre 50% hasta 80% y el estrato III de 0 a 50%.

A diferencia del índice de Shannon, el índice A caracteriza la ubicación de las especies en diferentes estratos de altura. A toma valores entre 0 y un valor máximo (A_{max}). Un valor $A = 0$ significa que el rodal está constituido por una sola especie que ocurre además en un sólo estrato. A_{max} se obtiene cuando la totalidad de las especies ocurren en la misma proporción tanto en el rodal como en los diferentes estratos. A_{max} es función del número de especies (S) y de estratos (Z) y se obtiene mediante (Biber 1997):

$$A_{max} = \ln(S*Z)$$

En un ecosistema constituido por 11 especies arbóreas en el Noreste de México se obtuvieron valores de $A = 2.07$ y $A_{max} = 3.50$ (Tabla 1), lo que representa un valor de equitatividad $E = 0.59$.

Estructura Horizontal del Ecosistema

Los árboles se distribuyen en el terreno en forma aleatoria, regular o conformando grupos. El índice de ángulos W_i

Tabla 1.—Indice del perfil de especies *A* de Pretzsch

Estrato	Especie	No. árboles	pij	lnpij	pij*lnpij
80-100%	1	27	0.041666667	−3.17805383	−0.13241891
50-80%	1	192	0.296296296	−1.216395324	−0.360413429
	2	10	0.015432099	−4.171305603	−0.064372
	3	6	0.009259259	−4.682131227	−0.043353067
	4	10	0.015432099	−4.171305603	−0.064372
	5	6	0.009259259	−4.682131227	−0.043353067
0-50 %	1	147	0.226851852	−1.48345811	−0.336525219
	2	72	0.111111111	−2.197224577	−0.244136064
	3	43	0.066358025	−2.712690581	−0.180008789
	4	33	0.050925926	−2.977383135	−0.151625993
	5	58	0.089506173	−2.413447686	−0.216018466
	6	37	0.057098765	−2.862972784	−0.163472211
	7	2	0.00308642	−5.780743516	−0.017841801
	8	1	0.00154321	−6.473890696	−0.009990572
	9	2	0.00308642	−5.780743516	−0.017841801
	10	1	0.00154321	−6.473890696	−0.009990572
	11	1	0.00154321	−6.473890696	−0.009990572
		648	1		**A = 2.065724533**
				A max =	3.4965076

(Gadow et al. 1998) describe la regularidad de la distribución de los árboles vecinos a un árbol-cero de referencia i. La determinación de este índice se basa en la medición de los ángulos entre dos vecinos al árbol-cero i y su comparación con un ángulo estándar α_0 obtenido mediante:

$$\alpha_0 = 360/n \pm 360/10n$$

n = número de árboles vecinos considerados

El índice de ángulos W_i se define entonces por la proporción de los ángulos α menores al ángulo estándar α_0:

$$Wi = \frac{1}{n}\sum_{j=1}^{n} w_{ij}$$

w_{ij} tiene un valor = 1 cuando el j-ésimo ángulo α entre dos árboles vecinos próximos es menor o igual al ángulo estándar α_0, en caso contrario toma un valor = 0.

Si n = 4, W_i puede presentar los siguientes valores:

- 0.0 ninguno de los ángulos α es menor a α_0, esto es, todos los ángulos α se encuentran en el rango de α_0
- 0.25 uno de los ángulos α es menor a α_0
- 0.50 dos de los ángulos α son menores a α_0
- 0.75 tres de los ángulos α son menores a α_0
- 1.0 los cuatro ángulos α son menores a α_0

El valor promedio del índice de ángulos se calcula mediante:

$$\overline{W} = \frac{1}{N}\sum_{i}^{N} W_i$$

Valores de $\overline{W}$ de 0.5 corresponden a una distribución aleatoria de los árboles, aquellos mayores a esta cifra denotan tendencia al agrupamiento y los menores indican tendencia a la regularidad. En la Figura 1 se presenta la distribución de los árboles de acuerdo al índice de ángulos W_i. $\overline{W}$ = 0.60 corresponde a una tendencia al agrupamiento de los individuos mientras que $\overline{W}$ = 0.53 indica una distribución aleatoria de los árboles.

El índice de mezcla de especies M_i se define para el i-ésimo árbol (i = 1..N) y sus tres vecinos próximos j (j = 1..3) como la proporción relativa de árboles vecinos de una especie distinta (Füldner 1995). Este índice se desarrolló a fin de salvar la limitación del índice de Shannon, que no permite derivar información sobre la distribución espacial de las especies (Gadow y Füldner 1992). Rodales con igual H' pueden presentar una distribución espacial de los árboles muy distinta.

El índice de mezcla de especies se obtiene de la función:

$$M_i = \frac{1}{n}\sum_{j=1}^{n} m_{ij}$$

m_{ij} toma un valor 0 cuando el vecino j-ésimo pertenece a la misma especie del árbol objeto i; de lo contrario tiene un valor 1.

Dado que m_{ij} es una variable discreta dual, M_i puede tomar los siguientes valores:

- 0.0 todos los individuos del grupo (cuatro) pertenecen a la misma especie
- 0.33 uno de los vecinos del árbol cero pertenece a otra especie
- 0.67 dos de los tres vecinos pertenecen a otra especie
- 1.00 los tres vecinos del árbol cero pertenecen a una especie distinta

El valor medio de mezcla de especies se calcula mediante:

$$\overline{M} = \frac{1}{N}\sum_{i=1}^{N} Mi$$

N = número de árboles en el rodal

En la Figura 2 se muestran los valores de mezcla de especies para un rodal de *Pinus pseudostrobus*, *Juniperus flaccida* y *Quercus ryzophylla* en Nuevo León, México. Los valores respectivos se presentan para las tres especies por separado. *P. pseudostrobus* se encuentra tanto conformando grupos puros (Mi = 0) como rodeado de uno o más individuos de otra especie ($Mi \geq 0.33$). *J. flaccida* y *Q. ryzophylla* se presentan preponderantemente con vecinos de una especie distinta; en una alta proporción, *J. flaccida* ocurre distribuido en forma individual.

Estructura Dimensional

Los índices de diferenciación dimensional describen la relación entre un árbol cero i y su vecino próximo j y se definen por el cociente entre una variable dimensional del

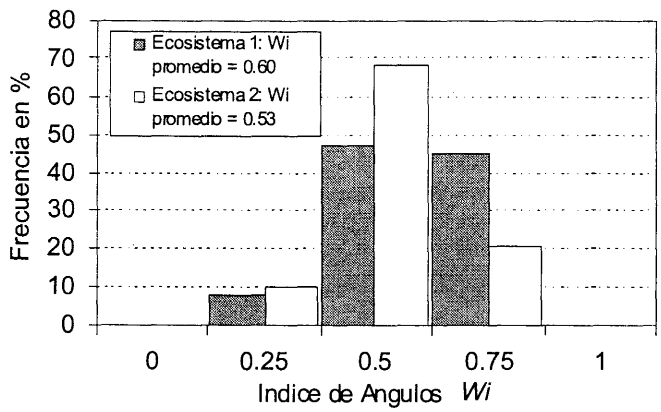

Figura 1.—Indice de ángulos W_i, en dos ecosistemas con diferente distribución horizontal del estrato arbóreo.

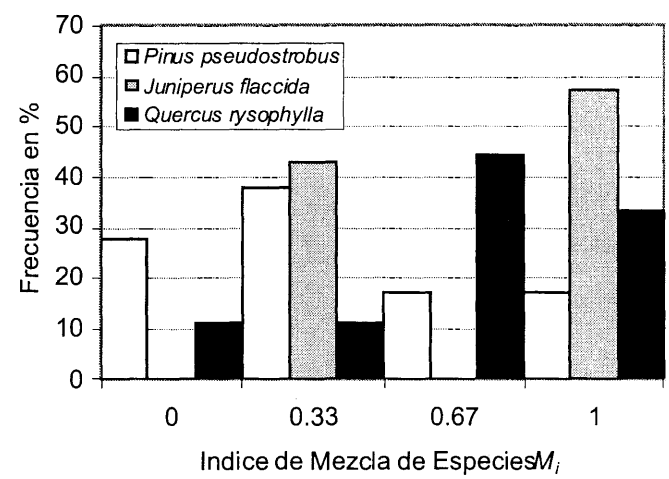

Figura 2.—Distribución del índice de mezcla de especies M_i en un ecosistema mixto.

árbol más pequeño y la correspondiente del árbol mayor, sustraído de 1 (Gadow 1993; Füldner y Gadow 1994; Albert et al. 1995). La diferenciación diamétrica TD_i, por ejemplo, se obtiene mediante la función:

$$TDi = \frac{1}{n}\sum_{j=1}^{n} td_{ij}$$

td_{ij} se deriva de la relación de los diámetros normales de árboles vecinos sustraída de 1:

$$td_{ij} = 1 - \frac{menor(d_{1.3i}, d_{1.3j})}{mayor(d_{1.3i}, d_{1.3j})}$$

El valor medio de diferenciación diamétrica es:

$$\overline{TD} = \frac{1}{N}\sum_{i=1}^{N} TD_i$$

N = número de árboles del rodal

Un valor TDi = 0 significa que ambos árboles tienen el mismo diámetro normal. Conforme la diferencia de los diámetros incrementa, crece también el valor de TDi.

De manera análoga puede emplearse además de la diferenciación diamétrica TD_i, otra variable dimensional, lo que conformaría, por ejemplo, los índices de diferenciación en altura TH_i, y de diferenciación en área de Copa TKS_i (Aguirre et al. 1997, Aguirre et al. 1998a).

En la Figura 3 se muestra la distribución de los árboles de un rodal mixto en las clases de diferenciación diamétrica 0.0-0.2, 0.2-0.4, etc. Para *Pinus pseudostrobus* se observa que la mayor proporción de los árboles presentan una escasa diferenciación diamétrica con respecto a sus vecinos (clase 0.0-0.2); una frecuencia similar muestra *Quercus rysophylla*, para la que en más del 50% de los casos la diferencia diamétrica con su vecino próximo es menor a 20%. Mayor diferenciación presenta *Juniperus flaccida*, especie en la que la mayor proporción de individuos muestra diferencias de diámetro entre 40 y 60% (clase 0.4-0.6).

La frecuencia de clases de diferenciación en altura para las especies anteriores se observa en la Figura 4. *Pinus pseudostrobus* presenta en este análisis menor diferenciación en altura que el resto de las especies, cerca del 60% de los árboles tiene valores menores a 0.2. Para *Juniperus flaccida*

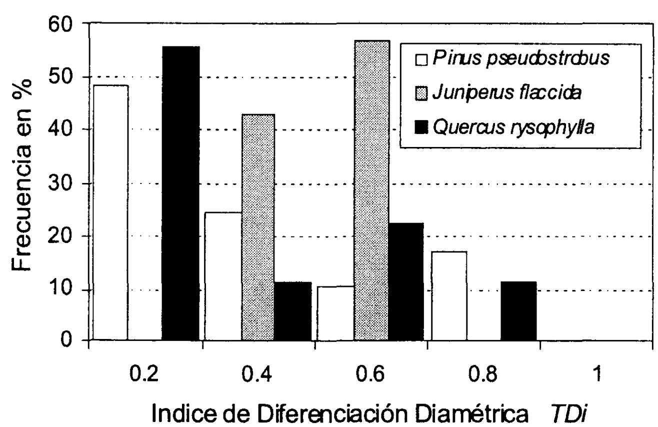

Figura 3.—Indice de diferenciación diamétrica TD_i en un ecosistema mixto multicohortal.

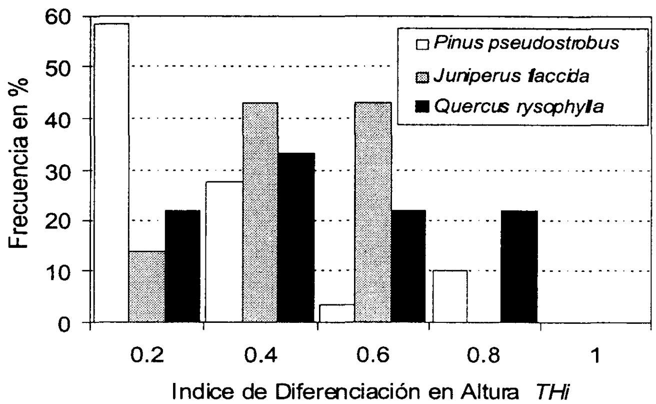

Figura 4.—Indice de diferenciación en altura TH_i en un ecosistema mixto multicohortal.

se observa una menor diferenciación en altura que la obtenida para el diámetro normal (compare Figura 3), mientras que en el caso de *Quercus rysophylla* se incrementa la frecuencia de individuos en la clase 0.6-0.8, esto es, más del 20% de los árboles presentan una diferenciación en altura superior al 60%.

Metodo de Inventario Para la Obtencion de Indices Estructurales

Una alternativa para la obtención de índices estructurales la constituye el procedimiento de inventario denominado "grupos estructurales de cuatro árboles" (Füldner 1995; Pommerening 1997), procedimiento sistemático de inventario en el que los sitios de muestreo se ubican conformando una red a distancias de 20 m o 50 m (Füldner 1995) a partir de un punto inicial aleatorio; este esquema de inventario es particularmente adecuado para ecosistemas inhomogéneos (Saborowsky 1990). El árbol más próximo a los puntos de intersección de la red se designa árbol-cero y a partir de éste se determina la distancia a los tres árboles más cercanos (Figura 5). A los cuatro individuos que conforman el grupo de muestreo se les determina diámetro normal, altura y especie. Adicionalmente pueden obtenerse datos de área de copa, altura de copa, edad, etc.

A partir de la información de los grupos de cuatro árboles pueden obtenerse diversos índices estructurales basados en relaciones de vecindad entre árboles. El índice de mezcla de especies M_i y los de diferenciación dimensional TD_i, TH_i y TKS_i se derivan de manera sencilla a partir de los datos obtenidos mediante este procedimiento de inventario. La inclusión de un quinto árbol en el grupo y la medición de los ángulos entre los árboles posibilita la estimación del índice de ángulos W_i.

Conclusiones

Los índices considerados en este trabajo para la caracterización de la estructura de ecosistemas forestales,

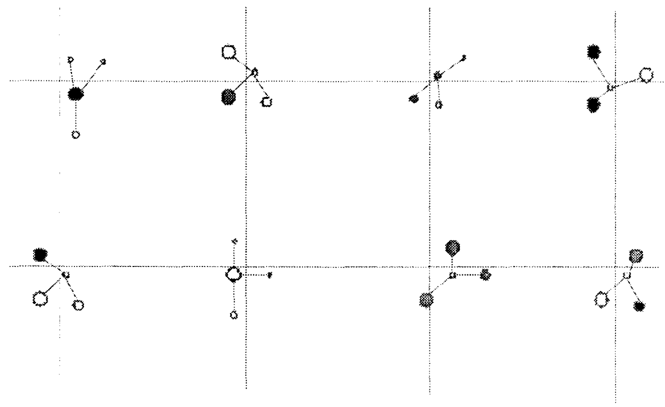

Figura 5.—Grupos estructurales de cuatro árboles distribuidos en una red de muestreo.

constituyen algunas de las opciones disponibles para este objeto. Su aplicación debe basarse en los objetivos propuestos, así como en un análisis de las condiciones propias de las áreas a evaluar, considerando fundamentalmente las especies, su distribución espacial y las características dimensonales de los individuos.

El procedimiento de inventario denominado grupos estructurales de cuatro árboles, representa una alternativa para la obtención de índices cuantitativos para la evaluación y monitoreo de la estructura del estrato arbóreo de ecosistemas forestales.

Literatura Citada

Aguirre C., O. A.; Jiménez P., J.; Vargas L., B. 1997: Análisis estructural del estrato arbóreo de ecosistemas forestales multicohortales. Memoria del III Congreso Mexicano sobre Recursos Forestales. p. 36.

Aguirre C., O. A.; Kramer, H.; Jiménez P., J. 1998a: Strukturuntersuchungen in einem Kiefern-Durchforstungsversuch Nordmexikos. Allgemeine Forst- und Jagdzeitung 169 (12): 213-218.

Albert, M. Gadow, K. v.; Kramer, H. 1995: Zur Strukturbeschreibung in Douglasien-Jungbeständen am Beispiel der Versuchsflächen Manderscheid und Uslar. Allgemeine Forst- und Jagdzeitung 166 (11): 205-210.

Biber, P. 1997: Analyse verschiedener Strukturaspekte von Waldbeständen mit dem Wachstumssimulator SILVA 2. Deutscher Verband Forstlicher Forschungsanstalten. Sektion Ertragskunde. Jahrestagung in Grünberg. pp: 100-120.

Füldner, K. 1995: Strukturbeschreibung von Buchen – Edellaubholz –Mischwäldern. Tesis doctoral. Universidad de Göttingen. Cuvillier Verlag Göttingen. 145 p.

Gadow, K. v.; Füldner, K. 1992: Zur Methodik der Bestandesbeschreibung. Arbeitsgruppe Forsteinrichtung. Jahrestagung in Klieken b. Dessau. pp: 122-138.

Gadow, K. v. 1993: Zur Bestandesbeschreibung in der Forsteinrichtung. Forst und Holz 48 (21): 602-606.

Gadow, K. v. 1997: Strukturentwicklung eines Buchen-Fichten-Mischbestandes. Allgemeine Forst- und Jagdzeitung 168 (6-7): 103-106.

Gadow, K. v.; Huy, G. Y.; Albert, M. 1998: Das Winkelmaß–ein Strukturparameter zur Beschreibung der Individualverteilung in Waldbeständen. Centralblatt für das Gesamte Forstwesen. En prensa.

Gleichmar, W.; Gerold, D. 1998: Indizes zur Charakterisierung der horizontalen Baumverteilung. Forstwissenschaftliches Centralblatt 117 (1): 69-80.

Nagel, J. 1998: Möglichkeiten der Einschätzung von Artendiversität und Struktur im Rahmen von Betriebsinventuren. Manuscrito. 24 p.

Pommerening, A. 1997: Eine Analyse neuer Ansätze zur Bestandesinventur in Strukturreichen Wäldern. Tesis doctoral. Universidad de Göttingen. Cuvillier Verlag, Göttingen. 150 p.

Pretzsch, H. 1996: Strukturvielfalt als Ergebnis waldbaulichen Handels. Allgemeine Forst-und Jagdzeitung 67 (11): 213-221.

Saborowsky, J. 1990: Schätzung von Varianzen und Konfidenzintervallen aus mehrstufigen Stichproben. Schriften aus der Forstlichen Fakultät der Universität Göttingen und der Niedersächsischen Forstliche Versuchsanstalt 99. 68 p.

Shannon, C. E. 1948: The mathematical theory of communication. En C. E. Shannon; W. Weaver (Ed.): The mathematical theory of communication. Urbana, Univ. of Illinois Press. pp: 3-91.

Thomasius, H.; Schmidt, P. A. 1996: Wald, Forstwirtschaft und Umwelt. Economica Verlag. Bonn. 435 p.

Field Methods And Data Processing Techniques Associated With Mapped Inventory Plots[1]

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Abstract—The U.S. Forest Inventory and Analysis (FIA) and Forest Health Monitoring (FHM) programs utilize a fixed-area mapped-plot design as the national standard for extensive forest inventories. The mapped-plot design is explained, as well as the rationale for its selection as the national standard. Ratio-of-means estimators are presented as a method to process data from mapped inventory plots.

It is particularly timely that we have convened to develop a sampling framework for forest ecosystems that is unified across the entire North American continent. In the United States we have been engaged in a similar effort to standardize our inventory system for the past decade. The purpose of this paper is to describe the sampling design implemented nationally in the U.S., provide background information about how this design evolved, explain how the resulting data can be processed, and describe our experience with this design since its implementation in 1991.

U.S. National Plot Design

The plot design currently utilized for forest inventory and monitoring in all regions of the U.S. is based on a cluster of four points spaced 36.6 m (120 ft) apart (Figure 1). Each plot consists of a central point surrounded by three satellite points separated by 120 degrees. Each of the four points is circled by a 7.3 m (24.0 ft) fixed-radius subplot, where trees 12.7 cm (5.0 inches) in diameter and larger are measured. Together, all four subplots cover 1⁄15 hectare (1⁄6 acre).

Each subplot includes a 2.1 m (6.8 ft) fixed-radius microplot used to measure seedlings and saplings smaller than 12.7 cm (5.0 inches) in diameter. Together, all four microplots encompass about 1⁄188 hectare (1⁄75 acre). Microplots are offset from subplot centers to reduce the impact of trampling by field crews.

Each subplot is surrounded by an annular plot. The annular plot is a ring extending from the edge of each subplot to a total distance of 18 m (58.9 ft) from each subplot center. The annular plot is optional, designed to sample large trees with diameters of 100 cm (40 inches) or greater in regions characterized by large trees. Annular plots are currently considered for implementation only in the Pacific Northwest region of the U.S.

In addition to the trees measured on these plots, data are also gathered about the area, or setting in which the trees are located. Area data are particularly useful for subdivision of the forest into meaningful categories, and to enable post-stratification. Some of these area attributes are measured (e.g., percent slope), some are assigned by definition (e.g., disturbance history), and some are computed from the tree data (e.g., percent stocking).

For proper analysis it is crucial that the tree data recorded on these plots are properly associated with the area data. To accomplish this, all plots are mapped by "condition class." Survey crews assign an arbitrary number (usually 1) to the first condition class encountered on a plot. This number is then defined by a series of predetermined discrete variables

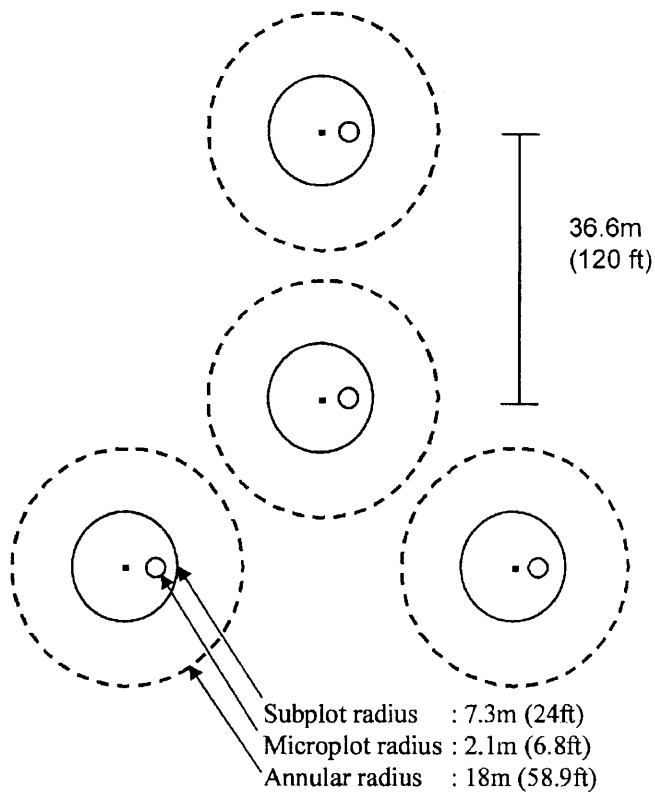

Figure 1.—Plot configuration.

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attached to it, such as land use, forest type, stand origin, and disturbance history. Additional condition classes are identified if there is a distinct change in any of the condition-class variables on the plot.

It sometimes happens that a single plot straddles two or more distinct conditions. Boundaries between these conditions can bisect the subplots, or they could be located between the subplots. When condition-class boundaries bisect a subplot, they are mapped with a series of two or three azimuths. The crew identifies the condition class at subplot center, and the condition class that contrasts with the condition at subplot center. Standing at subplot center, facing the contrasting condition, they then record the two azimuths where the boundary crosses the subplot perimeter. A third azimuth is permissible if the boundary contains a sharp curve or a corner. Trees tallied on the subplot are then assigned to the condition class in which they occur. The area in each condition is computed when the data are processed. Microplots and annular plots are mapped in a similar fashion. So for each plot the microplot, subplot, and annular area in each condition class is known, as well as the location and condition-class of every tree tallied.

Rationale for Main Features of the U.S. Plot Design

Many aspects of this design were assembled from a variety of earlier regional designs. Other aspects were contrived to correct known problems with the regional designs. Three important features of the new design deserve further elaboration.

First, it involves clusters of points, as opposed to a single point. Cluster sampling spreads each plot over a larger area than a single-point plot of the same size. This results in larger within-plot variance, but smaller between-plot variance—so population attributes computed from clusters require fewer plots to produce a given sampling error. Field crews thus spend more time collecting data and less time traveling between plots. Another advantage is that clusters are easier to manage in the field. Single-point plots with large radii are more prone to missed trees and other measurement error than the smaller radii of cluster subplots. This is especially true on steep slopes, where slope distance must be converted to horizontal distance. Since the cluster design is more cost-effective for extensive inventories than single-point plots of similar size (Scott 1993), it was commonly utilized in all of our earlier regional inventories, and is now being used for the national design as well.

The second feature of our national design, mapping plots by condition class, is relatively new. This was adopted to overcome problems with the correct matching of tree data with area data. Some of the earlier regional designs addressed this problem by moving plots to confine them to a single condition class. This introduced bias by altering tree selection probabilities. Trees on borders between conditions were clearly under-sampled. Other regional designs addressed this problem by prohibiting the movement of plots, but then blended area data from distinctly different conditions. This was unbiased, but resulted in area misclassifications. For example, a plot that straddled a pure oak forest type and a pure pine forest type might be classified as a mixed oak/pine forest type. The current design circumvents these problems by prohibiting the movement of plots, and then mapping them to correctly proportion plot area by condition-class variables important for proper stratification of the forest (Hahn et al. 1995).

The third main feature is that the new design is based on fixed-area plots. Prior to implementation of the current design, most regional inventories utilized variable-radius prism plots. The decision to use fixed-radius plots is partially related to difficulties in mapping variable-radius plots. As mentioned previously, some stand-level area attributes (e.g., percent stocking or stand size) are computed from the tree data. For subplots with boundaries this means that tree selection probabilities for some small trees on fragmented subplots could be zero (for the purpose of computing a stand-level attribute for a condition class). Fixed-radius plots avoid this problem since all trees have equal selection probabilities. Additional advantages of fixed-area plots include their utility for spatial modeling, and their intuitive simplicity as compared to variable-radius plots.

Processing Mapped-Plot Data With Ratios of Means

There are numerous attributes of interest in a forest inventory, but most can be collapsed into three main categories:

1. Per-hectare attributes (e.g., mean number of trees/hectare)
2. Per-tree attributes (e.g., mean number of conks per tree)
3. Stand-level attributes (e.g., mean stand age).

All of these categories involve ratios (y/x) where y is the sum of some attribute of interest and x is a correlated auxiliary variable (usually an area or a tree total). Population totals, means, and variances associated with these attributes can be derived from several alternative estimators. One such estimator used by our FHM Program, the ratio of means (Cochran 1977), is appealing because it is based on classical statistics and is relatively easy to compute. Demonstrations of how ratios of means apply to mapped inventory data follow. Additional details are covered in Scott and Bechtold (1995) and Zarnoch and Bechtold (1999).

The ratio-of-means estimator is defined as

$$\hat{R} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} = \frac{\bar{y}}{\bar{x}} \tag{1}$$

where

y_i = the variable of interest on plot i,
x_i = an auxiliary variable on plot i which is correlated with y_i and
n = number of plots containing at least 1 condition class of interest.

The variance associated with this estimator is

$$\hat{V}(\hat{R}) = \frac{\left(S_y^2 + \hat{R}^2 S_x^2 - 2\hat{R}S_{yx}\right)}{n\left(\bar{x}^2\right)} \tag{2}$$

where S_y^2 and S_x^2 are the typical sample variances of y and x, and S_{yx} is their covariance.

Ratios of means are straightforward for estimates derived singly from only subplots or only microplots. However, simple ratios must be combined when data are aggregated across microplots and subplots. There are two ways to do this. The first method is for attributes where simple ratios can be added together (e.g., estimates of microplot sapling basal area per hectare can be added to subplot basal area per hectare to yield a total for all trees). The additive combined estimator is specified as

$$\hat{R}^* = \hat{R} + \hat{R}' \tag{3}$$

where

$\hat{R}$ = *the first ratio-of-means estimator, and*
$\hat{R}'$ = *the second ratio-of-means estimator.*

The variance associated with this estimator, which incorporates the covariance between both estimators, is

$$\hat{V}\left(\hat{R}^*\right) = \hat{V}\left(\hat{R}\right) + \hat{V}\left(\hat{R}'\right) + 2\hat{C}\left(\hat{R}, \hat{R}'\right) \tag{4}$$

where the covariance is defined as

$$\hat{C}\left(\hat{R}, \hat{R}'\right) = \frac{S_{yy'} - \hat{R}S_{y'x} - \hat{R}'S_{yx'} + \hat{R}\hat{R}'S_{xx'}}{n(\bar{x})\bar{x}'} \tag{5}$$

A different combined estimator is used for aggregating microplot and subplot ratios that are not additive (e.g., mean number of conks per tree for microplot saplings cannot be added to a similar mean for subplot trees). Nonadditive ratios can be combined by using an estimator that is the ratio of two correlated ratios. This estimator is defined as

$$\hat{R}^{**} = \frac{\hat{R}_1^*}{\hat{R}_2^*} \tag{6}$$

with estimated variance

$$\hat{V}\left(\hat{R}^{**}\right) = \hat{R}^{**2}\left(\frac{\hat{V}\left(\hat{R}_1^*\right)}{\hat{R}_1^{*2}} + \frac{\hat{V}\left(\hat{R}_2^*\right)}{\hat{R}_2^{*2}} - \frac{2\hat{C}\left(\hat{R}_1^*, \hat{R}_2^*\right)}{\hat{R}_1^*\hat{R}_2^*}\right) \tag{7}$$

where

$$\hat{C}\left(\hat{R}_1^*, \hat{R}_2^*\right) = \hat{C}\left(\hat{R}_1, \hat{R}_2\right) + \hat{C}\left(\hat{R}_1, \hat{R}_2'\right) + C\left(\hat{R}_1', \hat{R}_2\right) + \hat{C}\left(\hat{R}_1', \hat{R}_2'\right) \tag{8}$$

If mean number of conks per tree is the attribute of interest, the ratio in the numerator of Equation (6) would be the combined estimate of conks per hectare (which is additive) and the ratio in the denominator would be the combined estimate of trees per hectare (which is additive).

Combined estimators involving microplots and subplots can easily be extended to include annular plots.

Estimation of Population Means

Using Equation (1), the simple uncombined ratio, we now illustrate how mapped subplot data are processed for each of the 3 main categories of interest (i.e., per-hectare, per-tree, and stand-level attributes). First, all data are summed across the four subplots and stored at the plot level, by condition class. There is usually no interest in variability among subplots in routine summarizations of inventory data, so the sampling unit is the plot.

For a given plot i, y_i, and x_i in Equation (1) are defined as

$$y_i = \sum_{i=1}^{c_i} I_{ij} y_{ij}$$

and

$$x_i = \sum_{i=1}^{c_i} I_{ij} x_{ij}$$

where

y_{ij} = the value of the y variable of interest on plot i and condition class j
x_{ij} = the value of the x variable of interest on plot i and condition class j
c_i = the number of condition classes on plot i
I_{ij} = 1 if condition class j on plot i is of interest or
= 0 if condition class j on plot i is not of interest.

So, for examples in the three main categories of interest, y_{ij} and x_{ij} would be defined for each condition class as follows:

(1) per-hectare attributes (e.g., mean number of trees/ hectare)
y_{ij} = sum of the number of all trees tallied on plot i in condition class j
x_{ij} = area of plot i in condition class j

(2) per-tree attributes (e.g., mean number of conks per tree)
y_{ij} = sum of all conks on tally trees on plot i in condition class j
x_{ij} = the number of trees tallied on plot i in condition class j

(3) st[illegible]-level attributes (e.g., mean stand age)
y_{ij} [illegible]ubplot area of plot i in condition class j) x (stand age of plot i in condition class j)
x_{ij} = subplot area of plot i in condition class j.

The condition-class values y_{ij} and x_{ij} are thus summed across the condition classes of interest to yield the plot values y_i and x_i, which are then summed across plots to produce the ratio of interest.

Estimation of Population Totals

In the U.S., population totals are usually calculated by expanding per-hectare values by an estimate of total *forest* area in the region of interest. For example, the mean number of trees per hectare ($\hat{R}$) is multiplied by the total forest area in the region (A_F) to yield $\hat{T}$, the estimate of total trees in the region:

$$\hat{T} = A_F \hat{R} \tag{9}$$

where

A_F = total forest area in the region

$$\hat{R} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_{Fi}}$$

y_i = number of trees tallied on plot i
x_{Fi} = sum of forest area sampled on plot i, and
n = the number of plots in the region with at least 1 forested condition class.

Note that the numerator of $\hat{R}$ in this example is based on the sum of the tree attribute of interest in the condition classes of interest as previously explained, but the denominator is based on the sum of all condition classes in *forest*. When expanding per-hectare values, the denominator of $\hat{R}$ must be formulated on the same basis as the expander (A_F). So the condition classes of interest in the numerator of may or may not be the same as the denominator—depending on the estimation problem at hand.

Area totals are obtained in the same manner as tree totals. If the population total of interest ($\hat{T}$) were defined as the total area of a particular forest type, y_i in the above example would be replaced with the sum of the sampled area in the forest type of interest.

As opposed to expanding on the basis of *forest* area, *total* land area could be used as the basis for expansion. If total land area is used, A_F and x_{Fi} in equation (9) would be replaced by A_T and x_{Ti}, respectively, as follows:

$$\hat{T} = A_T \hat{R} \qquad (10)$$

where

A_T = total land area in the region

$$\hat{R} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_{Ti}}$$

y_i = sum of the attribute of interest on plot i

x_{Ti} = sum of total land area sampled on plot i

n = the total number of plots in the region.

The variance associated with the population total ($\hat{T}$) depends on how the expansion factor (A) is obtained. If the expansion factor is known, as may be the case for total land area in the region of interest, then the sample variance is

$$\hat{V}(\hat{T}) = \hat{A}^2 \hat{V}(\hat{R})$$

If the expansion factor is estimated, as it is in the U.S., where forest area independently estimated from aerial photography is the basis for expansion, then the variance is increased to account for this additional independent estimator

$$\hat{V}(\hat{T}) = \hat{A}^2 \hat{V}(\hat{R}) + \hat{R}^2 \hat{V}(\hat{A})$$

Implementation of Mapped Inventory Plots

In addition to the U.S., this plot design has been implemented in Lithuania, Latvia, Estonia, Belarus, and Indonesia. No internationally implemented plot design can be expected to achieve optimal efficiency for all inventory attributes in all regions, but so far this design has worked reasonably well wherever implemented. Some criticisms and potential disadvantages have surfaced, but all are minor and solutions are available to circumvent them. A few remarks regarding concerns about this design should be of interest.

Total numbers of trees tallied on each plot average around 30-60, depending on the region. Once a crew reaches the site, most plots are completed in about half a day. However, some regions with high populations of planted trees in the 13-18 cm (5-7 inch) diameter range have complained that too many trees are sampled per plot. Variance between plantation trees is fairly low, and a 1⁄15 ha (1⁄6 acre) fixed plot in a young plantation often yields upwards of 100 tally trees. For regions with a high proportion of young planted stands, sampling efficiencies might be improved by dropping one of the four subplots to reduce the number of tally trees. Although all regions are currently required to measure all four subplots, some consideration should be given to making the fourth subplot optional.

There has been some concern that mapped designs might yield unrealistic values for conditions occupying a small fragment of a plot. This is definitely not a problem for population estimates because the ratio-of-means estimator pools all conditions of interest prior to computing population means or totals. On the other hand, such fragments might pose problems for some discrete area classifications computed from tree tally, such as forest type. Insufficient tree tally on small fragments can be handled with supplemental sampling for the purpose of area classification, or reliance on subjective classification by field crews.

Some indices, such as species diversity index, work best when all plots are the same size. Multiple condition classes on mapped plots can always be collapsed back together to satisfy this requirement. This is the case with the U.S. design, except where plots contain mixtures of forest and nonforest, because no vegetation is sampled on nonforest lands. Even so, species-area curves (Pielou 1966) could be used to adjust partially forested plots, or partially forested plots could simply be excluded from some analyses, or we could simply decide to sample nonforest vegetation on plots that contain mixtures of forest and nonforest.

On the surface it appears mapped designs have the potential to create an unwieldy number of condition-class permutations at the regional level, or even at the plot level. When the data are processed with ratios of means, this is clearly not the case. For any attribute of interest, all condition classes eventually collapse into two—those condition classes that are of interest, and those that are not.

All things considered, the fixed-area mapped-plot design has proven to be robust across a wide variety of field conditions. It has some minor disadvantages, as would any broad-scale design implemented across such a wide range of field conditions, but these are readily overcome. This design now forms the basis of a unified sampling framework across the U.S. It also deserves serious consideration as the choice for implementing a unified sampling framework across the North American continent.

Literature Cited

Cochran, W. G. 1977. Sampling techniques. Third Edition. John Wiley & Sons, Inc. New York. 428 p.

Hahn, J. T., C. D. MacLean, S. L. Arner and W. A. Bechtold. 1995. Procedures to handle FIA cluster plots that straddle two or more conditions. For. Sci. Monogr. 31:12-25.

Pielou, E.C. 1969. An introduction to mathematical ecology. John Wiley & Sons, Inc. New York. 286 p.

Scott, C. T. 1993. Optimal design of a plot cluster for monitoring. In: The optimal design of forest experiments and forest surveys, Sept 10-14. School of Math, Statistics and Computing. Univ. of Greenwich, London. Pages. 233-242.

Scott, C. T. and W. A. Bechtold. 1995. Techniques and computations for mapping plot clusters that straddle stand boundaries. For. Sci. Monogr. 31:46-61.

Zarnoch, S.J, and W.A. Bechtold. 1999. Estimating mapped-plot attributes with ratio of means. For. Sci. In review.

Global Strategy for Forest Information Exchange[1]

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Abstract—To address the need for improved access to forest information, a Global Forest Information Service (GFIS) is being developed under the auspices of the International Union of Forest Research Organizations (IUFRO 4.02) by a consortium of international agencies. The mission of GFIS is to provide coordinated worldwide access to forest information to assist meeting national and international efforts in achieving sustainable forests. The approach of the GFIS will be to improve communication between forest information users and providers through the Internet. A few of the benefits of a decentralized global information system include:

- Easier, user-friendly access to a greater amount of information
- Improved user needs feedback and quality assurance
- Better comparability of data sets
- Identification of information gaps and duplication
- Enhanced information dissemination for researcher

The organizational structure recommended for GFIS is the development of national or regional nodes that connect with existing networks and institutions. A national node for the United States is being proposed. The challenges in developing a forest information system for North American nations will be discussed including technical and management issues. Particular attention will be devoted to the issue of improving the availability and quality of forest monitoring information across North America.

Background to Improving Information Access

The importance of improving access to relevant and timely forest information was formally recognized at the United Nations Conference on Environment and Development in 1992 (UNCED, 1992). Since UNCED, initiatives for sustainable forests, including the various processes, protocols and the Intergovernmental Forum on Forests have also made calls for improving the availability of forest information (CSD, 1997).

To date, attempts to meet the information needs of an increasing number of forest stakeholders (Table 1) has been characterized by the development of independently designed and managed information systems. Examples of these systems are numerous. Rather than making information more easily accessible, this independent approach has lead to increased difficulty in locating and retrieving high quality data and information.

Failure to coordinate the efforts of forest information sources will continue to result in confusion for stakeholders with regards to what information is available, where it is located, and how it is retrieved. For information providers, non-coordination will result in a continuation of under-utilization of their data, non-comparability of data sets across jurisdictions, and dedicating more time to assist clients in locating and retrieving needed information.

Development of the Global Forest Information Service

In response for calls to improve access to information, the International Consultation on Research and Information Systems in Forestry (ICRIS) has recommended the establishment of the IUFRO-sponsored Global Forest Information Service, or GFIS (ICRIS, 1998). The implementation of GFIS will set a new framework for how forest information will be disseminated and accessed.

The GFIS is a decentralized information system that will improve communication between information users and providers. Its aim is to improve the dissemination of, and access to, existing and new information sources – not to replace them. Representatives from a diverse group of interests have participated in the design and development of GFIS since early 1996.

A key characteristic of the GFIS is that its organizational design (Figure 1) allows it to be adaptive to different information needs and circumstances across geographic and political boundaries and over time. Secondly, no single institution or organization controls or manages GFIS – it is a consortium-based initiative.

Each system within the GFIS remains semi-autonomous in that it develops its own guidelines, or "collection policy," for participation. In the United States, a proposal to establish such a national system has been developed. This proposal is presented to serve as a model for establishing national, regional or organizational systems that could be linked to the Global Forest Information Service.

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Table 1 – Current U.S. information users and their needs (Adapted from USDA Forest Service, *Strategic Plan for Forest Inventory and Monitoring*).

User group	Purpose of information	Information needed
State and national lawmakers	Evaluating bills; drafting legislation	Up-to-date state-level and comparable inventory data on variety of forest attributes
State forest agencies	Developing policy proposals; public affairs; evaluating compliance with C&Is	Broad range of inventory data from plot level to statewide; including summaries and analysis
Private industry	Business transactions including resource acquisition (land exchanges and purchase) & processing schedules	Principally up-to-date inventory information at forest stand, forest and county levels.
USDA Forest Service, USGS, BLM, other public agencies	Internal reports inc. RPA, FHM, reporting to public and Congress	Inventory data for all ecosystem attributes; plot level to national forest level; includes summaries and analysis
Research institutions	Conduct independent analysis for public and private sectors	Detailed inventory data for all forest attributes comparable across spatial and temporal scales
Environmental organizations	Evaluate effectiveness of forest policy; develop policy proposals; communicate to public sector	Detailed inventory data for all forest attributes; includes summaries and analysis

U.S. National Forest Information Dissemination and Access System: A Model

Goal and Objectives

The establishment a U.S. forest information dissemination and access system is in response to a national need and desire for improving the accessibility to forest information.

Figure 1.—Organizational Structure of GFIS.

The **goal** of the U.S. system is to ensure the provision and availability of relevant forest information by providing user-friendly and interactive access to forest data and information.

The **objectives** of the national system include:

- Provide a venue and means for improved communication among information users and providers
- Establish a system whereby relevant information sources, at all levels, can integrate their data sets and reports
- Provide an information access system that meets the information needs of current and future issues of forestry
- Enhance the quality of forest information and its comparability across data sets
- Provide a system that helps identify gaps in, and duplications of, data collection
- Enhance the capacity of information providers to disseminate their data and findings

To assure a successful implementation and long-term operation, certain elements must be incorporated into the process of establishing the system.

Key Operational Elements

The simplest and least costly way to ensure full participation is through the Internet. Thus, the proposed system is envisioned as an Internet-based service having several key operational elements. These elements include: a user-friendly interface; an efficient search engine, an interoperability protocol standard for linking multiple information sources, a collection policy, an interactive feedback mechanism, and a "push technology" component.

User-friendly interface—A well-structured interface that allows access to data sources through thematic, geographic and/or user-occupational paths facilitates ease of use. Users with well-defined information needs would be able to access the information they require through detailed specification of criteria. Less informed users would be offered a number of carefully tailored options which would help to define their area of interest and effectively limit the breadth of information to that most relevant to their immediate question.

Dedicated search engine—A dedicated search engine, through annotated metadata references, would access participating information sources. Having found the metadata reference to the information required by the user it would then be possible, in some cases, to extract the actual information - via a web page, ftp or gopher. As discussed in Appendix B, internationally accepted standards for cataloguing the data and location would be used in the system.

Interoperability protocol—An interoperability protocol would allow databases to "talk to each other" dynamically translating search commands to a commonly understood format. This allows a query to be submitted to multiple databases, transparent to the user. An existing interoperability protocol (Z39.50) is described in Appendix B.

Collection policy—Participation by data providers would be determined by the collection policy. The policy would comprise (1) a mechanism for identifying and labeling high quality relevant information, and (2) an information management strategy to organize better the wide range of national forest information. Typically, collection policies cover:

- Types of eligible information resources
- Format for metadata entries
- Quality of eligible information resources
- Conditions for entering metadata and information resources

Content providers would retain full ownership of their data and are responsible for selecting, assembling, maintaining and updating it.

Interactive feedback—The information user would be linked to the information source(s) housing the metadata or data they are accessing. This link provides an opportunity for the user to give feedback about data needs, content, quality, and other matters directly to the information provider. This element aims to encourage communication between the various stakeholders and information providers.

Push technology—Finally, the system is intended not only to respond to information inquiries, but also would facilitate proactive and directed information transmissions, such as data set updates, announcements, and research findings. Such "push" technology is becoming more common on the Internet and can be subject to a filtering process (like a "collection policy") to avoid unwanted or irrelevant communiqués.

Quality Assurance

The system would be responsible for the accuracy of individual datasets. Data that is inadequate for one purpose may be entirely suitable for another. The system, by including metadata requirements, would help filter out inaccurate or questionable data. Metadata requirements may include; data collection methods, definitions, monitoring methods, information about the quality assurance program in place, presentation and updating techniques, and institutional information. Inclusion of such metadata would automatically expose the data to informal peer review by users, likely to result in an upward trend in quality.

Structure and Information Flow

The system can be compared in many respects to a dedicated forest library. It has a card catalogue, a collection policy, a system to notify users of new acquisitions and other events, and a user-friendly interface that serves as a librarian. It would not replace any existing or planned database or information system, but would improve their availability, provide coordination between them, and enable them to be connected to a highly recognizable international information service in GFIS (Figure 2).

As with a library, there is no limit to the size of the collection (or number of data sets that can be on the system). The appropriateness of including an additional dataset in the system is determined by the collection policy.

Benefits of the System

The benefits of a coordinated forest information system are many and apply to both users and providers of forest information. While the total monetary savings acquired with such a system is unknown, each benefit brings with it a significant reduction in labor and/or materials. Appendix A presents a case study for how one USDA Forest Service monitoring program would benefit under such a system. The benefits include:

Easier, user-friendly access to a greater amount of information—With a recognized focal point for engaging in information gathering, the user is relieved of the task of conducting multiple data searches, adjusting to changing interfaces, and can be more confident that all possible sources of appropriate data have been located.

Reduction of dissemination burden and enhanced profile for researchers—The system would assist researchers and other information producers "post" their data so people can find it. Researchers would benefit as the network broadcasts their findings bringing enhanced opportunities for recognition and funding.

Better organization and comparability of data sets—In the short-term, the system organizes "like" information together. For example, "stand-size classes" can be retrieved across multiple political or geographic boundaries. In the long-term we can expect that data set compilers would voluntarily "migrate" to common and accepted methodologies, standards, and terminology. Such "migration" can be encouraged through the system's collection policy.

Improved user needs feedback to information providers—The system allows users to communicate their information needs to providers. This provides a "built-in" quality assurance and relevance component for the benefit of both users and providers of information.

Identification of information gaps and duplication—The system will reveal what data exists and what does not,

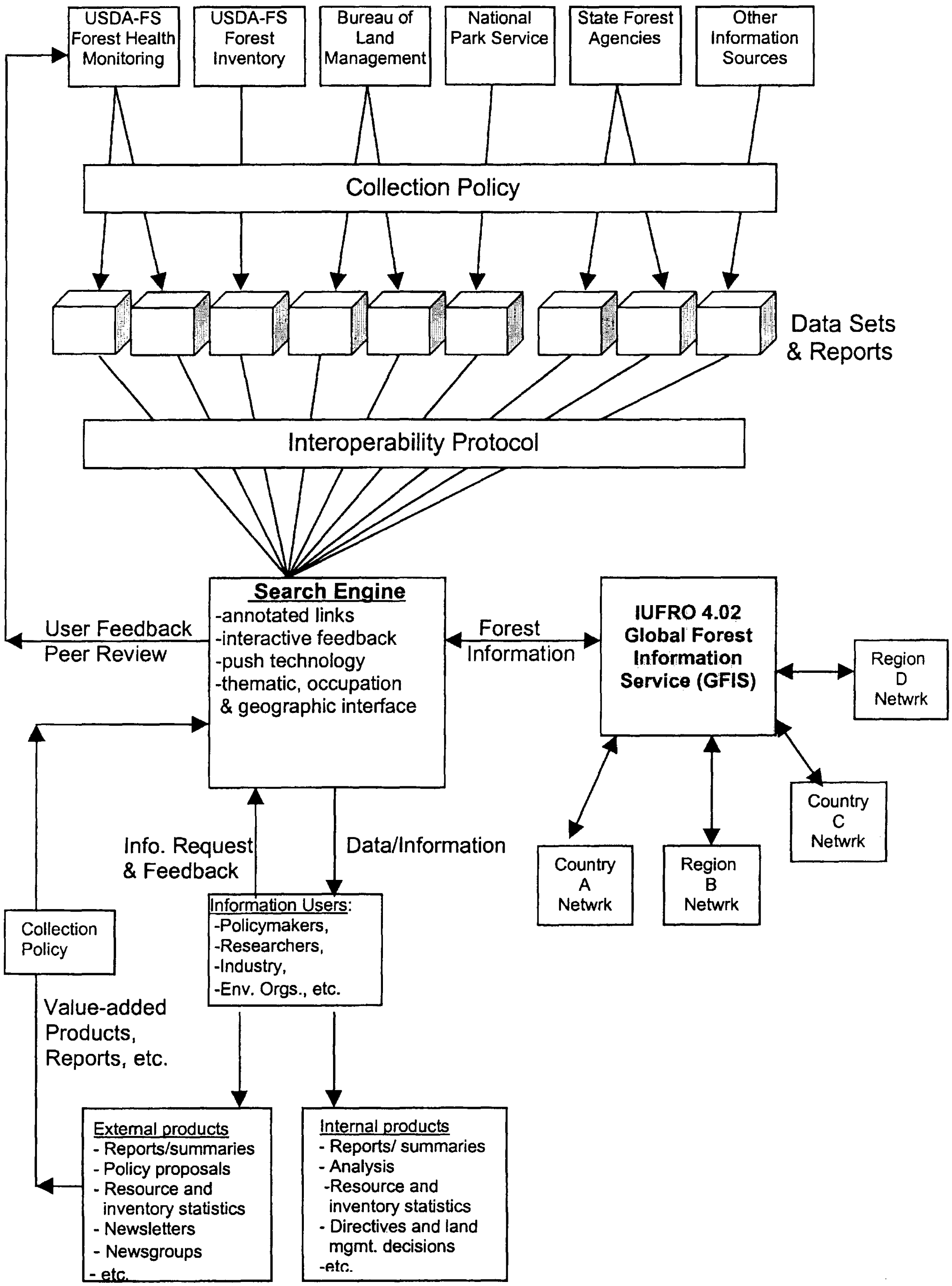

Figure 2.—Schematic diagram of coordinated U.S. forest information system with link to the Global Forest Information Service.

thus assisting researchers in determining where to focus their attention; and policy makers and donors where to devote additional resources.

Generation of value-added products—State Reports, regional or thematic user groups, policy discussion groups, analysis and summaries, brochures, and meetings are a few of the spin-off products that can arise from a national forest information system.

Forum for discussion—A recognized access location provides a focal point where forest specialists are given the opportunity to discuss and exchange ideas on a daily, rather than occasional, basis. These interactions can occur across user and/or provider groups; e.g. policy makers - researchers.

Open access and peer review—Greater amounts of information will be available to a greater number of stakeholders during the deliberative process prior to the drafting of research proposals, legislation or regulations. This will ensure fair and equal access to the "evidence" as well as greater peer review of the data prior to any funding or codification process.

International linkages—The system, with the appropriate interoperability protocol can be "linked" to the IUFRO-sponsored GFIS, and other national information systems. This step would allow integration with multiple forest information sites worldwide; and enhances the broadcasting of US forest information to a global audience. It also assists users to conveniently access non-U.S. data sources through a recognized U.S. gateway.

Literature Cited

Commission on Sustainable Development (CSD). Fifth Session. 7-25 April 1997. Report of the Ad Hoc Intergovernmental Panel on Forests on its Fourth Session. 20 March 1997 (E/CN.17/1997/12).

Inglis, K., 1997. Collection policy of the ENRM projects.

International Consultation for Research and Information Systems in Forestry (ICRIS).7-10 September 1998, Discussion Paper on the Impact of Information Technology: Better Access to Information on Forests. (ftp://iufro.boku.ac.at/icris/)

International Consultation for Research and Information Systems in Forestry (ICRIS).7-10 September 1998, Conclusions and Recommendations. (ftp://iufro.boku.ac.at/icris/)

National Information Standards Organization (NISO) (U.S.), 1992. ANSI Z39.50, information retrieval service and protocol : American national standard information retrieval application service definition and protocol specification for open systems interconnection. Version 2. NISO.

United Nations Conference on Environment and Development (UNCED), 1992. Agenda 21, Chapter 40 Information for Decision Making. A/CONF. 151/26 (Vol. III) 14 August 1992.

USDA Forest Service, 1998. Strategic Plan for Forest Inventory and Monitoring. (http://www.srsfia.usfs.msstate.edu/wo/strategy.htm)

Appendix A: Case Study: How the U.S. Forest Health Monitoring Program Can Benefit With a Coordinated Information Dissemination and Access System

The Forest Health Monitoring (FHM) program was established in 1990 to monitor status and trends in the ecological condition of the nation's forests. The USDA Forest Service and State Forestry and Agriculture agencies annually conduct FHM monitoring activities in cooperation with other federal agencies and several universities. During the 1998 field season, forest monitoring measurements were taken at over 2000 plots in 27 states. Approximately 150 different parameters were measured on each plot detailing forest productivity, diversity, tree condition, soil condition and evidence of air pollution effects. In addition, extensive aerial and ground surveys were conducted to identify the extent and severity of insect and disease damage in forests. The FHM program conducts comprehensive quality assurance activities to ensure that data are comparable in all regions of the country and of high quality. An information management system supports all FHM activities from field data collection to data distribution.

As a participant in the U.S. Forest Information Dissemination and Access System, the FHM program and its clients would derive many specific benefits. A primary benefit would be that more users would become aware of availability of FHM to assist in answering their forest information requests. This is a consequence of the overall system becoming the principal point of contact (one stop shopping) for those requiring forest information as well as the service the system provides in searching all of its data bases for specific thematic and/or geographic requests for information. In addition, the system will have a feature to "push" or notify users of data availability and the publication of new reports.

It is important to recognize that the FHM program itself would be a client to the system. FHM analysts frequently need to access other databases in the development of regional FHM reports. These databases include forest inventory, soil inventory, air quality, water quality data as well as other types of information. The overall system would assist in providing access to these data just as it would to others potentially interested in FHM data. The use of a common format to access these data along with the accessibility of meta-data describing monitoring information from these other programs would be extremely valuable to FHM analysts.

As with most monitoring programs, the FHM program is currently giving consideration to the question of how to make its data more accessible on the Internet. By participating in the development of a shared system, the FHM program can reduce its own specific cost of developing its own system including hardware, software and programming costs. All website development costs, maintenance and updating expenses could be shared among the many different monitoring programs participating in the system.

Participation in the development of a common system would provide the FHM program with many opportunities to interface with other forest monitoring programs. This interaction would not only occur at the national level, but would continue at the international level due to the participation of the U.S. system in the development of the Global Forest Information System. This would be of particular interest to the FHM program as six other countries currently have FHM programs and several others are considering adopting the FHM system of forest monitorin

Appendix B: Improving Access Through the use of a Common Interoperability Protocol (Adapted From ICRIS, Better Access to Information on Forests)

ANSI Z39.50

An essential requirement for accessing information in a multidisciplinary environment is the adoption of a common protocol specifying how to express a search and return results. Any client software using the protocol can then search any database which also recognizes it. One such protocol is defined in the international standard ISO 10163, better known as ANSI Z39.50, developed in the library and information communities and widely adopted at international, national and local level for a variety of purposes including full-text searching, spatial searching, natural language processing and abstract pattern matching (National Information Standards Organization, 1992). It has been implemented in the 'Global Information Locator Service' which is already used by a number of environmental information organisations world-wide and could provide an appropriate basis for any national system. This protocol enables databases to be interoperable. That is to say that diverse databases can talk to each other dynamically translating search commands to a commonly understood format. This allows a query to be submitted to multiple databases, transparently to the user; the result coming back to the user will be presented as if only one database had been queried. These databases would normally be catalogues containing metadata.

Appropriate Datasets for Inclusion

The initial selection of datasets would be determined partly by the willingness of the provider to offer the common access protocol (many already have Z39.50 gateways) and to supply metadata describing the dataset in an agreed format. These requirements are relatively trivial; no change to the database structure or existing access methods is required. Most suppliers are likely to welcome the higher profile for their data that such an additional "side door" to their datasets would provide. Technical standards and relevant subject areas would be defined in a collection policy statement.

Types of data supported may include:

- Forests mapping and assessment
- Sample plot data
- Coordinated research studies
- Forest statistics
- Bibliography

The system should also be capable of "trawling" automatically for relevant new sites and identifying those no longer functioning, to ensure the system is kept constantly up-to-date.

Information Management Challenges to Integrated Inventory and Monitoring of Forest Ecosystem Resources[1]

William K. Michener[2]

Abstract—Many complex research questions will guide science in the 21st century including issues related to sustainable production, protection of plant and animal diversity, and global climate change. A federated information infrastructure that can provide seamless access to shared data and information resources is required to address these issues. Impediments to developing this federated information infrastructure include technical (e.g., communication infrastructure, database interoperability, data archives), semantic (e.g., metadata, methods standardization), and social (e.g., scientific reward structure, cross-disciplinary communication) challenges. Although many of the challenges require long-term fixes, several proactive steps can be taken now to facilitate integrated research and monitoring of forest ecosystem resources.

Environmental scientists have become increasingly interested in issues related to sustainable production; climate and land use change; air, water, and soil pollution; decreases in plant and animal diversity; and human dimensions of global change. To address these issues, scientists and resource managers are increasingly working at broader spatial and longer temporal scales. Attempts to scale research to the region, continent, and globe require unprecedented collaboration among scientists, data sharing across borders, and ready access to high quality, well-documented data that have been preserved in data archives.

Data and information management represents a process that starts with project design and extends beyond the data analysis and publication phases. For example, information management within an organizational context includes design of paper and digital data entry forms, quality assurance and quality control, data processing (e.g., subsetting, merging), metadata development, and submission of data and metadata to a data center or data archive. Generally, a successful research program at an institution depends on a high quality information management program (see Michener et al. 1994, 1998).

Good institutional information management does not guarantee research success, particularly when the scope of inquiry is expanded to regional and global scales, and data from many institutions are required to address specific questions. Such attempts to broaden research efforts often fail because the data pertaining to environmental resources are incompatible, uncoordinated, stored in isolated locations, inadequately protected, and poorly documented. In essence, the requisite data are inaccessible or inadequate. In recognition of this persistent problem, a recent President's Committee of Advisors on Science and Technology proposed development of a federated information infrastructure whereby terabytes of data from many different sources (satellite, field, and laboratory) can be efficiently searched, data can be readily compiled in new ways for analysis and synthesis, and the resulting information can be presented in understandable and useful formats (PCAST 1998; also see Robbins 1996).

Numerous technical, semantic, and social challenges are inherent in developing the federated information infrastructure that is envisioned (Michener et al. 1994, Robbins 1996, PCAST 1998). In the following discussion, I outline impediments to a federated information infrastructure, many of which will require long-term funding, research, and infrastructure improvements. However, other actions can now be taken by various organizations to improve their information management capabilities and pave the way to the more responsive science and resource management needed for the 21st century.

Information Management Challenges

There are at least three different categories of impediments to achieving a true federated information infrastructure that can meet the information needs of science in the 21st century. These include technical, semantic, and social challenges.

Technical Challenges

Technical challenges include the need for an improved communication infrastructure (i.e., Internet-2) that can handle massive bandwidth requirements and advanced network architectures. Database interoperability must be significantly improved. New and expanded data archives will be necessary to provide both secure storage and ready access to environmental data.

Many of the most difficult challenges that lie ahead relate to translating data into information and, ultimately, knowledge. Data, for instance, consist entirely of characters and numbers that have little or no intrinsic meaning. On the other hand, information is a much higher level representation of data where the data have been given form or character, and confer meaning. Knowledge is the understanding that is gained through discovery, perception, and erudition of

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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information. From a scientific standpoint, the true value of data is directly related to our ability to extract higher level understanding from those data.

Knowledge about our environment entails the synthesis of data from many sources and typically requires that a human being has to acquire, manage, manipulate, correlate, analyze, and synthesize data from individual data sets, one at a time. The continuance of long-term monitoring programs coupled with significant improvements in sensors and data acquisition have led to the current situation where many organizations now have an excess of data. Exponential increases in the size of data holdings coupled with the recent development of new environmental remote sensing technology (e.g., multispectral data at 1-3m^2 spatial resolution) requires that we develop new approaches to exploit these massive data sets. Specifically, we need tools to analyze and synthesize data quickly and translate those data into useful information that can guide decision-making, policy formulation, and future research.

Critical technological challenges include the need to develop:

- Extraction and analytical tools for correlating, manipulating, analyzing and presenting distributed information (e.g., new analytical (statistical and modeling) techniques that work with multidimensional, large-volume data).
- New quality assurance methods that "correct" data errors with minimal human intervention.
- Metadata encoding routines to facilitate data mining of these massive data sets.
- Algorithms for analysis, change detection, and visualization that scale to large, multi-temporal, and multi-thematic databases.

Semantic Challenges

Semantic challenges encompass those factors that lead to difficulties in understanding and interpreting data. Environmental data are particularly complex. Forest ecosystem data encompass the complexity of millions of different organisms and hundreds to thousands of different communities and ecosystems. The data are collected by different countries, agencies, industries, academic institutions, and individuals, all of which have different needs, views, requirements, and skills. Furthermore, the data vary substantially in scale, precision, accuracy, type (text, measurements, images, sound, video), and volume (kilobytes to terabytes). Consequently, even within a single institution, data pertaining to one environmental parameter often cannot be compared with data on other parameters because of different data structures, scales of measurement, region of coverage, times data were collected, and so on. Problems associated with different data collection protocols, data storage mechanisms, and comprehensiveness of data documentation are compounded when more than one institution is involved.

Two specific actions that can minimize semantic conflicts include the development and adoption of metadata content standards, as well as the standardization of data collection protocols where possible. Metadata provide critical information for expanding the scales at which ecologists work. For example, field validation data from multiple sites are frequently used to calibrate (or, in some cases, are merged with) remotely sensed data, thereby expanding the spatial domain from the site to broader scales. Cross-site comparative studies depend heavily upon the availability of sufficient metadata. For cross-site comparisons, it is especially important that both methods and instrumentation calibration and inter-calibration (measurements of similar parameters by different methods or instruments) be well documented to confirm data integrity, proper use of experimental methods, and data acquisition.

Much of the *post hoc* effort that is devoted to managing (manipulating), merging, and analyzing data for parameters that were collected under different protocols can be reduced or eliminated when standard methods are employed *a priori*. Furthermore, development and adoption of standard data collection and management protocols also reduces the amount of time and effort expended in developing metadata.

Social Challenges

Research and resource management for the 21st century will require unprecedented collaboration among scientists from many disciplines, as well as data sharing across departmental, agency, academic, and national borders. Success will depend on the extent to which we alter existing scientific reward structures. Data sharing and collaboration are facilitated when the stakeholders perceive that there are real benefits in doing so (Porter and Callahan 1994). Thus, if the delivery of useful data products is part of an organization's objective, then those contributing to the development of the product (i.e., database) deserve credit for doing so. In essence, databases should be viewed as being synonymous to a publication and should be considered in personnel review and promotion procedures.

The lack of effective cross-disciplinary communication, data sharing, and collaboration often impedes attempts to broaden the scope of our scientific efforts. Strategies for success include: (1) taking that first step to initiating a dialogue; 90% of success is simply showing up; (2) build upon existing successful partnerships (i.e. past successes); (3) plan early for collaborative efforts; and (4) provide incentives and the reward structure for participation in cross-disciplinary ventures. Communication is the key to resolving conflicts among participants with different training, vocabularies, and world views.

Implications for Inventory and Monitoring

Research challenges include striking a rational balance between economic feasibility and the data scale(s) and volume that are optimally required to meet scientific and monitoring objectives. High quality, well documented, securely preserved, and accessible data are essential for addressing long-term and broad-scale environmental problems. Access to high quality data requires a strong commitment to implementation of effective information management procedures. The absence of such procedures impairs our ability to use data over long periods. For instance, the loss of information content associated with data through the degradation of the raw data or the metadata is unavoidable and has been referred to as "data entropy" (Michener et al. 1997). Adherence to recommended data management practices, especially the development of comprehensive metadata and the submission of both data and metadata to data archives greatly slows the progression of data entropy.

In this discussion, I have listed many of the challenges to developing the federated information infrastructure required for science and management in the 21st century. Solutions to many of the problems will require substantial infusion of money, personnel, creative thought, and technology by businesses, research and resource management organizations, and nations. However, there are at least seven steps (habits) related to information management that can be taken now to facilitate highly effective integrated research and monitoring of forest ecosystem resources:

1. Allocate a reasonable percentage of research funding for long-term management of data and information generated by the research. In most organizations, data management is seriously under-funded, resulting in data losses and delays in translating data to information.
2. Develop and adhere to data and metadata standards and best use protocols.
3. Provide funding for data rejuvenation (e.g., adding Global Positioning System fixes, i.e., latitude/longitude, to field sites) and rescue (e.g., convert paper records to digital format) to halt further data entropy.
4. Routinely evaluate data utility, research objectives, and management needs, and reestablish priorities. Use this information to revise sampling programs (e.g., reduce effort in certain areas, add new parameters) and to streamline data capture.
5. Coordinate software and systems development and purchases with other agencies or departments to eliminate duplication of effort and reduce expenditures (i.e., take advantage of economies of scale).
6. Cooperate with other agencies, scientists, and the private sector to establish and adopt data and metadata standards, authority files, and thesauruses for data.
7. Establish synthetic research as a top priority.

Literature Cited

Michener, W.K., J.W. Brunt, and S.G. Stafford. 1994. Environmental Information Management and Analysis: Ecosystem to Global Scales. Taylor and Francis, Ltd., London, England.

Michener, W.K., J.W. Brunt, J. Helly, T.B. Kirchner, and S.G. Stafford. 1997. Non-geospatial metadata for the ecological sciences. Ecological Applications 7:330-342.

Michener, W.K., J.H. Porter, and S.G. Stafford (eds.). 1998. Data and Information Management in the Ecological Sciences: A Resource Guide. University of New Mexico, Albuquerque, NM. {Available through http://www.lternet.edu/ecoinformatics/guide/frame.htm}

(PCAST) President's Committee of Advisors on Science and Technology. 1998. Teaming with Life: Investing in Science to Understand and Use America's Living Capital. Office of Science and Technology Policy, Washington, DC. (Available through http://www.whitehouse.gov/)

Porter, J.H. and J.T. Callahan. 1994. Circumventing a dilemma: Historical approaches to data sharing in ecological research. In: Environmental Information Management and Analysis: Ecosystem to Global Scales (eds W.K. Michener, J.W. Brunt, and S.G. Stafford), pp. 193-203. Taylor and Francis, Ltd., London, England.

Robbins, R.J. 1996. Bioinformatics: Essential infrastructure for global biology. Journal of Computational Biology 3:465-478.

The LTER Network Information System: a Framework for Ecological Information Management[1]

James W. Brunt[2]

Abstract—Access to data and metadata distributed throughout collaborating national and international research sites is the focus of a development effort to support ecological research. The U.S. LTER (Long Term Ecological Research) Network informatics group is developing, along with national and international partners, a Network Information System (NIS). The mission of the working group is to design and develop a modular framework that builds on existing site functionality. Platform independence and the capability to present data and information in a consistent fashion, independent of their original format and location, are essential elements of design for the system to function in heterogeneous site environments. The key element, however, is the use of interdisciplinary NIS task groups composed of scientists from existing research groups, information managers, and computer scientists to design and implement various components of the system. Current prototypes serve as data sharing models for improving access to ecological data across sites.

Design and implementation of an information system that seamlessly facilitates intersite research is a major challenge to the U.S. LTER network in the coming decade. The necessity of intersite research has driven the LTER mandate since workshops in the 1980's (Marzolf and Dyer 1986). Since its organization in 1988, the LTER information managers group has focused on facilitating this research. Although computer technology and ecological informatics have come a long way, the fundamentals of managing research information and developing an appropriate system for management have remained relatively stable. What have changed drastically in the last decade are researcher and community expectations. With the explosion of Internet connectivity and the birth of the World-Wide Web (WWW), scientists, administrators, and the general public have come to expect greater access to the products of valuable research dollars (Stafford et al. 1994). The LTER research network has a wealth of long-term data that are being collected by LTER investigators. With the publication of the LTER Catalog of Core Data Sets in 1990, this resource became more widely known within the ecological research community.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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The LTER Network Information System (1990-1995)

During the same period that the LTER information managers developed the catalog of core data sets, the LTER Connectivity Committee established nearly full Internet connectivity across the U.S. LTER Network. This infrastructure for electronic communication and data exchange substantially enhanced the traditional means of networking. Based on this rapidly evolving infrastructure, electronic versions of the Core Data set Catalog and the LTER Personnel Directory were made available to most researchers in 1991 (Table 1). The evolution of those data repositories from hardcopy versions to on-line databases accessible by e-mail, FTP, Gopher, WAIS, SQL and Web information servers reflects the successful use of emerging communications technology in the integration of individual sites into a coherent research network. When the LTER All-Site Bibliography was created in 1993, a hardcopy version was no longer considered an economical or even desirable implementation (Chinn and Bledsoe 1997). Instead, it was implemented as a searchable on-line database.

The improved accessibility to data and ease of use of web browsers highlighted gaps in the LTER information infrastructure. Gopher and Web servers simplified access to widely dispersed LTER information, but queries were still unwieldy. The All-Site Bibliography, for example, although on-line and seeing increasing use <BLINK></BLINK>eweeee has limitations in the type and number of queries that are possible. Most LTER data sets are available via WWW and other network information servers, but in many cases to find out what data are available on LTER site information servers, you need to make connections to each of the site

Table 1.—History of LTER Network Information System development 1988-1998.

1988	Minimum Standard Installation (MSI)
1988	BITNET e-mail
1989	LTERnet Internet-based e-mail forwarding system
1990	Internet Connectivity
1991	Gopher servers
1992	WAIS servers
1993	HTTP servers
1994	On-line Data
1995	Web to Database Connectivity
1996	NIS plan draft
1997	Prototypes developed
1998	Prototypes being evaluated

servers individually, and it is difficult to analyze and synthesize data from different sites because most site servers return data in different formats. The LTER information managers have formulated their vision for an integrated network information system (NIS) that will alleviate these and other difficulties with LTER data access. An NIS working group has been established to guide and advance the process to develop and to implement the vision.

Philosophy And Goals of LTER NIS (1996-2002)

The fundamental philosophy of the effort is "**Develop from a Research Perspective**." The primary function of the NIS will be the support of intersite research. Therefore, development of the NIS is closely linked to efforts by LTER cross-site and synthesis research groups (Fig. 1). Each intersite research effort includes at least one member from the LTER information management group. Initially, intersite research groups provide the main pool of users of new system functions and they provide the feedback required for testing. In addition, development is made with the recognition that information management systems are always evolving, due both to technological changes and to improvements in our understanding of how scientists most efficiently use data. The LTER NIS effort is integrating site information systems, not replacing them. The envisioned system will continue to take advantage of advances in network tools that ensures use into the coming decade.

The goals for this development effort are:

Goal 1: Increase the Utility of the Existing System—Some basic components of a network information system are available to LTER researchers (e.g., catalog, personnel directory, bibliography, integrated mail forwarding, and direct links to most site systems). A modular, step-by-step approach to the NIS development ensures that existing functions will be seamlessly integrated with the future system. With the objective of fulfilling its mission in information management, the LTER Network Office will be responsible for further development of the LTERnet Network Support System to maintain and expand the following core activities:

- LTERnet WWW server
- Personnel Directory
- Core Dataset Catalog
- Cross-site Bibliography
- Satellite Imagery Archive
- Electronic Connectivity
- Query and retrieval systems to integrate these functions

Goal 2: Increase Access and Query Capability on Intersite Data—The Network Information System working group has developed the following query and retrieval functions for the NIS based on input from the data management committee and researchers. An advanced access and query capability will facilitate:

- a search for data available anywhere in the LTER network,
- combining and analyzing data from different sites,
- answering standard information requests (those requests that occur >80 of the time)
- economically building query systems for specific projects and special information requests
- automatic retrieval of data and documentation
- query, analysis and display tools that are intuitive to researchers.

Goal 3: Maintain Strength in Diversity—Research Data Management at U.S. LTER sites is carried out with common objectives in mind, but under a variety of different circumstances and constraints. There are a number of heterogeneous approaches taken to meet research objectives (Conley and Brunt 1991, Briggs and Su 1994, Brunt 1994, Ingersol et al. 1997). Meeting standardized goals with a variety of solutions has built strength into this system. This strength is being maintained and nurtured in the development of the NIS.

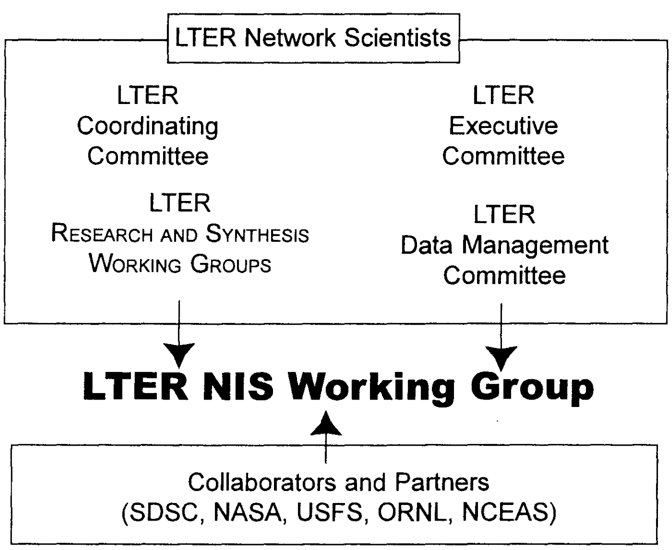

Figure 1.—Diagrammatic representation of the interaction of groups involved in the LTER NIS development.

NIS Development Strategies

Design and implementation of the NIS is being done in a modular, step-by-step fashion, using prototypes to evaluate different technologies, and involving subsequent evaluation for interoperability. These strategies require that teams of information specialists accomplish specific system parts in a coordinated way and in a predictable period. Such tasks include implementation of access and retrieval functions for data sets that are standardized in terms of content and apparent format. For example, measurement procedures of net primary productivity can vary considerably among such different ecosystems as lakes, forests, deserts, and grasslands. Correspondingly, the raw data reflecting those measurements may not be comparable. In these cases, a team of researchers and information specialists will work with the sites to add to the NIS the capability to access from all sites productivity data and metadata in a consistent format, with consistent tools.

Coordination

The development of an LTER-wide Information system depends on the efforts of many critical players: The LTER Coordinating Committee, site researchers, Network Office Staff, Data/Information Management Committee, and Collaborators (e.g., SDSC). These efforts are focused at a continuing series of workshops that form the basis for the design, funding, and implementation of the LTER NIS. Annual face-to-face meetings of the Data Management Committee and the NIS working group along with frequent conference calls serve to coordinate the effort. NIS task groups composed of researchers, data managers, and programmers provide the insight and labor necessary to design, fund, and implement various components of the system.

Task Workshops

The critical element in the NIS development is the use of interdisciplinary task groups composed of scientists from existing cross-site research groups, information managers, and computer scientists to design and implement specific components of the system (Fig. 1). The NIS working group solicits interest from intersite research groups and holds workshops to assess researchers needs. These workshops have been organized in conjunction with workshops that investigate specific intersite research questions, such as climate patterns, biodiversity distribution, litter decomposition processes or soil sampling methods (see: Conley 1991). The LTER Coordinating Committee determines which areas to cover first. The workshops address and attempt to resolve outstanding standardization issues that are relevant to how data and information are presented and distributed by the NIS. Data of interest to the group, such as the Climate Committee have been used by a task group to demonstrate present capabilities. For example, previously, to compile a web page of all climate data available on LTER site servers, one would download them from individual site servers into spreadsheets or other applications, and graph them. The task group evaluates these brute force approaches in use for what works and what doesn't work. Why are these methods insufficient in supporting the groups intersite research? The group then proposes solutions to fix the shortcomings, and sets a timetable for implementation of a prototype. Prototype development includes developing an exchange format, information model for the data, and a WWW interface to the data. The process would then proceed with testing and feedback. The positive aspects of the task group experiences are then used in other working groups.

Standards Development and Use

The key to developing a truly interoperable information system is the use of a flexible metadata model that is rooted in scientifically meaningful content. Standards such as the U.S. Federal Spatial Data Transfer Standard (SDTS), designed to facilitate communication of accurate information, fail to meet the expectations of the "20-year rule" for reuse (Fig. 2). This criterion, imposed by LTER researchers for preservation of complete information, states that data need to be documented such that independent scientists can understand and use the data 20 years after collection (Porter and Callahan 1994). This is necessary because of the degradation of information that occurs with incomplete documentation described by Michener and colleagues (1997). LTER information managers are continually involved in scrutiny of new standards and software being adopted elsewhere for possible implementation in the LTER Network (e.g., FGDC 1994), Dublin Core (Weibel 1997). They have also been active in the recent formalization of content standards for non-spatial ecological data (Michener et al. 1997).

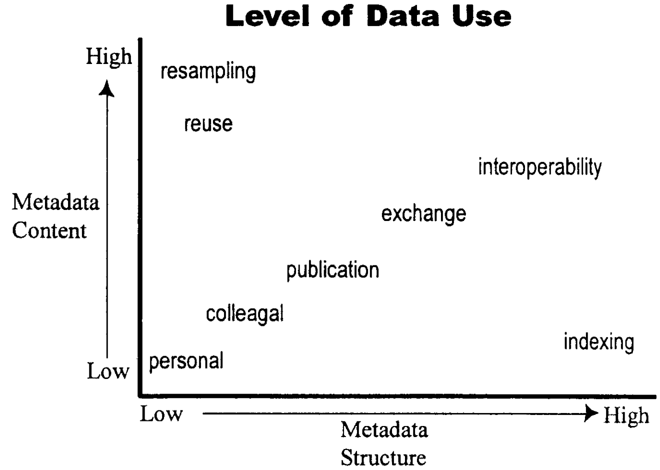

Figure 2.—The information content of metadata necessary to re-use data 20 years after collection is higher than that required for exchange of data. This demonstrates the need for broader, more flexible metadata for ecological data than is provided for in current standards.

Industry and de facto standards for network data communication that can help ensure hardware and software independent functionality have emerged and are being considered in the NIS design. For example, network client/server technology using ODBC is well suited to this application and can be implemented independent of the specific computer platform. There are also some recent developments with potentially major implications for the way future network information systems are implemented. In particular, executable content on Web servers by the Java language (an open standard for programming on the Web) could be used to package data together with their metadata—a requirement introduced by Conley and Brunt (1991).

NIS Prototypes

The NIS prototype developments take advantage of advances in web-based database interfaces to provide access to network-wide data sets via a single point of entry. A number of prototypes have been developed addressing dif-12ferent data types found in the network. Each of these prototypes was developed using a different database/web technology for comparison. The prototypes include the climate databases (project name: CLIMDB), the site description information (SITEDB), and a basic data catalog (DTOC), and the personnel database (PERSDB). The prototypes are being developed and tested at LTER sites prior to being installed on the new LTER Network information system infrastructure (LTERnet) at the Network Office.

CLIMDB

The climate database (CLIMDB) prototype is an interactive, web-based, interface to standardized LTER Network climate data (Henshaw et al. 1998). To develop CLIMDB, LTER information managers engaged with LTER climate researchers, in a relationship where current database technology was applied to the climate data standards (see: http://www.geog.unc.edu/~greenland/CLIMSTAN.html/Default.htm). The methods used to bring these two groups productively together are now being refined in such a way that they can be applied to other, more ecologically oriented data sets that will eventually become components of the LTER NIS. Plans are now in progress to migrate CLIMDB, from an ORACLE database supported by the North Temperate Lakes LTER in Madison (http://www.limnology.wisc.edu/climdb.html, to Microsoft SQL Server at the LTER Network Office.

DTOC

The Data Table of Contents (DTOC) is an automated, web-based data catalog for LTER site data sets. It contains a streamlined, standardized metadata set related to each research data set. This information is "harvested" from the site information systems, using similar conceptual methods to those developed in the CLIMDB project (Fig. 3). This project provides the groundwork for the implementation of a cross-site, standardized metadata model that would be the backbone of the NIS Interoperability Framework. The Data Management Committee, with the support of the LTER Network Office, developed this project which was housed on the Virginia Coast Reserve LTER site information system. The DTOC has just been moved and is being tested on the LTER Network Office Computer system (http://www.lternet.edu/DTOC/).

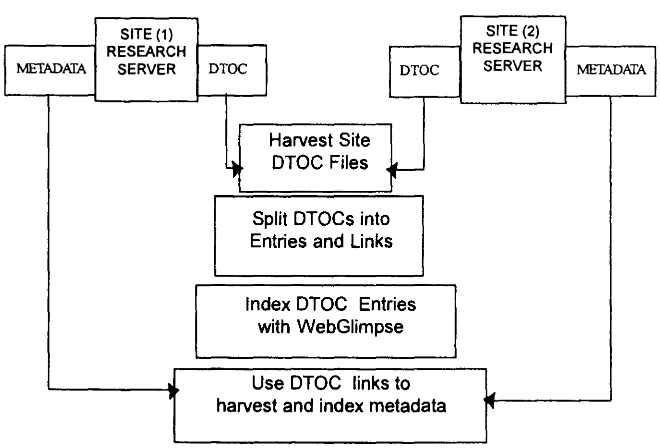

Figure 3.—The flow of information in the preparation of data table of contents (DTOC) indices. The harvesting server retrieves the data set entries along with URLs to more extensive metadata and data which can be accessed via the WWW searchable index using WebGlimpse.

SITEDB

The site description database (SITEDB) project adds another level of metadata compliance to the NIS. This work has been prompted both from a scientific and an administrative need for detailed, descriptive information about each LTER site. SITEDB presents standardized web page views for each site in addition to having all the relevant site information available in a single relational table. This information can be maintained by the site via web-based interface. The implementation is in miniSQL at the Palmer Island LTER headquarters in San Diego and it too will eventually be integrated into the NIS.

PERSDB

The LTER Network personnel database has been revised and migrated to MS SQL from an ingres database. Among the improvements is the ability to more closely control entries and mail lists, and integration with the developing LTER NIS. This database can now be managed updated by the sites via a web-based interface implemented in PERL.

All these advances were made both through financial support of the Network Office for work of the LTER Data Management and Climate Committees and by direct participation of NET and site personnel.

NIS Interoperability Framework

The group is currently in the process of evaluating the prototype modules, described above. The results will be developed into the LTER NIS interoperability framework – a set of specifications that describe the interoperability of the discrete units of the system, into which additional, future modules can be plugged (Fig. 4).

Components of the Framework

- Distribution Format Specification
- "Centributed" Harvester Specification
- Indexer Specification
- Metadatabase Specification
- Server Specification
- WWW Interface Specification

Resources

The development of a distributed NIS depends upon the readiness of individual sites to participate but will not exclude the site's information. Sites that do not yet have full capabilities can have their contributions supported by the Network Office server. The LTER Network Office is charged with supporting the expansion of the existing NIS and advanced query and information systems that integrate data from the individual site information systems. The Network Office also supports planning activities, aid in coordination of site activities, promote standards development, develop Network data sets, and provide access to software, storage and network resources.

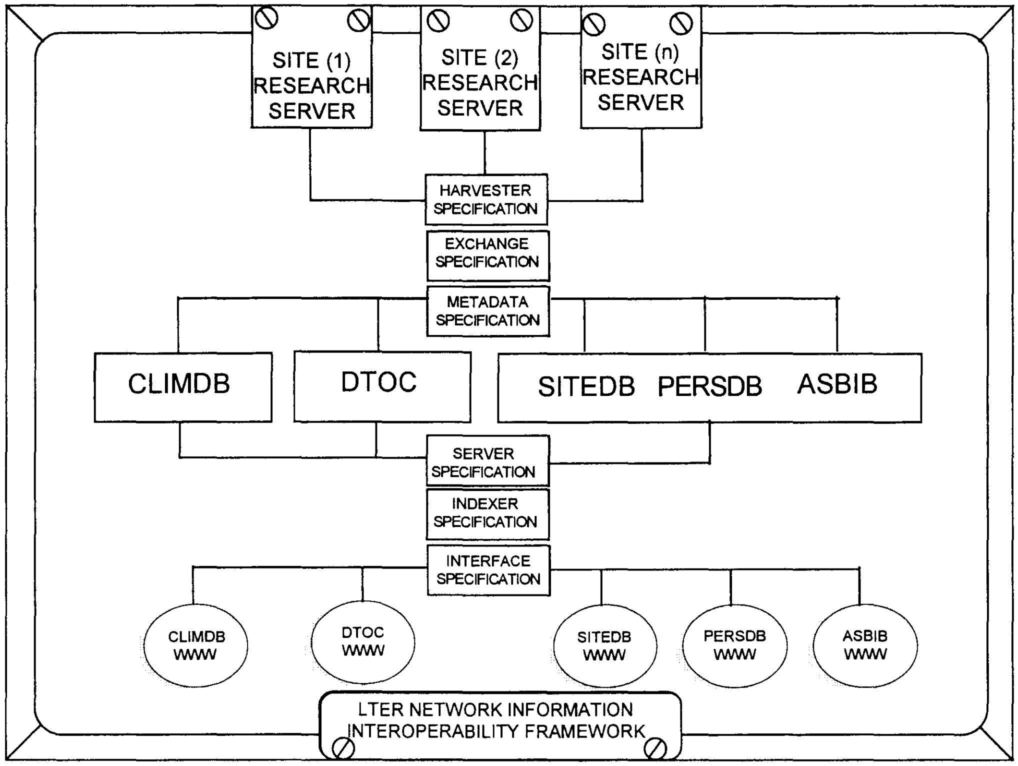

Figure 4.—Diagrammatic representation of the relationships of t specification components of the LTER Network Interoperability Framework. The Framework provides t tructure for specifications connecting LTER site information modules with the LTER Network Informati ystem. As envisioned, the system is completely modular allowing for databases and sites, to be plugged-in at any time.

Network Information System Infrastructure

The backbone of the NIS is the computational infrastructure at the LTER Network Office. Recently installed scalable servers and increased network bandwidth will better serve the LTER Network and ecological community. Two Sun 450 Enterprise servers and two Dell Poweredge servers are the primary computers serving LTERNET. The combination of Sun Solaris operating system on the UltraSparc platform and the Windows NT operating system on the Intel platform allows for maximum flexibility in incorporating new developments and technology, each with strengths that compliment the other. The LTER Network Office is the process of upgrading its connection to the vBNS internet to Gigabit speeds (1000 Mb/s).

International Information Management Integration

LTER information managers are actively cooperating with several international efforts to assure interoperability between the LTER Network and the greater scientific community. LTER Network Office personnel and Network Information managers participated in a data management working group as part of the ILTER meeting June, 1997 in Brazil. This workshop led to the development of a planning meeting that was held in early December in Albuquerque hosted by the LTER Network Office to prepare Latin American Information Management experts for a data management training effort in Venezuela in June, 1998. The June meeting brought together data managers from LTER sites all over Latin America and established the groundwork for developing international standards for data exchange and interoperability and will provided exchange of information that will be valuable to developing ILTER networks.

Future Developments

Activities for the future will focus on the development of the Network Information System Interoperability Framework for connecting LTER site information modules with the LTER Network Information System. Organizational activities have begun towards developing the Nitrogen Deposition module for LTER NIS and discussions are in progress on other LTER Network data areas for integration. All these efforts include the implementation of broad metadata interoperability specifications.

This manuscript has benefited from the input of many LTER data and information specialists over several years. All these advances were made possible both through financial support of the Network Office (NSF DEB 9634135) for work of the LTER Data Management and Climate Committees and by direct participation of NET and site personnel. The NIS prototypes can be reached via http://www.lternet.edu/research/data/.

Literature Cited

Briggs, J. & Su, H. 1994. Development and refinement of the Konza Prairie LTER research information management program. In: Environmental information management and analysis: ecosystem to global scales (eds W. K. Michener, J. W. Brunt, & S. G. Stafford), pp. 87-100. Taylor and Francis, Ltd., London, England.

Brunt, J. W., & Brigham, W. 1992. Data standards for collaboration in science. In: Data management at biological field stations and coastal marine labs: report of an invitational workshop (ed J. Gorentz), pp. 15-17. Kellogg Biological Station, Kalamazoo, Michigan, USA.

Brunt, J. W. 1994. Research data management in ecology: a practical approach for long term projects. In: Seventh international working conference on scientific and statistical database management (eds J.C. French & H. Hinterberger), pp. 272-275. IEEE Computer Society Press, Washington, DC., USA

Chinn, H. and C. Bledsoe. 1997. Internet Access to Ecological Information:The U.S. LTER All-Site Bibliography Project. BioScience 47(1).

Conley, W. 1991. An Institute for theoretical ecology? – part IV: "computational workshops": a planned activity for theoretical ecology. Coenoses 6, (2), 113-120.

Conley, W., & Brunt, J. W. 1991. An institute for theoretical ecology? Part V: practical data management for cross-site analysis and synthesis of ecological information. Coenoses 6, (3), 173-180.

Federal Geographic Data Committee. 1994. Content Standards for Digital Geospatial Metadata (June 8). Federal Geographic Data Committee, Washington, DC, USA.

Henshaw, D. L., et al. (1998) Climate database project: a strategy for improving information access across research sites. In: Data and information management in the ecological sciences: a resource guide (eds W. K. Michener, J. H. Porter, & S. G. Stafford), pp. 29-31. LTER Network Office, University of New Mexico, Albuquerque, New Mexico, USA.

Ingersoll, R. C., Seastedt, T. R. & Hartman, M. 1997. A model information management system for ecological research. BioScience 47, 310-316.

Marzolf, G. R., & Dyer, M. I. 1986. Future directions for research data management in ecology. In: Research data management in the ecological sciences (ed W.K. Michener), pp. 411-420 University of South Carolina Press, Columbia, South Carolina, USA.

Michener, W. K., Brunt, J. W., Helly, J., Kirchner, T. B., & Stafford, S. G. 1997. Nongeospatial metadata for the ecological sciences. Ecological Applications, 7, (1), 330-342.

Porter, J. H., & Callahan, J. T. 1994. Circumventing a dilemma: historical approaches to data sharing in ecological research. In: Environmental information management and analysis: ecosystem to global scales (eds W. K. Michener, J. W. Brunt, & S. G. Stafford), pp. 194-202. Taylor and Francis, Ltd., London, England.

Stafford, S. G., Brunt, J. W., & Michener, W. K. 1994. Integration of scientific information management and environmental research. In: Environmental information management and analysis: ecosystem to global scales (eds W. K. Michener, J. W. Brunt, & S. G. Stafford), pp. 3-19. Taylor and Francis, Ltd., London, England.

Weibel, S. 1997. The Dublin Core: a simple content description for electronic resources. Bulletin of the American Society for Information Sciences. October/November, 9-11.

The Role of Data and Metadata Archives in Environmental Monitoring and Research Programs[1]

William K. Michener[2]

Abstract—Environmental monitoring and research programs depend on being able to store, retrieve, and understand data that are collected over long periods. However, long-term accessibility of high quality data is hindered by "data entropy," the natural tendency for data to degrade in information content over time. Two approaches are necessary to impede data entropy: developing comprehensive documentation (i.e., metadata) for the data and contributing both the data and metadata to secure data archives. In this chapter, I discuss data archives, identify metadata content and format standards relevant to spatial and non-geospatial data, and present examples of several North American data archives. The long-term, integrated inventory and monitoring of forest ecosystem resources depend on the availability of high quality metadata and archives for supporting data and metadata storage and retrieval.

Environmental monitoring and research programs are increasingly attempting to address questions that require long-term, broad-scale, and multi-disciplinary data. The ultimate success of such programs depends on being able to store, retrieve, and understand data that are collected over long time periods (Michener et al. 1994). Long-term accessibility of high quality data is hindered by "data entropy," the natural tendency for data to degrade in information content over time (Michener et al. 1997). Two complimentary approaches are necessary to impede data entropy: developing comprehensive documentation (i.e., metadata) for the data and contributing both the data and metadata to secure data archives. In this chapter, I identify metadata content and format standards relevant to spatial and non-geospatial data, discuss the role of data archives, and present examples of several North American data archives.

Metadata

Metadata are the information necessary to understand and effectively use data, including documentation of the data set contents, context, quality, structure, and accessibility. Ideally, metadata describe the *who*, *what*, *when*, *where*, and *how* about every aspect of the data. For instance, metadata should address the five basic questions that normally arise when a scientist attempts to acquire and use a specific data set: (1) What relevant data exist?; (2) Why were the data collected and are they suitable for a particular need?; (3) How can the data be obtained?; (4) How are the data organized?; and (5) What additional information is available to facilitate data use and interpretation?

Investing adequate time and energy into metadata development is beneficial for several reasons (Michener et al. 1997). First, data entropy is delayed and data longevity increases. Second, data sharing is facilitated. Scientists often find that data that were previously collected for a particular purpose can later be 'mined' to answer new questions that are posed by themselves and others. Metadata that describe sampling and analytical procedures, data quality, and data set structure facilitate subsequent analyses and data interpretation. Furthermore, well-documented data can be used to expand the scale of scientific inquiry. Many of the questions now being addressed by environmental scientists require more data than could be realistically collected, managed, and analyzed by a single individual. Consequently, scientists increasingly rely upon data that were collected by other scientists for different purposes.

Metadata are receiving increased attention from the scientific community. For example, considerable resources have been devoted to developing, adopting, and implementing spatial metadata standards. In 1994, the U.S. Federal Geographic Data Committee completed the Content Standards for Digital Geospatial Metadata (FGDC 1994). These standards were developed as part of the National Biological Information Infrastructure (NBII) in the United States and attempts to standardize geographical data collected by the Federal Government. The Content Standards contain more than 200 metadata fields that are categorized into seven classes of metadata descriptors: identification, data quality, spatial data organization, spatial reference, entity and attribute, distribution, and metadata. Additional extensions to the Content Standards relevant to vegetation classification, cultural, demographic, and other types of data are in development. International (ISO) geospatial metadata standards, based on the Content Standards, are also forthcoming.

Metadata standards for non-geospatial data typically do not exist in any accepted format beyond individual studies, projects, or organizations. Environmental studies often require large amounts of diverse data related to the chemical and physical environment, as well as the organisms, populations, communities, and ecosystems comprising the biotic portion of the environment. It is, therefore, unlikely that a single metadata standard, no matter how comprehensive, could encompass all environmental data.

Consequently, a generic set of non-geospatial metadata descriptors for environmental data was recently introduced

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(Michener et al. 1997). The metadata descriptors were proposed as a template that could serve as the basis for more refined discipline-specific metadata guidelines. Five classes of metadata descriptors were included:

1. **Data set descriptors**—basic attributes of the data set (e.g., data set title, scientists, abstract, and keywords)
2. **Research origin descriptors**—descriptions of the research leading to a particular data set (e.g., hypotheses, site characteristics, experimental design, and research methods)
3. **Data set status and accessibility descriptors**—the status and accessibility of the data set and associated metadata
4. **Data structural descriptors**—all attributes related to the physical structure of the data
5. **Supplemental descriptors**—related information that may be necessary for data interpretation, publishing the data set, or supporting an audit of the data set.

The lack of software tools that can facilitate metadata entry has been a major impediment to metadata implementation. Metadata development is frequently an *ad hoc* process performed by the data originators, although some organizations have independently developed word processing or database forms that can be filled in to meet in-house requirements. One notable exception is the NBII MetaMaker, a PC-based program that was developed to support geospatial metadata generation in a format conforming to Federal Geographic Data Committee (FGDC 1994) guidelines. For the most recent version of this program, visit the NBII web site (http://www.nbii.gov). Commercial geographic information system software for spatial metadata, as well as other software tools that support non-geospatial metadata generation should be forthcoming.

Data Archives

Data Sources and the Global Change Master Directory

The Global Change Master Directory (GCMD; http://gcmd.gsfc.nasa.gov) is a comprehensive directory of data set descriptions that are particularly relevant to global change research. The GCMD is maintained by the American node of the Committee on Earth Observation Satellites' International Directory Network (CEOS IDN) and is operated by NASA's Global Change Data Center at NASA/Goddard Space Flight Center. The GCMD includes descriptions of data sets covering climate change, the biosphere (e.g., land use and forest cover), hydrosphere and oceans (e.g., water quality, sea surface temperature), geology (e.g., soils), geography, and human dimensions of global change (e.g., disease outbreaks, resource inventories) (Table 1).

The GCMD employs a user-friendly search interface that allows individuals to easily search for specific data. Resulting metadata records provide information on the nature of the data (e.g., parameters measured, geographic location)

Table 1.—Types of data in Global Change Master Directory.

General classes	Data types
Atmosphere	Aerosols, Air quality, Altitude, Chemistry, Phenomena, Pressure, Temperature, Water vapor, Winds, Clouds, Precipitation, Radiation budget
Biosphere	Aquatic habitat, Ecological dynamics, Fungi, Microbiota, Terrestrial habitat, Vegetation, Wetlands, Zoology
Cryosphere	Snow, Ice, Sea ice
Hydrosphere	Ground water, Snow, Ice, Surface water, Water quality
Land Surface	Erosion, Sedimentation, Landscape, Temperature, Land use/land cover, Soils, Radiative properties, Topography
Human Dimensions	Attitudes, Preferences, Behaviors, Boundaries, Economic resources, Environmental effects, Population, Food resources, Human health, Infrastructure
Oceans	Coastal processes, Marine geophysics, Salinity, Marine sediments, Chemistry, Circulation, Winds, Heat budget, Tides, Pressure, Temperature, Waves
Paleoclimate	Geologic time, Ice core records, Land records, Ocean records, Lake records
Radiance	Gamma ray, Infrared, Microwave, Radar, Radio, Ultraviolet, Visible, X-ray
Solar Physics	Solar activity, Solar energetic particles
Solid Earth	Geochemistry, Geodetics, Geomagnetism, Geothermal, Natural resources, Rocks/minerals, Seismology, Tectonics,

and where the data are stored. The actual data and metadata "pointed to" in the GCMD are stored by universities, government agencies, and other organizations in locations that are variously referred to as data repositories, digital libraries, data clearinghouses, data centers, or data archives. Some data sources that may be relevant to forest scientists are presented in Table 2. Especially comprehensive data sources include the distributed active archive centers (DAACs) that are funded as part of the U.S. National Aeronautical and Space Administration's (NASA) Earth Observing System (EOS) program.

Data Archives

A data archive is a collection of digital data sets and metadata that are organized and stored so that users can easily locate, acquire, and use data that meet a particular objective. Furthermore, data in an archive are generally stored in multiple locations so they are secure against natural and anthropogenic disasters. With the primary exception of the Global Change Master Directory which acts as a pointer to data that reside elsewhere, the online data centers listed in Table 2 qualify as data archives. Many of the data archives focus on a restricted set of themes. One example of a data archive with a specific focus is the National Climatic Data Center (NCDC) which was established in 1951 by the U.S. National Oceanographic and Atmospheric Administration. The NCDC has one of the largest environmental data archives in relation to length (data date to the 1800s), volume (55 gigabytes are added daily), and users (more than 170,000 requests annually).

A major objective for every data archive, as well as institutional data centers, is the secure storage of the data and metadata. Many different approaches to data storage can be taken depending on the size of the data holdings, anticipated rate of access by users, and other factors. For example, a relatively small volume of data can be stored on a single hard disk and made available via the World Wide Web. In this case, some form of manual or automated backup scheme will be required. Moderate data holdings (e.g., >10-100 gigabytes) may be stored online in a series of disks (e.g., redundant array of independent devices, RAID) that can be configured to support various levels of redundancy. Extremely large data holdings, such as those maintained by the NCDC in the previous example, may be stored in a large mass storage system consisting of multiple RAID units and automated tape libraries. In this latter case, data are either online or near-line, and data backup may be performed offsite (at a mirror location).

One of the primary benefits of focussing on a particular theme is the ability of the data archive to easily add value to data. For instance, the Carbon Dioxide Information Analysis Center (CDIAC), which is funded by the U.S. Department of Energy, emphasizes the value-added component of data sets that results from the participation of scientists and users in metadata preparation, rigorous QA/QC processing, peer-review of data and metadata, beta testing of data sets prior to general release, and incorporation of user feedback into its data packages. In addition to extensive metadata, CDIAC data packages contain examples of data applications and copies of important associated literature. By focusing on a few types of data, a data archive can establish and maintain high standards (e.g., QA/QC) and develop the requisite pool of experts for data and metadata peer-review.

The process of data submission will vary from one data archive to another. Different data archives may have different data structure, QA/QC, and metadata content standards that must be adhered to. Frequently, data and metadata are reviewed by data archive staff for internal consistency and completeness. In some cases, the quality assurance

Table 2.—Online sources for environmental data.

Data center	Data center URL	Data center focus
Alaska SAR Facility-DAAC	http://www.asf.alaska.edu	Synthetic aperture radar data.
Carbon Dioxide Information Analysis Center	http://www.cdiac.esd.ornl.gov	Greenhouse gases and climate change.
EROS Data Center-DAAC	http://epcwww.cr.usgs.gov/landdaac/landdaac.html	Land processes and characteristics data.
Langley Research Center-DAAC	http://eosweb.larc.nasa.gov	Radiation budget, clouds, aerosols, and tropospheric chemistry.
Marshall Space Flight Center-DAAC	http://ghrc.msfc.nasa.gov	Global hydrology and climate data.
National Climatic Data Center	http://www.ncdc.noaa.gov	Climate data.
National Snow and Ice Data Center-DAAC	http://eosims.colorado.edu	Snow and ice data.
Oak Ridge National Lab-DAAC	http://www-eosdis.ornl.gov	Biogeochemical dynamics (i.e., biological, geological, and chemical components of the Earth's environment) data.
The Consortium for International Earth Science Information Network - Socioeconomic Data and Applications Center	http://sedac.ciesin.org	Integrated social and natural science data.
National Oceanic and Atmospheric Administration - Satellite Active Archive	http://www.saa.noaa.gov/Index3.html	Real-time and historical satellite data.

procedures that are documented in the metadata will be reviewed. After going through the review process, data and metadata may then be incorporated into the archive database and made publicly accessible.

Following submission to an archive, the availability of a data set may be "publicized" in a data directory like the Global Change Master Directory (GCMD). Listing a data set in the GCMD is relatively straightforward and primarily requires filling out a form, known as a DIF, that describes the data. A DIF, an acronym for Directory Interchange Format, consists of several fields that describe the data and essentially represent a subset of the metadata for that particular data set (Table 3). Several fields are required including the entry id, title, parameters, originating center, data center, and summary. Other fields that provide location keywords and describe the spatial and temporal coverage of the data are deemed critical for data set selection (i.e., searching) and user understanding of the data. The GCMD provides a number of guidelines to facilitate DIF writing such as recommended keywords and definitions of what constitutes a good title and summary. Furthermore, there are several free, downloadable tools that can be used to author DIFs for UNIX (using the Emacs editor), PCs (both DOS and Microsoft Windows), and the World Wide Web. Once entered, the GCMD can perform very effective searches to match users with data that meet their particular objectives.

Table 3.—Summary of Global Change Master Directory (GCMD) online data set description.

Contents	Description
Title	**Data set title**
Summary	Short description of the data set. Resolution General attribute information Data source (i.e., digitized from paper maps, derived from satellite data, etc.)
Coverage	Temporal coverage • start and stop date Geographic coverage • southwest and northeast extent Location keywords
Attributes	Parameters • category • topic • term • variable • detailed variable Discipline/Sub-discipline General keywords Entry ID/Originating center
Distribution	Data center contact Storage media
Personnel	Technical contact Directory Interchange Format (DIF) author
Reference	Data set citation International Directory Network (IDN) node Revision date Review date

Conclusions

The long-term, integrated inventory and monitoring of forest ecosystem resources will depend on adopting or developing relevant metadata standards and developing new federated approaches to data storage and retrieval. In many cases, organizations will benefit from adopting existing metadata standards (e.g., the geospatial metadata content standard developed by the FGDC (1994) or the related ISO standard). For other types of data (i.e., non-geospatial), new metadata content standards must be developed. Ideally, these standardization efforts would benefit from international collaboration so that data and metadata can be shared across political borders to address common problems. New national and international data archives are also required to support the long-term, integrated inventory and monitoring of forest ecosystem resources. Typically, the data that are required to address critical questions related to forest ecosystem resources at regional and continental scales are either not available in digital form (e.g., due to lack of data archives) or are inadequate in their present form (e.g., different data structures, lack of quality assurance, insufficient metadata).

Literature Cited

Federal Geographic Data Committee. 1994. Content standards for digital spatial metadata. Federal Geographic Data Committee. Washington, DC. http://geochange.er.usgs.gov/pub/tools/metadata/standard/metadata.html.

Michener, W.K., J.W. Brunt, and S.G. Stafford. 1994. Environmental Information Management and Analysis: Ecosystem to Global Scales. Taylor and Francis, Ltd., London, England.

Michener, W.K., J.W. Brunt, J. Helly, T.B. Kirchner, and S.G. Stafford. 1997. Non-geospatial metadata for the ecological sciences. Ecological Applications 7:330-342.

Evolution of Ecological Metadata Structures at the H. J. Andrews Experimental Forest Long-Term Ecological Research (LTER) Site[1]

Donald L. Henshaw[2]
Gody Spycher[3]

Abstract—The success of any monitoring program depends on an information management system that supports the collection, quality control, archival and long-term accessibility of collected data and associated metadata. Intensive, research-driven site monitoring has been conducted on the H. J. Andrews Experimental Forest Long-Term Ecological Research (LTER) site since the 1950's. The resulting, diverse ecological databases are managed through the Forest Science Data Bank (FSDB) which features a metadata system to facilitate data production through the use of generic and database-specific tools. Increasing informational needs necessitate a system that is easily searchable and allows the integration of diverse types of information. Towards this end, FSDB personnel are developing an information system based on a normalized metadata database. The system consists of a catalog of research products such as databases and publications, and related tables to permit searching for these products by personnel, keywords, locations, and species.

Monitoring of forest ecosystem resources was initiated on the H. J. Andrews Experimental Forest shortly after its establishment in 1948. Early research efforts were conducted predominantly by the U.S. Forest Service Pacific Northwest Research Station (USFS PNW) and concentrated on forest watersheds, soils, and vegetation. With the inception of the International Biological Program/Coniferous Forest Biome (IBP/CFB) in 1969, university scientists began to play increasingly important roles. Long-term measurement programs that focused on climate, streamflow, water quality, and vegetation succession were established as part of the National Science Foundation (NSF)-funded Long-Term Ecological Research (LTER) program in 1980. The Andrews Forest LTER site now serves as a focal point for stream and forest ecosystem research, bringing together a community of over 50 university and federal research scientists. Building on these central themes and long-term research projects, research currently emphasizes predicting the effects of natural disturbance, land use, and climate change on ecosystem structure, function, and species composition.

The Forest Science Data Bank (FSDB) was created to house data generated from LTER scientists and other collaborating researchers (Stafford et al. 1984, 1988, Stafford 1993). The FSDB currently stores over 250 long-term and opportunistic databases from diverse scientific disciplines. The FSDB is funded by the USFS PNW, Oregon State University (OSU), and the LTER, and is supported by the Quantitative Sciences Group (QSG). The QSG is staffed by both OSU and USFS PNW personnel and provides database, statistical, software, and hardware support to the local research community. The FSDB has benefited greatly from the support and participation of the scientific community, and conversely, long-term measurement programs do not exist independently of information management systems that maintain and preserve measurement data for the long-term.

While the strategy and most of the FSDB data structures remain unchanged, the demand for rapid access to well-documented, high-quality long-term data has increased dramatically. This demand for information, coupled with the development of the Internet, web-based access tools, improved relational data management systems (RDBMS), spatial databases and accompanying tools, has signaled the need for changes. The FSDB is now in a transitional period as we design and begin the implementation of a more integrated infrastructure for managing scientific information. The intent of this paper is to review the evolutionary phases of the FSDB, and to report on the progress of its newest phase as the FSDB moves toward modern technologies of client-server architecture and a web-based user interface.

The Forest Science Data Bank (FSDB)

The Human Context

Ecological data management is dependent on a strong collaboration of data managers with this research community (Stafford et al. 1986). Lack of cooperation between research scientists and data management staff often leads to the creation of data sets that require restructuring, are inadequately documented, or are never submitted to the data archive. Costs and time requirements for data documentation and validation in centralized information management systems are often underestimated (Thorley and Trathan 1994). These problems can be offset by understanding and accepting the costs of information management, and by following a systematic approach where scientists involve data managers in research planning and developing sampling protocols (Stafford 1993). The FSDB employed this

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.
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systematic approach into its conceptual structure from the beginning (Stafford et al. 1984), and resulting activities have brought discipline to the collection and organization of the data and metadata (NRC 1995). Science involvement with information management becomes more important as the complexity of the research information increases.

FSDB History

Early data management efforts were initiated in the 1970's during the IBP program, the predecessor of LTER. The need to compare and quantify ecosystem processes among the different biomes led to methods for documenting data (Gross et al. 1995). The concept of a data set abstract was established, and Andrews Forest IBP data sets were documented for data structure, descriptive variable definitions, and descriptive codes. The data were stored on mainframe computers, access was exclusively available through the data manager, and documentation existed only on hardcopy forms. Nevertheless, a tradition of managing research information was born and carried into the LTER years starting in 1980.

Throughout the 1980's the FSDB evolved and experienced substantial growth as both legacy and new databases were added into the system. Improved hardware and software technologies enabled a fuller implementation of FSDB's conceptual structure. Commercially available Relational Database Management Systems (RDBMS) lead to development of relational database structures for housing study metadata including global database catalogs and detailed documentation of individual study data structures, variable descriptions, and study abstract information. Networked computer systems also allowed local researchers direct access to FSDB data sets.

The LTER program has always emphasized data management to fulfill its primary goals of long-term collaborative research including comparative, cross-site analyses (Franklin et al. 1990). The LTER network of data managers has been a tremendous asset to the program and to each individual site. The Andrews LTER has consistently participated within this network and has incorporated most of the recommended data protocols and metadata standards into its data management system (NSF 1984, Gorentz 1990).

The Current Metadata System

The FSDB houses databases that are "wide" rather than "deep" (Porter 1998). Whereas a "deep" database might specialize in one topical area and might contain large numbers of observations for one data type, a "wide" database contains many types of data with different structures, data from diverse ecological research topics, and with relatively few observations for each data type. Given this diversity within the data repository, the FSDB has concentrated on the development of generic tools that operate on metadata content and that can be used for all individual study databases. This approach has significantly reduced the time required for data production and permits the maintenance of multiple databases (Spycher et al. 1996).

The current FSDB metadata system includes database catalogs, table definition files, domain tables, and tables containing database-specific rules (Stafford 1993, Spycher et al. 1996). Maintaining complex metadata in relational database structures has many advantages (Stonebraker 1994). The FSDB quality control system itself consists of a set of simple procedures providing flexible, generic data validation. By maintaining standardized metadata structures for every FSDB database, mechanisms were developed to automatically perform validation checks based on standard metadata and specific database rules. Additionally, metadata tools are used (1) to guide users in understanding database content, (2) for global queries of the data catalogs, (3) for packaging data set documentation reports and (4) for other generic access functions such as webpage creation, automatic data entry form setup, and automatic import/export of ASCII files to RDBMS files (Spycher et al. 1996).

Limitations of the Existing System

The FSDB has traditionally housed conventional, non-spatial study databases. However, there is a need to manage more diverse information products such as Geographical Information System (GIS) coverages, remote sensing images, research publications, models, maps, photographs, and other documents including study plans, proposals, methods manuals, and web page documents. Information managers at the Andrews Forest have tended to maintain these other information products such as spatial coverage data and research publications as separate entities. As a result we cannot, for example, relate a publication with a database, a spatial coverage with a companion non-spatial data set, or a database contact person with the personnel directory.

Pervasive redundancies also exist within the system. Separate keyword lists are maintained for both research publications and databases; identical study sites are often described in multiple study data abstracts; species lists do not always reference master taxonomic databases; and the domain for widely used coded variables such as "decay class" may be described multiple times.

Web-based tools and navigational aids, not dependent on the computer literacy of the user, are necessary to facilitate data sharing (Günther 1998). In this regard, the Andrews Forest LTER has made many databases, models, personnel, and publication lists available on its webpage (http://www.fsl.orst.edu/lter). However, not only has the number of information products to manage increased, but the metadata context has also expanded to include personnel, location, keyword, and species data. Web-based tools are needed to allow and assist researchers in producing metadata, as well as to dynamically search and integrate metadata databases with information products.

A New Structure for Ecological Metadata

Recent publications have provided strong guidance on metadata content for spatial data sets (Federal Geographic Data Committee (FGDC)) and non-geospatial data (Gross et al. 1995, Michener et al. 1997). However, little advice has been provided on how this content might be structured for efficient management and access. The need to conform to developing metadata standards, and to manage all information products in an integrated, comprehensive information

Table 1.—Information product tables and descriptions maintained in the metadata database.

Information product table	Description of information product table
Study_data	Catalog of conventional, non-spatial databases
Remote_image	Catalog of remote sensing images, i.e., satellite images, scanned aerial photographs
Publication	Bibliography and abstracts of research publications
GIS_coverage	Catalog of Geographical Information System spatial coverage data
Document	Catalog of study plans, proposals, method manuals, and Web documents

management system, has motivated efforts to rationally structure and supplement the FSDB metadata database.

The objective was to design a normalized metadata database, "one thing in one place" (ERwin 1996), for ecological data objects as a foundation for an ecological information system. The main components or entities include a central CATALOG of information products, information product tables (STUDY_DATA, REMOTE_IMAGE, PUBLICATION, GIS_COVERAGE, and DOCUMENT) (See Table 1) and metadata tables (SPECIES, LOCATION, KEYWORD, and PERSONNEL) for finding and documenting information products. All components are linked through the central CATALOG (See Fig. 1). The implementation of a normalized database structure within the RDBMS will allow searches and linkages of entities through Structured Query Language (SQL).

In practice, CATALOG contains a list of all products as well as general information pertaining to the product, such as title, security restrictions or last revision date. The table CATALOG_TYPE indicates the type of data object or information product. The information product tables are metadata catalogs of that particular data object and contain information specific to that type of product. (Note that the information product tables do not include the actual data objects.) Additionally, each catalog item can be linked to appropriate keywords, locations, personnel, or species if applicable through associative tables such as CATALOG_KEYWORD or CATALOG_LOCATION. One CATALOG item can also be linked with any other through the RELATED_CATALOG table, allowing, for example, the capability to connect a study database with a companion spatial database or publication (See Fig. 2).

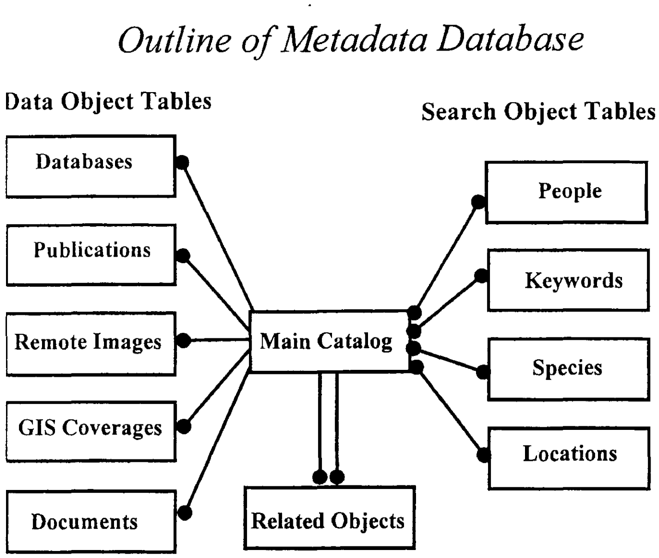

Figure 1.—A simplified structure including only the main entities and relationships of the FSDB Metadata Database (——• represents one-to-many relationships, •——• represents many-to-many relationships).

Of the five information product tables shown, only the metadata for conventional, non-spatial databases (STUDY_DATA) have been fully integrated (See Fig. 3). This subsystem provides for shared variables and codes. The VARIABLE table contains the attributes of all variables in the entire system. The variables may be generic (shared by several databases) or database-specific. In practice this means a reduction in the number of definitions for commonly used variables such as "percent vegetative cover". Similar redundancies are avoided for variable domains, which have been sub-typed, i.e., divided into mutually exclusive categories, into GENERAL_CODE, SPECIES, and LOCATION. For example, a coded variable such as "decay class" can be described in GENERAL_CODE and be shared among all study data using this same coding method. In addition, coded variables of species and location can directly refer to the master catalogs, and need not be redefined. SPECIES can be set up with the desired degree of taxonomic hierarchical detail. LOCATION is sub-typed into various groups such as point locations, watersheds or Research Natural Areas because the attribute sets are group-specific.

The metadata tables SPECIES, LOCATION, KEYWORD, and PERSONNEL serve multiple functions:

1. They can function as independent 'data', i.e., a comprehensive species list, a sub-typed location system, a keyword and a personnel facility
2. They provide the basis for finding data objects by single or multiple metadata categories
3. They serve as an integral part of the metadata for any given data object, permitting for example the compilation of complete documentation for any data object using SQL queries
4. They are actively used in generic quality control of conventional databases

Three of these metadata tables are recursive; that is, the table is hierarchically structured. In the case of SPECIES this is used to reflect taxonomic hierarchies. LOCATION has an indeterminate number of levels and permits the extraction of all locations (or a specified number of levels of

Logical Model of the Metadata Database

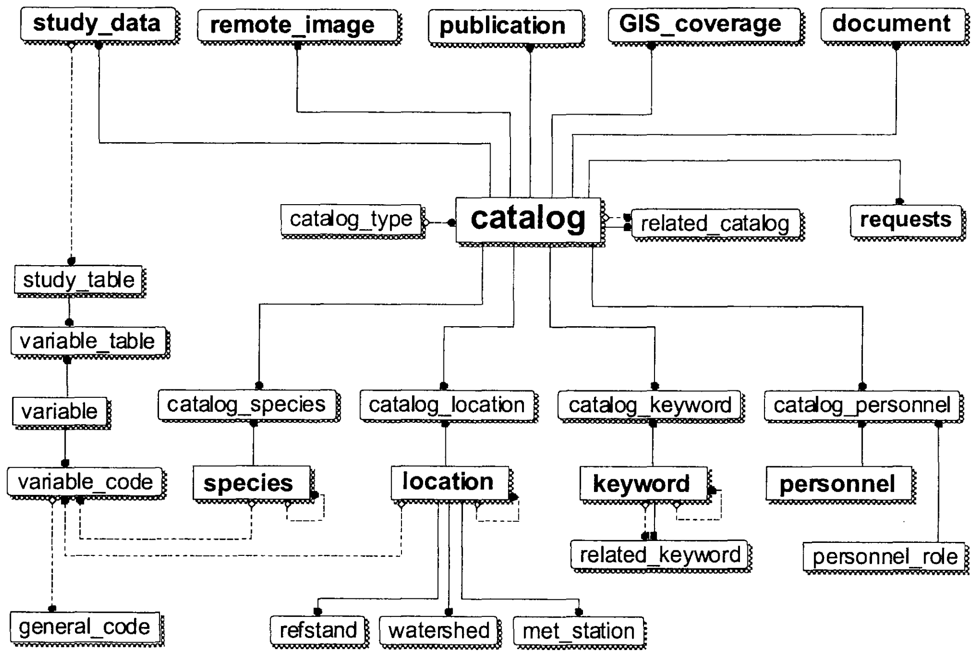

Figure 2.—Entity-Relationship diagram of the FSDB Metadata Database (——• represents one-to-many relationships; solid lines denote identifying relationships; dashed lines show non-identifying relationships, i.e., there is no identification dependency between two tables).

Study_data Section of Metadata Database

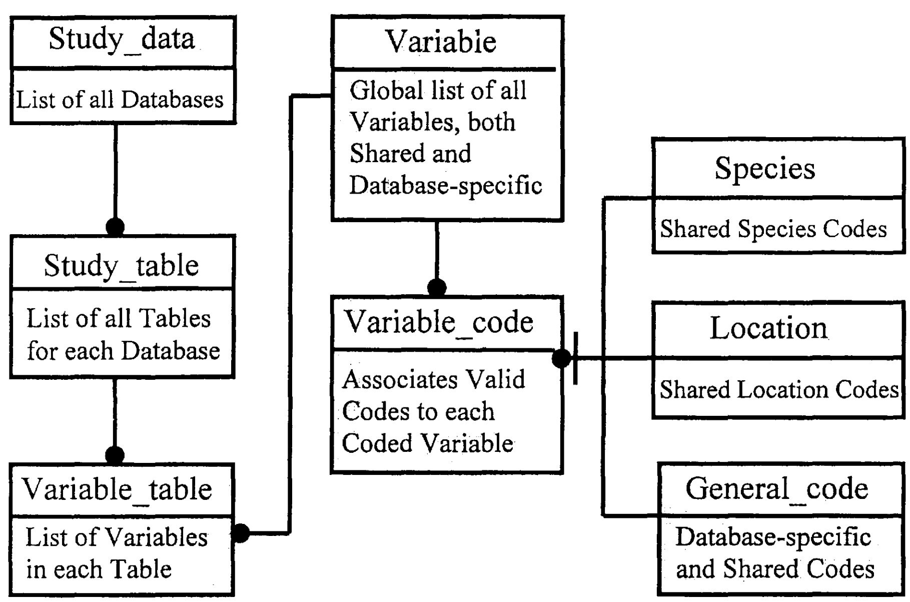

Figure 3.—The entities and relationships of the Study_data Section of the FSDB Metadata Database. Relationships are all one-to-many, and the variable_code table is sub-typed into three mutually exclusive tables.

locations) within a given location. For example, one can query for all locations within Oregon, all watersheds within the Andrews Forest, and all study plots within a watershed. KEYWORD has a 3-level hierarchy implementing a controlled keyword list developed locally for Pacific Northwest forest ecosystem studies. A RELATED_KEYWORD table also allows the ability to relate keywords with each other. The PERSONNEL table lists people and their attributes only once. The PERSONNEL_ROLE table associates functional roles for a given person in the associative CATALOG_PERSONNEL entity. These roles may include ownership of data objects, authorship roles in publications, contact persons, and others.

The REQUESTS table tracks secondary usage of information products, primarily the database products. The table logs information on users requesting the data and for what purpose. User feedback involving encountered limitations or problems with the data are stored here.

This normalized data structure is currently being implemented within the FSDB. It should be noted that all figures only show the simplified structure showing the main entities and relationships. Specific attributes within each table are not listed and are still evolving, but the intent is to conform to current standards for metadata content (FGDC, FLED). Other information product tables may be added such as models and photographs. Security features as well as research project descriptions including funding sources are also planned.

Conclusions

The success of any monitoring program depends on the implementation of data management strategies that support the collection, quality control, and long-term accessibility of generated information. Increasingly, funding agencies require online access to data soon after collection to facilitate intersite exchange of information. Information systems must also accommodate a growing number of information products including conventional databases, GIS spatial data coverages, remote sensing images, publications and other documents. These increasing demands necessitate information systems that are easily searchable and allow the integration of diverse types of information.

The FSDB is pursuing the development of a comprehensive metadata database to help meet these needs. A normalized metadata database structure was designed to avoid redundant information from multiple data sources. The design facilitates searches to locate information products using multiple categories of metadata. Personnel, keyword, location, and species databases are an integral part of the metadata and serve multiple functions. The new structure is complex and demands discipline in the collection and organization of the data and metadata. Strong support and involvement from the research community is an essential ingredient to success.

Acknowledgments

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Literature Cited

Committee for a Pilot Study on Database Interfaces, U.S. National Committee for CODATA

Commission on Physical Sciences Mathematics and Applications National Research Council [NRC]. 1995. The H.J. Andrews Experimental Forest Long-Term Ecological Research Site. In: The committee finding the forest in the trees: the challenge of combining diverse environmental data. Selected case studies. Washington, DC: National Academy Press: 46-55.

Franklin, J.F.; Bledsoe C.S.; Callahan J.T. 1990. The Long-Term Ecological Research Program: a contributor to ecological science. BioScience 40: 509-523.

Gorentz, John, ed. 1990. Data management at biological field stations and coastal marine laboratories: report of an invitational workshop; 1990 April 22-26; W. K. Kellogg Biological Station, Michigan State University, Lansing, Michigan.

Gross, K.L.; Pake, C.E.; Allen, E. [and others] [FLED]. 1995. Final report of the Ecological Society of

America Committee on the future of long-term ecological data (FLED). Volume I. Text of the report, [Online]. Available: http:/ /www.sdsc.edu/~ESA/FLED/FLED.html.

Günther, O. 1998. Environmental information systems. Berlin; Heidelberg: Springer-Verlag. 244 p.

Michener, William K.; Brunt, James W.; Helly, John J. [and others]. 1997. Nongeospatial metadata for the ecological sciences. Ecological Applications 7(1): 330-342.

National Science Foundation [NSF]. 1984. Data management at biological field stations: report of a workshop; 1982 May 17-20; W.K. Kellogg Biological Station, Michigan State University, Lansing, Michigan.

Platinum Technology, Inc. [ERwin] 1998. ERwin methods guide. Princeton, NJ: Platinum Technology, Inc. 96 p.

Porter, John H. 1998. Scientific databases for environmental research. In: Michener, William

K.; Porter, John H.; Stafford, Susan G., eds. Data and information management in the ecological sciences: a resource guide; 1997 August 8-9; Albuquerque, NM. Albuquerque, NM: LTER Network Office, University of Mexico: 117-122.

Spycher, G.; Cushing, J.B.; Henshaw, D.L. [and others]. 1996. Solving problems for validation, federation, and migration of ecological databases. In: Global networks for environmental information: Proceedings of Eco-Informa '96; 1996 November 4-7; Lake Buena Vista, FL. Ann Arbor, MI: Environmental Research Institute of Michigan (ERIM); 11: 695-700.

Stafford, S.G.; Alaback, P.B.; Koerper, G.J.; Klopsch, M.W. 1984. Creation of a forest science data bank. Journal of Forestry 82(7): 432-433.

Stafford, S.G.; Alaback, P.B.; Waddell, K.L.; Slagle, R.L. 1986. Data management procedures in ecological research. In: Michener, William K., ed. Research data management in the ecological sciences. The Belle W. Baruch Library in Marine Science No. 16. Columbia, SC: University of South Carolina Press: 93-113.

Stafford, Susan G. 1993. Data, data everywhere but not a byte to read: managing monitoring information. Environmental Monitoring and Assessment 26: 125-141.

Stafford, Susan G.; Spycher, Gody; Klopsch, Mark W. 1988. Evolution of the Forest Science Data Bank. Journal of Forestry 86(9): 50-51.

Stonebraker, M. 1994. Sequoia 2000—A reflection on the first three years. IEEE: 108-116.

Thorley, M.R.; Trathan, P.N. 1994. The history of the BIOMASS data centre and lessons learned during its lifetime. Southern Ocean Ecology: The BIOMASS Perspective. Cambridge: 313-322.

Situación Actual de los Sistemas para el Manejo de Información de Inventario y Monitoreo Forestales en México[1]

Octavio S. Magaña Torres[2]

Resumen—Se presenta un análisis de la situación actual del desarrollo de sistemas de información en el área forestal de México. Para ello, se consideran diferentes aspectos entre los que sobresalen el objetivo por el cual se desarrollo el sistema, tipo de equipo que se usa, los paquetes que se utilizan para el procesamiento de los datos; el personal que tiene a su cargo el análisis, desarrollo, implementación y mantenimiento de los sistemas; el uso de estándares en los formatos de almacenamiento de la información, entre otros.

Finalmente, se definen prioridades y se sugieren una serie de medidas a considerar para el futuro desarrollo de sistemas de información de inventario y monitoreo forestal en México.

México cuenta aproximadamente con 55 millones de hectáreas de bosques y selvas que representan más del 25% del territorio nacional; aproximadamente 32.5 millones de ha son formaciones cerradas (58% del total del arbolado) y 22.9 millones de ha son formaciones abiertas (42%). Los bosques templados incluyen coníferas, latifoliadas y mesófilos que se distribuyen principalmente en las áreas montañosas del país, con tres cuartas partes de ellos concentrados en los estados de Chihuahua, Durango, Guerrero, Michoacán, Jalisco y Oaxaca. Los bosques de coníferas ocupan 21 millones de ha, las latifoliadas 9.5 y 1.4 el mesófilo (SARH, 1994).

Las selvas están integradas por vegetación del trópico húmedo y trópico seco; la primera incluye los tipos de selva alta y mediana, según el Inventario Nacional Forestal Periódico ocupan aproximadamente 14.1 millones de ha, incluyendo otras asociaciones, y se ubican en 80% en los estados de Campeche, Chiapas, Oaxaca, Quintana Roo y Veracruz. Las selvas del trópico seco que incluyen selva baja caducifolia, se localizan en los declives de la Sierra Madre Oriental y Occidental, cuencas del Balsas y del Papaloapan, Istmo de Tehuantepec, Chiapas y Península de Yucatán, ocupando una extensión de 11 millones de ha. Existen áreas con selva fragmentada que ocupan 6.7 millones de ha en zonas con vegetación tropical húmeda y seca, particularmente en la Península de Yucatán y en las franjas costeras de ambos litorales del país.

La importancia de los ecosistemas forestales de México se basa en cuatro consideraciones:

- **Biológica**, está considerado como un país con megadiversidad con el 10% de la biodiversidad del mundo, incluyendo un alto número de especies endémicas, es decir exclusivas del país, principalmente en sus desiertos y bosques templados, sobre todo en bosques mesófilos. Por ejemplo, los bosques de pino-encino mexicanos son, en su tipo, los que muestran mayor riqueza biológica en el mundo, ya que en ellos habitan 55 especies de pinos (85% endémicas) y 138 de encinos (70% endémicas). Los bosques mesófilos, aunque cubren únicamente 1% del territorio, incluyen el 10% de las especies de plantas del país, muchas de ellas también endémicas.
- **Ambiental**, ya que son elementos de estabilización de suelos y conservación de los ciclos de agua, así como para captura de carbono;
- **Social**, constituyen una fuente amplia de productos de subsistencia utilizados por la población rural y,
- **Económica**, como fuente de productos maderables y no maderables para consumo nacional o de exportación, y para el turismo y la recreación.

Además de su riqueza biológica los ecosistemas forestales de México ofrecen condiciones de hábitat requeridas por poblaciones de numerosas especies de fauna que habitan temporal o permanentemente en estas áreas. Entre estas especies, se incluyen importantes grupos de aves y algunos insectos migratorios, como la mariposa monarca que migra de Estados Unidos y Canadá y dependen de los bosques mexicanos de oyamel para invernar y complementar su ciclo de vida.

Situacion Actual

A continuación se enumeran una serie de factores que están influyendo de manera directa en la situación actual de los sistemas de información para el manejo de información de inventario y monitoreo forestales en México.

- Diferentes instituciones realizan los trabajos de inventario (SEMARNAP, Instituciones de Enseñanza e Institutos de Investigación).
- Se realizan actividades de inventario a diferentes niveles de escala, desde nacional, regional, estatal o local por predios o conjuntos de predios.
- Para el análisis de la información se usan diferentes plataformas de cómputo (desde computadoras personales hasta estaciones de trabajo).

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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- Cada Institución toma la decisiones que cree convenientes para su organización y dentro de su presupuesto. Esto se refleja principalmente en el número de variables consideradas en el inventario y en la calidad de estas.
- No existen estándares de como se deben de medir las variables, ni cuantas variables medir. Como resultado, cada institución toma diferentes variables y por ello cada quien ha desarrollado en algunos casos solamente la bases de datos y en otros sistemas de información ajustados a sus datos colectados.
- Si bien es cierto que se ha usado tecnología que incluye el uso de imágenes de satélite y la verificación en campo de la interpretación de las imágenes, como fue en el caso de la realización del Inventario Nacional Forestal Periódico de 1994, la mayor parte de los inventarios forestales consisten en una serie de parcelas sistemáticamente localizadas en el terreno, las cuales son remedidas periódicamente. Estos intervalos pueden variar desde 5 a 10 años. Los datos de las parcelas proveen una estimación de la condiciones del bosque para cierto grupo biológico o área geográfica. El objetivo de este monitoreo es el mantener los planes de manejo del bosque actualizados. El monitoreo puede ayudar a identificar áreas donde el énfasis del manejo debe de cambiarse o donde los planes de manejo se necesitan corregir.
- Existen incluso estados en los que se tienen dos o más organizaciones realizan inventarios, con la consecuente duplicidad de esfuerzos en el análisis de los datos.
- Falta de consistencia y de control de la calidad de la información.
- La mayoría de los sistemas de inventario de nuestro país se concentran básicamente en la vegetación forestal maderable, quedando otras partes del medio ambiente como lo es el clima, la calidad del aire, la calidad del agua, productos forestales no maderables y la fauna en encuestas que se hacen por separado.
- Se ha trabajado más en el inventario de bosques de clima templado-frío, que en vegetación de zonas áridas y tropicales.
- Es común que las decisiones relativas al análisis y manejo de información son tomadas por personal que no es especialistas en esta área, de ahí que se usen diferentes tipos de paquetes para llevar a cabo el análisis y que no existan metadatos.

Necesidades A Futuro

- Determinar a una Institución que sea la responsable de coordinar los esfuerzos de las distintas organizaciones, públicas y privadas, del país que de una u otra forma están realizando trabajos de inventario y monitoreo. Dentro de las funciones que debe de realizar esta institución se podrían mencionar las siguientes:
- Establecer protocolos estándares, los cuales permitan eliminar la redundancia e inconsistencia de los datos y promover procedimientos que aseguren la calidad en la colección de datos de inventario y monitoreo.
- Coordinar, priorizar y promover la investigación y desarrollo de técnicas de inventario y monitoreo a diferentes niveles de escala.
- Un aspecto que debe de quedar claro es que el tener un estándar nacional no implica de manera alguna el coartar la libertad de que cada organización pueda colectar más datos de acuerdos a sus necesidades y recursos económicos.
- Determinar que necesita ser inventariado y monitoreado en cada una de las tres condiciones ecológicas (árida, tropical y de bosque templado-frío) y como se llevarían a cabo estas actividades.
- Establecer la forma en que se puedan manejar los datos e información de tal forma que puedan ser compartidos y analizados entre las diferentes organizaciones.
- Desarrollo de programas que permita automatizar la creación de reportes estándares
- Coordinar las actividades relacionadas al desarrollo de bases de datos y paquetes de cómputo que faciliten la síntesis y el análisis de la información de datos de los sitios, su clasificación y mapeo.
- Esta institución será el lugar en donde se encuentre la base de datos de inventarios forestales a nivel nacional.
- Se facilitaría la participación de instituciones internacionales relacionadas con estudios de inventario y monitoreo de ecosistemas.
- Finalmaente, con la designación de tal Institución se aseguraría la continuidad de las bases de datos a través del tiempo y de las administraciones.

Literatura Citada

SARH. 1994. Inventario Nacional Forestal Periódico.

The Development of a Data Management System in the Luquillo Experimental Forest Long-Term Ecological Research (LUQ LTER) Site[1]

Eda C. Melendez-Colom[2]

Abstract—Data Management Systems (DMS) address the organization of large amounts of data and their documentation to make the data accessible to current and future generations. They facilitate interdisciplinary collaboration among scientists and synthesis of scientific results. The development of the Luquillo (LUQ) Long-Term Ecological Research (LTER) data management system provides a case study. The LUQ LTER program began in 1988 with the goal of integrating studies of disturbance regime and forest structure and dynamics. A wide range of meteorological and ecological data are collected by collaborators from many academic, governmental, and private institutions. The development of data management systems at the LTER sites was mandated by the National Science Foundation (NSF) as part of its commitment to data accessibility. A thorough appreciation of DMS by the principal investigators at the site strengthened its development. The LTER Network Office has played a critical role in the implementation of this system by providing economic, professional, and computer resources. The formation of a DMS should be modular in its nature since it does not only respond to the developing needs of the researchers it supports but also must respond to the rapid development of computer technology. The World Wide Web has fueled and revolutionized this process. Interactions among the LTER Data Managers who meet annually to work on common network projects and discuss common issues has been a critical component of the LUQ DMS development.

The need for an organized effort to maintain and store ecological data in a usable form emerged nearly twenty years ago with the initiation of the Long-Term Ecological Research (LTER) program. The histories of some of the USA LTER sites reveal the development of independent methods to organize data to answer particular research questions (Veen et al. 1994, Baker 1996, Spycher et al. 1996). At some LTER sites, Data Management Systems (DMS) were developed prior to the LTER program (Veen et al. 1994, Spycher et al. 1996). Other sites initiated development of such systems at the onset of the LTER program (Benson 1996). The initiative for creating a DMS at Luquillo was in part was a consequence of National Science Foundation's (NSF) directives. However, the utility of establish a DMS became evident to the principal investigators and the Data Manager as soon as we started to organize old files of data. Most of the existing data at that time, was stored as stack of papers showing sometimes no author, date of observation, or other metadata. Efforts in organizing these data were time consuming and were frustrated by the lack of information and documentation of data files.

The appreciation of Luquillo's principal investigators of the importance of a DMS and their collaboration with their Data Manager aided the development and implementation of the system at the site.

Several factors determine the development of a successful Data Management System. The primary factor is the recognition of the value of the system by the investigators at the site. Investigators, in general, tend to resist compliance with the guidelines and regulations established as data management policies at their site. Collaboration of the site Data Manager with the principal investigators is essential to data management efforts. A successful DMS allows searches for data, saves time in the manipulation of data, and facilitates responses to requests for data. As success is achieved, site investigators gain an awareness of the importance of the system and rely on the system to satisfy their own requests for data and services. The availability of computer and telecommunication resources is essential for the development of a DMS on a site. The access to a human network of data managers from other sites is crucial in determining how fast the system responds to continuously changing demands of the scientific community and rapid progress in technology.

One of the basic goals of a DMS is to respond to the needs of the site it serves, and simultaneously allow data sharing and preserving of data for future generations. Data sharing is essential to cross-site comparisons and synthesis. The need to preserve data for future generations should be obvious to the scientific community who are in constant search for data to validate and expand their studies. At Luquillo, Data Management is committed to make the data gathered by our researchers available in a timely manner to the scientific community and to the public in general, with sufficient accompanying information and metadata to optimize its use.

The development of a system that achieve these goals requires time, human resources, and the motivation and enthusiasm from the Data Manager(s) in charge. This paper presents the basic components of a DMS, some of the main issues and difficulties encountered in its development, and the solutions implemented at the LUQ LTER site. The details of the technology used at the site will be not be discussed since the selection of the tools to make the system

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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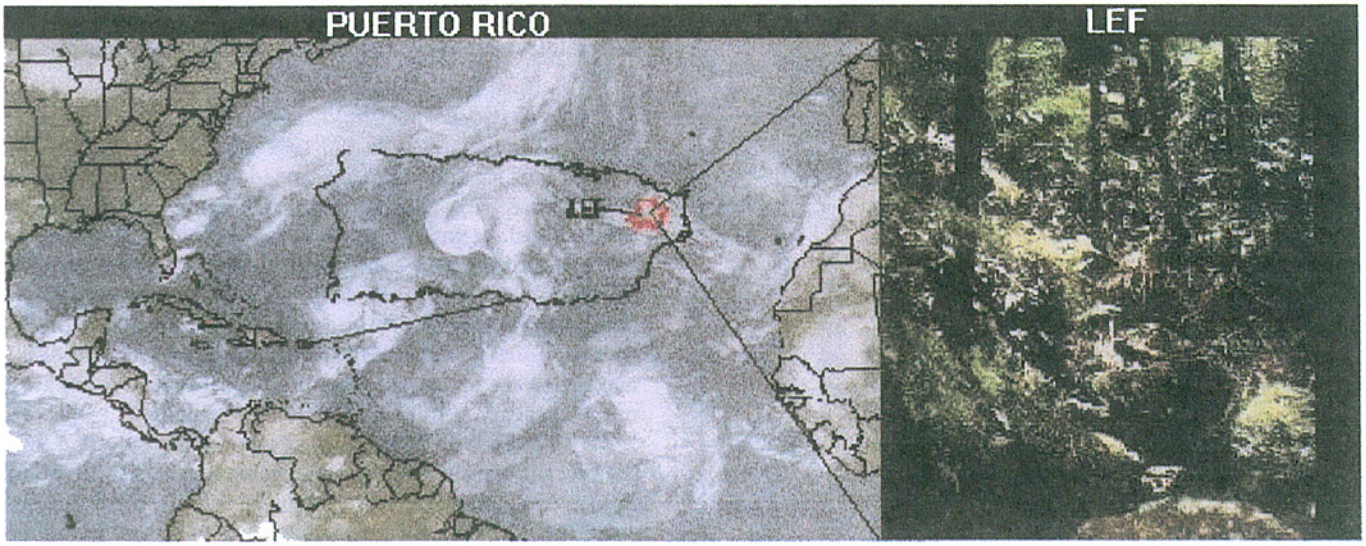

Figure 1.—Satellite image taken on August 25, 1995.

work depend on several site-specific factors like the prevailing preferences and needs of the site's investigators, the availability of training, and cost factors. The emphasis will be on the lessons learned from the process in developing and implementing this system at the Luquillo site, the importance of using common sense in its implementation and the importance of good communication between the scientists and Information Managers.

The LUQ LTER Site

The LUQ LTER performs most of its research at the Luquillo Experimental Forest (LEF). The LEF is located at 30 km southeast of San Juan, Puerto Rico at the latitude 18°18'N and longitude 65°47'W. Figure 1 locates the LEF within Puerto Rico. The LEF covers around 11,100 ha in land area at elevations from 100 1070 m above the sea level. The forest has four different life zones and four different vegetation types. Figure 2 shows the distribution of the tabonuco, palo colorado, palm and dwarf (also called cloud forests) from an 1936 aerial photo. Most of the research is conducted in tabonuco forest. The cloud forest is located at the highest elevations. Figure 3 presents the monthly summary of precipitation totals at the El Verde Field Station, one of the research sites of LEF located in the northwest part the forest. A quadratic function (Rain = ELEV2 + 3.8ELEV + 2300) describes how precipitation varies with elevation.

Research

The LUQ LTER program studies the four types of disturbances that affect the LEF: treefalls, landslides, hurricanes, and human land use. The first LTER phase started in 1988 and ended in 1994. The main goal was to understand the interaction between these four types of disturbances, the physical parameters, and the fauna and flora from population to landscape. LTER II, begun 1994, continues these studies and amplifies their scope by studying other areas. The scientific community is preparing the scientific proposal for the LTER phase III which will start in year 2000.

The research is organized around five working hypotheses. The research involves, like in any other LTER site, the acquisition of long-term data from permanent plots, the integration of several monitoring programs, and the use of consistent methodology and metadata. Long-term studies permit the separation of knowledge obtained from the damage caused by sequential hurricanes and studies of recovery to begin immediately after the disturbance (Walker et al. 1991). The integration of several monitoring programs are a mean of justifying, explaining and linking the effects of hurricanes on many ecological processes like litterfall, tree growth, or animal population dynamics (Walker et al. 1991).

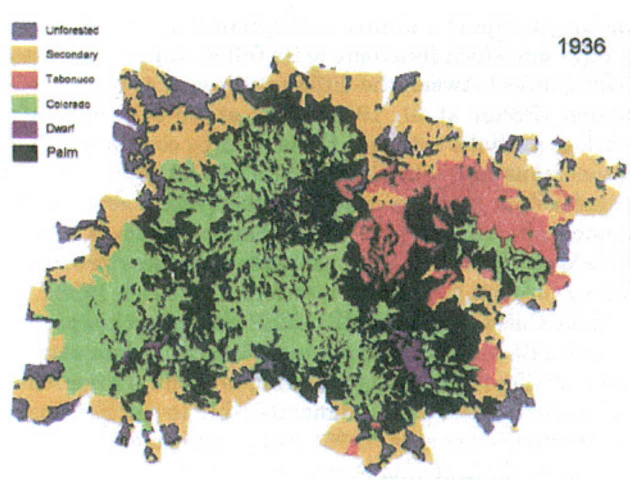

Figure 2.—The distribution of the Tabonuco, palo colorado, palm, and dwarf forests from an 1936 aerial photo.

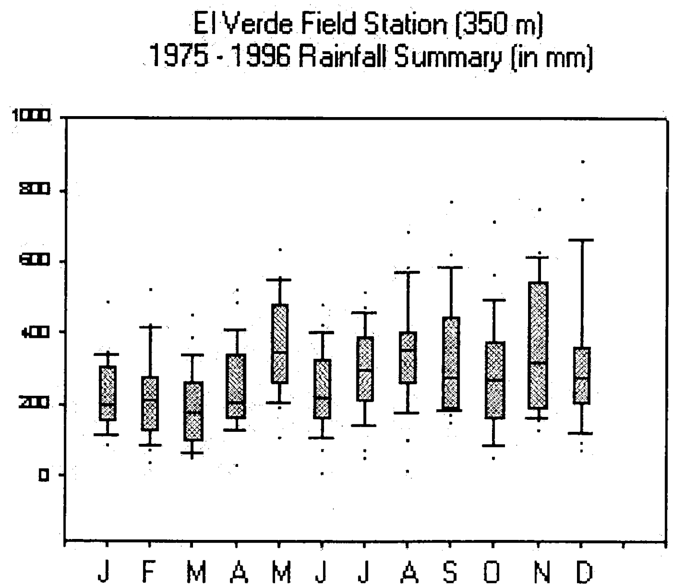

Figure 3.—Monthly summary precipitation averages from 1975 to 1996 at the El Verde Field Station.

Consistency in the methodology and metadata allows the site to make cross site comparison. LUQ LTER metadata is an essential part of the DMS and follows the minimal standards set by the Network.

Data Management System Development

The existing Data Management System at the Luquillo LTER is the product of the completion of a series of projects that have been addressed at the site since the Data Manager was hired in 1989. Each project addresses a need identified by either the principal investigators or by the Data Manager of the site, or responds to a stipulation of the National Science Foundation (NSF).

A system designed this way might be thought of as opposing the concept of a unified and dynamic system. The later is a system which functions to its fullest capacity by establishing links between the different types of available information (Porter et al. 1996). In a static system, central catalogs partially establish these links by coupling with the autonomous data sets (Spycher et al. 1996). Web forms that transfer data between users and the system establish dynamic links. An example of a dynamic system is a World Wide Web (WWW) tool that connects a business' products to orders through the use of web forms (Wasser 1996). The Virginia Coast Reserve (VCR) LTER site links a hierarchical project data base comprising metadata with data sets to a research directory database linking individual researchers' publications, abstracts and membership to electronic mailing groups (Porter et al. 1996). At Luquillo, most of the data bases have distinct data structures. The Web provides links from an on-line version of the data set catalog to the metadata, which links to data files and abstracts, when available. Locally, a Relational Data Base Management System (RDBMS) joins data columns from different data bases using key field(s) that allow to merge data from different projects.

Cataloguing

LUQ LTER Data Management identified around 320 sets of old data during the first year after the Data Manager was hired. The data sheets were old, written by hand, sometimes with no names and even no dates. In most cases it was impossible to identify the author. There was no possibility of obtaining further information about the data. The principal investigators at the site identified only 81 of the 320 as useful data sets; the rest were filed in cabinets with a catalog name and record number for future revision.

As we examined more sets we needed to prepare a list of the records of data. We also needed to record all the available information to allow easy retrieval when searching for a specific type of data. The solution was to design and implement a Data Set Catalog. Cataloguing facilitates the identification of the sets with a catalog name and a record number that ease the retrieval of the data after archiving the file in a file cabinet. Each file cabinet is labeled with the catalog name and the record numbers of the sets of data they contain. Paradox is used to save and maintain the Data Set catalog. When querying the Catalog data base, one can search by any keyword under any field. The catalog contains the information of the exact physical location of each data set. In the case of a growing catalog, this brings more maintenance activities. This means that the exact location of a data set changes with time, thus needing to update the on line catalog. Copies of the raw data sheets are kept in the fireproof file cabinets as backup and for future reference.

Two distinct catalogs store the main information of the site's data sets to separate LTER from other LEF data. At the present, both hold records for 99 data sets (198 data sets in total) which have been catalogued since the LTER 1 inception in 1988.

Completing the project of cataloguing old data sets made us aware of the need to have ready access to more information about the collection, purpose, methodology, etc., of these data, that is, the need for metadata.

Designing Documentation Forms

The Data Manager developed a hierarchy of three forms that document a data set at three different levels. The Data Set Form provides the information on the investigator in charge, start and end dates, periodicity of samples, keywords, abstract, methods, and a list of the data files that constitute the data set. The Data File Form holds specific information of the data set structure, and the description of the research site. One Data File Form must be completed for each different data file listed on the Data Set Form. The Documentation for Data Variables holds information of the measurements taken, such as, definition of the variable, precision of measurement, range of values, and missing data codes. One Variable form must be completed for each unique measurement of the data set. These forms were designed using the following resources: (1) interviews with eleven LUQ LTER investigators and collaborators; (2) samples of other LTER sites' documentation forms, and (3) the 1982

Report of the Workshop held at Kellog Biological Stations on Data Managements. The interviews of the investigators rendered benefits far greater than simply designing useful data documentation forms. It was our first chance to establishing communication between Data Management and the scientific community of the site. The importance of establishing good communication practices between Data Management and the scientific community will be discussed later in this paper.

Developing Special Data Bases

As the system develops, the quantity of data sets and investigators contributing with their data grow, the site gets involved in new research activities, and the need to establish special lists that hold information related to the collaborators increases. Electronic mail (e-mail) address lists, on-line personnel directories and publication lists are the three main special data bases that become a useful and necessary tool as the DMS grows.

The e-mail lists are groups of users that can send a single message simultaneously to all the other members of the group. The Latin American LTER (LA-LTER) group of Information Managers identified the need of e-mail lists in their first meeting held at the US-LTER Network Office in New Mexico. The e-mail lists are defined on special computer system or "Host" accessible to all users in the group. In the US-LTER case, the LTER Network Office located at Albuquerque, New Mexico, provides this service to all the US-LTER sites. In the LA-LTER case, a host at Venezuela provides this service for the Latin American. Each network defines their different mailing groups depending on their needs and preferences.

The personnel directory is another type of data base that can be managed by a centralized system. Several options exist for its implementation. The US-LTER network experience illustrate these options perfectly. The system evolved from one in which the individual sites kept their own static lists for personnel that are combined into to one static list generated and maintained by the Network Office. Today all US-LTER sites have access to a data base held at the Central computer at the Network office but maintained and updated dynamically from the site by an authorized user, most commonly the site's Data Manager. A fourth option involves the mixture of two types of concepts: centralization and distribution. The system is known informally as the "contributed" system among US-LTER Data Managers and requires the establishment and maintenance of the data bases at the site level. A retrieval engine is designed, implemented and maintained at a single computer or host, most commonly the Network Office's host (www.lternet.edu /documents /Reports/Datamanagementcommittee/ 1995committeereport /im_1995_report.htm).

Publication lists are a special kind of data base that are difficult to implement at both the site level and at the Network level. At the beginning of LUQ LTER, the list was generated and maintained using text editing computer software. This created management problems in updating the list be the difficulty involved in sorting when using a text editor. The addition of keywords for easy retrieval of subsets of the list was practically impossible, and the same format for citation always had to be used unless a great amount of time and effort was dedicated to change the format of the list. The system for entering publications was switched to a non-tagged system that merged several fields into one. The Data Manager and the principal investigator of the site decided to switch to another DBMS that separates each type of information like the authors' names that can be accessed individually, journal names, reference page numbers, etc. With this system we can automatically extract a specific subset of references from the list and we can also generate bibliographies using different styles of citation. Although the new software serves its purpose, it requires the training of the person that enters and retrieve the information of the publications. This person usually does not have the specialized knowledge that is needed to prepare a bibliography. A continuous coordination between the investigator and the computer specialist is needed. At the Network level, large amounts of resources and time had to be allocated in order to achieve a static bibliography. In 1994 a centralized bibliography was in place after programming special scripts, or computer programs, that filtered each data format of the bibliographies that were delivered from the sites. The variety of software packages used at the 18 existing sites of the network hindered this project. In spite of the obstacles, the project was useful to the scientific community (Ingersoll and Brunt, eds. 1994). Furthermore, the idea of a "contributed" system emerged from this project.

Developing a Policy

NSF mandated the development of Data Management policy at the site level. At our site, the Data Management Committee, made up by the Data Manager and two principal investigators, prepared a document based on the guidelines designed by the LTER Data Managers' Committee of the Network. The investigators of the site had the opportunity to evaluate a draft of the document. A final document containing the LUQ LTER Data Management Policies is in place and is part of the LTER Data Management Guidelines manual that can be found at the LUQ LTER Web site (http:/ /sunceer.upr.clu.edu/ltexmoni /datamng/ division.htm). The need for a policy becomes obvious especially to the Data Manager and the principal investigators of the site, as they try to gather data from the investigators. These policies, along with the threat of restricting funding, is really the principal mean to make non-cooperative researchers to share their data.

Developing Procedures

Archiving—At Luquillo, most of the Data Management activities involve making the data and its metadata available. Safe archiving processes make sure that information will be available to the existing scientists and general public and to future generations. The prevailing method of archiving at LUQ LTER is to save two copies of the data files on two three-and-a-half inch floppy disks stored at different locations. If the use of data is not restricted, a copy is posted on the LUQ LTER Web site. In addition, each investigator, most of whom live outside Puerto Rico, keep a copy of the data files at his or her site. We must constantly transfer the computer files to media that will last longer. In October 1997, we obtained a new device that saves data on a CD-R (Compact Disks-Recordable). The intention is to archive on these disks all data sets whose collecting period is longer than five years.

Making Data Available—The present idea of availability of data is not the same as few years ago. Until 1995, we made sure that the data were delivered in a timely manner after receiving a data request either by mail, phone or e-mail. Today "availability" means that data can be retrieved from a Web site. In this process nobody has to be contacted at the site to deliver the data. At Luquillo, we have kept track of requests for data since 1990, excluding the data that have been downloaded from our Web site. Table 1 shows these figures up to 1997. The overall decline in requests corresponds to a decline in requests for rainfall and temperature data gathered at the El Verde Field Station, which constitutes the largest number of annual data requests. We believe this decline is a direct consequence of the establishment of our Web site in 1992.

This new concept of availability begets new issues and technical problems. The principal one is knowing how to keep track of the use of the data. Scientists like to know how their data are used. Data Managers need to know the quantity and type of users accessing the data so they can make reports and evaluate new systems. Web sites offer a way to retrieve this kind of information but the process is not automatic and requires further manipulation of the information.

Establishing Quality Control (QC) and Quality Assurance (QA) procedures—The process of establishing quality control and quality assurance procedures of the data gathered should start at the designing stage of the project. Although Data Management has the responsibility of certifying that the data entered in the computer correspond to the data shown on the data sheets from the field, at LUQ LTER, we make clear to the investigator that they are responsible for the quality of the data gathered in the field.

Use of Lookup tables—The entry of data in a computer file always involves the possibility of human error. The processes of data entry can contain procedures that will minimize errors, but very rarely eliminate them completely. The creation of a lookup table containing all the possible values that can be entered in a field is one of the procedures that can be used to minimize data entry errors. This practice is particularly useful to assure the uniformity of the species names or species codes entered in a particular field of a data set. After entering all possible values in the desired column of the table, a query is made to yield a list of values without repetitions. This list is checked manually and mistakes are corrected in the computer file. The file then becomes a Paradox (Luquillo's official Relational Data Base Management System) "lookup" table. Basically, this is a data base that allows the user to automatically enter values in a specific field.

Setting range of values in the data entry table—This is only applicable when the range of values has a maximum and a minimum. If a "validity check" is defined for a field on a table, Paradox will not allow the user to enter anything that is not in the defined range of values.

Setting default values for the field—Some measurements are not supposed to have blank values. A blank value in these cases could mean that the datum is missing. The absence of values in these cases can bring problems when the data files are further manipulated. To make sure a value is always entered one can set the default value and whenever a data is not entered, the software will automatically enter the default value in the field. The person that enters the data must be very cautious to avoid entering the default values in records that are not suppose to hold that value.

Table 1.—Total of data requests received at the LUQ LTER site since 1990 (each period includes from June to May).

Period	Total
1990-1991	37
1991-1992	57
1992-1993	34
1993-1994	45
1994-1995	22
1995-1996	20
1996-1997	34

Transposing—Sometimes a data file structure has to be changed such that it allows the user to interpret the data in a different way. In many occasions we are asked to re-organize data that is entered in a row (or a record) to a column (or a field). Every time we have performed this process, the new file shows missing data values which the standard quality control procedures did not reveal. An example of this is the summary done on the data from our Landslide Revegetation project which measures plants higher than a certain value. The original file contains the information by plant in rows, each row for one plant measured at a specific date. The manipulated file contains the same information by row but a column exist for each of the measurements done by date. Consistently, this process reveals missing species codes for certain individuals plants. In many instances the errors shows a mistake done when collecting the data, others when the data are entered.

Double checking—There are several ways to perform this quality control procedure on the data entered (Ingersoll 1996). At LUQ LTER we use the process of two people, one being the person that entered the data, checking the data entered against the original data sheets. The process can be performed using a printout of the data entered or a screen (monitor) display of the data entered. Since reading from a monitor is a uncomfortable activity, we prefer to perform this process using a printout of the data entered. Although this process does not prevent making mistakes, it is necessary to assure that the data in the computer file are the same as the data gathered at the field. A second level of this process is performed by the investigators when they receive reports of the data. The detail 2 of Figure 4 represents this process.

Communication With Investigators

The key to establishing a successful data management system is to maintain good communication with the

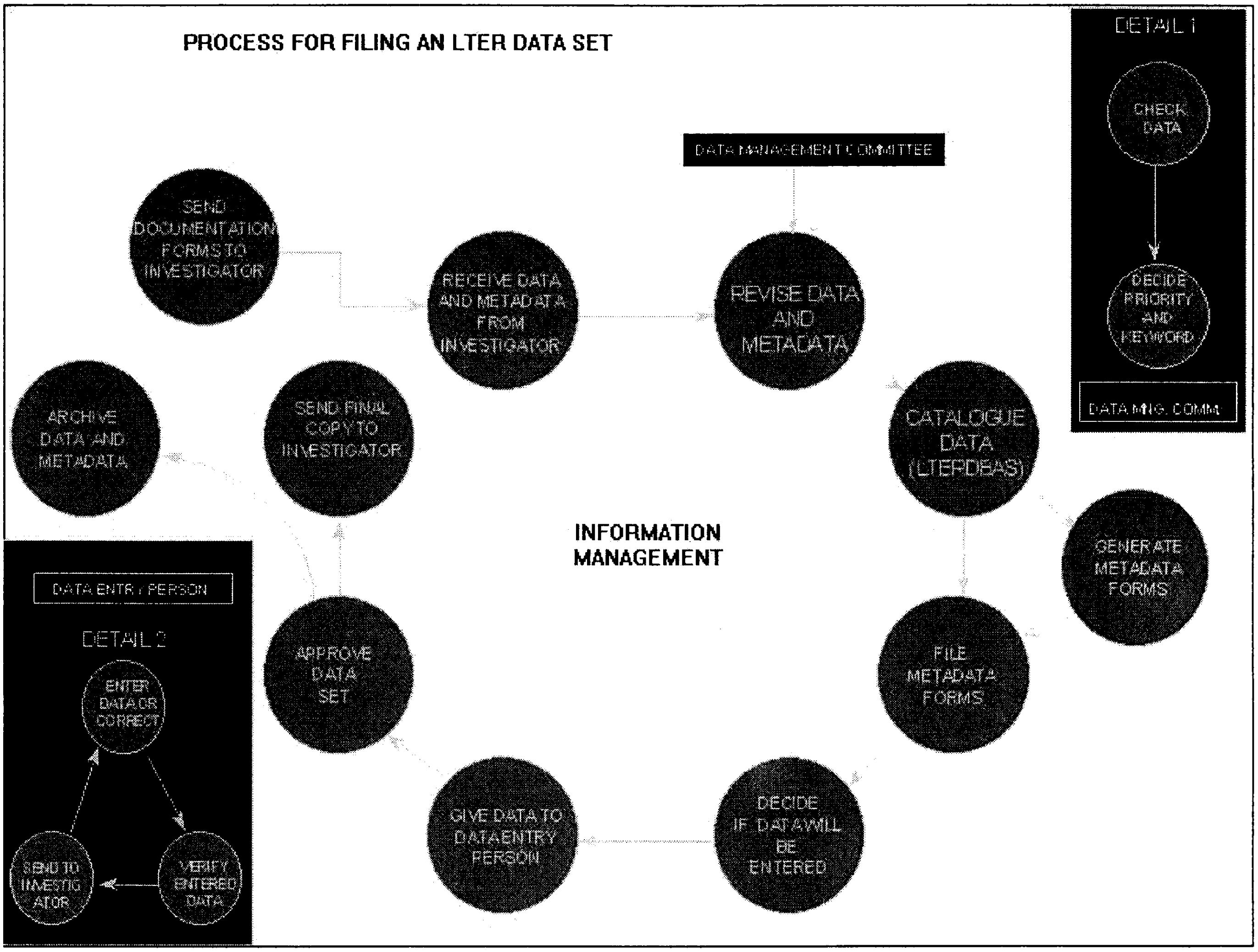

Figure 4.—Data filing process at the LUQ LTER.

investigators from the site. This communication should start at the beginning of the project, previous to data collection. When the data will be entered at Data Management, the data manager and the investigator should agree on the software and the procedure used for data entry and verification.

Obtaining Data From the Investigators

Figure 4 shows the cycle of completion for filing a data set with Data Management at Luquillo. The constant interaction with the investigator included in this procedure enhances the communication between the investigator, the data manager, and the data entry person. The selection of the software for data entry strongly depends on the type of manipulation the data will receive from the investigator. DBMS should be used for entering data that will be summarized and searched. Spreadsheets are best for data that will be used for creating charts and for analyses. Present software's portability are beginning to eliminate these constraints.

Other Services

Other activities involve the training of investigators and students in the procedures of data entry and quality control, the training for the use of software, and in some cases, administrating a Local Area Network (LAN). More essential to Data Management is requesting data from other agencies, and responding to data requests. Figure 5 shows the flow of data and/or information from LUQ LTER Data Management to the rest of the world.

Publication of Guidelines

The need to publish a manual that contains all the protocols, guidelines and procedures of the DBMS system arises as part of the need to create better ways to communicate with the investigators. At Luquillo we created a manual that contains all the protocols, forms and the guidelines to complete them, and the list of steps to file data sets and publications with Data Management. Its principal target is the scientific community that do not live on the island, which

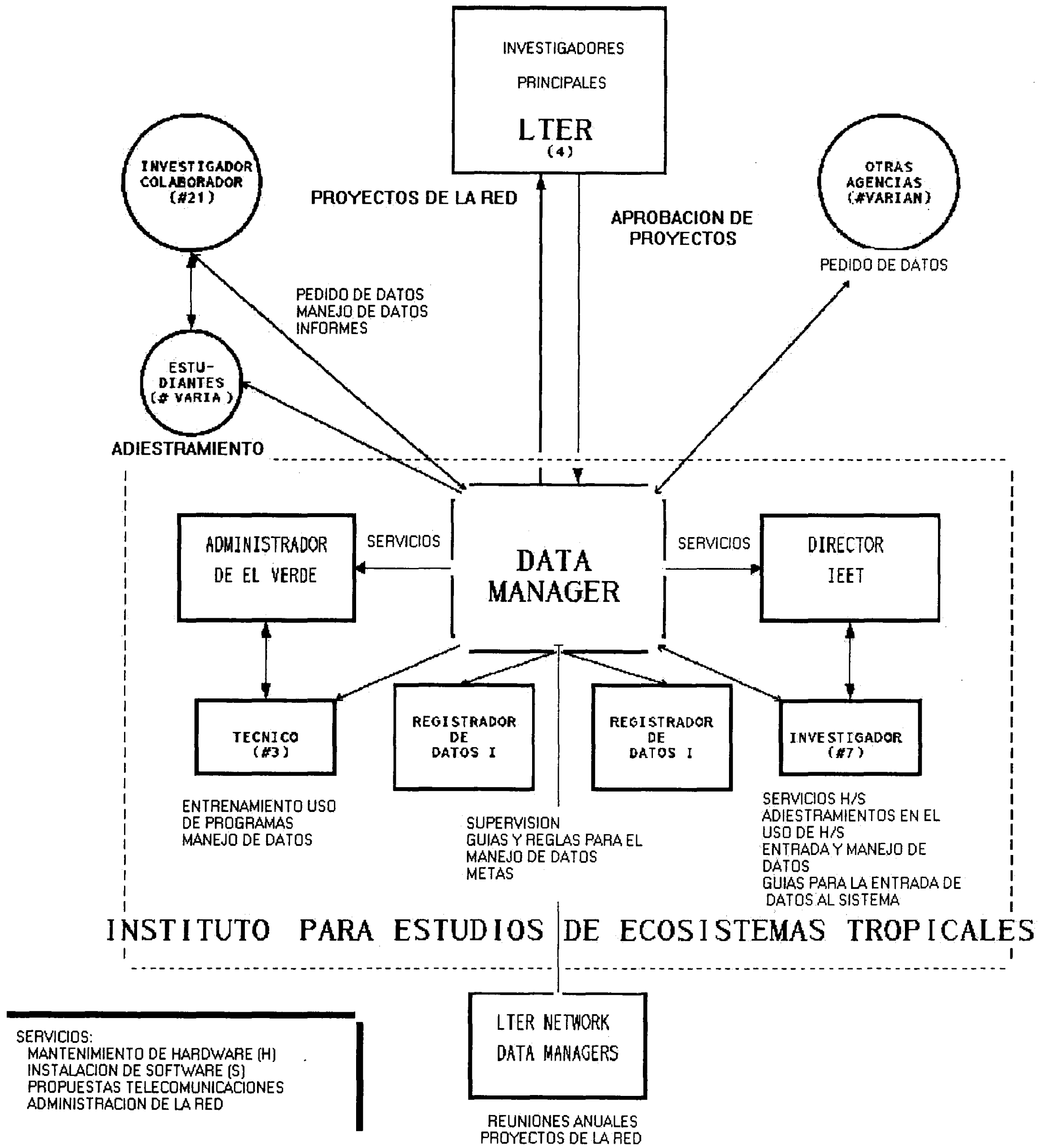

Figure 5.—Flujo de informacion entre el Gerente de Datos y otros.

constitutes the majority of our investigators. This collaborators come periodically to the El Verde Field Station (EVFS) to gather their data at the LEF, and most of the time cannot meet with the data manager when they come. In order to include their data sets in the official LTER Data Set Catalog, the investigators must file and fill out the documentation forms with Data Management. This process is best accomplished when the investigator and the Data Manager collaborate in filling out the documentation forms. The investigators can accelerate this process if they inspect the Guidelines previous to the their meeting with the Data Manager. Both benefit from the process of completing the forms together since the investigator spends less time filling out the documentation forms, and the Data Manager gets the opportunity to get acquainted with the data file. In turn, this practice strengthens the communication and understanding between the Data Manager and the investigator.

Web Technology and Interaction With Other Data Managers of the Network

In many instances in this paper we have referred to the influence of the technology of the WWW in the design of a DBMS. The trajectory of the use of the Internet at the LUQ LTER began in 1992 with the use of a Gopher server and continues with the creation of the Web site in 1996. The LUQ LTER Web site was developed originally to comply with NSF requirement for data availability. The first version of this site was posted on January 1996, and its present version was posted in June of 1997. Currently, forms are available on the site to enter abstracts and documentation. The system is still not dynamic since it does not provide searching capabilities to the user. We believe that is the reason why these online forms are not yet widely used by our investigators.

The data manager received an in-house training from the VCR LTER site Data Manager to create programming procedures to the Web site that impart this searching capability using a very simple Web tool known as miniSQL. This clearly illustrates the main advantage of belonging to a larger group of Information Managers whose expertise vary nearly as much as the variability in computer hardware and software.

The group of USA-LTER Data Managers meet annually to discuss different issues and complete network projects. In this annual meetings the individual site's Data Managers have the opportunity to interact with their colleagues who encounter similar problems at their own sites. In many occasions, this has been the primary source to find a solution to problems related to the design or implementation of the DMS at Luquillo. At the network level the sites have different levels of development so the newer sites benefit from the experiences of the older sites, and the latter benefit from the new, fresh ideas of the newer sites. This dynamic nourishes the whole group in return.

Another edifying practice is the development of common projects. This is another way of learning computer techniques necessary to participate in these projects and get new ideas for your own site. Participating in conducting surveys in the group is an example of this learning experience. One survey primarily shows the diversity of the types of computer tools that are used by the sites (Porter et al. 1996) and serve as a reference for the searching support within the members of the group.

Future Projects

The projects of Data Management will always involve the enhancement of its DMS in order to provide better services to the scientists and the community in general. At the moment, the Web tools being developed mark the future of the next generations of DMS (Wasser 1996). At Luquillo, the plans are to move from a static to a dynamic Web system where the forms are used to interact with the users, that is to give as well as to receive information. These activities go hand in hand with the inclusion of more data and metadata on the Web site to comply with the present commitment and directives of the Network. It is also important to Luquillo Data Management to increase the collaboration to the development of the Network's Information System (NIS). Currently, we maintain our local Data Table of Contents (DTOC, a data set catalog with a standard format) up to date. We will incorporate more data variables into the local file of the NIS' Climate Data Base (ClimDB).

Our ultimate goal is to expand our services to include the analysis and visualization of the data generated by our investigators.

Literature Cited

Baker, K.S. 1996. Development of Palmer Long-Term Ecological Research Information Management. Presented at the Eco-Informa 1996, Lake Buena Vista, Florida, 4-7 November 1996.

Benson, B.J. 1996. The North Temperate Lakes research information management system. Presented at the Eco-Informa 1996, Lake Buena Vista, Florida, 4-7 November 1996.

Ingersoll, R. And J. Brunt, editors. 1994. Proceedings of the LTER Data Managers Meeting, Seattle, Washington.

Gorentz, J. et al. 1982. Data Management Stations at Biologicla Field Stations: Report of a Workshop May 17-20, 1982, W.K. Kellog Biological Station, Michigan State University. 45p.

Porter, J.H., B.P. Hayden, and D.L. Richardson. 1996. Data and information management at the Virginia Coast Reserve Long-Term Ecological Research site. Presented at the Eco-Informa 1996, Lake Buena Vista, Florida, 4-7 November 1996.

Porter, J.H., R.W. Nottrott, and K. Baker. 1996. Tools for managing ecological data. 1996. Presented at the Eco-Informa 1996, Lake Buena Vista, Florida, 4-7 November 1996.

Spycher, G., J.B. Cushing, D.L. Henshaw, S.G. Stafford, and N. Nadkarni. 1996. Solving problems for validation, federation, and migration of ecological data bases. Presented at the Eco-Informa 1996, Lake Buena Vista, Florida, 4-7 November 1996. Research support provided by the National Science Foundation grant DEB-9011663.

Veen, C. D. Buso, and T. Siccama. 1994. Structure and function of the Hubbard Brook data management system. Bulleting of the Ecological Society of America 75(1):45-48.

Walker, L.R., D.J. Lodge, N.V.L. Brokaw, and R.B. Waide. 1991. An introduction to Hurricanes in the Caribbean. Biotropica 23(4a): 313-316.

Wasser, C. 1996. Dynamic data transfer via the World Wide Web: increasing your visitors' understanding of ecological data. Presented at the Eco-Informa 1996, Lake Buena Vista, Florida, November 4-7 1996.

Examples of Innovative Information Management for Reporting Forest Data and Information[1]

Adam Fenech[2]

Abstract—Today's readily available technologies allow for some innovative handling, management and presentation of forest data and information. The Internet is no longer simply an electronic mail exchange and provider of text documents. In Canada, the Internet is now being used as a training tool, a tool for submitting environmental observations or measurements to a database, as a data management tool, and as a tool for reporting information to decision-makers in real time. This paper will detail the specifics about the Canadian examples - the SI/MAB Biodiversity Database, the Ontario Forest Health Co-operative Database, the MacKay Phenology Database and the Frogwatch-Ontario Website.

The EMAN Co-ordinating Office of Environment Canada has extended the normal uses of Websites as providers of text documents by using readily available technologies for the Internet. These include using Websites as a training tool, a tool for submitting environmental observations or measurements to a database, as a data management tool, and as a tool for reporting information to decision-makers in real time. This paper will detail the specifics about the Canadian examples - the SI/MAB Biodiversity Database, the Ontario Forest Health Co-operative Database, the MacKay Phenology Database and the Frogwatch-Ontario Website - followed by a technical explanation about how these Websites work.

The SI/MAB Biodiversity Database and Website

The SI/MAB Program

In 1986, UNESCO MAB and the Smithsonian Institution joined to create SI/MAB with the express purpose of developing a protocol for surveying and monitoring biodiversity in a global network of forested areas under different management regimes. Over the years, SI/MAB has fostered a network of permanent, long-term biodiversity monitoring plots and associated sponsors, researchers and land managers who are dedicated to the conservation of biodiversity.

The vegetation protocols have been adopted at nearly 200 research sites in 23 countries, facilitating the transfer of comparable data, and providing a framework for data analysis and dissemination. Other protocols are being developed, tested and implemented in conjunction with the vegetation monitoring. The vegetation protocols survey SI/MAB plots of one hectare in size divided into 25 quadrats of 20 metres by 20 metres. Each tree is located, tagged, identified (by species), evaluated (by condition) and measured (height and diameter at breast height).

It is envisioned that the protocols will enable users to integrate scientific research methods and analysis with strategies for getting the resulting information into the hands of a wider range of users - in particular, decision-makers and resource managers involved with issues of sustainable use and conservation of natural resources.

The Objectives of an SI/MAB Database and Dynamically-Linked Website

Several concerns/needs led to the development of the SI/MAB Biodiversity Database - (1) a central archive was required for the data in order that the results of the labour-intensive efforts in establishing SI/MAB plots were not lost; (2) a queriable database so that analysis between sampling years at plots, and analysis between plots was available to researchers; (3) a compilation of the meta-information about the plots was needed to answer questions such as where are the plots located worldwide? What species are found by plot, by world biomes, by country, worldwide? Who do we contact at each site for more information?

Additional concerns/needs were added in order that the data and information available from the SI/MAB Biodiversity Database was accessible to researchers, decision-makers and the general public including: (1) providing the methods for establishing the SI/MAB biodiversity monitoring plots and applying the vegetation protocol; (2) allowing for the submission and handling of data from a remote user over the Internet; (3) reporting back to the public on the results of establishing the biodiversity plots especially "canned" means for viewing summaries and basic statistics of the plots; (4) reporting back to communities and other groups with respect to a "canned" analysis for each of the SI/MAB biodiversity plots.

The Dynamically-Linked SI/MAB Biodiversity Database

The SI/MAB Biodiversity Database (see *www.cciw.ca/simab-data/* for the test Website), a Website with pages dynamically linked to the database stored at the CCIW server, was established in 1997 (see Figure 1). At the moment, maps of the plots can be generated (see Figure 2),

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species lists can be compiled (see Figure 3), and basic statistics (see Figure 4) can be automatically generated on the basis of plot, country (see Figure 5), world biome (see Figure 6) and globally (see Figure 7). Only 25 (17 Canadian) of the 200 surveys in existence worldwide are in the database at this time. The public find it particularly relevant to compare sites in Canada with those on other continents including South America, Africa and Asia. The ability to track change within plots, and to compare different plots is being developed as an overall analysis package. The Website also respects data ownership by providing a password protected editing function (see Figure 8) on the Website to allow data owners to edit their own data.

The Ontario Forest Health Co-operative Database and Website

Ontario Forest Health Monitoring

There are a number of agencies in the province of Ontario who collect data on the health of forested ecosystems - the Canadian Forest Service (CFS), Environment Canada (DOE), the Ontario Ministry of Natural Resources (MNR), the Ontario Ministry of the Environment (MOE) and others. The Canadian Forest Service maintains the Acid Rain National Early Warning System (ARNEWS) plots initiated in 1984 as a national program to detect early signs of air pollution damage to Canada's forests; the North American Maple Project (NAMP) plots which monitor sugar maple tree condition based primarily on crown dieback and crown density; historical plots with data from the Forest Insect and Disease Survey (FIDS); and other tree species specific networks such as Oak, Maple, Jack Pine and Spruce/Fir. The Ontario Ministry of Natural Resources maintains numerous Forest Health plots in Maple and Oak stands throughout Ontario as well as numerous growth and yield plots. The Ontario Ministry of the Environment maintains numerous plots for dendro research. Environment Canada co-ordinates several SI/MAB biodiversity plots throughout Ontario. Other groups such as universities and non-government agencies also maintain monitoring or research networks on forest health.

While the separate, unintegrated, single-purpose, sample plot networks mentioned above are necessary to meet individual scientific or policy related goals, information must be obtained at a larger scale to meet many obligations of the various agencies with respect to providing the knowledge to adaptively manage resources sustainably and to meet provincial and national obligations such as the environmental assessment and criteria and indicators

Objectives of the Ontario Forest Health Co-operative Database and Dynamically-Linked Website

The Ontario Forest Health Data Co-operative was developed as a way of obtaining and storing information from existing sources on the health of Ontario's forest ecosystems.

The primary objective of the Forest Health Data Co-operative is to establish what information is presently available that can contribute to our understanding about the health of Ontario's forests including: (1) compiling a list of all forest survey plot locations by ecozone, forest region and administrative district; (2) listing basic information on each plot, e.g.; purpose, vegetation type, variables measured, years assessed; (3) listing other plot locations where forest related studies occur e.g., soils, biodiversity, birds, etc.; (4) listing other associated datasets such as climate or water data. The expected results of the project are a database of plot locations, contacts and basic plot information; and a database of forest studies occurring in Ontario.

The Dynamically-Linked Ontario Forest Health Co-operative Database

An operation similar to the SI/MAB Biodiversity Database has been established for the Ontario Forest Data Co-operative (see *www.cciw.ca/Forest-Health/* for a test Website), whereby a database of meta-information about monitoring plots (their location, the variables measured, contact names and information, responsible agency, etc.) is dynamically linked to a Website (see Figure 9). The Website presents maps of Ontario showing locations of the monitoring sites as red dots (see Figure 10) - dots which when "clicked" by the mouse then bring up the detailed meta-information about the monitoring site (see Figure 11). This allows the public, teachers, students, community groups, and, more importantly, other researchers know the specifics (who, what, when, where and why) about forest monitoring activities in Ontario. Currently, monitoring sites from the Canadian Forest Service, the Ontario Ministry of Natural Resources and Environment Canada are accessible from the Website. Other agencies including Conservation Authorities, Naturalist Organizations and Universities will be pressed to have their monitoring sites and metadata included in the database.

The Mackay Phenology Database

The Mackay Phenology Records

From 1891 to 1923, an influential inspector of schools in Nova Scotia, Dr. A.H. McKay, recruited a number of knowledgeable teachers around the province to have them and their students observe 100 natural occurrences each year, and report them in a standard manner. McKay was an acclaimed botanist whose lichen collection and publications are part of the Nova Scotia Museum of Natural History resources. The records from his environmental observation project are also part of the Nova Scotia Museum collection, and are a valuable source of data but not in their original form. There are 20 thick volumes of records, of which 6 are summary volumes, which contain all the basic data. The summaries contain approximately 800 large ledger-type pages, each containing date of occurrence of 100 phenological events at approximately 200 communities in Nova Scotia. About 65 of these observations are first and widespread

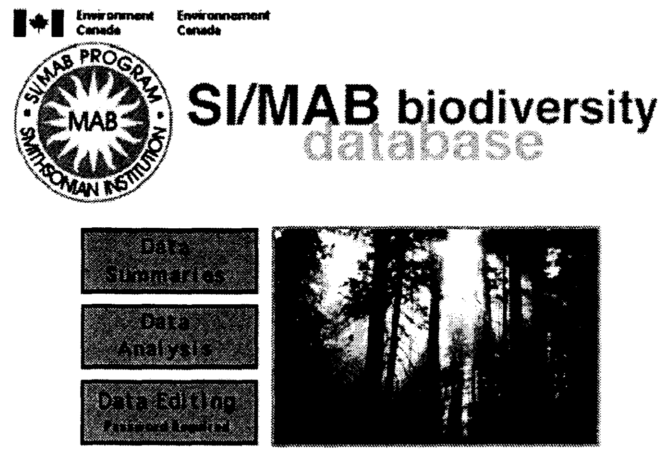


Figure 1.—SI/MAB Biodiversity Database Website HomePage

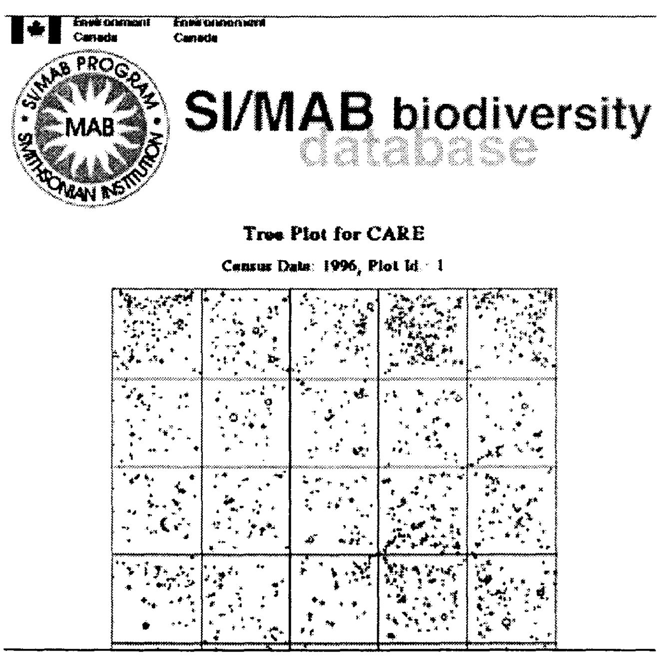
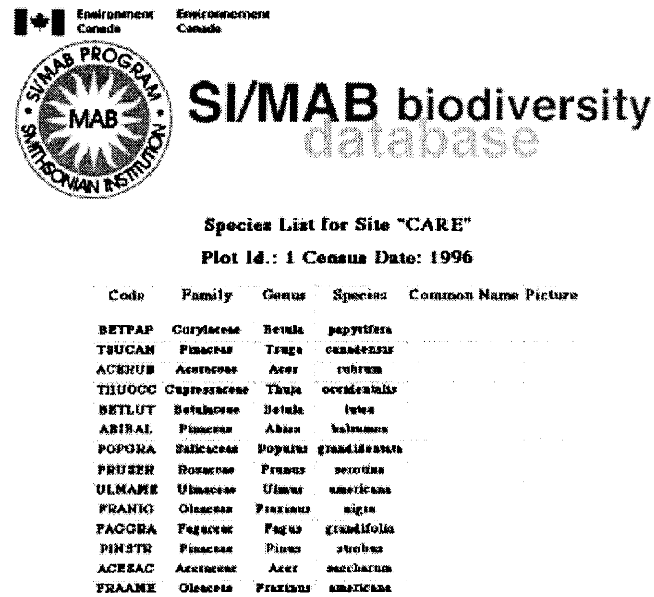


Figure 2.—SI/MAB biodiversity plot map automatically drawn from database and displayed at website.

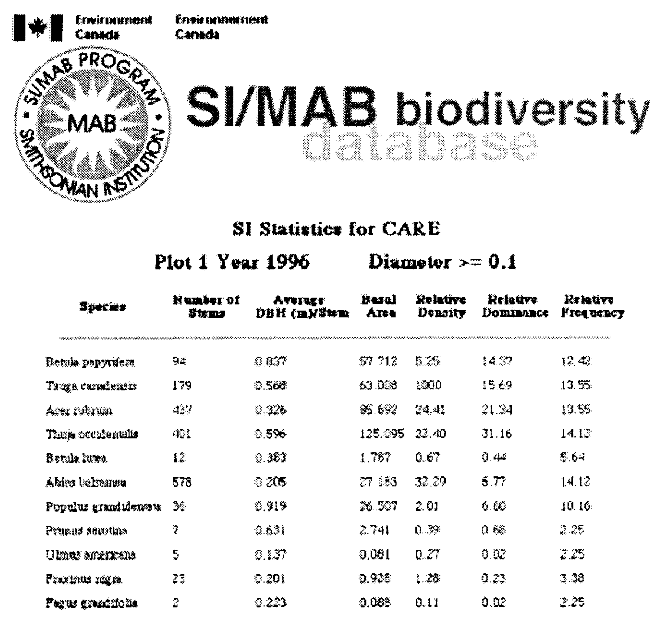


Species List for Site "CARE"

Plot Id.: 1 Census Date: 1996

Code	Family	Genus	Species	Common Name	Picture
BETPAP	Corylaceae	Betula	papyrifera		
TSUCAN	Pinaceae	Tsuga	canadensis		
ACERUB	Aceraceae	Acer	rubrum		
THUOCC	Cupressaceae	Thuja	occidentalis		
BETLUT	Betulaceae	Betula	lutea		
ABIBAL	Pinaceae	Abies	balsamea		
POPGRA	Salicaceae	Populus	grandidentata		
PRUSER	Rosaceae	Prunus	serotina		
ULMAME	Ulmaceae	Ulmus	americana		
FRANIG	Oleaceae	Fraxinus	nigra		
FAGGRA	Fagaceae	Fagus	grandifolia		
PINSTR	Pinaceae	Pinus	strobus		
ACESAC	Aceraceae	Acer	saccharum		
FRAAME	Oleaceae	Fraxinus	americana		

Figure 3.—SI/MAB biodiversity plot species list automatically compiled from database and displayed at website.



SI Statistics for CARE

Plot 1 Year 1996 Diameter >= 0.1

Species	Number of Stems	Average DBH (m)/Stem	Basal Area	Relative Density	Relative Dominance	Relative Frequency
Betula papyrifera	94	0.837	57.712	5.25	14.37	12.42
Tsuga canadensis	179	0.568	63.038	1000	15.69	13.55
Acer rubrum	437	0.326	85.692	24.41	21.34	13.55
Thuja occidentalis	401	0.596	125.095	22.40	31.16	14.12
Betula lutea	12	0.383	1.767	0.67	0.44	5.64
Abies balsamea	578	0.205	27.153	32.29	6.77	14.12
Populus grandidentata	36	0.919	26.507	2.01	6.60	10.16
Prunus serotina	7	0.631	2.741	0.39	0.68	2.25
Ulmus americana	5	0.137	0.061	0.27	0.02	2.25
Fraxinus nigra	23	0.201	0.928	1.28	0.23	3.38
Fagus grandifolia	2	0.223	0.088	0.11	0.02	2.25
Pinus strobus	4	1.759	10.264	0.22	2.55	1.69

Figure 4.—SI/MAB biodiversity plot statistics automatically compiled from database and displayed at website.

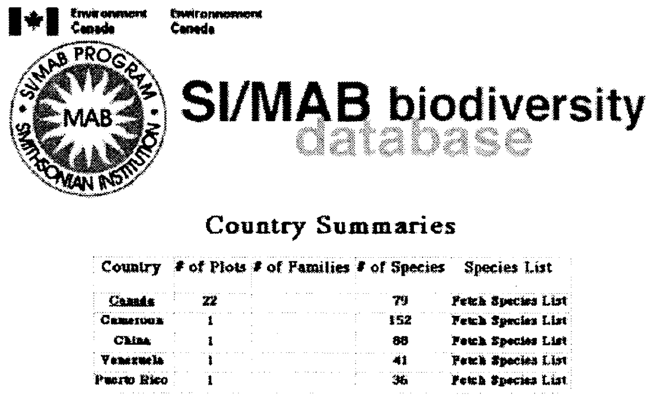


Figure 5.—SI/MAB biodiversity plot summaries compiled by country from database and displayed at website.

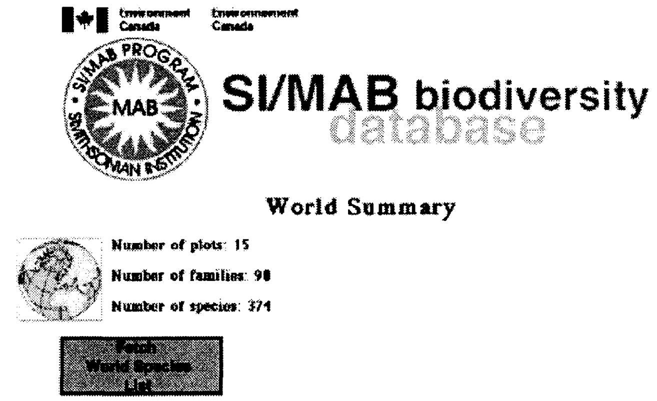


Figure 7.—SI/MAB biodiversity plot summaries compiled globally from database and displayed at website.

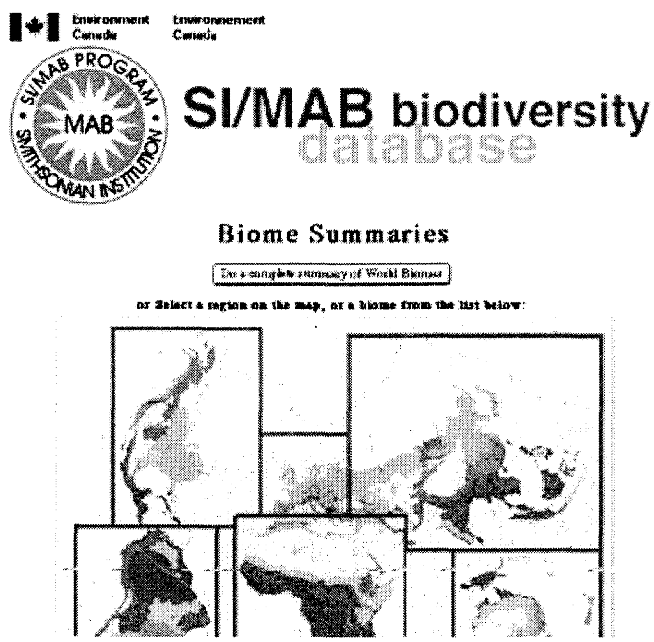


Figure 6.—SI/MAB biodiversity plot summaries compiled by major world biome from database and displayed at website.

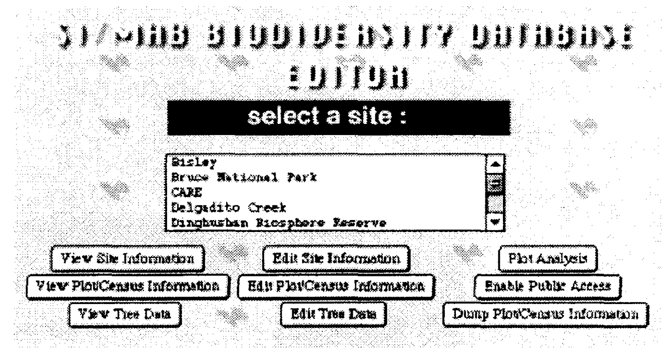


Figure 8.—SI/MAB biodiversity plot editing function available at website.

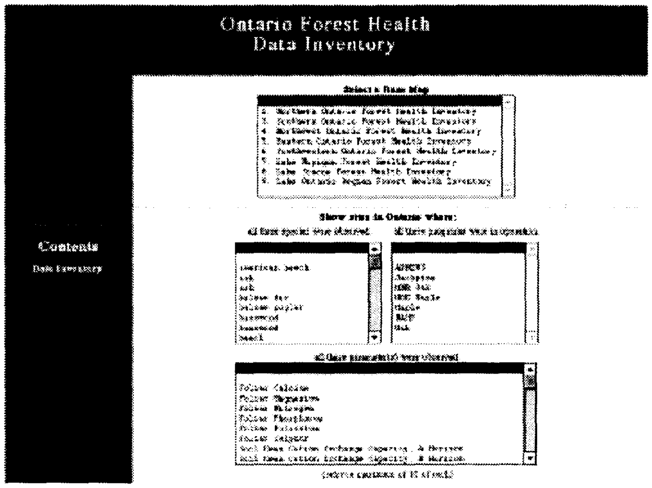


Figure 9.—Ontario forest health database website.

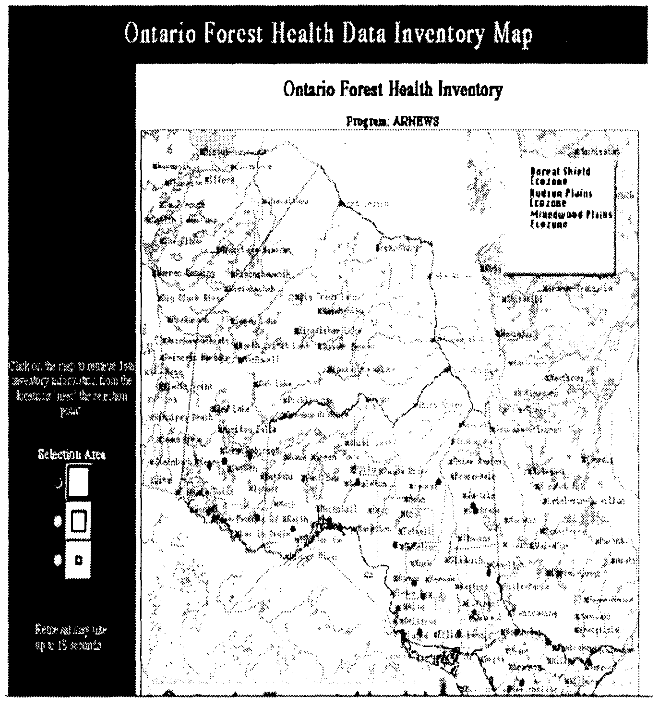
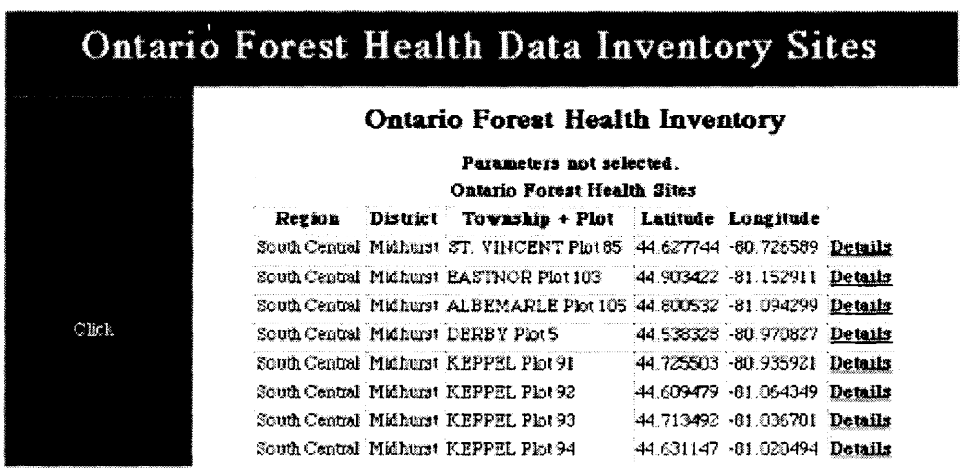


Figure 10.—Ontario forest health map automatically drawn from database.



Region	District	Township + Plot	Latitude	Longitude	
South Central	Midhurst	ST. VINCENT Plot 85	44.627744	-80.726589	Details
South Central	Midhurst	EASTNOR Plot 103	44.903422	-81.152911	Details
South Central	Midhurst	ALBEMARLE Plot 105	44.800532	-81.094299	Details
South Central	Midhurst	DERBY Plot 5	44.538328	-80.970827	Details
South Central	Midhurst	KEPPEL Plot 91	44.725503	-80.935921	Details
South Central	Midhurst	KEPPEL Plot 92	44.609479	-81.064349	Details
South Central	Midhurst	KEPPEL Plot 93	44.713492	-81.036701	Details
South Central	Midhurst	KEPPEL Plot 94	44.631147	-81.020494	Details

Figure 11.—Ontario forest health site details compiled from the database.

flowering dates of common plants; about 15 fields record migrant birds; and the remainder record dates of events such as frogs calling, weather and agricultural activity.

Objectives of the Mackay Phenology Database And Dynamically-Linked Website

By digitizing these records, and putting them into a database, maps could be produced detailing the ecological changes of Nova Scotia in the early 20th Century; and the database and summaries of the data made available to the public through the Nova Scotia Museum and EMAN Websites.

An added objective was the reinstatement of a community/school-based observation program similar to the MacKay observations.

The Dynamically-Linked Mackay Phenology Database

The MacKay Phenology Database Website (see *www.cciw.ca/MacKay-data/* for a test Website) is similar to the Websites of the SI/MAB Biodiversity Database and the Ontario Forest Health Database whereby a database of phenological observations (wildflowers, birds, weather and agriculture) are dynamically linked to a Website (see Figure 12). The Website presents maps of Nova Scotia showing the timing of phenological observations (see Figure 13) as the "green wave" of Spring flows over the province.

The Frogwatch Ontario Website

While this information is about amphibians, it is important to show the computer capabilities created for this Website that could be applied to forest health information management.

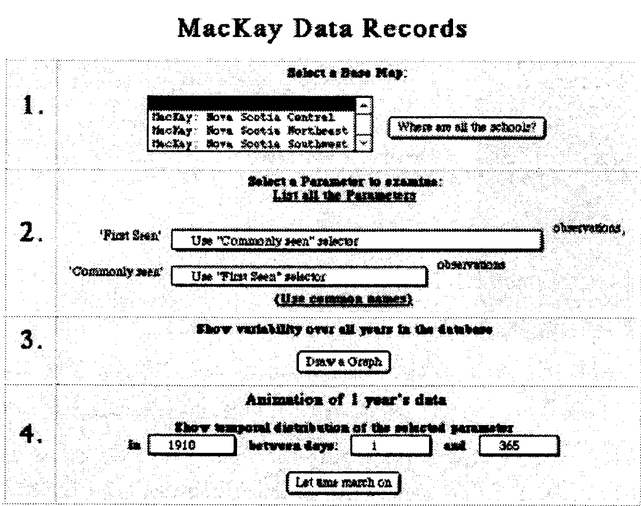


Figure 12.—Parameters of MacKay Phenology website.

Frogwatch Ontario

Frogwatch-Ontario is an educational program of frog and toad observations that contribute to scientific databases in Ontario. By listening to frog and toad mating calls, schools and communities can record and submit observations in monitoring the health of Ontario's wetlands.

The Objectives of the Frogwatch-Ontario Website

The Frogwatch-Ontario Website required several capabilities to be handled by the Internet including: (1) a presentation of the methods to be followed by the public/community/school in observing amphibians; (2) a training mechanism to test observer abilities in identifying mating calls of Ontario's frogs and amphibians; (3) a data reporting capability that would allow observations to be reported over the Web or using an automated telephone answering device; (4) a queriable database of historical and current observations; (5) an ability to map, at different resolutions, historical and current observations in real time.

The Frogwatch-Ontario Website

The Frogwatch-Ontario Website (see *www.cciw.ca/frogwatching/* for a test Website) is similar to the other Websites above, but integrates the aspects of providing training (see Figure 14), submitting data (see Figure 15), and reporting back observations in real time (see Figure 16).

The Technical End

A Brief Introduction to Web Servers

A Glossary of Computer Terms is provided as an introduction to the technical section.

Clients and servers—Some computers function as information sources—the servers—while other computers act as sinks—the clients. The client's computer makes requests to the server computers and the server computers respond with the requested information. The computers involved can be at a substantial geographical distance from each other, and are connected through some communication link (e.g. telephone lines, satellite).

The web—The Web is the totality of information stored on server computers around the world who are connected to the Internet. Information at the servers can be easily retrieved and displayed to a client whose computer is also connected to the Internet.

Web browser—Web browsers are commercially available software programs used by client computers to make communication linkages to servers around the world, and retrieve and display information on a client's computer screen. Some examples are Netscape or Microsoft Explorer.

Web document—Web documents are the text and graphics of information that are stored in server computers around the world. The language for communicating Web

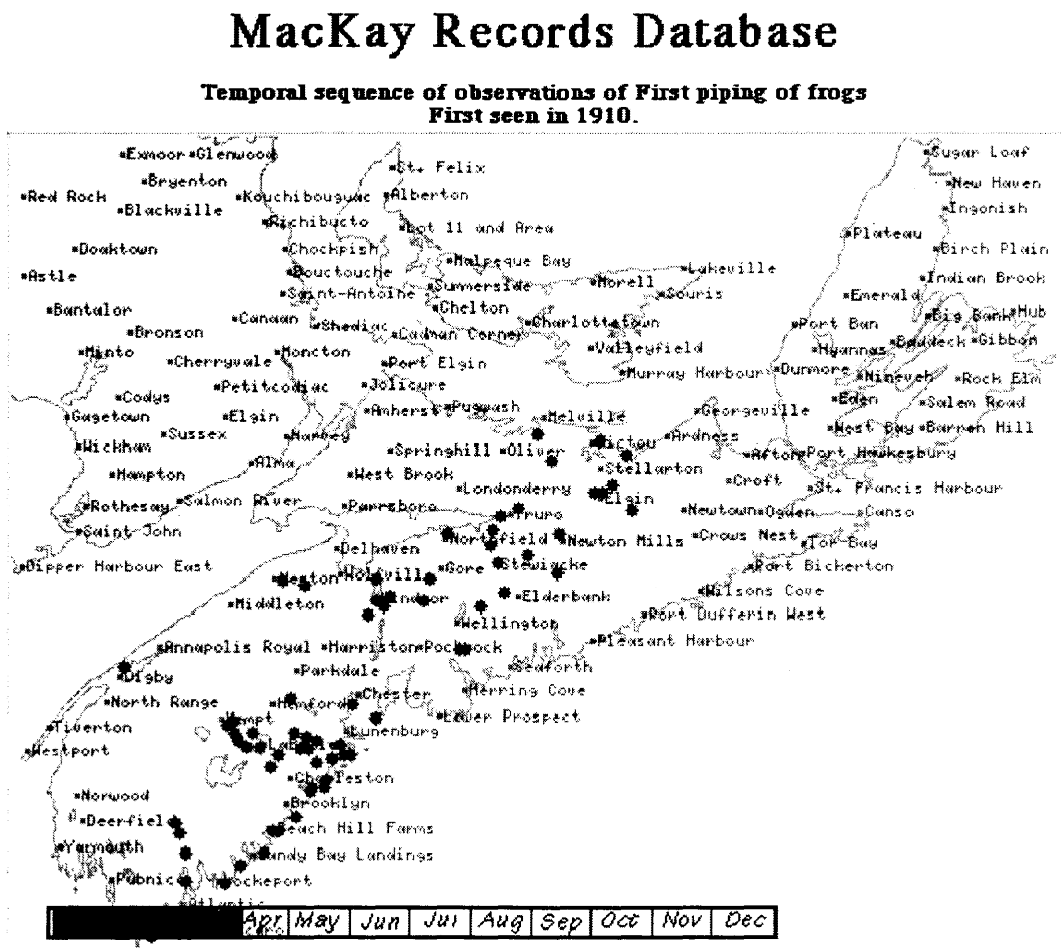


Figure 13.—Dynamic map of phenologies from MacKay phenology database automatically drawn from website.

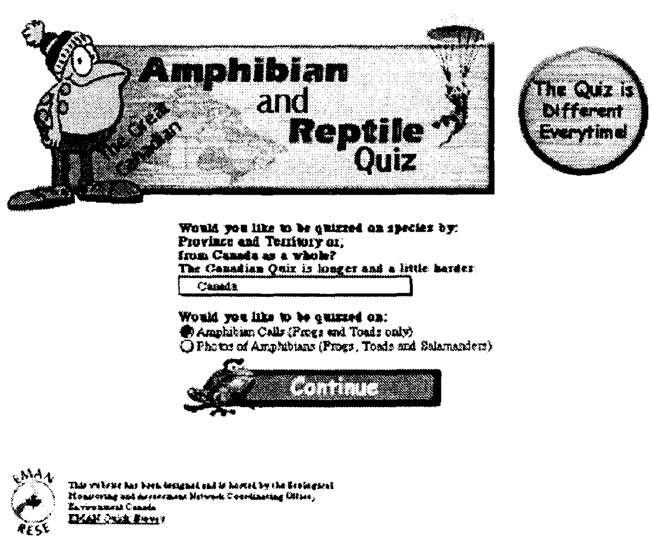


Figure 14.—Training page for Ontario Frogwatch website.

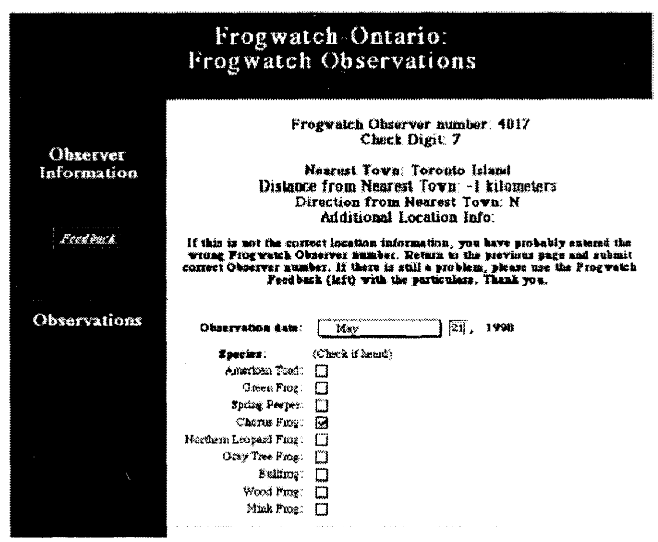


Figure 15.—Website data form for automatic updating of Frogwatch database.

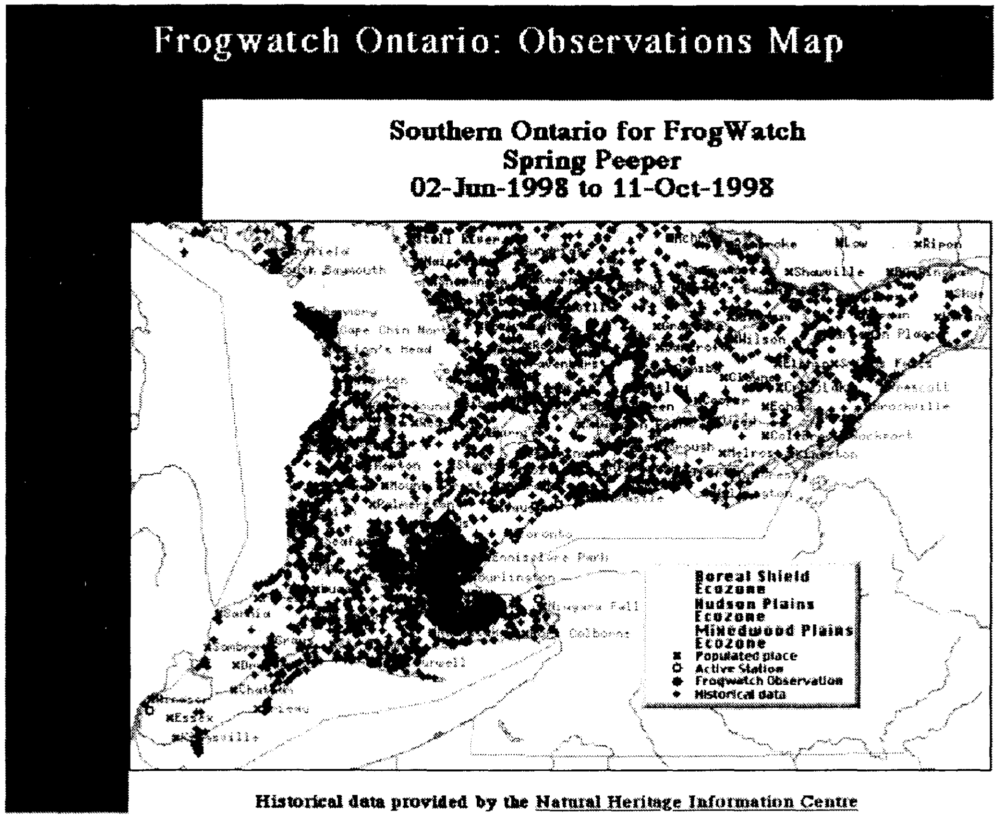


Figure 16.—Historical and current amphibian observations map automatically drawn from website.

documents from the server to the clients is Hyper-Text Markup Language or HTML.

HTML (Hypertext Markup Language)—Hypertext Markup Language or HTML as it is known, is a set of commands embedded in a Web document (text data) which controls how the text is displayed by a Web browser.

Hyperlink—A hyperlink is a code contained in Web documents that can cause actions to be performed on behalf of the client either automatically as the document is loaded on the client's computer, or upon selection by the user (in the latter case, the hyperlink usually has human-visible attributes distinguishing it from other text in the document - for example, a button).

Hypertext Transport Protocol (HTTP) or Transmission Control Protocol/Internet (TCP/IP)—HTTP and TCP/IP are two sets of communication 'rules' that govern access to the information stored on various Web servers around the world connected to the Internet. TCP/IP describes how connections may be made between client and server computers, while HTTP describes the communication 'language' used on the connection.

Uniform resource locator or URL—A URL is an address that tells a Web browser on a client's computer where to find information at a server computer connected to the Internet somewhere around the world. The URL contains both the TCP/IP 'dialing instructions' (the name of the server computer that holds the information), the information to be conveyed (a request or a message), and additional instructions about the types of responses that can be processed.

Basic Web Server Operation

The first action occurs to establish a communication link (at Figure 17). A client using a Web browser on his computer issues a URL address specifying a request for information. The client may have typed the specific URL into the Web browser, or a hyperlink (such as a button saying "fetch me the information") in an already loaded document may have been selected. The URL in the example is *http://www.cciw.ca/page.html* and contains the following information: the Web browser wishes to establish a HTTP transaction (http://) with the server computer at the Canada Centre for Inland Waters, in Canada (whose address is www.cciw.ca) to retrieve the document identified as "/page.html".

The Web browser passes the address information to the TCP/IP layer, which, together with other layers of protocols, establishes a connection (communication channel) with the Web server at CCIW. Once the connection has been made, the request for the document is passed over the communication channel. When the server receives the request, it begins an internal process (at Figure 17) to locate the requested information among its many information sources at the Web server. The information takes the form of a simple file somewhere on the server machine's disk, and when found, it is read by the server ( ) and written to the

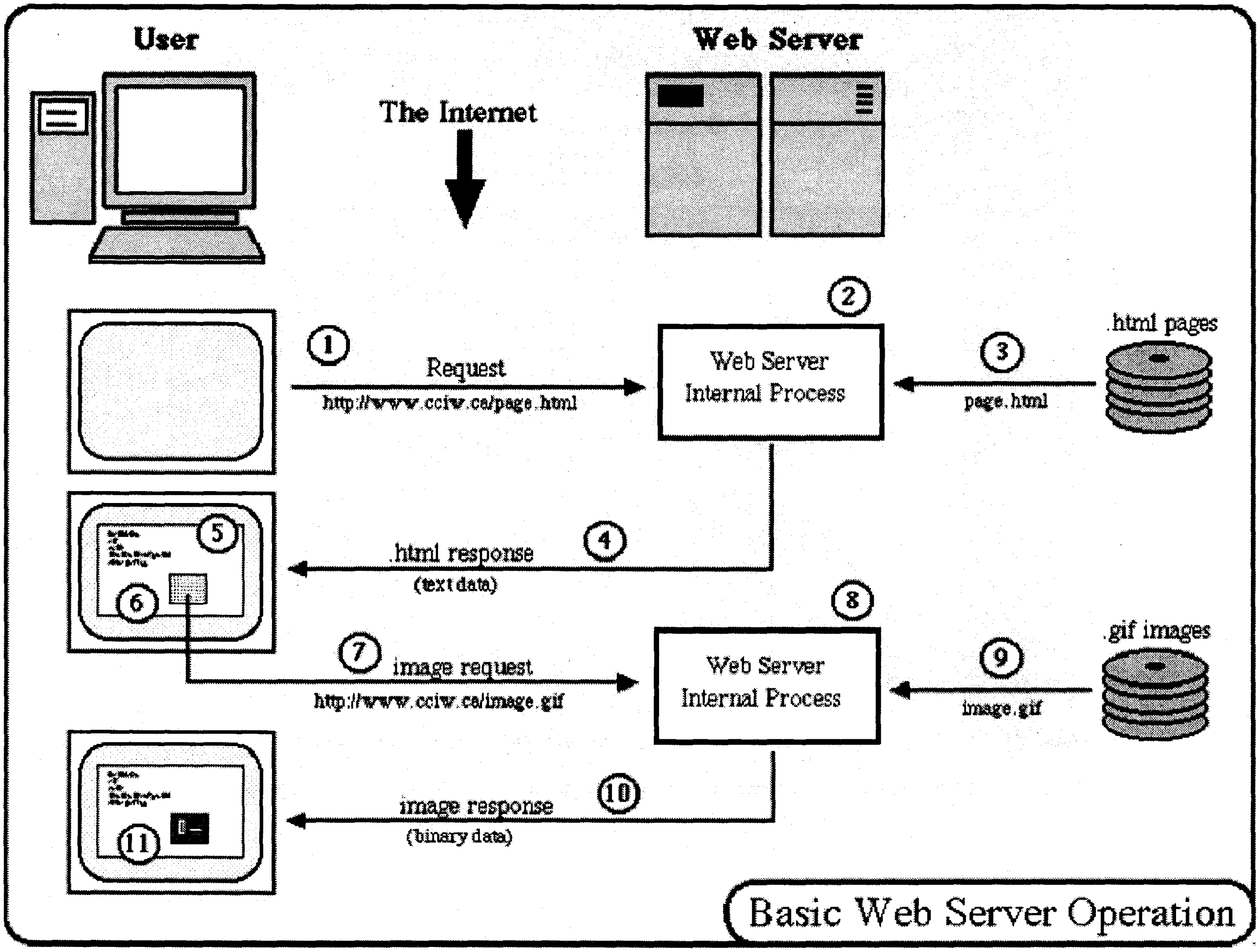


Figure 17.—Basic web server operations

communication channel as the response to the client ( ), together with some information about the meaning of the data in the response (the response is to be interpreted as HTML and displayed on the screen, for example).

When the response arrives at the client, the browser software interprets it and may cause the text to be displayed on the screen ( ). At this point, the initial transaction is complete and the server may choose to break the connection with the client.

It is possible there might be a hyperlink embedded in the response from the Web server. This hyperlink represents the URL of a graphical image (shows the place the image should appear on the page). The browser will recognize this occurrence and will automatically initiate another transaction across the communication link to try to retrieve this object. In the diagram shown as Figure 17, represents the request for the image item whose URL, or address, is *http://www.cciw.ca/image.gif*.

Another process will be started when the request for the image reaches the Web server to read the image from the server's disk . The data in the file will be sent over the communication channel to the client , which will display it to the client's screen once it is received. Once again, the channel may be closed at the server's discretion.

The process of opening the connection, requesting a file, receiving the response and drawing it to the screen is repeated as often as necessary to fetch the entire page and its images, although many browsers have the ability to establish several communications channels with the server simultaneously to reduce the time taken to load the page.

Simple CGI Program

For the process described above as *Basic Web Server Operation*, only the Web server software running the server machine has been involved. It is possible, however, to have the Web server cause another program to be run and to have the output from that program sent back to the client as a response, rather than the contents of a file on the server disk. Most Web servers implement a scheme called the *Common Gateway Interface* or CGI, as a connection between the running Web server process and another program producing the output.

Figure 18 reveals a similar transaction to that shown in Figure 17. Step , the request and step the Web server internal process are similar. Step shows the Web server process starting another program, , the CGI program which produces an output routed to the channel back to the client . The Web browser is unaware the data was produced by a program, rather than copied from a file, and if the content is correctly formatted, it is dutifully displayed on the client's computer .

Basic Data-Driven Operation

A more sophisticated example of a CGI program is presented in Figure 19, the Basic Data-driven Operation. The CGI program to be executed by the server is a complex routine that produces HTML formatted text from the "template" files from the server disk and performs database operations directed by special commands in the templates. This text, when sent back to the browser, will be displayed on the client's computer as if it were a simple file from the first example.

This mechanism allows the the format and content of the HTML response to be computed on demand, based on the data in the database and the logic of the commands in the template files. In addition, the user can supply input to the process with some optional data transmitted with the initial request.

The initial request , when handled by the Web server process , creates and runs the CGI program (called w3-msql at). This program reads the template file, in this case "page.html" as specified in the initial request, from the server disk at . The program examines the file and locates any commands requiring database access and executes them ( ). The results of the database operations are formatted into normal HTML code and written to the channel back to the client ( ) where they are displayed on the client's computer screen ( ).

Dynamic Graphic Content

This mechanism generates many of the data-driven images found on the SI/MAB, Forest Health, Frogwatch and MacKay

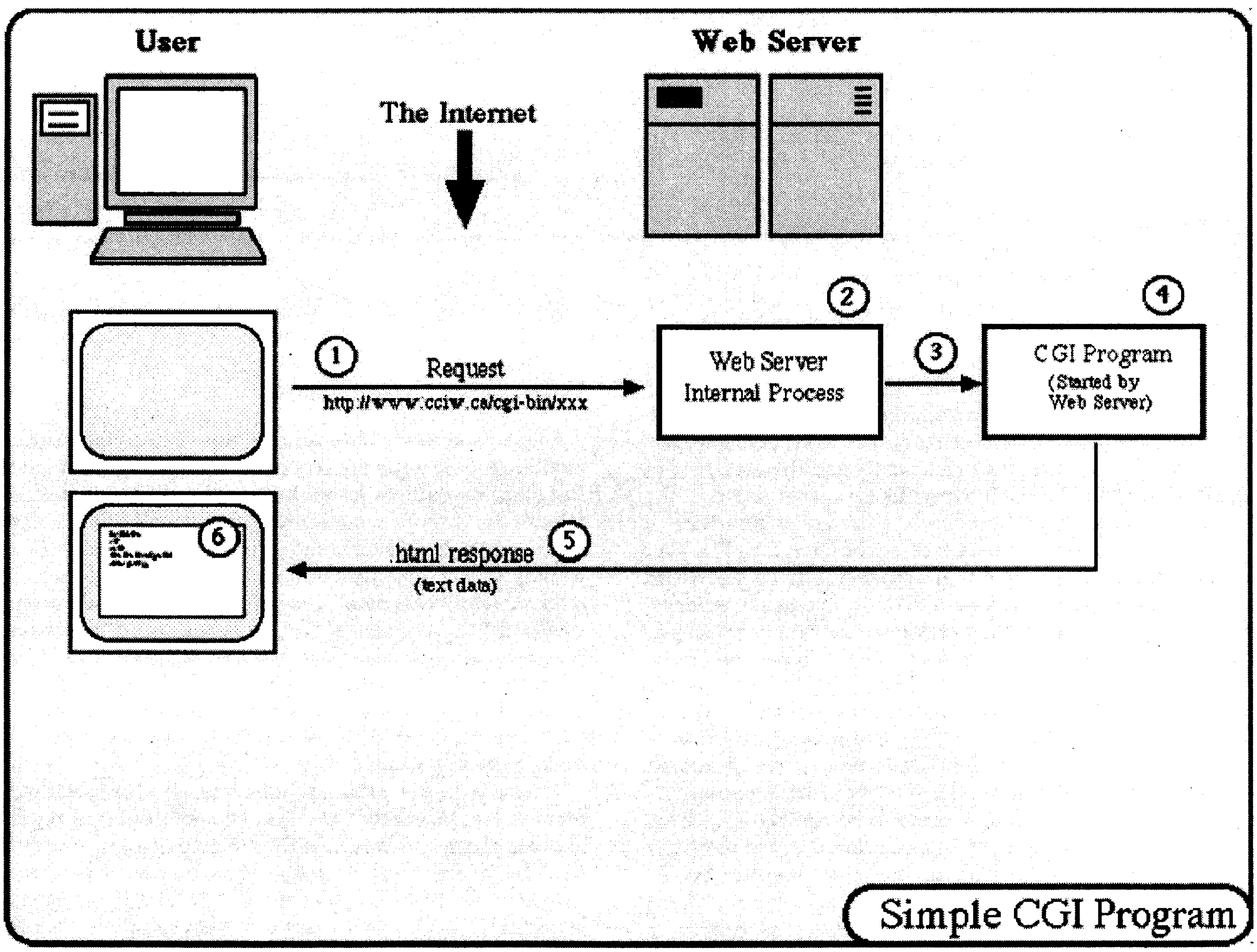


Figure 18.—Simple CGI progam.

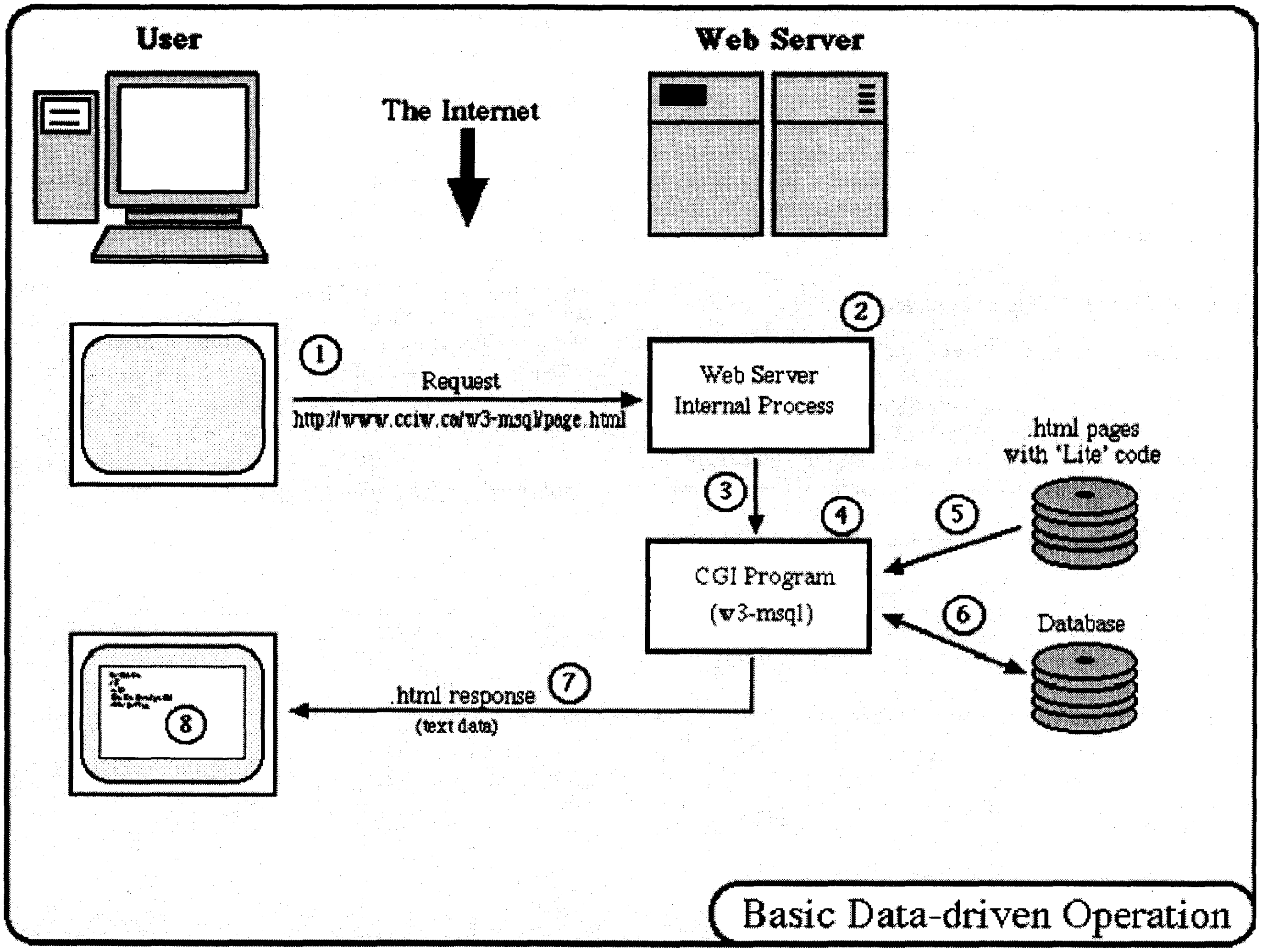


Figure 19.—Basic data-driven operation.

data portions of the EMAN Web Site. As far as the browser is concerned, it functions in a similar way to the "Basic Web Server Operation" described above. In the server, however, the images are generated dynamically and then referred to by CGI-generated HTML hyperlinks.

As all HTTP transactions do, this one begins with a request from a Web browser (see at Figure 20). The Web server determines that a CGI program is to be started to handle the request (, and). The CGI program performs some database operations to retrieve the data necessary to generate the images ( ), then creates an image file on the server disk, using a unique name ( ) which contains the graphical content representing the data. The CGI program then writes HTML text to the channel back to the browser ( ), including a hyperlink referencing the newly created image file. The HTML is rendered to the browser screen ( ), and the hyperlink for the image is recognized ( ). This causes another transaction to be initiated ( ) to fetch the image, and this is satisfied in the usual manner by the internal server process ( ): the image is fetched ( ) and sent back along the channel ( ) to the browser, where it is displayed visible on the client's computer screen ( ).

Form Data Submission

Requests sent to a Web server may be accompanied by auxilliary information to be used in completing the request. Database operations for maintaining a mailing list might require the entry of a name, address and telephone number, for example. The diagram shown in Figure 21 illustrates the process of sending user defined information, commonly referred to as "form data", to a server. HTML defines objects used in the construction of "forms". Some, called "text boxes," provide space on a page for a user to type information using the browser's keyboard. Another object HTML defines is called a "Submit Button." It signals the browser to encapsulate all the information in the text boxes in a request to be sent back to the server computer.

The steps in processing this information begin with the request for an empty form page to be displayed on the browser screen. This is usually a simple operation such as that shown previously in Figure 17. The user is presented with several places to type information, and is expected to provide it by typing on the keyboard. As shown at on the diagram, the user has already completed the 3 fields Name,

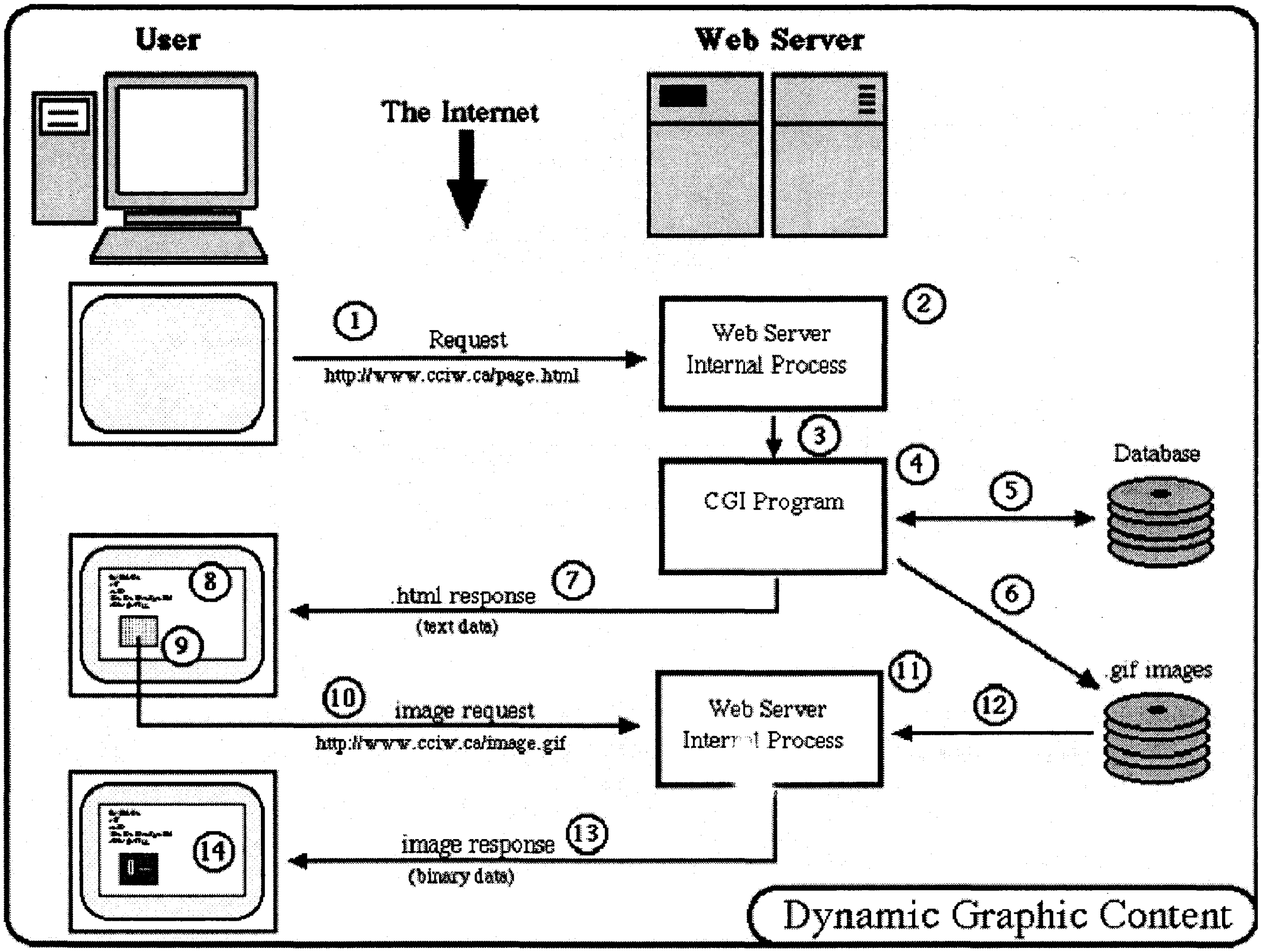


Figure 20.—Dynamic graphic content

Address and Phone. At this point, it is a simple matter of clicking on the oval submit button (here labelled "Update") which begins the process of sending the data to the server. The browser begins by making a connection to the server (http://www.cciw.ca) and requesting the process "/cgi-bin/data-op" be run ( ). The user data is also sent as part of the request: each text box field content is sent preceded by its name and separated by a delimiter. Thus the Name field from the form is transmitted as "name=Joe", while the Address field is sent as "address=123+First" and a "&" character as a delimiter is placed between them. (The space which is present in the address data has been replaced by a "+" sign, and specific others are replaced with other encodings, as certain characters are not allowed in the transmission.)

The Web server receives the request at and causes the requested CGI program to be run ( ). When this program begins, it reads the auxilliary information from the communication channel and saves it in its own storage area. Based on the data sent by the user in the form fields, the program will perform its programmed operations at , perhaps checking for duplications, or that all information is complete, and will then use the information in some database operation ( ). Once the operation is complete, a HTML response is generated, perhaps containing error messages or other results of the operations.

This response is sent to the browser through the communications channel and ends up as a display on the user's screen, signifying the end of the operation.

Note: Not shown on the diagrams are any internal maintenance utilities of the Web server which look after deleting these transient files at some specified future time.

Conclusions

There are many applications for ready available Internet technologies, be it for training, data submission direct to a database, data management, or for reporting information over Websites in real time and formats easily accessible to decision-makers and the general public (i.e. maps, charts).

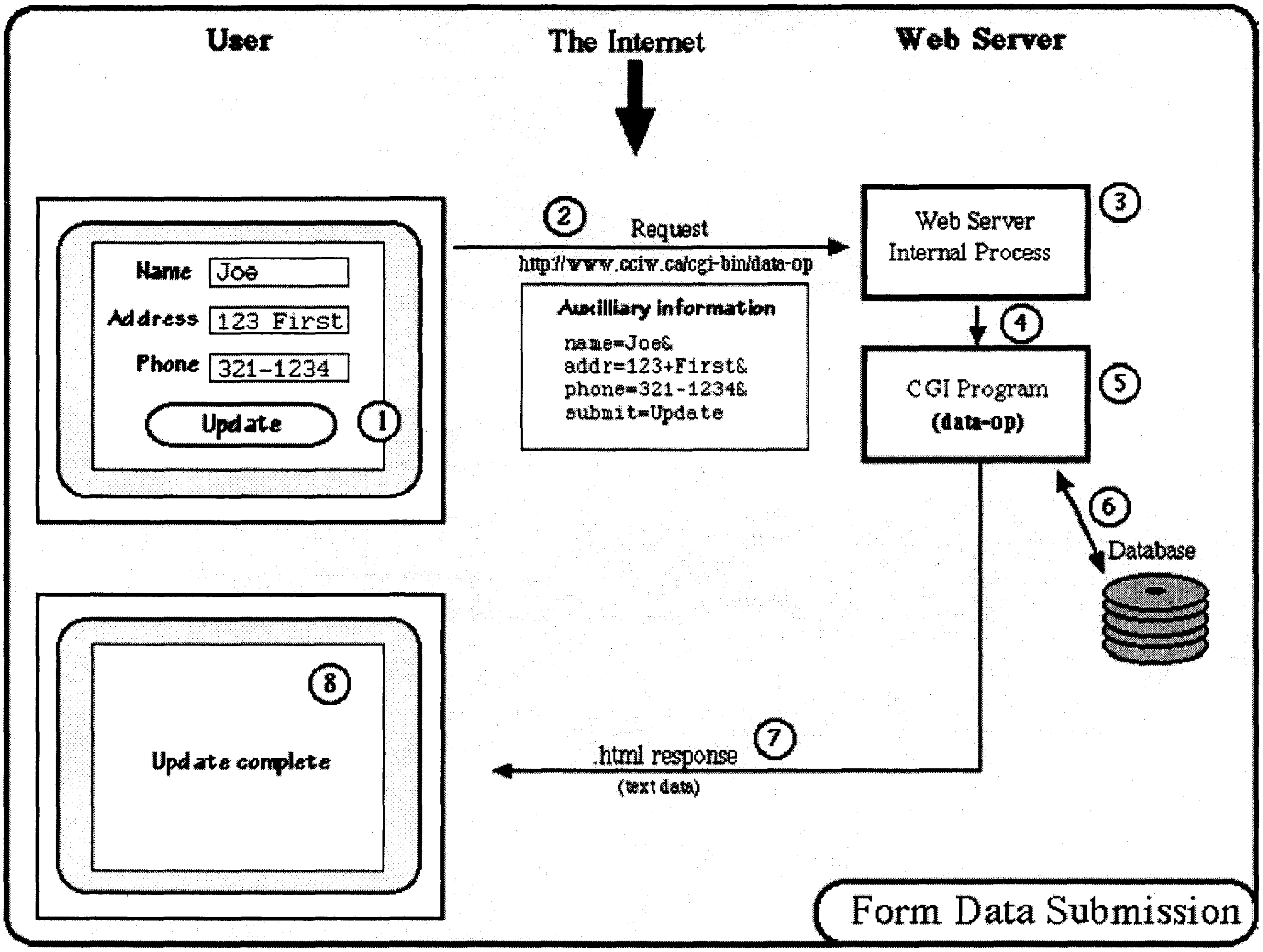


Figure 21.—Form data submission via the website directly into a database.

Forest Health Monitoring Information Management System[1]

Audrey Mac Leod[2]
Harvey Berenberg[3]
Brian Cordova[4]
Susan Hua[5]
Matthew Kinkenon[6]
Chuck Liff[7]

Abstract—The United States Department of Agriculture (USDA) Forest Health Monitoring (FHM) program was established by several Federal and State agencies to monitor, make assessments, and report on the health of the Nation's forest. The FHM program reports on the long-term status, changes, and trends in the health of US forests. The mission of the FHM Information Management System (FHM-IMS) is to produce and maintain a system that supports all FHM activities from field data collection to data distribution. Data are collected in the field using handheld Portable Data recorders. The field data are loaded into an Oracle database. The unique feature of the FHM-IMS is that all data processing takes place in the Oracle database environment. This allows for quick and efficient data processing to meet the goal of providing the users with data of known quality. To meet that goal, the system uses a number of innovative mechanisms including a database model that incorporates the business rules of FHM. Changes to the data are tracked with an automated audit system. The FHM-IMS provides the FHM community and others users with quality FHM data in various formats suitable for scientific analysis. The data are distributed in a number of ways including the World Wide Web.

FHM Indicators

FHM indicators are measurements or groups of measurements. An indicator is defined as any biological and nonbiological component of the environment that quantitatively estimates the condition or change in condition of ecological resources, the magnitude of stress, or the exposure of a biological component to stress. The core FHM indicators are mensuration, crown evaluation, damage, lichen communities, soils, and ozone bioindicator plants.

FHM Data Model

The FHM data model mirrors the business rules of FHM data acquisition and provides enough flexibility so that the data may be stored in the FHM database and used for a variety of studies. The FHM data model has two points of emphasis:

1. The model stores variable plot data annually, but stores permanent plot data only in the year that the plot was established. For example, when a plot is established the tree species codes and diameters at breast height (DBH) are stored. Thereafter, only the DBHs are stored. The FHM database consists of a set of permanent and yearly tables to support this philosophy. This design paradigm accurately mirrors the functionality of a fixed-area plot design and is used in other United States Forest Service (USFS) projects.
2. In support of the FHM common plot and sampling design the model stores data that are common to various projects in a single database and shares it among the projects.

Data Acquisition

FHM field data are collected on a Portable Data Recorder (PDR) running a customized data acquisition program (Tally). Tally uses various configuration files, menus, and display screens to present data and request input from the person collecting the data. The configuration files are defined on a regional basis. They allow the individual FHM regions to make modifications to the National FHM data set and still operate within the framework established by the FHM Information Management. Once data are entered, logic and completion checks are run against the data in real time to ensure data quality.

Data Loading

The field data contained in the Tally data files are loaded into an Oracle Relational Database Management System (RDBMS). The FHM data loading program, Tally cracker, parses the Tally data files and loads the field data into the

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.
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FHM database. Once the data has been loaded into the FHM database, the Tally data files are archived and maintained for historical purposes. The FHM database field data are considered official and used for all further processing.

Tally cracker was designed and built to maximize the use of the standard UNIX tools and to utilize configuration files. This approach has lead to greater system efficiency and cost savings. The configuration files provide flexibility in loading data from various regions and adaptability with respect to annual design changes. Processing the field data wholly within the RDBMS offers greater reliability and efficiency.

Referential Integrity Checks

Referential Integrity (RI) is the process that Oracle uses to enforce the business rules of the database. The business rules are the foreign key constraints placed on table attributes by virtue of their relationship. For example, a business rule is that the condition class for a tree must be in the subplot condition class list. A foreign key constraint would be defined for the attribute condition class in the tree table referencing the attribute condition class in the subplot condition class table. If there are condition class data that violate the RI check, the foreign key constraint, then RI will not be enabled for that constraint and the offending data will be placed in error tables.

The FHM-IMS utilizes the built-in features of the Oracle product to implement the RI checks. Prior to loading the field data, RI is disabled, which insures that all the field data are loaded into the FHM database. Once the data are loaded, the RI checks are enabled. If there are data that violate an RI check, the constraint will not be enabled and the offending data will be inserted into error tables. A report generation program queries the error tables and produces a file containing the RI errors. This file is sent to the appropriate regional lead for correction. The corrections are returned to the FHM-IMS staff, entered into the database, and the RI check process is repeated until all RI errors have been resolved.

The mechanisms used by the FHM-IMS RI check process provide an efficient and flexible means of adding, modifying, and deleting relationships without having to modify customized software.

SQL Logic Checks

Approximately four hundred (400) data checks were of sufficient complexity that they required the development of a validation system. An example of this type of check is: Saplings must have a diameter at breast height (DBH) between 1 and 4.9 inches. The approach taken to implement these checks was to develop a set of queries and error tables within the FHM database. Each logic check was categorized, given a unique number within its category, coded as a SQL query, and stored in the FHM database SQL check table. This approach allows new logic checks to be developed quickly and efficiently. And since each check is a self-contained item, concerns about the second order affects of changing an individual check are eliminated. Prior to being stored in the SQL check table the SQL query is transformed into an SQL insert statement. When executed this statement places data that violates the logic check into the appropriate error table. The SQL check error tables are the boundary, condition class, plot, point, seedling, site tree, and tree error tables.

The FHM-IMS SQL check process executes each of the checks in the SQL check table, then queries the SQL check error tables and produces the error reports. These reports are ASCII files in a predefined format suitable for editing. The regional leads correct the erroneous data. The corrected error reports are then processed, that is, data that was changed are loaded into the appropriate SQL check error table. The corrected data are stored in the same row as the original data. This allows a single query to identify both the original and corrected data associated with a given check. The SQL check error tables also provide an audit trail for tracking data errors. Once the corrections have been loaded, the SQL check process queries the error tables and updates the actual FHM database table rows. This process is repeated until all data errors are resolved.

Value Added Processing

Additional checks that could not be adequately handled using the SQL check process have been grouped together in a process referred to as outside checks. The FHM plot design is a fixed pattern containing four subplots. Some plots have more than one land use, forest type, stand origin, stand size or past disturbance resulting in different condition classes being mapped on subplots by the crews. Errors can sometimes arise due to improper coding of condition classes by field crews. For example, a crew may record missed trees in a previous condition class that was in a non forested condition or that was in a condition class not on the subplot. Another example would be a crew entering more than one condition class on a plot that differs only by the stand age (less than 50 years). And as a final example, a crew changing the previous DBH, DRC, or site tree DBH that was downloaded to the PDR from the previous survey. A report is produced for each of these potential errors and the regional leads make a determination if a change is required to the database. This process is contained in an easy to follow three step process: (1) Determine the error, (2) decide what change to make and, (3) update the database.

Special value-added processes are contained in a program called PNSN (Program Needing Snappy Name). The following is a list of some of the functions of PNSN: Identifying sapling outgrowth, providing pointers for plot entrance year, plot exit year, previous visit year, previous tally year and condition class year, assigning tree numbers for missed and extra trees, shrunken trees, and creating multiple plot numbers. The design of the database allows for multiple "layers" of data. The main layer of the database is the detection monitoring data. The database can handle additional layers such as quality assurance, pilot studies or special projects. PNSN provides a method for separating the data for easier access by the user community. Additionally, PNSN allows the analyst an easier means of tracking the progression of a tree from entrance to exit in the database.

The FHM-IMS needs to handle infrequently occurring situations, but important nevertheless. For example, there is a process in the FHM_IMS that handles the situation where a tree is tallied as a living tree during one visit, dead during a subsequent visit and then living again during the current visit. It is appropriately called the zombie process. The zombie process is driven by the business rules and accordingly handles each occurrence in exactly the same predictable way.

The FHM-IMS also contains processes that derive additional data from the field data and then store it in the database. Calculating the percent of area for each condition class on a plot is one of those processes. This process would take too long to run in realtime and therefore is run only once after the data are loaded. It can then be accessed by the same means as the field data for use in further analysis. This fulfills the requirement that the percent of area data can be used for area expansion in the map plot design.

View-Like Units (VLU) Creation

For most users the relational database and relational technology can be confusing. The design of the database lays out like a London Subway map, with data contained in several tables. In this form the data is not very useful to the end user. The information management group has created several tables based on what the user community has determined most useful for data analysis. The tables that are most useful for the user community are the PLOT_VIEW, POINT_VIEW, CONDITION_CLASS_VIEW, and TREE_VIEW. The TREE_VIEW was essentially designed to be one stop shopping for the end user. It contains plot, point, condition class and tree level information. These VLU's have been constructed in method that allows quick access to the data in the database.

FHM-IMS Audit System

The FHM-IMS audit system uses the built-in features of the database to track changes to the database after the data have been verified. FHM data are not static and the audit system provides a means of auditing data changes.

Data Distribution

Creating easy to understand and useful tables, tailor made for the end user, are only part of the task. The FHM-IMS needs to provide access to the data as well as providing the data to the end-user in a usable format. The Oracle Data Browser is a tool that is available to the user and allows the user to graphically view the data contained in the VLU's. The end user can connect to the database and point and click the attributes they require. The Oracle database can be reached across the network as easily as if the database was sitting on their desk. For those users who do not have access to the Internet the FHM-IM staff provides the data to the user community in SAS data sets. The SAS data sets mirror the original VLU tables. The data sets are compressed and available through FTP or direct mail. In some cases the data can be output to ASCII comma delimited files. This allows the data to be read into another format most comfortable for the end user.

Conclusions

The FHM-IMS provides a flexible, efficient, portable, and scalable system for loading, verifying, maintaining, and distributing a change history of forestry data taken on a permanent plot network. The FHM database design is robust enough to handle data for many studies, allowing data to be shared among studies where appropriate. The paradigm of only storing certain "permanent" data one time in the FHM database has improved consistency and given analyst higher quality data. The Tally cracker program allows configuration files to be updated on a yearly basis, and has eliminated the need for special programming to load data files. The general approach taken by FHM Information Management in solving the data verification problem has allowed the system to be extremely flexible and portable. It has also cut down on programming maintenance because all logic checks are SQL queries and these are simple to construct. The FHM-IMS has addressed the needs of the user community by presenting data to the user in a variety of formats. The use of the FHM-IMS has increased the quality of the data presented to the user community. It has also provided a flexible framework to allow data to be processed efficiently even when design changes take place within the FHM sampling system.

Forest Health Assessment: Science to Policy Link—an Interesting Challenge[1]

Harry Hirvonen[2]

Abstract—The Canadian Forest Service has recently completed a national health assessment of Canada's major forests. This assessment is a major departure from historical reporting on forest health within Canada. A broad definition of forest health is used which includes impacts on forest ecosystems from air pollution, land use activities as well as endemic influences such as insects and drought. The national ecological classification of Canada is used as the reporting framework. The combination of an ecological reporting framework, a broad definition of forest health, the need to link science with policy questions and the need to report in a concise, nontechnical manner created interesting challenges to the completion of the Assessment. Some of these challenges were science-based, some were philosophical and others were institutional.

Canada is a forest nation with 45% of the country's landscape being forested. Canadians are stewards of 10% of the world's forests. These forest ecosystems form much of the ecological backbone of the country. They are a source of recreation, of inspiration, and of wealth to a large number of Canadians. Forests are essential in providing habitat, food and shelter to wildlife. Our forests are home to 140,000 wildlife species. The nation is also the world's largest exporter of forest products, contributing $32 billion to the country's balance of trade and providing 840,000 jobs to Canadians (Natural Resources Canada 1998). Without sustained healthy forests, Canada would be devastated environmentally, culturally, and economically.

To maintain healthy forests, we have to understand how they function, their ecological interactions at various spatial scales and how these interactions are influenced by human intervention. We must draw on our collective scientific research and monitoring results and initiatives to determine what is happening, how it is occurring and why is it taking place.

This synthesis and assessment of forest health is not an exacting science. Information is often drawn from disparate sources and is of varying rigour and quality. There are very few straightforward cause and effect relations. In fact, in the literature, there are often, divergent conclusions based on a similar data, reflecting the various interpretations placed on the source data.

In the end, the assessment, with its inevitable imperfections must be communicated to Canadians in a credible, clear and concise manner. Otherwise, all the science and research behind the assessment is essentially for nought. Translation from science jargon to everyday language is always an interesting exercise. To put it mildly, determination of forest health is not straightforward.

In 1997, the Forest Health Network, one of the ten Science and Technology Networks of the Canadian Forest Service, undertook this challenge with the view to publish, by the end of 1998, Canada's first national Forest Health Assessment. This Assessment is one of a family of products to be produced that communicates to various audiences, from the scientist to the school pupil, the status and change in the health of Canadian forests (Forest Health Network 1998). This paper focuses on the process and hurdles associated with producing this assessment.

What Does Forest Health Really Mean?

In tracking and reporting on forest health, the first hurdle to overcome is the understanding of what forest health means. This term continues to be freely tossed around the global forest sector as if its meaning is intuitive to all. It may be intuitive, but it is also hard to pin down. Existing views may differ widely (McLaughlin and Percy 1998; O'Laughlin et al. 1994). As examples, if one's primary purpose is timber production, forest health is an issue about dying or threatened trees, most often illustrated through management activities aimed at reducing insect and disease infestations. For wildlife specialists, it is largely about forest habitat, its availability and condition. Other perspectives may incorporate aesthetic, recreational or spiritual values to define forest health. These perspectives have value and validity, as long the limited focus is understood.

Because of these varying concepts of forest health, efforts to define it are largely meaningless. The Canadian Council of Forest Ministers states that the Canadian forest sector, collectively, has the obligation to "maintain and enhance the long-term health of forest ecosystems for the benefit of all living things both nationally and globally while providing environmental, economic and social and cultural opportunities for the benefit of present and future generations." (Canadian Council of Forest Ministers 1998). This is a classic motherhood statement that sounds nice but really offers no direction. What it does imply is that forest health must be considered in a holistic sense considering all values of the forest ecosystem. The emphasis is on the forest ecosystem and not on any one element.

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In this broad ecological context, we may view a healthy forest as *one that maintains the qualities that society values including biodiversity, resiliency, wildlife habitat, aesthetic appeal and resource sustainability.* (Forest Health Network 1998). Inherent in this perspective is a spatial connotation. Forest health is not viewed as a single tree issue or even a stand issue, but in a regional context. Certainly, if one's favourite urban tree is showing signs of decline, it may be very important; or, if a highly valued commercial plantation is ravaged by insects, it is an immediate concern. But stand health and single tree health are different from forest ecosystem health. The former are not really sustainability issues. Ecosystem "Sustainability" is both a long-term and regional concept. One must think not of species alone but of ecological cycles, interactions among ecosystems and changing dynamics over time.

Forest health is also all about measuring, tracking and reporting on impacts on forest ecosystems from stressors. Stress, simply put, is an unusual load on the ecosystem. It may stem from natural factors such as drought or indigenous insects or from human-induced factors such as air pollution or land use. Normally, forest ecosystems are adapted to frequently occurring climatic and endemic biotic events and may even rely on these events to perpetuate themselves. Extreme natural events may result in irreversible harm to desirable forests, but our ability to foresee and mitigate these events is minimal.

Human-induced stressors on forest ecosystems we can influence, alter and mitigate. Thus, this assessment concentrates on interactions between forest ecosystems and human influences. Such influences include air pollution, introduction of non-native species, and land use activities, including forest management. Resultant effects may be beneficial, negligible or harmful to the ecosystem. Impacts may occur directly on forest species, or indirectly through impacts on ecological processes such as nutrient cycling. They may alter life cycles of native insect and disease populations (Fleming and Volney 1995) or predispose ecosystems to decline from natural influences of wind, drought and other climatic elements. What we are really striving for is to identify and document changes to forest health due to anthropogenic stress from those changes attributable to inherent natural variation.

Forest Health Assessment: How We Went About It

The Conundrum

Under ideal assessment conditions, we would:

1) be able to discern changes in forest ecosystems caused by human interference from the natural ecological variability inherent in these systems.
ii have a clear mental and measurable image, of a healthy forest; in essence a benchmark by which to measure forest health.

Unfortunately, basic information or agreement on these conditions does not exist. Yet, strong pressure to assess the health of our forests is continuous from both the public and the decision-makers who must answer to this public. We are forced to carry out these assessments without a true understanding of what a healthy forest ecosystem consists of in terms of measurable parameters. Without a baseline, the answer to the question: are things better or worse? is unclear. The assessment process, necessarily becomes more qualitative and often more intuitive then we would like. The synthesis tests the interpretive and comfort limits of scientists, who by nature, tend to be conservative and cautious with unproven cause/effect relationships.

Policy analysts and decision-makers however, have immediate questions to answer from both the public and their political masters. Available science-based conclusions and results serve to provide direction as much as possible. Yet, the immediacy of the issue extends the meaning of "science-based" for these decision-makers. And perhaps rightly so, Our frontline people with the public do not have the luxury of waiting for incontrovertible proof of cause and effect. They do their best with what they have. We, as scientists, must actively participate in this "interpretive" process. If we collectively, as forest scientists, are not willing to make the link between science and policy, others, with their own agendas will do it for us.

Basic Principles

Three underlying principles served to direct our forest health assessment:

- We must think, plan and act in terms of ecosystems. Political and other jurisdictional boundaries are not conducive to the assessment of any ecosystem as ecological interactions and relationships inevitably transcend these boundaries.
- Natural disturbances or influences on forest ecosystems such as wildfire, native insects and diseases, and climatic events are essential to the health of forest ecosystems. They are the drivers of ecological sustainability.
- Human activities impact on forest processes and ecological functions; some activities are benign, others could be devastating. Forest ecosystems considered as being minimally influenced by human activity are generally viewed as healthy.

Our Approach

In the development of this assessment, it was necessary to define clearly what we meant by an "assessment." The term 'science assessment,' has become almost meaningless because of its ubiquitous attachment to a multiplicity of studies. It has been used for literature reviews, status reports and for comprehensive encyclopedias about given topic areas.

Our task was to focus the exercise, to set out some guiding principles. The primary purpose was to communicate to an interested public the status and concerns regarding the health of Canada's major forest ecosystems. This clear, directed purpose meant that the language of the final report had to be nontechnical. In doing this, it also had to:

- provide an ecologically-based, concise synthesis of published results for a forest health issue of concern;
- be effects-oriented addressing what is happening, why it is happening and how it is happening; and

- provide the link between science and policy. Policy is driven by public priorities and concerns. Issues high on the public agenda must become high on the agenda of the scientific community and addressed by that community.

The 1998 national forest health assessment, in putting theory to practice:

- *used the national ecological framework of Canada for reporting purposes*: This ecological framework delineates the country into 15 ecological zones (ecozones) and hierarchical subdivisions (Ecological Stratification Working Group 1996). Nine of these ecozones have a substantial forest component. These nine ecozones served as the reporting framework for our national forest health assessment. Arbitrary, ecologically inappropriate, jurisdictional boundaries were ignored. This approach also emphasized the diversity of Canadian forests. Canadian forests are a mosaic of many forest ecosystem. The ecological framework points out the absurdity of discussing Canadian forests as a single entity.
- *concentrated on effects*: Methodologies, status, philosophy, and general musings were left for other venues of communication and for other audiences. The authors were to provide the key messages with just enough dialogue around these messages to set the context.
- *was issue oriented*. Issues such as, harvest of old growth, increase in plantations, biodiversity and acid rain are at the fore in the minds of the public. We had to address these and other forest health issues although our information base may have been limited. Ignoring discussion of these issues was not an option. If the assessment did not address these issues, at least in a cursory manner, the entire assessment would be suspect to a large segment of the public.
- *linked with monitoring and indicators*, to the degree possible. The forest health assessment is all about tracking change over time and determination of the ecological impacts of any such change. This assessment considered, as general reference, the four ecological criteria of the initiative to develop Canadian Criteria and Indicators of sustainable forest management: conserving biological diversity, ecosystem condition and productivity, conserving soil and water resources and global ecological cycles (Canadian Council of Forest Ministers 1997).
- *relied on partnerships*. Forest health is an issue that transcends the Canadian Forest Service. Except for the Territories, provincial agencies and private landowners, after all, are the land managers of most of Canada's forests. As well, several federal agencies have regulatory and general interest in our forest ecosystems. The breadth and depth of issues involve research and monitoring initiatives of all these organizations. Only through partnerships, can a national assessment of forest health be carried out.
- *used nontechnical language*. The intended audience includes both those involved with policy and the general public. The use of science jargon has limited communicative value with these groups. No matter how good the message, if we cannot communicate it effectively, we have no message.
- *had a limited target length of pages*. This focuses the discussion, eliminates filler and forces the contributors to stick to their key messages.

Regional Issue-Based

I do acknowledge that an issue perspective limits the opportunity to present forest health as a holistic concept. Important ecological interactions and impacts may be missed. Yet, the decision to proceed in this manner relates to one of communication. Despite inherent constraints, I feel that, through an issues approach, the Assessment becomes manageable and responds directly to both policy and public issues and concerns. The use of ecozones as a reporting framework allows for application of the ecological perspective to the synthesis. The use of the common headings of "changing atmospheric conditions," "changing landscape conditions," and "changing biodiversity" allows for national consistency, yet regional flexibility.

Changing atmospheric conditions—Topic areas include effects from potential climate change, acid rain, tropospheric ozone (smog), and ultraviolet radiation. A major gap exists in that no information is available on the effects of toxic chemicals on forest ecosystems. The CFS, itself, does not have an active research program in this issue area. Effects from acid rain are drawn from the recently released report by the Canadian Forest Service '*Effects of Acidic Deposition on Canada's Forests*' (Hall et al. 1998). Discussion on potential effects from ultraviolet radiation is based on the Canadian forest sector contribution to the report *Ozone Science- A Canadian Perspective on the Changing Ozone Layer* released as part of the 10th Anniversary meetings of the Montreal Protocol on Ozone-depleting Substances held in Montreal in the Fall of 1997 (Wardle et al. 1997).

Changing landscape conditions—Factors influencing changing landscape conditions include, harvesting regimes, regeneration after harvesting, fire and insect and disease infestations. For the latter, data are limited on human influence on cycles and intensity of infestation. Discussion focuses on impacts on commercial forest tree species. Fire is a major ecological factor in the evolution of Canadian forests. Data are sparse however, on fire severity and the ecological impacts of fire suppression. Key references include the 1996/1997 national State of the Forests Report produced by CFS, the forest health monitoring database of CFS, the National Forestry Database of the Canadian Council of Forest Ministers and CFS Information Reports on the nature and extent of insect and disease infestations.

Changing biodiversity—Indicators of biodiversity change include protected areas (area, but not representatively was available, which remains a major gap in information needed), threatened species and ecosystems and exotic or non-native species. Exotic species are of particular interest in assessing the health of Canadian Forests. They are generally aggressive, lacking natural enemies and may replace or reduce indigenous species within the forest. Certain species cause severe economic harm as they attack and kill or reduce the vigour of commercial forest species.

Plantations, old growth and rare forest ecosystems were discussed as to their overall implications to forest health of specific ecozones.

The Obstacles

We have an acceptable concept of forest health. We can visualize what a forest health assessment is all about. On the surface, it seemed like a relatively straightforward task of carrying it out. It was not. The hurdles were many, some institutional and others practical, most of which resulted in interesting, if not frustrating, bumps along the way. The key ones included:

Monitoring ecological change for forest ecosystems—There is no capability in Canada to measure status and change over time within our forest ecosystems. Without an understanding of change, how can we determine natural fluctuation from a human-induced one? There is no valid basis for determination of whether things are getting better or worse. The lack of ecological monitoring data severely tested the interpretive limits of the assessment.

Ecological framework—We must think, plan and act in terms of ecosystems. The problem is that much of the available background data, reports and related infrastructure is linked to institutional rather than ecological boundaries. This fact caused, and continues to cause, problems in the synthesis of forest health by ecozone.

The compulsion to generalize—One hears on a regular basis that the forests of Canada are generally healthy. This statement may be true, but it is also meaningless. It ignores, albeit unintentionally, the diversity and mosaic of forest ecosystems that characterize our nation. We are not one forest, but many forests. Each has its own physical and biological characteristics and stressors with varying degrees of impact. Yet, ecological generalities relating to 'healthy forests' pervade our literature. These generalizations serve little else but to unobtrusive background, a sort of "ecological muzak."

This demand to generalize is fed, in part, by international sources requesting the state, condition and health of Canada's forests. Such requests inevitably seek an overall statement for the country. We must resist this; Canada is not a small country. We have ecoregions, the fine subdivisions of ecozones that are larger than many European countries (Ecological Stratification Working Group 1996).

It is also fed, in part, by politicians and others who seek simplistic answers to complicated questions. Determination of forest health is not a mathematical problem having a yes or no answer. The country is too diverse for a national index or statement on forest health. We should not continue promulgate Canada as one large relatively homogenous forest.

Striving for the bottom line: Historically, ecological scientists have been reluctant to deliver results clearly. Oftentimes, more effort is put on caveats than results. We are the masters of the waffle. How do we become more proactive without sacrificing ecological integrity. More is required of risk modeling, of interpretation of results and of transmitting our collective experience. We must be willing to test the limits of quantitative evidence, contribute our professional judgement to the ecological debate and, dare I say it, make the best of qualitative evidence. Still, the issue of scientific rigour is one that the assessment was continually addressing.

Communication—We must communicate results of research and monitoring in a meaningful manner to the intended audience, which inevitably is the interested public. This task is part translation of scientific English and French to normal English and French and part the art of communication. The way I look at much of the forest research that we do is that, if in the end, the value and results of this research cannot be communicated in a manner that my seventeen year old daughter understands then that research is of questionable value. The assessment is based on science but, in fact, has a healthy dose of art attached to it to facilitate communication.

The Major Gaps

Currently there is no capability in place in Canada to measure ecological change over time. There is an urgent need for a national ecological monitoring program. Without this CFS, and its provincial partners, cannot meet requirements imposed by Canadian Council of Forest Ministers to measure and tract ecological criteria and indicators of sustainable forest management. Neither can we meet our obligations for international reporting as required under the criteria and indicators of the Montreal Process for sustainable forest management within temperate and boreal countries.

Canada lacks any field studies or monitoring programs to assess regional or nationwide risks of the nation's forests to tropospheric ozone and UV-B. Research has shown that several Canadian tree species are sensitive to UV-B episodes (Percy and Cameron 1997). As well, lakes and wetlands and associated wildlife within our forests have been adversely impacted by high levels of UV-B or through the accumulative affect of UV-B with acid rain (Schindler et al. 1996).

Research into the risk that toxic chemicals and heavy metals may impose to Canadian forest wildlife and ecosystems is very limited. Lack of published information prevent an assessment of these pollutants on Canadian forest ecosystems.

Very little information exists on what one may consider as the inherent biodiversity and ecological functions associated with what are considered as "healthy forest ecosystems." We need to define and establish such baseline data from which we could assess "change." We need to know whether our management activities are helping or hindering our progress towards ecological sustainability.

Summary

Determination of the health of Canadian forests is not an exact science. The definition of 'health' is more qualitative than quantitative. Rarely, will we be able to satisfy ourselves of direct human-induced cause and ecological effect. Risk and uncertainty will remain as constants in forest health assessment.

Currently, the state of nationwide forest health monitoring, and ecological monitoring in general, is inadequate for determination of ecosystem change over time. A national ecological monitoring program involving forest and non-forest land is a prerequisite to meet our national and international obligations on measuring and reporting progress towards sustainable development.

Despite lack of consistent trend information for national reporting purposes, the status of the health of our forests, and predictions for the future are essential, and, in fact, demanded by public and decision-makers. This fact puts scientists in a dilemma. It forces science to its interpretive limit relying often on qualitative information and sketchy statistical validity for many issues of forest health. Yet, advice and interpretations must be provided even if based on less than solid evidence. Decisions will be made whether or not appropriate supporting information and advice are available.

The initial conclusions presented in this paper serve to reflect the interdisciplinary nature of any science assessment even if it has a specific focus such as forest health. With diminishing funds and the complex nature of many of our environmental stressors, interdisciplinary and cooperative research and monitoring among provincial federal, industrial and university groups is essential.

Interdisciplinary science is one requirement, communication of results is another. If we, as scientists, cannot communicate our results and concerns in a manner that the public and decision-makers understand, our work is futile and exposed to cutbacks. Communication involves a couple of prerequisites. Firstly, we must relate information and advice in a manner and language understandable by our intended audience. The forest health program of the CFS is developing a family of products to reach a wide variety of audiences from peers to children. We are good at communicating with our peers, not so good with others. Remember, it is most often the "others" that determine our research and operating budgets.

Basic and long-term research are both essential. What is needed is a continuing profile from existing research and monitoring initiatives that address the short-term policy and public concerns. If properly carried out, long-term research would be buffered from constant scrutiny. We must remember that the synthesis and reporting of results from ecological research and monitoring to a broad audience is part science and part art and it is often the art portion that allows the science to continue.

Literature Citations

Canadian Council of Forest Ministers 1998. Sustainable Forests - Canadian Commitment.

Canadian Council of Forest Ministers 1997. Criteria and Indicators of Sustainable Forest Management in Canada - Technical Report 1997. Natural resources Canada, Canadian Forest Service, Ottawa, Canada. 137 p.

Canadian Forest Service 1995. Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests: The Montreal Process. Pamphlet. Natural Resources Canada, Ottawa. 27 p.

Ecological Stratification Working Group. 1996. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Centre for Land and Biological Resources Research, Research Branch; and Environment Canada, Environment Conservation Service, State of the Environment Directorate. Ottawa. 125 p. + map.

Fleming, R.A.; Volney, W.J.A. 1995. Effects of climate change on insect defoliator population processes in Canada's boreal forest: some plausible scenarios. Water, Air, and Soil Pollution 82: 445-454.

Forest Health Network 1998. A Health Assessment of Canada's Forests - 1998. Natural Resources Canada, Canadian Forest Service, Information Report. *In press*.

Hall, P.; Bowers, W.; Hirvonen, H.; Hogan, G.; Foster, N.; Morrison, I.; Percy, K.; Cox, R.; and Arp, P. 1998. Effects of acidic deposition on Canada's forests. Natural Resources Canada. Canadian Forest Service. Ottawa, Ontario. 23 p.

McLaughlin, S; Percy, K. 1998. Forest health in North America: some perspectives on actual and potential roles of climate and air pollution. J. Air, Water and Soil Pollut. *In press*.

Natural Resources Canada 1998. The State of Canada's Forests: The People's Forests 1997-1998. Canadian Forest Service, Ottawa, Canada 108 p.

O'Laughlin, J.; Livingston, R.L.; Thier, R.; Thornton, J.; Toweill, D.; Morelan, L. 1994. Defining and measuring forest health. J. Sustainable Forestry. 2:1/2, 65-85.

Percy, K; Cameron, S. 1997. Chapter 5: Forests *In:* Wardle, D.J.; Kerr, J.B.; McElroy, C.T.; Francis, D.R. 1997. Ozone science: A Canadian perspective on the changing ozone layer. Environment Canada, Downsview, Ontario, Canada. Pages 97-100.

Schindler, D.W.; Curtis, P.J.; Parker, B.R.; Stainton, M.P. 1996. Consequences of climate warming and lake acidification for UV-B penetration in North American boreal lakes. Nature, 379:705-708.

Wardle, D.J.; Kerr, J.B.; McElroy, C.T.; Francis, D.R. 1997. Ozone science: A Canadian perspective on the changing ozone layer. Environment Canada, Downsview, Ontario, Canada 119 p.

An Effective and Efficient Assessment Process[1]

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Abstract—Depending on the agency, discipline, or audience, assessments supply data and information to address relevant policy questions and to help make decisions. If properly executed, assessment processes can draw conclusions and make recommendations on how to manage natural resources. Assessments, especially large ones, can be easily influenced by internal and external forces. Completing a design prior to collecting data is the most efficient and logical way of conducting assessments. The most important step in the assessment process is to define the assessment problems or questions that address resource management issues. Questions that address well defined issues set goals for the remainder of the assessment process.

Delineation of assessment and ecosystem boundaries should be based on the questions, agency needs, and the biophysical, economic, and social attributes of the areas of concern. Collecting data prior to developing an assessment design leads to inefficiencies and redundancies and wastes time, money, and people. Moreover, often the data collected does not provide the information for making inferences at the scale appropriate to address the questions. Foremost, the assessment process should be designed and driven by the issues. This approach ensures that data, data resolution, and data analysis are all tailored to addressing the right question using the right temporal and spatial scales.

Depending on the agency, discipline, or audience, assessments supply data and information to address relevant policy questions and to help make decisions (Streets 1989; Thorton et al. 1994). Data collected in assessments estimate, measure, appraise, rate, characterize, or describe various resource conditions. If properly executed, assessment processes can draw conclusions and make recommendations on how to manage natural resources (Deuel and D'Aloia 1995). Assessments range from those required by the Resources Planning Act (national), to describing stand conditions (site) prior to applying treatments (Forest and Rangeland Renewable Resources Planning Act 1974; Daniel et al. 1979). Assessments have always been an integral part of natural resource management.

The rationale for conducting assessments varies. Some assessments are directed by law or regulation while others answer a specific research question (National Environmental Policy Act 1969; National Research Council 1990). Addressing issues or concerns about land use is a common reason for completing an ecological assessment (Zonneveld 1988). Changes in ecological conditions also indicate need for an assessment (Noss and Cooperrider 1994). The latter two reasons are in particular, fundamental to most adaptive management models used in managing natural resources (Holling 1978; McGinty 1995). These models usually contain a minimum of four components: monitoring, assessments, decisions, and implementation (Holling 1978; McGinty 1995; Haynes et al. 1996).

Ecosystems

An ecosystem, which is a human construct, can be defined as: "communities of organisms working together with their environments as integrated units. They are places where all plants, animals, soils, waters, climate, people, and processes of life interact as a whole. The smaller ecosystems are subsets of the larger ecosystems; that is, a pond is a subset of a watershed, which is a subset of a landscape, and so forth. All ecosystems have flows of things-organisms, energy, water, air, nutrients-moving among them. And all ecosystems change over space and time (Thomas 1956; Burgess and Sharpe 1981; Shugart 1984; Waring and Schlesinger 1985; Botkin 1990; Kimmins 1992). Therefore, it is not possible to draw a line around an ecosystem and mandate that it stay the same or stay in place for all time" (Salwasser et al. 1993).

Managing ecosystems means manipulating and understanding their processes, and their structural, and functional components. These components are evaluated during the assessment process. Structures are the patterns of association (vertical, horizontal, or temporal) among ecosystem elements. For example, structures might include plant species composition, forest fragmentation, or road density. Processes are the actions that link organisms (including humans) and their environment (Lindeman 1942; Aber and Melillo 1991; Noss and Cooperrider 1994). Examples include successional development, nutrient cycling, carbon sequestration, decomposition, and photosynthesis. Functions are the specific role or activity of an ecosystem element. For example, fire functions as a rapid decomposer of organic material and erosion moves soil surface materials (Hunt 1972; Agee 1993; Sala and Rubio 1994).

Ecosystems and their processes, structures, and functions are all defined by the observer (Rosen 1975; Pattee 1978), who needs to understand several principles on ecosystems' organization and how they interact with each other. These principles include understanding that ecosystems: change over time; can be viewed as having multiple organizational levels; have economic, social, and biophysical limits; and have limited predictably.

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Ecosystems are Dynamic

Ecosystems change; and develop along many pathways (O'Neill et al. 1986, Urban et al. 1987). They are the products of their history (Barret et al. 1991). They can be stable in the sense that when disturbed they tend to return to some constant state, or they can be cyclic such that the steady state is always changing within some definable bounds. Fires, volcanic eruptions, floods, and wind events along with people setting fires, clearing land, and introducing new (exotic) species are sources of ecosystem disturbance (Agee 1994; Robbins and Wolf 1994). Within limits, forest and grassland ecosystems are generally resilient to a variety of disturbances (Hilborn and Walters 1992). Past management decisions, combined with natural environmental disturbances and conditions, limit future management options (O'Laughlin et al. 1993; Maser 1994). And just as past disturbances and actions of past human generations shaped the ecosystems of today, actions of this generation will define ecosystems of the future.

Ecosystems can be Viewed Hierarchically

Defining ecosystems with multiple organizational levels varying over time and space is useful. These levels can be organized within a hierarchy, in which every level has discrete ecological functions but at the same time is part of a larger whole (Koestler 1967; Allen and Starr 1982; Allen et al. 1984,). Higher levels usually occupy larger areas and are usually characterized by longer time frames (Delcourt and Delcourt 1988; King et al. 1990).

In landscape ecology, hierarchy theory allows for the definition of ecosystems and the linkages between the different levels of ecological organization. In a vegetation hierarchy, trees are nested within forests, forests nested within series, and series nested within formations. Many environmental constraints, vegetative patterns, human behavior, and disturbance processes can be described for each level, time frame, and area (Pickett et al. 1989; Robbins and Wolf 1994). Spatial extent can range from a few square meters to hundreds of kilometers, and time frames can range from less than a year to thousands or millions of years.

Human hierarchies may also be defined temporally and spatially. Societies can be described along organizational or institutional continua (Haynes et al. 1996). However, organizational levels, time frames, and spatial extents that are significant to human decision making often do not correspond to the same time and spatial hierarchies of biophysical systems. For example, ecosystem processes (such as soil formation) that occur over long time frames (centuries or millennia) hold little meaning for political processes that operate biennially. In addition, because people respond to environments symbolically, places cannot usually be defined using biophysical hierarchies. Moreover, some economic processes operate simultaneously across multiple levels.

Assessment Management

Assessments, especially large ones, can be easily influenced by internal and external forces. Strong management is necessary to prevent these forces from compromising the assessment. National to local special interest and political entities can control budgets and the availability of information. Likewise, forces within agencies can change budget and people priorities. Attaching it to a specific decision document (Environmental Impact Assessment-EIS) can direct the assessment to provide information for only that decision. An assessment of this type would not likely characterize ecosystems fully and would not draw independent conclusions. Assessment team members can also have priorities and desires. Singly or in combination, such factors can disrupt, delay, mis-direct, or complicate assessments, and they are often overlooked and difficult to handle.

Assessment Design

Completing a design prior to collecting data is the most efficient and logical way of conducting assessments. Design includes problem definition, boundaries, scales, analysis procedures, and determining data resolution and needs. The most important step in the assessment process is to define the assessment problems or questions that address resource management issues. This step can begin with the collection of information through public, agency, interagency forums, and other methods. This information can be used to identify issues the assessment needs to address. For example: What are the important attitudes and values residents hold toward natural resources? Is timber quantity declining? Are old-growth forests rare? Is water quality declining? Who are the stakeholders ? Is sight-seeing the most common form of recreation in an area? Addressing such questions clarifies the values society places on natural resources. Recognizing the values comes through the participation of tribal, federal, state, local, and public entities. Because ecosystems seldom conform to jurisdictional boundaries, the participation of these stakeholders is essential.

Public participation helps agencies understand people's values and helps the public understand the agencies' objectives, methods, data sources, and assumptions. Participation by all parties should promote increased understanding and improve cooperation and trust. Information needs to be gathered to ensure that the issues are well defined and the concerns of stakeholders are recognized. Emotions (job losses), traditions (hunting), resource changes (fire frequency), and values (commodity vs. preservation), for example, all define an issue. In some circumstances, policy makers in the absence of assessment management may provide an issue that masks the real issue. For example, policy makers might define the loss of the habitat for an endangered wildlife species, as an issue but the real issue is the amount and location of big, old trees and their harvesting (spotted owl vs. old-growth). Under these circumstances tremendous pressure is placed on management to provide an assessment for a poorly defined issue.

The issues and accompanying background information are used to define specific assessment questions or problems. Ideally problems should be stated as a testable hypothesis (Salwasser 1995). This might not be possible in all cases, but precise questions that address issues will define the past, present, and future structures, processes, and functions of ecosystems to be assessed. Questions determine how the ecosystems will be defined and what the components are. Questions that address well defined issues set the goals for the remainder of the assessment process.

Ecosystems are places where a multitude of biophysical and social components interact as a whole. They contain complex flows of energy, organisms, water, information, capital, etc. within and among the social and biophysical components. Because of this complexity, assessment teams tend to gather large amounts of data describing ecosystems in great detail, but the information does not always address relevant questions. Well-designed questions can focus the researchers and limit the ecosystem components and interactions evaluated in the assessment to those that address the issues.

Boundaries

Delineation of assessment and ecosystem boundaries should be based on the questions, agency needs, and the biophysical, economic, and social attributes of the areas of concern (Lackey 1996). Ecosystem boundaries should strive to encompass similar: biophysical patterns and processes (for example, existing vegetation, potential vegetation, regional climate, geology, and landform), hydrologic and aquatic processes (for example, river basin and watershed boundaries), and social settings (for example, land-use patterns). But boundaries used in assessments are highly individual depending on the questions, agencies, and political necessity. For example, for the Interior Columbia River Basin (ICRB) assessment a combination of state boundaries, river basin boundaries, and international boundaries was used to define the assessment area. This combination led the ICRB assessment to include portions of eastern Oregon and Washington, the state of Idaho and a portion of western Montana, but it excluded a large amount of the Columbia River Basin in Canada (Quigley et al. 1996).

Scales

The choice of the assessment geographic scales depends on the questions and the selected ecosystem components. Geographic scales can range from the regional and subregional areas to the smaller landscape and site specific areas. It is highly desirable for assessments to include multiple spatial scales because it may be difficult to adequately address regional ecosystem patterns and processes that are only apparent at landscape or smaller spatial scales.

Regional to continental spatial scales are the appropriate size to describe general trends and rates of change in resource conditions. At these scales we can describe broad-based conditions of biophysical, economic, and social ecosystem components. Regional to continental spatial scales can provide information on the patterns of resources (for example, species distributions) and associated risks to resource values (for example, fire and insect hazard) that may not be apparent when assessing smaller areas. Ecosystem processes such as air pollution, climate, and industrialization are not always recognizable using small geographic areas.

Biophysical, social, economic, and political rationale can be used for defining subregional units. In the Interior Columbia River Basin (ICRB) the entire assessment area was divided into 12 smaller ecosystem delineations based basically on biophysical attributes (Quigley et al. 1996). Similarly, the New Hampshire assessment (1995) area was divided into nine eco-regions, which were further divided into landscapes. In some cases, questions are not easily addressed using biophysical attributes as the primary attribute for determining boundaries. Counties and state boundaries are often the preferred delineation.

Smaller spatial areas can provide more specific information on items such as vegetation patterns or species composition that are not readily recognized using larger geographic areas. Similarly, smaller geographic areas can show trends in social well-being for communities of interest stratified by counties or groups of counties that would be impracticable and probably nonsensical for larger spatial areas. By applying various scales, characterizations of large geographic areas provide context for ecosystem processes, structures, and functions that can only be characterized using these smaller areas.

Landscape to site-specific spatial scales provide the greatest detail. This geographic extent may cover landscapes, watersheds, or individual project sites and specific human communities. This geographic extent typically relied on detailed information regarding vegetation patches, stands, meadows, streams, and social and economic data. These characterizations can describe processes, structures, and functions such as nutrient cycling, nitrification, individual communities, and existing land uses that are not readily observed when assessing larger geographic areas. The processes, structures, and functions observed using these smaller geographic areas can be set in context using the characterizations of the larger geographic areas.

Use of multiple geographic scales also requires using different temporal scales that can range from hours to centuries. As with spatial scales some biophysical components may not be recognizable using short time frames (for example, soil formation), while others can only be recognized using small time increments (for example, soil heating by fire). By describing ecosystems using multiple time frames, the longer periods can provide context for components using shorter time frames, similar to describing ecosystems using multiple spatial scales.

The choices of spatial and temporal scales and the units used for an assessment are a compromise among the disciplines involved (economics to landscape ecology). For example, spatial and temporal scales commonly used to describe biophysical components do not necessarily conform to the temporal and spatial scales used to describe economic and social components. Often biophysical components are best described using watershed boundaries, while counties are the basic unit for describing social and economic attributes. At the larger geographic scales, terrestrial assessments tend to use domains as their units, while social assessments use continents. At the regional and subregional scales, provinces and sections are often used in terrestrial assessments, and social assessments tend to use communities.

Using various spatial and temporal scales also results in information for planning and decision making at various levels within organizations. Continental and regional scale assessments provide information for national level planning such as those required by the Resources Planning Act (1974).

Section and subsection ecological units as described by the National Hierarchy of Ecological Units (1993) are often found in regional and subregional assessments and address planning at regional and multiforest planning levels. Ecological assessments need also to characterize rare or unique components of ecosystems. These can range from rare communities such as cobble bars, swamp forest-bog complexes, or karst lands. Lists of rare or endangered species, or other sources are starting points to identify these rare elements.

Indicator Variables

Indicator variables should be chosen to adequately describe the ecosystem condition (Hirvonen 1992; Landres 1992). In assessments they are used to describe the current, past, and future trends of ecosystems. Indicator variables can be used to detect ecosystem changes. For example, quantifying changes in forest composition can indicate changes in forest biodiversity, wildlife habitat, or disturbance regimes. The ICRB assessment used changes in species composition in dry forest types to indicate changes in fire regimes (Quigley et al. 1996). They noted that lack of fire in dry forest tended to change species composition from primarily ponderosa pine (*Pinus ponderosa*) forests to mixed confer forests.

Indicator variables are also communication tools (Hirvonen 1992). For example, number of chocolate chips, cookie size, and texture are all indicators of cookie taste--variables manufactures use to convey taste information to consumers. A similar approach is necessary in ecological assessments. Indicator variables need to communicate relevant information (fire risk, species loss, jobs loss) about the status of the ecosystem. Therefore, indicator variables should be chosen and defined with care because their definition takes time, people, and money (Hirvonen 1992; Landres 1992). It is imperative that they are used to address questions at the appropriate spatial and temporal scale.

Indicator variables and objectives should be stated concisely, in an understandable format, ideally in one concise sentence. This sentence can help avoid deviation from pursuit of preset goals. If the indicator variable is to determine detrimental effects, then the variable should have thresholds identified. If indicator variables are used to determine cause and effect, a controlled experiment is required that adheres to the assumptions of randomness and treatments to experimental units. In natural resource assessments, this statistical rigor can seldom be achieved. Therefore, indicator variables used in assessments should not try to describe cause and effect but rather differences, trends, or changes.

Indicator variables used to describe ecosystems should adhere to sound sampling protocols and be drawn from appropriately sized areas or populations (Mouat et al. 1992). These protocols should include the scale at which the indicator variable is being used, the sampling frame, suggested method of sampling, and the optimal time to collect data. This ensures that inferences can be described and detected differences, relationships, changes, or trends will be credible.

The use of indicator variables in assessments is experimental, and future knowledge may change how they are used. They do not provide a complete description of an ecosystem, necessitating flexibility in their use. Indicator variables can be used and applied inconsistently. Interpreted results from a selected indicator variable in one assessment may not necessarily be applied to another.

Data Analysis

Good data analysis depends on the preceding steps in the assessment design being handled correctly, beginning with problem definitions through variable selection. Data analysis techniques will further define the scope and intensity of data needed, resulting in increased assessment efficiency, decreased costs and valuable time used wisely. Analysis techniques include statistical procedures such as T-tests, frag-stats, ANOVA, and discriminate functions. Models, scenarios, or rating an ecosystem to determine its integrity or resiliency are other techniques.

An ideal assessment would consist of information integrated from the inception by addressing integrated questions. However, although most resource information is collected by individual disciplines addressing separate questions, through coordination, data of mutual interest can be shared. For example, assessments often use watersheds as the basic sample units. The biophysical environment described in these watersheds can be used to describe potential habitats of wildlife and plant species.

Data

Often data collection commences early in the assessment. Collecting data prior to developing an assessment design leads to inefficiencies and redundancies and wastes time, money, and people. Moreover, often the data collected do not provide the information for making inferences at the scale appropriate to address the questions. Data should conform to the determined indicator variables and must describe ecosystem structures, processes, and functions at a resolution appropriate for the spatial and temporal scales of the assessment. Data resolution pertains to the amount of detail incorporated in the data for a given area. For example, using a hand lens to examine a rotting log would give more detail (finer resolution) than taking pictures from an airplane. The degree of resolution generally focuses on ecosystem patterns and processes that are best addressed at a particular spatial scale.

Assessment Products

Assessments can result in a variety of products. Hard copies of results can range from single volumes to multiple volumes with summary chapters including data and data tabulations. Assessments have produced less obvious results such as improving the credibility of the agency or developing partnerships among agencies and the stakeholders. The following is a tabulation of some of the products resulting from assessments (Shaw et al. 1996).

I. Technical data and information
   A. Tabular data
   B. Spatial data
   C. Meta data
   D. Models

1. Descriptive
2. Predictive
3. Knowledge based
E. List of references
F. Glossary
II. Findings at multiple spatial and temporal scales
A. Spatial relationships of the issues
B. Current conditions and future trends
1. Historic variation
2. Scarcity and abundance
C. Integrity and sustainability
D. Threats and opportunities
III. Information gaps
A. Research needs
B. Risks and uncertainty
C. Adaptative management opportunities
IV. Synthesis
V. Packaging (Hard copy reports, Internet, CD ROM)
VI. Relationships among employees, other agency personnel, and the public
VII. Institutional
A. Technological and knowledge transfer
B. Managerial and research linkages
C. Credibility of agency
D. Encouragement for more informed decisions
E. More legally defensible decisions

Assessments and Monitoring

Linking assessments to monitoring programs is key in most adaptive management models. However, most monitoring occurs at the site level, and methods and tools linking multiple-scale assessments to monitoring programs have not been established or applied (Delfs et al. 1996). The most effective way to link assessments and monitoring is to consider both programs in initial planning. This provides several advantages. Assessments identify knowledge gaps, provide baseline data, and address issues that are important for monitoring programs. During the assessment, each indicator variable used should also have a defined monitoring objective and be designed appropriately following good sampling protocols across various spatial and temporal scales (Mouat et al. 1992). All questions and subsequent inferences made during the assessment should be applicable to monitoring. If multiple scales are included in the assessment, the monitoring program should use the same scales. Therefore, by using indicator variables for both the assessment and monitoring program the monitoring program can apply any information from the assessment more effectively.

Assessment Contract

So that both managers and the assessment teams are in accord, assessment contracts must be made between the managers and the teams at the beginning. While these contracts can take various forms, at a minimum they need to identify the desired products and the resources and time required. For example an assessment contract might include the following items:

- The product name, a map, data base, model, etc.
- What question the product relates to and what was the priority of completing the product to address the question
- The primary users of the product
- The geographical extent of the product
- Listing required intermediate products
- Data security issues
- Who is responsible for the product
- Can it be completed within the time frame
- Cost
- Data source
- Intensity of data collection

A form listing these item can form a contract between the individual teams and the managers. Data and information not described by a product form and agreed to by the team leaders and managers would not included in the assessment. The rigor of this contract would enable a project to be finished on time and within budget.

Summary

Ecological assessments have always been part of natural resource management. Current ecological assessments are a refinement and expansion of many of the technologies and approaches that have been used in the past. Past assessments usually addressed problems of a local nature involving small geographic areas and limited numbers of stakeholders and interested participants. Today we have a better understanding of ecological systems and how they are interconnected often over extremely large areas. Our interest in maintaining ecosystems and their components has also increased. Natural resource issues are no longer local. Regional, national, and international environmental issues need to be addressed. The foundation for making decisions depends on the availability of information.

Ecological assessments using a variety of spatial and temporal scales can provide this information. Foremost, the assessment process should be designed and driven by the issues. Using the scientific method as the framework for planning and completing assessments will help avoid the most common error—collecting data before a plan is prepared. Moreover, this approach ensures that data, data resolution, and data analysis are all tailored to addressing the right question using the right temporal and spatial scales.

Literature Cited

Aber, J.D., and J.M. Melillo. 1991. Terrestrial Ecosystems. Saunders College Publishing, Philadelphia, PA.

Agee, J.K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, DC.

Agee, J.K. 1994. Fire and Weather Disturbances in Terrestrial Ecosystems of the Eastern Cascades. USDA Forest Service General Technical Report PNW-GTR-320. Portland, OR: Pacific Northwest Research Station.

Allen, T.F.H., R.V. O'Neill, and T.W. Hoekstra. 1984. Interlevel Relations in Ecological Research and Management: Some Working Principles from Hierarchy Theory. USDA Forest Service General Technical Report RM-110. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station.

Allen, T.F.H., and T.B. Starr. 1982. Hierarchy: Perspectives for Ecological Complexity. University of Chicago Press.
Barret, S.W., S.F. Arno, and C.H. Key. 1991. Fire Regimes of Western Larch-lodgepole Pine Forests in Glacier National Park, Montana. Can. J. For. Res. 21: 1711-1720.
Botkin, D.B. 1990. Discordant Harmonies: a New Ecology for the Twenty-first Century. Oxford University Press, New York.
Burgess, R.L., and D.M. Sharpe. 1981. Forest Island Dynamics in Man-Dominated Landscapes. Springer-Verlag, New York.
Daniel, T.W., J.A. Helms, and F.S. Baker. 1979. Principles of Silviculture. McGraw-Hill, New York.
Delcourt, H.R., and P.A. Delcourt. 1988. Quaternary Landscape Ecology: Relevant Scales in Space and Time. Landscape Ecology 2: 23-44.
Delfs, M., B. Davis, and S. Stewart. 1996. Linkages to Other Assessments and Programs. In: Lessons Learned Workshop: Policy, Process, and Purpose for Conducting Ecoregion Assessments: *Draft*. pp. 17-20. Albuquerque, NM: USDA Forest Service Southwestern Region.
Deuel, J.K., and J. D'Aloia, Jr. 1995. Defining Our Vocabulary. The Co-Evolution Quarterly Fall: 24-35.
Haynes, R.W., R.T. Graham, and T.M. Quigley (tech. eds.). 1996. A Framework for Ecosystem Management in the Interior Columbia Basin. USDA Forest Service General Technical Report PNW-GTR-374. Portland, OR: Pacific Northwest Research Station.
Hilborn, R., and C.J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choices, Dynamics, and Uncertainty. Chapman and Hall, New York.
Hirvonen, H. 1992. The Development of Regional Scale Ecological Indicators: a Canadian Approach. In: McKenzie, D.H., E. Hyatt, and J.V. McDonald (eds.), Ecological Indicators. pp. 901-916. Elsevier Science Publishers LTD, New York.
Holling, C.S. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons, New York.
Hunt, C.B. 1972. Geology of Soils. W.H. Freeman and Company, San Francisco, CA.
Kimmins, H. 1992. Balancing Act: Environmental Issues in Forestry. University of British Columbia Press, Vancouver.
King, A.W., W.R. Emanuel, and R.V. O'Neill. 1990. Linking Mechanistic Models of Tree Physiology with Models of Forest Dynamics: Problems of Temporal Scale. In: Dixon, R.K., R.S. Meldahl, G.A. Ruark, and W.G. Warren (Eds.), Process Modeling of Forest Growth Responses to Environmental Stress. pp 241-248. Timber Press, Portland, OR.
Koestler, A. 1967. The Ghost in the Machine. Macmillan, New York.
Lackey, R.T. 1996. Seven Pillars of Ecosystem Management. Landscape and Urban Planning. January: 1-17.
Landres, Peter B. 1992. Ecological Indicators: Panacea or Liability? In: McKenzie, D.H., E. Hyatt, and J.V. McDonald (eds.), Ecological Indicators. pp. 1295-1318. Elsevier Science Publishers LTD, New York.
Lindeman, R. 1942. The Trophic Dynamic Aspect of Ecology. Ecology 4: 399-418.
Maser, C. 1994. Sustainable Forestry: Philosophy, Science, and Economics. St. Lucie Press, Delray Beach, FL.
McGinty, K. 1995. The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies. In: Interagency Ecosystem Management Task Force: Volume 1 - Overview. Springfield, VA: U.S. Department of Commerce, National Technical Information Service.
Mouat, D., C.A. Fox, and M.R. Rose. 1992. Ecological Indicator Strategy for Monitoring Arid Ecosystems. In: McKenzie, D.H., E. Hyatt, and J.V. McDonald (eds.), Ecological Indicators, pp. 717-738. Elsevier Science Publishers LTD, New York.
National hierarchical framework of ecological units: Final Draft. 1993. Washington, DC: ECOMAP and USDA Forest Service.
National Research Council. 1990. Forestry Research. National Academy Press, Washington, DC.
New Hampshire forest resources plan: Assessment report. 1995. Concord, NH: State of New Hampshire, Department of Resources and Economic Development, Division of Forests and Lands.
Noss, R.F., and A.Y. Cooperrider. 1994. Saving Nature's Legacy. Island Press, Washington, DC.
O'Laughlin, J., J.G. MacCracken, D.L. Adams, S.C. Bunting, K.A. Blatner, and C.E. Keegan, III. 1993. Forest Health Conditions in Idaho: Policy Analysis Group Report 11. Moscow, ID: Forest, Wildlife, and Range Experiment Station, University of Idaho.
O'Neill, R.V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen. 1986. A Hierarchical Concept of Ecosystems. Princeton University Press, NJ.
Pickett, S.T.A., J. Kolasa, J.J. Armesto, and S.L. Collins. 1989. The Ecological Concept of Disturbance and its Expression at Various Hierarchical Levels. Oikos 54: 129-136.
Quigley, T.M., R.T. Graham, and R.W. Haynes (Tech. Eds). 1996. Integrated Scientific Assessment for Ecosystem Management of the Interior Columbia Basin and Portions of the Klammath and Great Basins. USDA Forest Service General Technical Report PNW-GTR-382 Portland, OR: Pacific Northwest Research Station.
Regier, H.A. 1992. Indicators of Ecosystem Integrity. In: McKenzie, D.H., E. Hyatt, and J.V. McDonald (eds.), Ecological Indicators. pp. 183-198. Elsevier Science Publishers LTD, New York.
Robbins, W.D. and D.W. Wolf. 1994. Landscape and the Intermontane Northwest: an Environmental History. USDA Forest Service General Technical Report PNW-GTR-319. Portland, OR: Pacific Northwest Research Station.
Rosen, R. 1975. Biological Systems as Paradigms for Adaptation. In: Day, R.H. and T. Groves (eds.), Adaptive Economic Models. pp. 39-72. Academic Press, New York.
Sala, M. and J.L. Rubio (eds). 1994. Soil Erosion and Degradation as a Consequence of Forest Fires. Geoforma ediciones, Logrono, Spain.
Salwasser, H. 1995. Factors Influencing the Context and Principles of Ecosystem Management. In: Wagner, F.H. (ed.), Proceedings of the Symposium: Ecosystem Management of Natural Resources in the Intermountain West. pp. 5-17. Logan, UT: Utah State University, College of Natural Resources.
Salwasser, H., D.W. MacCleery, and T.A. Snellgrove. 1993. An Ecosystem Perspective on Sustainable Forestry and New Directions for the U.S. National Forest System. In: Aplet, G.H., N. Johnson, J.T. Olson, and A.V. Sample (eds.), Defining Sustainable Forestry. pp. 44-89. Island Press, Washington, DC.
Shaw, D., D. Nelson, L. McCarthy, T. Wilson, R. Hall, J. Berg. 1996. Assessment Products. In: Lessons Learned Workshop: Policy, Process, and Purpose for Conducting Ecoregion Assessments: *Draft*. pp. 27-32. Albuquerque, NM: USDA Forest Service Southwestern Region.
Shugart, H.H. 1984. A Theory of Forest Dynamics: the Ecological Implications of Forest Succession Models. Springer-Verlag, New York.
Streets, D.G. 1989. Integrated Assessment: Missing Link in the Acid Rain Debate. Environmental Management 13: 393-399.
Thomas, W.L. Jr. (ed.) 1956. Man's Role in Changing the Face of the Earth: an International Symposium. University of Chicago Press.
Thorton, K.W., G.E. Saul, and E.D. Hyatt. 1994. Environmental Monitoring and Assessment Program: Assessment Framework. Research Triangle Park, NC: U.S. Environmental Protection Agency.
Urban, D.L., R.V. O'Neill, and H.H. Shugart, Jr. 1987. Landscape Ecology: a Hierarchical Perspective Can Help Scientists Understand Spatial Patterns. Bioscience 37(2): 119-127.
U.S. Laws, Statutes Etc and Public Law 93-378, Forest and Rangeland Renewable Resources Planning Act of 1974. Act of August 17 1974. U. S. C. 1600-1614.
U.S. Laws, Statutes etc. and Public Law 94-190. [s.1075]. National Environmental Policy Act of 1969. Act of Jan. 1, 1970. [An act to establish a national policy for the environment, to provide for the establishment of a Council of Environmental Quality, and for other purposes.] In: United States Statutes at Large, 1969, 42 U.S.C. sec. 4231, et seq. (1970). Washington, DC: U.S. Government Printing Office. 83 852-856.
Waring, R.H., and W.H. Schlesinger. 1985. Forest Ecosystems: Concepts and Management. Academic Press, Orlando, FL.
Zonneveld, I.S. 1988. Basic Principles of Land Evaluation Using Vegetation and Other Attributes. In: Kuchler, A.W. and I.S. Zonneveld (eds.), Vegetation Mapping. pp. 499-517. Kluwer Academic Publishers, Dorchet, Netherlands.

Problemas Practicos Que Reducen la Eficiencia de los Sistemas de Apoyo a la Toma de Decisiones Para el Manejo Forestal[1]

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Los sistemas de apoyo a la toma de decisiones (SATD) son sistemas (cerrados o abiertos) cuyo objetivo es ayudar a la toma de decisiones a través de la conjugación de bases de datos, herramientas de análisis, sistemas expertos e interfaces que permiten proponer alternativas de acción para un determinado problema. Los SATD en el sector forestal han proliferado en los últimos años y se han convertido en una herramienta muy importante para el manejo de los recursos forestales. Gracias a ellos se han podido desarrollar sistemas de planeación que incluyen mucho más elementos de análisis y que permiten sensibilizar el efecto de diferentes variables endógenas y exógenas al proceso de toma de decisiones.

A nivel internacional estos esfuerzos han resultado en extraordinarias herramientas de planeación y análisis y sobre todo, han ayudado a cumplir con una tarea importante dentro de la actividad forestal, que es aquella de estandarizar la toma de datos de los inventarios, estandarizar las formas básicas de análisis de información y sobre todo estandarizar las salidas o productos de análisis. Esto es un avance extraordinario en la actividad forestal, ya que permite comparar diferentes inventarios, permite registrar variables comparables en largo plazo y facilita el uso de diferentes estrategias de análisis de información.

Sin embargo en México, el desarrollo de los SATD es relativamente reciente. El primero que aparece es el Sistema de Conservación y Desarrollo Silvícola conocido como SICODESI. Este sistema fue desarrollado por el convenio de cooperación México-Finalandia y tuvo una amplia difusión en los años iniciales a su desarrollo, principalmente por presión gubernamental. El sistema es de excelente calidad y se puede considerar como un sistema abierto, adaptable a cualquier condición de bosque de coníferas. Desde sus inicios se intentó aplicarlo a una gran variedad de condiciones, sin embargo en algunas de ellas hizo evidentes algunas de las desventajas de su diseño, y actualmente se encuentra en proceso de revisión.

Posteriormente a inicios de 1992 empiezan a surgir otros sistemas bajo la concepción de sistemas cerrados, esto es sistemas diseñados solo para condiciones específicas. De esta forma surge el Sistema Integral de Manejo de Bosques con Aplicaciones Terrestres (SIMBAT), sistemas cerrado diseñado para proporcionar alternativas de manejo forestal exclusivamente para los predios del Estado de México incluidos en el Segundo Estudio Dasonómico de esa entidad. A partir de 1995 se da un crecimiento considerable en el desarrollo de SATD's para el sector forestal entre los que sobresalen el Sistema de Manejo de Bosques de la Unidad Santiago Papasquiaro (SIMBUS)—1995, el Sistema de Manejo Forestal Tepehuanes (SMFT)—1996, el Sistema de Cortas Sucesivas y de Protección (SICOSUP)— 1996, y el Sistema Silvícola de Selección (SISISE)—1997, entre otros. Así mismo se continúa el desarrollo de sistemas abiertos entre los que se pueden señalar el Sistema de Manejo de Bosque Regular (SMBR)—1994, y el MANFOR (Sistema de Manejo Forestal).

El desarrollo de SATD's sin duda ha sido positivo para la actividad forestal del país. Gracias a estos sistemas se han detectado graves problemas de falta de información, falta de metodologías de análisis para condiciones propias del país y falta de estrategias de monitoreo de los recursos forestales. De aquí que el diseño, uso y la aplicación de los resultados de los SATD's presenta graves problemas de mediano plazo debido a la falta de estándares tanto de entrada como de salida de información que permita comparar bases de datos, estrategias de análisis y resultados. Por tanto, a pesar de que el diseño de un SATD cumpla con los objetivos planteados, es muy probable que no se utilice su potencial para monitorear la dinámica de los recursos forestales, para evaluar metodologías alternativas y para evaluar estrategias de aprovechamiento en el largo plazo y en un contexto unificado. El propósito de este documento es señalar algunos de los principales problemas en el manejo de información de inventario y monitoreo de los SATD's y proponer algunas alternativas de solución.

Problemas Relacionados con los Requerimientos de Informacion de los SATD'S

La mayor parte de los SATD's han surgido de iniciativas institucionales y en la mayoría de los casos iniciativas propias. Son sistemas que se han diseñado de acuerdo a los estándares locales (cuando existen) y en la mayoría de los casos sin considerar estrategias de largo plazo (e.g. monitoreo de recursos, criterios de sustentabilidad y otros). Los requerimientos de información de la mayoría de estos sistemas son muy variables y ello causa un problema medular al limitar el uso de información solo a un sistema en particular.

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De aquí que regularmente la información de un inventario realizado para utilizar un sistema no puede utilizarse para el uso de otro sistema no solamente por falta de compatibilidad en las bases de datos, sino por la diversidad de información. A continuación se señalan algunos de los problemas más evidentes:

Información de Inventario

El principal problema en el manejo de información de inventario es que las bases de datos no son compatibles. Si bien esta falta de compatibilidad entre bases de datos no es muy limitante en el caso de las variables dasométricas, si lo es en el caso de las variables ecológicas, de regeneración, de recursos alternos y de variables físicas. Lo cual obviamente limita el uso de otro tipo de SATD para una misma zona o para presentar información estandarizada. Un ejemplo por demás evidente es la ausencia de estándares para las claves de especies. Así en unas zonas el *Pinus durangensis* tiene una clave numérica y en otras zonas se le asigna otra clave. No solo eso, por su ritmo de crecimiento este pino en unas zonas es considerado dentro de un grupo de crecimiento mientras que en otras zonas es considerado dentro de otro grupo, lo cual dificulta enormemente el seguimiento de la dinámica de las especies. La ausencia de estándares en variables dasométricas se refleja en variables tan simples como la identificación de la altura comercial, la altura dominante, el diámetro dominante o incluso diámetro de copa, diámetro de la regeneración, entre otras variables.

La ausencia de estos estándares es más evidente en la evaluación de las variables ecológicas y de sitio, donde las variables son evaluadas de una amplia diversidad de formas sin considerar incluso la estrategia metodológica de evaluación. Así por ejemplo las características de suelo, uso del suelo, dinámica de agua entre otras variables de gran relevancia para evaluar alternativas de tratamientos son evaluadas de formas muy diversas en cada SATD.

Cabe señalar que algunos de los SATD's siguen algunos estándares marcados por SICODESI, SEDEMEX y formatos diversos como los desarrollados por Mas(197?). Quizá uno de los aciertos más importantes del sistema SICODESI ha sido la estandarización de muchas de las variables, sin embargo en algunos casos debido al análisis que se realiza, las variables resultan no ser propias o adecuadas para análisis más complejos. En este sentido es necesaria la creación de estándares para la captura de información de regeneración, información ecológica, de sitio e información socioeconómica

Sitios de Muestreo y Muestreo

En la actualidad el tipo de muestreo más común es el muestro sistemático con sitios circulares de un décimo de hectárea. En la mayoría de los casos el muestreo se sigue realizando por líneas a los largo del predio, sin importar el numero de sitios que se asignan a cada rodal, de tal forma que existe la posibilidad de que algunos rodales no tengan muestra alguna.

La estandarización en el muestreo que se realiza en los inventarios es un tema muy polémico. En otros piases se ha tratado de crear estándares, pero estos han fracasado porque no es posible abarcar en un estándar la amplia gama de condiciones a muestrear y las posibilidades económicas para llevar a cabo la evaluación. Para el caso de nuestro país las condiciones a muestrear son todavía mas variables dada la gran variedad de especies, condiciones de sitio y disponibilidad de recursos para realizar el inventario. Es por ello que la estandarización resulta mas complicada. A pesar de ello existen elementos básicos de un muestreo que pueden ser estandarizados como por ejemplo, el hecho de que exista un mínimo de muestras para cada rodal independientemente de su tamaño. Esto obliga a que cada rodal pueda ser caracterizado sin la necesidad de recurrir a extrapolaciones, muchas de las cuales carecen de alguna base. Otro criterio de estandarización pueden incluir la forma de inicio de los cadenamientos, dirección de los cadenamientos, o estándares en cuanto al tamaño mínimo del sitio de acuerdo al tipo de bosque donde se obtiene la muestra. Este ultimo criterio es de especial importancia en el uso de SATD. Ello debido a que el tamaño del sitio afecta en gran medida el número de árboles y con ello las características de la distribución de tamaños muestreada. Usualmente se recomienda el uso de sitios grandes para condiciones de bosque con arbolado muy disperso e irregular, mientras que sitios pequeños son apropiados para zonas con arbolado menos disperso y con una distribución de tamaños más regular. Estos son elementos que afectan en gran medida el funcionamiento de un SATD, sobretodo en sus componente de modelado del crecimiento y rendimiento.

Estándares de Formato de Información

La mayor parte de los SATD's que se han desarrollado en el país tienen formatos específicos en sus bases de datos. En la mayor parte de los casos tales formatos no son compatibles y la mayoría de ellos no obedecen a algún estándar de bases de datos como d-BASE, ACCES u ODBC. Ello debido a que estos programas han sido desarrollados en diversos lenguajes como C, PASCAL, FORTRAN, BASIC y algunos hasta como macros de sistemas como EXCEL, SAS o LOTUS. La ausencia de un formato compatible entre los diferentes SATD's, obviamente creará problemas para la integración de información y para comparaciones que se deseen realizar sobre los datos.

Información Adicional al Inventario

El propósito de los SATD's es identificar alternativas viables de manejo forestal. Ello implica que además de la información silvícola-ecológica deben incluir información socioeconómica, antropológica y de ingeniería (operaciones de extracción). Este tipo de información tampoco esta estandarizada, e incluso en la mayoría de los casos ni siquiera es recopilada. Quizá esta parte de la evaluación y el monitoreo de los recursos forestales es el más olvidada, ya que no existen registros de precios de productos por regiones, costos, y otras variables socioeconómicas que permitan identificar las mejores alternativas de manejo forestal.

Problemas Derivados del Analisis Preliminar de la Informacion de Inventario

Este tipo de problemas surgen cuando se inicia el análisis de la información de inventario forestal. La simple estimación de promedios de la mayoría de las variables o la agrupación en estratos es quizá la fuente de la mayor cantidad de diferencias en el manejo de información. De igual forma, los análisis preliminares de información sobre caracterización de rodales es muy diversa y generalmente lleva a conclusiones muy diferentes. A continuación se describen algunos de los problemas derivados del análisis preliminar de información:

Distribución de la Hectárea Tipo

La mayor parte de los SATD's agrupan la información de inventario en una estructura promedio que frecuentemente se denomina hectárea tipo. Así, la hectárea tipo es el resumen de promedios de frecuencias de diámetros y alturas de un rodal. Esta información es la que frecuentemente se utiliza para realizar las proyecciones de crecimiento y rendimiento, para el análisis de diferentes alternativas de cosecha a nivel rodal y para analizar el efecto de diferentes restricciones de manejo o intensidades y formas de manejo de bienes o servicios alternos.

A pesar de que la hectárea tipo resulta ser el elemento básico de trabajo de un SATD frecuentemente se le da muy poca atención. Es común que en su estimación sólo se utilicen promedios, frecuentemente redondeados a unidades (enteras) por hectárea, sin considerar las variaciones en las frecuencias de cada categoría. El uso de hectáreas tipo es una actividad muy común en manejo forestal de nuestro país. Sin embargo, es un procedimiento que se ve fuertemente afectado por el tipo de muestreo y la forma en la que se hace el análisis preliminar. Por ejemplo, cuando se muestrean rodales con poco arbolado y muy irregulares usando sitios de muestreo pequeños, el efecto de las observaciones aberrantes es muy fuerte, ya que en la extrapolación se pueden estimar cantidades enormes de tales observaciones aberrantes que frecuentemente no existe. Por tal razón resulta de interés realizar correcciones a las estructuras estimadas de acuerdo a las características del arbolado, el diseño muestreo, tamaño de sitios y la aproximación que se use. Sin duda, investigación en este sentido es necesaria para el monitoreo de recursos y el uso de la información de inventario; en este rubro el diseño de estándares para la estimación de una hectárea tipo es indispensable.

Interacción y Análisis Preliminar de la Información Ecológica

Mucha de la información ecológica y de sitio que se colecta en los inventarios es de excelente calidad. Sin embargo en muchos casos el uso e interpretación que se da a los resultados preliminares de análisis no corresponde ya sea a la calidad de información o a la estrategia de uso. Así por ejemplo para calcular el nivel de erosión de un rodal a partir de una clasificación cualitativa se acude a valores promedio, mismos que carecen de significado dado que estos valores son meramente cualitativos y cuyo promedio no refleja en muchos de los casos una situación promedio. En otros casos la situación promedio que se refleja no existe en la realidad. De aquí que la creación de estándares para evaluar elementos cualitativos es de vital importancia no solo para hacer compatible los SATD's, sino para lograr un verdadero monitoreo de las variables de interés.

Problemas Derivados del Análisis de Información

El análisis de información de inventario permite derivar los conjuntos de modelos utilizados para realizar las proyecciones de crecimiento y rendimiento, precios, relaciones de producción entre bienes dentro de un mismo rodal, etc. Obviamente el nivel de análisis de información depende de los objetivos de análisis, las características del SATD y del presupuesto disponible. Lo anterior hace pensar que existen varios niveles de análisis, por lo que dos SATD's a pesar de que usen la misma estrategia metodológica pueden proporcionar resultados muy diferentes que dan por resultado interpretaciones diferentes a la información de inventario y obviamente alternativas de manejo diferente. A continuación se señalan algunas fuentes básicas de variación entre diferentes tipos de análisis y se resalta la necesidad de la creación de estándares.

Uso Indiscriminado de Modelos

El desarrollo de modelos de predicción usados en los SATD's tiene su base en la calidad de información de campo colectada y en la teoría detrás de cada modelo. Muy frecuentemente los analistas dejan a un lado la teoría detrás de cada modelo por dar preferencia a los ajustes que se obtienen. Esto es, los modelos de los SATD's frecuentemente obedecen más a las características los datos que a la teoría detrás del funcionamiento. Esto origina que cuando estos sistemas son enfrentados a condiciones diferentes o integrados con un conjunto más grande de ecuaciones, frecuentemente resulten en estimaciones muy sesgadas, mismas que regularmente no son validadas.

Lo anterior hace necesario reconsiderar el tipo de modelo que se deben integrar a los SATD. Tales modelos deben seguir los fundamentos teóricos básicos, no deben ser modelos definidos totalmente por los datos, esto es, no deben emplearse técnicas de estimación como STEPWISE u otro tipo de estrategias de selección de variables que sea dependiente de los datos. Finalmente, dado que son modelos que se integraran a otros modelos, se debe procurar que cumplan con los supuestos básicos de las técnicas de ajuste de modelo que se este utilizando. La violación a los supuesto básicos frecuentemente produce sesgos muy importantes cuando se integran muchas ecuaciones. Por ejemplo, si estos supuestos no se cuidan una estimación fuera del rango de datos puede originar valores sesgados, mismos que al ser utilizados en otra predicción pueden originar sesgos aún más grandes.

Validación de modelos o diseño de estrategias de validación

Los modelos usados en el desarrollo de los SATD's en México generalmente carecen de una validación. Es común observar modelos de crecimiento o rendimiento, modelos de densidad, índices de sitio y otros, sin validación alguna al menos con conjuntos diferentes de datos. Obviamente la validación es un proceso más complicado que cambiar las series de datos y volver a correr los modelos, sin embargo, es una estrategia que al menos proporciona una estimación de la dependencia del modelo sobre las características de los datos.

A pesar de que la validación de información es un proceso tan importante en el análisis y monitoreo de información de inventario, rara vez se consideran estrategias de validación de largo plazo de las técnicas de estimación o análisis de la información.

Algoritmos de Toma de Decisiones

El diseño de algoritmos de análisis y toma de decisiones que sirvan para el diseño de un SATD es una actividad que ha sido poco favorecida en el país. Son casi nulos los trabajos sobre algoritmos, árboles de decisión o cualquier otra herramienta de teoría de decisiones o análisis, que permita integrar la información ecológico silvícola para la toma de decisiones en un SATD. Este tipo de algoritmos son útiles tanto en la etapa de inventario como en la etapa de análisis de información. En la etapa de inventario pueden ser aplicados para validar la captura de datos, identificar tamaños de muestra apropiados en campo, tamaños de sitio y otros, mientras que en el análisis pueden ser usados para definir regímenes de manejo, intensidades de manejo, tipos de corta, etc.

Sin duda, el mayor énfasis en la investigación sobre algoritmos de estimación, algoritmos de toma de decisiones y algoritmos de validación es indispensable para unificar los criterios de inventarios, manejo de información, análisis y presentación de resultados de un SATD.

Problemas Derivados de la Ausencia de Estandares de Presentación de Información

El uso más importante de los SATD's en México es el diseño y evaluación de alternativas de manejo forestal. Tales alternativas se generan y analizan a través de una amplia gama de estrategias metodológicas y bajo diferentes objetivos. Esto da por resultado que exista una amplia diversidad de salidas (resultados) de los SATD's para proporcionar alternativas de manejo. Tal diversidad de salidas causa un problema de compatibilidad en los resultados dado que en ocasiones las salidas no son comparables y en otros casos la información no es suficiente para juzgar la conveniencia de adoptar la o las alternativas de manejo propuestas. A continuación se señalan dos problemas relacionados con las salidas de los SATD.

Información Mínima Derivada de un SATD

Como se ha señalado existe una amplia diversidad de resultados derivados de los SATD. Esta amplia diversidad hace que muchos de los resultados no sean comparables por problemas de escala o unidades, problemas metodológicos o problemas de falta de información. Tales problemas surgen de la ausencia de estándares mínimos de información derivada de los SATD's, dado que en presencia de estándares la información debería ser totalmente compatible.

Lo anterior sugiere que es necesario estandarizar muchas de las variables que se derivan de los SATD's. Tales estándares serán útiles no solo en el proceso de toma de decisiones sino en el monitoreo de las actividades de manejo y aprovechamiento de los recursos forestales. Obviamente estos estándares deben de considerar el objetivo para el cual se ha desarrollado el SATD, la normatividad que rige tal información, el contexto en el cual se derivan los valores de las principales variables (cosecha, sustentabilidad, etc.) y los costos involucrados en obtener la información.

Criterios de Evaluación de Programas de Manejo

Los programas de manejo forestal derivados de los SATD's son muy diversos. Algunos de ellos solo estiman el volumen de cosecha en función del crecimiento esperado mientras que otros resultan ser más sofisticados al incluir simuladores de crecimiento, optimizadores e incluso sistemas expertos para evaluar alternativas de manejo. Curiosamente las salidas de los SATD's desarrollados en el país solo son compatibles en una variable: volumen de corta. Sin embargo otras variables de amplia aplicación no sólo para evaluar la dinámica del recurso, sino para juzgar sobre la pertinencia de utilizar la alternativa de manejo propuesta, generalmente no están presentes. Dentro de estas variables se incluyen los criterios de sustentabilidad, los criterios de evaluación del volumen de cosecha y los criterios sobre el sistema, método y régimen de manejo forestal propuesto. Lo anterior es solo para incluir algunos de los elementos de análisis de la cosecha maderable, sin embargo existe una enorme cantidad de criterios adicionales indispensables para juzgar la sustentabilidad de recursos alternos, los niveles de cosecha de los mismos y la dinámica que siguen.

Lo anterior solo indica que resulta sumamente importante el definir estándares sobre las variables que deben incluirse en un programa de manejo forestal. Tales estándares preferentemente deben reunir los requisitos de los estándares internacionales y deben diseñarse de tal forma que puedan servir como incentivo para homologar la inversión en la actividad forestal, particularmente la destinada al conocimiento de la dinámica del bosque.

Conclusiones

El manejo de información de bases de datos de inventario y monitoreo de recursos forestales en la actualidad es muy dependiente de sistemas de información y SATD's. Ello indica que un diseño apropiado de los estándares de entrada y salida de información, así como los procesos de análisis de información básica es fundamental para unificar los criterios de inventario y monitoreo de recursos. Solo en la medida en que estos formatos y estrategias de análisis sean compatibles, será mucho más simple el seguimiento de la información de inventario. Esta estandarización debe considerar el inventario y monitoreo de recursos, procedimientos de análisis preliminar, procedimientos y estrategias de análisis, así como los resultados derivado de los SATD's.

La creación de estándares es una tarea interdisciplinaria en la cual no solo deben acudir los especialistas en evaluación y valoración de las variables de interés, sino también especialistas de disciplinas relacionadas con tales variables, así como especialista en manejo de bases de datos digitales y espaciales. Ello permitirá que los estándares tengan compatibilidad, sean lo suficientemente específicos para ser usados por varias disciplinas y que puedan perdurar como estándares por largo tiempo.

Subject V

Challenges to Achieving Integration

Seeing the Trees, Forests, and the Earth[1]

H. Gyde Lund[2]

Abstract—There is an old adage, *we can't see the forest for the trees*—meaning that we often get too wrapped up in details to see the overall picture. In our forest inventories, we often spend too much effort measuring trees and not enough time trying to get an overall view of the total resources and functions of the forests. Similarly, we often spend a lot of time measuring, monitoring and reporting on the status forests. Yet, in spite of all our forest monitoring efforts, we find that we are constantly loosing forest lands. This may be because we fail to look at the forests in relation to human needs and in relation to the Earth's other land resources. *We can't see the Earth for the forests!* This paper explores some of the technical and political problems with current forest inventory and monitoring methods at the national and global level and presents some politically and scientifically-correct recommendations for solving them.

Buenos dias! The goal for this Symposium is to assure that the data and information produced in future inventory and monitoring programs are comparable, quality assured, available, and adequate for their intended purposes, thereby providing a reliable framework for characterization, assessment, and management of forest ecosystems in North America. In order to have comparable data we need to know what we see, see all that we need to know and to have common definitions, objectives and efficient approaches in our inventories.

There is an old saying *"We cannot see the forest for the trees"*—meaning, for this paper, that we place a lot of emphasis in our timber inventories without understanding how the other forest resources may be affected by management decisions. A companion saying may be *"We cannot see the Earth for the Forests."* As with trees, we often pay attention to the roles forests play in society, but often overlook the roles and functions other lands serve.

Data collection is expensive and time consuming. What can we do to ensure we have adequate and comparable information? This paper reviews explores some of the technical and political problems with current forest inventory and monitoring methods at the national and global level and presents some politically and scientifically correct recommendations for solving them.

Seeing the Trees

Knowledge of trees is for forest management. While we have excellent information on trees through our national inventories, do we all agree what is a tree and do we have all the information we need?

What Do We See?

Many countries have different definitions of what they consider a tree. Nations often base their definition of a tree on life form and a minimum height. The height threshold varies country to country (Lund 1998b). In the U.S. alone, there are at least four national definitions used by various federal agencies. There is no single tree definition for North America as a whole. A common North American definition is fundamental for having comparable forest data.

How Do We View Our Trees?

Forest inventories typically involve the use of sample plots unbiasedly located on forested lands but maximized to collect tree data. On those plots, we generally collect data on the species, d.b.h., height, crown characteristics, age, bark thickness, growth, volume, defects, etc.

During our inventories, however, we may ignore non-commercial species. For example, consider our experience in the western United States. We had very good inventories of our timber resources on our National Forests. However, we only collected data on trees that were of a commercial species at that time and on trees that were of a certain minimum size. In the early 1990s, researchers found that Pacific yew *(Taxus brevifolia)* was a good source of Taxol, a drug that has proven effective against ovarian cancer. Almost overnight, interest in and the demand for Pacific yew mushroomed. Because Pacific yew is generally a very small tree and was not considered a commercial species at the time of the forest surveys, the Forest Service did not inventory it. Consequently the inventory records contained little or no information about the abundance and distribution of the species. Because inventory data were lacking, some people assumed that the species was rare. Some moves were made to list the species as "threatened." If that were the case, then the species would have to be protected. In other words if listed as *threatened*, the plant could not be harvested. So here we have an example of a resource having a definite market, but federal laws restricting its harvest. Fortunately subsequent inventories have shown that the plant is widely distributed and fairly common throughout the Pacific Northwest. The development of its use continues.

How Can We Improve Our View?

One way to get around this problem to collect data on all tree species on the sample plots. This, however, only solves only one part of the much larger problem of seeing the forest as well as the trees.

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Seeing the Forests

Forests provide a variety of goods and services in addition to timber. Forests are sources of non-wood forest products, water, fisheries, minerals, biodiversity, and recreational opportunities. Forests filter the air, store water, accumulate carbon, and stabilize soils. These other functions are especially important at the national and global levels. We need common definitions in these subject areas as well or the ability to crosswalk, if we are to have comparable data in these subject areas. The Interim Resource Inventory Glossary (USDA Forest Service 1989) may be a good starting point in defining needed terms.

What Do We See?

As with "tree" a challenge in seeing the "forest" is to have a shared understanding of what is a "forest." In a recent survey, the International Union of Forestry Research Organization (IUFRO) identified over 90 different definitions of forest land (Lund 1998b). Mexico's definition differs from Canada's which differs from the USA's. In the US alone we have at least five different "official" definitions of forest land.

We can group the various forest land definitions into three broad categories—those describing an administrative unit, a type of land cover, or a land use. An administrative unit a designated area like a National Forest. ***Land cover** is something that covers the ground* (WWWebster 1998). ***Land use** is the predominant purpose for which an area is employed* (USDA Forest Service 1989). A given land use may take place on one, or more than one, piece of land and several land uses may occur on the same piece of land.

Identifying the population (administrative unit, land cover or land use) we wish to sample is key for land and resource management decisions. If we are going to have comparable data in North America, then as a minimum we should have a common definition of forest land.

How Do We View Our Forests?

As indicated above, we have very efficient inventory procedures for gathering tree information. Unfortunately the inventory designs we use to capture tree information may not be effective for gathering data about the other good and services offered from forest lands. Consequently, we often must use separate, less "tree efficient" systems to gather this additional information.

Inventories of biodiversity are essential when surveying new areas and wanting to seek out new non-wood forest products. They do require the employment of specialists in identifying plants and animals. They are most successful when done in small areas, limited to either plants or animals, and where one does not anticipate a great variety of species. For more information on how to inventory biodiversity, see Boyle and Boontawee (1995), Heywood and Watson (1995), and Yorks and Dabydeen (1998). While biodiversity inventories tell us what species may be available in a given area, they do not tell us what are used and what the abundance and distribution of the resource are.

Guidance on how to sample for wildlife is contained in Cooperider et al. (1983), for soils in Carter (1993), water (Chapman 1996), vegetation (Francis 1982), rangeland (National Research Council 1994), forests (Päivinen et al. 1994), agroforestry (Kohli et al. 1996 and Leakey et al. 1996), and recreation (Yuan et al. 1995). Readers may find techniques for conducting cultural surveys in Carter (1996) and Leakey et al. (1996).

Some inventory systems require direct observation in the field, others may be done indirectly by remote sensing, and yet others by a combination (Table 1). The use of remote sensing is especially good for inventorying and monitoring some of the functions and services of the forest, such as watershed protection, soil stabilization, and carbon sequestration. The amount and extent of vegetation cover which interpreters can generally extract from imagery reflect many of these activities. Some ecological functions may also be derived from remote sensing such as biodiversity. This depends on the type, resolution, and scale of the imagery being used. For a good review of how to use imagery for mapping vegetation, see Maus (1995).

A shortcoming of all these various inventory techniques is that they are often independent of one another - some times duplicating work and at other times leaving gaps. In addition, the gathering of resource information is not free - it demands resources (labor, technology, energy, transport, etc.) and therefore implies costs (Päivinen and Solberg 1996). Therefore, we need to carefully plan and maximize our data gathering activities.

How Can We Improve Our View?

To maximize data collection and to minimize costs consider using integrated or *multipurpose resource inventories (MRIs)*. *Multipurpose resource inventories* are data collection efforts **designed** to meet all or part of the information requirements

Table 1.—Direct and indirect methods of gathering field data (Correll et al.1997).

Direct methods include	Indirect sampling includes
Mark-recapture (banding/tagging)	Visual observation (counts of wildlife)
Dimensional plots (circular, rectangular, etc.)	Fixed-point/ground based photography
Point sampling (horizontal and vertical)	Aerial photography and videography
Transect/traverse sampling	Satellite imagery
Profile/content sampling (soils)	Laser profiling
Volume/content/flow sampling (air and water)	Radio telemetry
	Radar/sonar and other remote sensing systems

Table 2.— Minimum data for modeling the extent of forest resources (Päivinen et al.1994 and Lund 1998c).

Desired resource attribute	Source of information
Type of vegetation cover (overstory and understory)	Remote sensing, field surveys
Vegetation height (overstory and understory)	Field surveys
Percent vegetation cover	Field surveys
Soil type	Field surveys, existing maps
Climatic data	Weather Service
Topography (aspect, slope, elevation)	Digital elevation models, field surveys
Geographic co-ordinates	Field surveys (global positioning systems)
Past treatment, uses	Historical records, interviews, field surveys
Planned treatment, use	Interviews

for two or more resources, goods, products, services (such as timber production and watershed protection) and/or sectors (such as agriculture and forestry). Table 2 lists a minimum set of data to have on hand to help model the extent of forest resources and services.

Many of the papers presented in this Symposium addressed techniques for developing integrated inventories. Integrated or MRIs are technically possible. However, their design and implementation do require a considerable amount of negotiating and politicking. See Lund (1998c) for assistance.

Seeing the Earth

I believe we can all agree on the definition of "Earth"—our home planet and the source of all our needs and resources. However, do we agree on what kind of world we would like to have? Parties to the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, identified and agreed to common global goals including improving the quality of life and the environment, maintaining biodiversity, reducing deforestation, mitigating climate change and promoting sustainable resource management. Thus, we all have some common objectives for our resource management activities. It is these objectives that makes the need for comparable data between nations necessary.

What Do We See?

The title of this Symposium was "Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources" and I believed it accomplished its goals. To meet the needs from UNCED, future inventories and management strategies, however, must look beyond the trees and forests. To understand how to best manage trees and forests, we need to understand how forests relate to other land uses and covers and vice-versa. Agricultural lands are essential for providing food and forage for maintaining a healthy environment. Growing human populations are placing increasing demands for new lands for agriculture production. Increasing human populations drive a need for more agricultural lands which, in turn, affects how much forest land we may have. Figure 1 shows the trends in human population, agricultural lands and forest lands from 1961 projected to 2019. Note that with an increase in human population there is an increase in agricultural lands and a similar decrease in forest lands.

From such a graph, one can see that if we want to maintain or increase forest cover, we need to address human population growth and the need for increased productivity from all lands. Thus to maintain or increase forest cover in the future, we have to look beyond the trees and the forests.

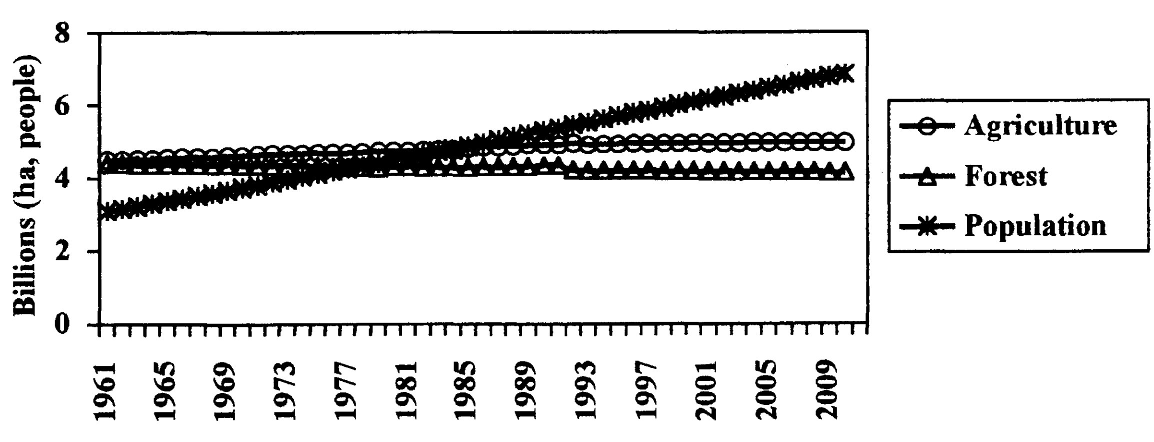

Figure 1.—Trends in land use 1961-2010. (Source: http://apps.fao.org/lim500/nph-wrap.pl?LandUse&Domain for LUI to 1994 and Lund and Iremonger 1998 for beyond.

How Do We View Our Earth?

Nations usually carry out assessments of agriculture and forested lands by separate entities. Often there is duplication of data collection, information gaps, etc. The bottom line is that we do not really know how much land currently serves the needs of agriculture and forestry, which lands are best suited for conversion to the alternate use, and where they are located. In order for decision makers to make more informed decisions, we need complete and up-to-date geo-referenced inventories.

Effective resource and ecosystem management to meet the needs of future populations, whether it is at the local or global level, must be underpinned by a sound knowledge base. Resource inventories provide the information necessary to create a picture of the current resources, and from these estimates of future supplies and shortages can be developed.

Currently our global estimates of forest and agricultural lands are questionable (Figure 2). With the increasing need for agricultural and forest lands, accurate estimates of current land cover and land use, and the rate at which the areas are changing, are all-important.

How Can We Improve Our View?

In order to plan for the living standards of the world's population in the future, we need to know (Lund and Iremonger 1998):

- The area and geographical location of land used for agriculture,
- The area and geographical location of land used for forest goods and services,
- The current and forecasted ratio of each to the world's population (an estimate of the amount needed per person), and
- The rate of change and distribution of change patterns in the population, agricultural lands and forest lands.

To look at the forests and beyond we have to have an objective, land classification system. Such a system should be based upon either land use or land cover. Mixing the two leads to confusion. Of the two systems, **land cover** is the most objective and easiest to determine from remote sensing. However, as shown in Figure 2, there is a variety of different land cover systems available and each can lead to different estimates and conclusions. The Food and Agriculture Organization (FAO) of the United Nations has developed an outstanding land cover classification system for its AFRICOVER program (Di Gregorio and Jansen 1998). FAO has coordinated and linked their system with other land cover and vegetation classification systems developed elsewhere including the U.S. This system has global utility, is very objective, and eliminates most of the Land Use classification problems.

Seeing It All

We gather information to improve decisions and, thus, to get a better use of our natural resources. The benefit of increased information is the wiser use of the resource base over time.

What Do We See?

Nearly all natural resource issues, whether they are environmental, social, economic, ecological or political, are national as well as global issues. For these reasons, there is an increasing need for the inventory and monitoring of all lands and waters and the sharing of the resulting information with the international community especially through the United Nations.

How Do We View Our Resources?

Current National and Global Assessments are sectorially oriented resulting in omissions and commission errors. The results of UNCED and the need to integrate our data collection and reporting should change the way we approach global assessments in the next century. Nearly every nation agreed to the documents resulting from UNCED. Therefore they have some responsibility for gathering and providing the necessary data. Currently, however, there is no agreed

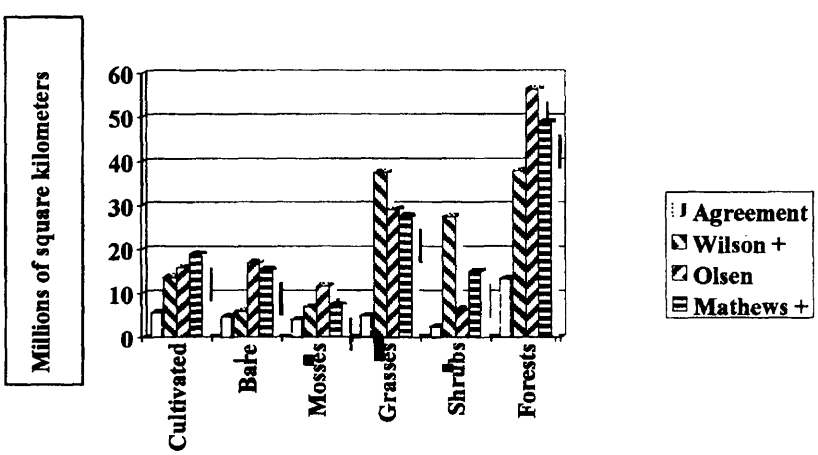

Figure 2.—Estimates of land cover by various sources. (Source: DeFires and Townshend 1994.)

system in place that gives the necessary truly integrated picture of the world's resources. Without such a system, developing an effective strategy for planning for future needs is not possible.

In 1997, the International Union of Forestry Research Organizations (IUFRO) Subject Group 4.02, with the support of the European Forest Institute (EFI) and the U.S. Department of Agriculture, Forest Service (USFS) conducted a literature review and survey of countries using multipurpose resource inventories. Lund (1998a) found:

Σ There is considerable interest in developing MRIs throughout the world. As nations implement the various agreements from UNCED, the need for MRIs will increase.

- Most existing MRIs focus on the environmental and economic needs.
- Most reported had a national scope.
- Most MRIs had foresters involved in the design. However, a surprisingly large number had other disciplines involved in the development of the inventory.
- Inventory designers made most decisions through an interdisciplinary team effort.
- National level inventories are collecting some of the data because of UNCED and other international obligations. None were collecting all the information needed through the inventory reported. The countries may be gathering the remaining information through additional surveys.
- Most MRIs used a systematic sample design, probably with some form of stratification. This design should have use outside the 'forests' as well.
- Most surveys used remote sensing. Airborne (aerial photography, videography) remote sensing was the most common.
- Most surveys employed a circular (including the variable radius or Bitterlich plot design) configuration. Many of these were nested to gather a variety of vegetation data.
- Nearly all those surveyed reported that the MRIs met most of their needs. The biggest problems were costs and time. These problems are common to any types of inventories.

How Can We Improve Our View?

To properly manage our limited natural resources, we have to see more than the trees and more than the forests. We need to see how our trees and forests fit in with the rest of the Earth's land cover and uses. We can improve future assessments by:

- Integrating data collection efforts to cover all lands and resources.
- To keep costs low, using latest technologies and sharing assets (imagery, personnel, equipment, and facilities) to get the work done.
- Using remote sensing to map land cover according to an internationally acceptable classification scheme like that used in the United Nations' AFRICOVER project.
- Using statistical sampling to determine vegetation and its condition and a sub-sample of field plots to determine land use.
- Establishing a network of permanent plots across all lands. Plots may be field plots or large scale, high resolution imagery.
- Collecting and storing basic (uninterpreted) data according to international definitions and standards including:
  - Name/address of land owner, location of tract, and site information
  - Vegetation species grown or present, height, and percent cover
  - Identification of person collecting data and date of collection
  - Coordinates of plots
  - Land cover type from remote sensing
  - Topographic information from digital elevation models (DEMs).
- Merging field data with remote sensing/ancillary data and where correlations exist, building necessary models.
- Using remote sensing and ancillary data to expand field plot data to entire inventory unit.
- Combining all data in a common GIS.
- Collecting and reporting results in conformity with the guidelines and recommendations given by the international bodies including timing, concepts, standards, definitions, and coverage of data.
- Using remote sensing to monitor changes in land cover. Where changes occur, sub sample to determine the affect of the change and the cause.

By following these suggestions, we should be able to see the trees, forests and the Earth. Muchas gracias!

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References

Boyle, Timothy J.B.; Boontawee, Boonchoob (eds.) 1995. Measuring and monitoring biodiversity in tropical and temperate forests. Proceedings of an IUFRO Symposium. 27 August - 2 September 1994. Chiang Mai, Thailand. Bogor, Indonesia: Center for International Forestry Research. 395 p.

Carter, Jane. 1996. Recent approaches to participatory forest resource assessment. Rural Development Forestry Study Guide 2. London, UK: Overseas Development Institute. 322 p.

Carter, M.R. (ed.) 1993. Soil sampling and methods of analysis. Boca Raton, FL: Lewis Publishers. 864 p.

Chapman, D. 1996. Water quality assessment. 2nd edition. New York, NY: Chapman & Hall. 640 p.

Cooperider, Allen Y.; Boyd, Raymond J.; Stuart, Hanson R. (eds.) 1986. Inventory and monitoring of wildlife habitat. Denver, CO: U.S. Department of Interior, Bureau of Land Management, Service Centre. 858 p.

Correll, Cynthia S.; Askren, Catherine A.; Smith, W. Brad; Holmes, Rob; Lachwoski, Henry M.; Panos, Gust C., Fincher, James M. 1997. MT30 - Data management, collection, and inventory. Draft report. Washington, DC: U.S. Department of Agriculture, Forest Service. 29 p.

DeFries, R.S.; Townshend, J. 1994, Global land cover: Comparison of ground-based data sets to classifications with AVHRR data. In: Foody, G.; Curran, P. (eds.) Environmental Remote Sensing from Regional to Global Scales. New York: John Wiley and Sons, U.K.: 84-110.

Di Gregorio, A.; Jansen, L.J.M. 1998. Land cover classification system: classification concepts and user manual. FAO GCP/RAF/

287/ITA Africover East Africa Project/AGLS/SDRN, Nairobi/ Rome.
Francis, Richard E. 1982. Vegetation measurements for multiresource inventories...an ecological concept. In: Brann, Thomas B.; House, Louis O.; Lund, H. Gyde (eds.) In-place resource inventories: principles and practices: Proceedings of a national workshop; 9-14 August 1981; Orono, ME. SAF 82-02. Bethesda, MD: Society of American Foresters: 339-344.
Heywood, V.H.; Watson, R.T. (eds.) 1995. Global biodiversity assessment. Cambridge, UK: University of Cambridge Press. 1140 p.
Kohli, R.K.; Arya, K.S.; Atul (eds.) 1996. Proceedings of the IUFRO-DNAES International meeting on resource inventory techniques to support agroforestry and environment. 1-3 October 1996, Chandigarh, India. Chandigarh, India: HKT Publications. 387 p.
Leakey, R.R.B.; Temu, A.B.; Melnyk, M; Vantomme, P. (eds.) 1996. Domestication and commercialization of non-timber forest products in agroforestry systems. Proceedings of an international conference; 19-23 February 1996; Nairobi, Kenya. Non-wood forest products 9. Rome, Italy: Food and Agriculture Organization of the United Nations. 297 p.
Lund, H. Gyde. 1998a. A comparison study of multipurpose resource inventories (MRIs) throughout the world. Working Paper No. 14. Joensuu, Finland: European Forest Institute. 46 p.
Lund, H. Gyde (ed.) 1998b. Definitions of deforestation, afforestation, and reforestation. Report prepared for IUFRO Working Unit 6.03.02. Misc. pagination. http://home.att.net/~gklund/DEFpaper.html.
Lund, H. Gyde (ed.) 1998c. IUFRO Guidelines for designing multipurpose resource inventories. World Series Vol. 8. Vienna, Austria: International Union of Forestry Research Organizations. 216 p.
Lund, H. Gyde; Iremonger, Susan. 1998 Omissions, commissions, and decisions: the need for integrated resource assessments. In: Proceedings First International Conference on Geospatial Information in Agriculture and Forestry. Decision Support, Technology, and Applications. 1-3 June 1998. Lake Buena Vista, FL. Ann Arbor, MI: ERIM International, Inc. Volume I: 182-189.
Maus, Paul (ed.) 1995. Guidelines for the use of digital imagery for vegetation mapping. EM-7140-25. Washington, DC: U.S. Department of Agriculture, Forest Service. 125 p. + appendices.
National Research Council. 1994. Rangeland health - new methods to classify, inventory and monitor rangelands. Washington, DC: National Academy Press. 180 p.
Päivinen, Risto; Lund, H. Gyde; Poso, Simo; Zawila-Niedzwiecki, Tomasz. (eds.) 1994. IUFRO international guidelines for forest monitoring. IUFRO World Series Report 5. Vienna, Austria. International Union of Forestry Research Organizations. 102 p.
Päivinen, Risto; Solberg, Birger. 1996. From raw data to value-added forest inventory information. In: Korpilahti, Eeva: Mikkelä, Heli; Salonen, Tommi (eds.) Caring for the Forest: Research in a Changing World. Congress Report Volume II. IUFRO XX World Congress; 6-12 August 1995; Tampere, Finland. Jyväskylä, Finland: Gummerus Printing: 410-414.
USDA Forest Service. 1989. Interim resource inventory glossary. File 1900. Washington, DC: U.S. Department of Agriculture, Forest Service. 96 p. http://forestry.miningco.com/blforgls.htm
WWWebster. 1998. Dictionary. http://www.m-w.com/cgi-bin/dictionary
York, Thad E.; Dabydeen, Simon. 1998. Modification of the Whittaker sampling technique to assess plant diversity in forested natural areas. Natural Areas Journal 18(2):185-189.
Yuan, Susan, et al.1995. Techniques and equipment for gathering visitor use data on recreation sites. 2300 Recreation. 9523-2838 MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Technology and Development Center. 78 p.

Retos Para Lograr el Manejo Integrado y Sustenable de los Ecosistemas Forestales[1]

Hugo Manzanilla[2]

Resumen—En México al igual que en otras partes del mundo las herramientas más importantes del Manejo Integrado y Sustentable de los Ecosistemas Forestales son los inventarios y el monitoreo continuo que se enfrentan, a un gran número de retos que hasta ahora no han sido posibles superar y que se reflejan en el hecho irrefutable de que el Manejo se ha vuelto cada vez más complejo, caro y difícil de lograr.

Para poder superar estos retos es necesario entender que está ocurriendo, por lo que se requiere repasar algunos conceptos relacionados, tales como el de la Biosfera y los Ecosistemas Forestales así como de sus funciones ligadas con la vida y las actividades humanas. Los Ecosistemas Forestales son sumamente productivos y han sido, son y seguirán siendo claves para el desarrollo de las economías del mundo y para la permanencia de la vida en este planeta. En muchos casos han servido de pivote para el desarrollo, aunque paradójicamente, a costa de su propia destrucción.

Para analizar su importancia y poder estudiarlos se les identifica con por lo menos seis diferentes sistemas de producción, los de bienes y/o servicios Ecológicos, Energéticos, Recreativos y/o Culturales, Alimenticios y/o Medicinales y los de bienes Primarios y los Procesados.

Estos Sistemas son sumamente complejos e implican profundos conocimientos, que apenas empezamos a entender, sobre los procesos naturales, económicos, políticos y sociales. Muy especialmente si queremos aprovecharlos integradamente y de acuerdo con los principios de Sustentabilidad.

El gran reto evidentemente no sólo consiste en dar respuesta a los enormes huecos del conocimiento que se tiene sobre estos procesos integrados sino en algo que a simple vista parece muy sencillo pero que en la práctica resulta mucho más complicado y que se puede tratar de sintetizar en la siguiente cuestión. ¿Cómo se puede garantizar que se buscará la respuesta de una manera continua y ordenada a través de largos períodos de tiempo como lo exigen los procesos naturales y los cada día más cambiantes, complejos y demandantes procesos sociales? Bien sabido es, que los desarrollos tecnológicos en general han rebasado las capacidades de la sociedad de organizarse para aprovecharlos ventajosamente en beneficio del ser humano, muy especialmente en cuanto se refiere a la sociedad rural y los sistemas de producción ligados con los recursos naturales.

En México sin duda alguna existe una enorme variedad de Ecosistemas Forestales relacionados con un gran mosaico cultural y socioeconómico muy complejo, que se refleja en un desarrollo muy disparejo del conocimiento, de la economía, de la sociedad y sobre todo de las organizaciones, para lograr el Manejo Integrado y Sustentable, por lo que los retos son innumerables.

Sin embargo, si es necesario señalar el Reto más importante, sin duda alguna se pensaría primero en lograr la organización activa, la que no sólo se ocupe en filosofar, criticar y planear, sino en la que se arremangue las mangas y se ponga a trabajar hasta que se resuelvan los problemas, que la constituya gentes que se esfuercen más allá del mínimo requerido, que vean más allá de sus escritorios, que tengan una visión de la organización en su totalidad y que sepan como hacerle para que funcione toda la tecnología en conjunto.

La respuesta sin duda alguna está en manos de la propia sociedad, es decir, nosotros mismos, mediante la creación de Organismos No Gubernamentales que aprovechen las enormes ventajas que tienen, de poder responder mucho más ágilmente a los cambios tecnológicos y las demandas de la sociedad por períodos de tiempo más largos acordes con los que se requieren para conocer los procesos dinámicos y las interrelaciones de los diferentes sistemas de producción de los Ecosistemas Forestales.

En México al igual que en Canadá, Estados Unidos y otras partes del mundo las herramientas más importantes del manejo integrado y sustentable de los Ecosistemas Forestales son los inventarios y el monitoreo continuo, que se enfrentan, al gran reto de integración de resultados, pero más que todo, al de conocer los procesos naturales de una manera holística, por largos períodos de tiempo. Aparentemente estos retos y otros muchos hasta ahora no han sido superados y se reflejan en el hecho irrefutable de que el manejo forestal integrado y sustentable, es actualmente muy complejo, caro y difícil de lograr.

Para entender mejor lo anterior e identificar los verdaderos retos de integración para que los tres países podamos trabajar juntos voy a hacer primeramente un breve repaso de algunos conceptos básicos, ligados principalmente con la biosfera, los Ecosistemas Forestales y su manejo integrado y sustentable. Voy a resaltar lo complejo que representa utilizar resultados integrados de una manera práctica, barata y en el menor tiempo posible, desde una perspectiva muy amplia, de manera que pueda ser válida para los tres países participantes, aunque utilice algunos ejemplos referidos a México y finalmente voy a hacer algunas consideraciones señalando los retos y una propuesta para trabajar conjuntamente entre los tres países.

La Biosfera y los Ecosistemas Forestales

La Biosfera es el entorno del planeta tierra en donde se desarrollan y ocurren la mayoría de los procesos ligados con los seres vivos. Es en la Biosfera en donde se llevan a cabo las funciones principales ligadas con la vida y con las actividades económicas de la humanidad. Es la responsable de regular el clima y la composición gaseosa de la atmósfera, asimila los productos desechados por las actividades humanas y los propios procesos naturales, tiene la gran función de mantener

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la biodiversidad así como de proveer de recursos naturales renovables y no renovables. Algunos autores se refieren también a su capacidad de filtrar los rayos solares que representan un recurso inagotable de energía, que se requiere, para casi todos los procesos que permiten la vida sobre este planeta.

Una vez explicado brevemente lo anterior entonces ya podemos hablar de los Ecosistemas Forestales que definidos de una manera simple son aquellos espacios de la biosfera en donde se desarrolla la vegetación forestal nativa y/o introducida como el componente más importante de la biota.

Los Ecosistemas Forestales son la expresión máxima de la biosfera, ya que casi todas las funciones atribuibles a ella, ligadas con las actividades económicas y la vida, son también atribuibles a ellos y así se ocupan entre otras cosas de influir en la regulación del clima y la composición gaseosa de la atmósfera, en asimilar productos desechados por las actividades humanas y los propios procesos naturales, de mantener la biodiversidad, y también de proveer de recursos naturales renovables y no renovables.

El ecosistema forestal como su nombre lleva implícito es un sistema natural de producción que aporta una gran variedad de productos y servicios. Como es sabido tienen tres grandes funciones, la ecológica la económica y la social. Para su análisis, sin embargo los he agrupado dentro de seis grandes sistemas de producción, el primero, el ecológico que se da en forma completamente natural en tanto que los otros cinco requieren un cierto grado de intervención humana para obtener beneficios económicos y sociales:

- El ecológico donde se obtiene una gran cantidad de bienes y servicios ligados con la regulación del clima, la composición gaseosa de la atmósfera, el mantenimiento de la biodiversidad, la asimilación de productos desechados por las actividades humanas y los propios procesos naturales, etc.,
- El energético que proporciona entre otras cosas leña combustible, y contribuye a regular el régimen hidrológico para evitar erosión y azolve de presas generadoras de energía.
- El recreativo y cultural que representan un potencial enorme de ingresos a través del ecoturismo y la cacería deportiva, entre otras cosas.
- Los alimenticios y medicinales dentro de los cuales podemos incluir las cuencas naturales y las diseñadas por el hombre para captación de agua para beber, por cierto cada vez más escasa en las grandes urbes, y para riego de otros sistemas de producción como el agrícola y el ganadero, tan importantes para disminuir el hambre de algunas poblaciones, así como la aportación de productos con propiedades medicinales para la cura de muchas enfermedades.
- Otro sistema de producción es el de bienes primarios y es quizás con el que más estamos familiarizado, ya que utiliza la materia prima que brindan los Ecosistemas Forestales, sin darle un mayor valor agregado que el que se obtiene al cortar un árbol en trozas o al cosechar la resina, el látex, frutos o cualquier parte vegetativa de una planta.
- El de bienes procesados que busca por medio de la transformación tecnológica del producto maderable o no, dar un mayor valor agregado al bien.

Es muy importante entender que aunque enfoquemos la atención en aprovechar productos de uno solo de los sistemas de producción del ecosistema forestal y no nos interese el obtener productos de los otros sistemas, estamos produciendo un efecto similar al que se ve cuando arrojamos un guijarro sobre la tranquila superficie de un depósito de agua. Las ondas que se producen se expanden sobre toda la superficie del agua, solo que los efectos para el caso de los Ecosistemas Forestales no son tan simples y muchas veces ni tan inofensivos, ya que pueden llegar a resultar catastróficos, como ocurre cuando el agua se encuentra cargada de sedimentos de suelos arrastrados por ella misma. Esto sucede cuando se rompen los hilos invisibles del equilibrio que fija la naturaleza entre los diferentes componentes de los Ecosistemas Forestales y que la mayoría de las veces son desconocidos para nosotros.

El Manejo Integrado y Sustentable de los Ecosistemas Forestales

Para poder saber que debemos inventariar y monitorear y a que retos nos enfrentamos para integrar la información, debemos preguntarnos: ¿qué debemos hacer? Siendo tan productivos los Ecosistemas Forestales y considerando que ya están ahí para satisfacer nuestras necesidades, la respuesta lógica y muy simple a primera vista es: aprovechar todos los bienes y servicios que nos brindan los sistemas de producción de los Ecosistemas Forestales de una manera integrada y sustentable, en vez de destruirlos, como ha venido ocurriendo a lo largo de la historia de la humanidad en prácticamente todo el mundo. Pero, ¿Porqué entonces si son tan productivos los hemos destruido?

Con el ánimo de contribuir a entender porqué, a pesar de que los Ecosistemas Forestales ofrecen tanto a la humanidad, han venido siendo destruidos en prácticamente todas las naciones del mundo, en diferentes etapas de su desarrollo es necesario entender primero algunas cuestiones muy elementales ligadas con el desarrollo de los pueblos y los sistemas de mercadeo, por lo que debemos preguntarnos. ¿Qué hemos hecho y qué estamos haciendo con los Ecosistemas Forestales?

Para responder a esta cuestión me gustaría iniciar (Ver Fig. 1) por el proceso que se da cuando alguno de nosotros como consumidor trata de obtener cualquier producto para satisfacer nuestras necesidades, la primera reacción es que demandamos del industrial o del comerciante que lo vende, más producto por menos dinero (1), en tanto que ellos quieren exactamente lo contrario, (2) más dinero por menos producto. Para conseguirlo sin afectar tanto al consumidor lo que hacen es que castigan a los productores o a los propietarios, obteniendo (1) más producto por menos dinero a pesar del deseo de los productores de vender menos (2) producto por más dinero. La forma en que los productores buscan solucionar su problema es demandando de los técnicos y de los Ecosistemas Forestales (3) más producto por menos inversión de capital, tiempo, tecnología y conocimientos, en tanto que (4) los Ecosistemas Forestales requieren que se produzca sin alterar de manera irreversible sus procesos naturales, mayor inversión de tiempo, capital, conocimientos y tecnologías.

La sociedad en su proceso de desarrollo demanda (5) no solo productos derivados de los Ecosistemas Forestales sino

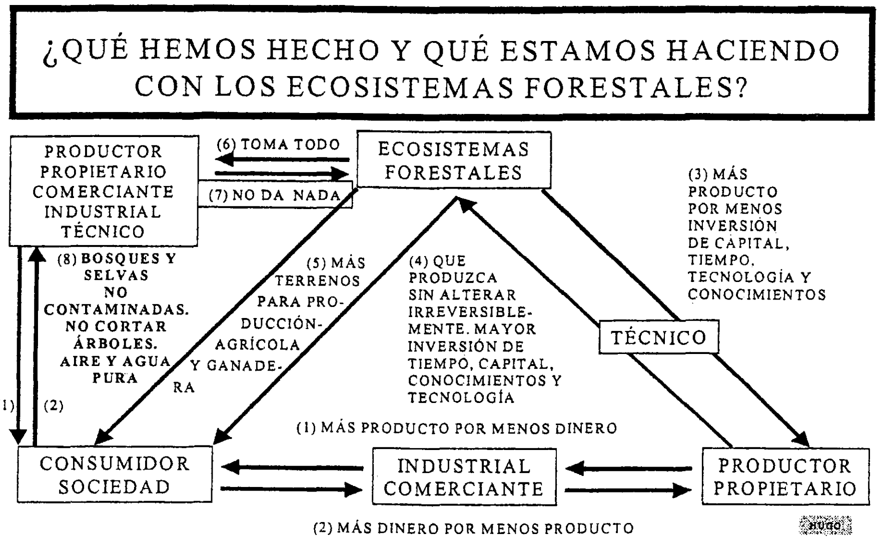

Figura 1.— Principales procesos de las sociedades en desarrollo que conducen a la destrucción de los Ecosistemas Forestales.

agrícolas y ganaderos principalmente, por lo que (6) se derriban los bosques y selvas, por productores, propietarios, comerciantes, técnicos, etc. Que no (7) retornan nada a los Ecosistemas Forestales, toman todo y no dan nada a cambio, de la misma manera ocurre con aquellos que hacen cortas ilegales o sin alguna técnica. Los daños al ecosistema forestal en muchos casos se vuelven irreversibles y no olvidemos la liga tan vital que tienen con las funciones de la biosfera. Esa misma sociedad, que a través de sus demandas empuja a la destrucción o a la degradación de los sistemas de producción de los Ecosistemas Forestales es la que también (8) paradójicamente demanda bosques y selvas no contaminados, intocables, por que se quieren bosques intocables, aire y agua puras, áreas que capten y filtren los desechos de las actividades humanas, especialmente de las grandes urbes citadinas y los centros industriales.

Todo esto conduce casi siempre a un deterioro de los Ecosistemas Forestales transformándolos en muchos casos en México, en sistemas de producción deficitarios y poco atractivos para las actividades económicas y para las funciones derivadas de la producción de los bienes y servicios ecológicos, funciones que están íntimamente ligadas con la vida, como hemos visto anteriormente. Enseguida, casi siempre, lo que queda del ecosistema es cortado o quemado para establecer otro tipo de actividad económica temporal y de subsistencia, como la agricultura o la ganadería de una manera extensiva, acompañada de empobrecimiento, erosión y degradación de los suelos y su posterior abandono, lo que provoca en muchos casos, procesos irreversibles, altamente dañinos a la economía y a la vida misma. En México, según datos del inventario forestal de gran visión de 1994 cerca de veintidós millones de hectáreas son áreas forestales perturbadas o sea, áreas forestales que han cambiado a otro uso y que presentan diferentes niveles de erosión debido a estos procesos.

De los cerca de 50 millones de hectáreas de bosques y selvas reportadas en el mismo inventario de 1994, actualmente se desconoce que porcentaje representa aquella área cubierta con bosques de escaso o nulo valor comercial y por lo tanto candidata a sufrir las transformaciones señaladas anteriormente.

De aquí pueden surgir los primeros retos de monitoreo para México. Conocer la superficie forestal total actual. ¿Qué superficie se destruye anualmente? ¿Qué superficie ocupa el bosque degradado con escaso o nulo valor comercial? Pero antes de seguir haciendo una lista interminable de retos específicos que seguramente ya fueron tocados por algunos de los ponentes que han expuesto a lo largo de estos 4 días, quisiera aprovechar el tiempo, para identificar retos que son comunes a los tres países participantes para lograr la integración.

Retos Para Lograr el Manejo Integrado Sustentable de los Ecosistemas Forestales

Si la sociedad está decidida, como parece estarlo, a aprovechar integrada y sustentablemente los Ecosistemas Forestales, debe estar consciente entonces de lo que significa aprovechar integrada y sustentablemente los Ecosistemas Forestales. ¿Es una respuesta única? ¿Sencilla? O, ¿Son varias diferentes? Algunos en la audiencia tal vez piensen con razón, de que esto podría ser el tema de un Simposio. Sin embargo, hay una pequeña lista de algunos aspectos ligados con esta cuestión, que cada uno implica una serie de acciones interrelacionadas que requieren la integración de esfuerzos casi simultáneos hacia un fin común, y así podremos decir que la respuesta a lo anterior implica entre otras cosas:

- Satisfacer las necesidades de las generaciones actuales aprovechando integradamente los sistemas de producción de los Ecosistemas Forestales sin comprometer su productividad para las generaciones futuras.
- Conocer más y educar a la sociedad acerca de la importancia que tienen los Ecosistemas Forestales sobre la vida y el desarrollo de las actividades económicas.

- Fortalecer la voluntad de hacer y de respetar programas a corto, mediano y largo plazo, por parte de la sociedad, el gobierno, los inversionistas, los comerciantes, los propietarios, los industriales, los científicos, los técnicos, etc.
- Aumentar la estabilidad social, económica, y política.
- Proyectar a largo plazo, ejecutar de inmediato y dar seguimiento continuamente a las acciones para hacer las correcciones necesarias.
- Conocer a corto, mediano y largo plazo, los procesos naturales ligados con los Ecosistemas Forestales, así como el impacto de las actividades humanas, voluntarias o involuntarias, sobre sus procesos evolutivos.
- Desarrollar sistemas integradores de almacenamiento, análisis e interpretación de datos, conocimientos y experiencias, que favorezcan las actividades inter y multidisciplinarias, así como la aplicación de las innovaciones tecnológicas.
- Atraer inversiones con proyectos innovadores para mejorar las cadenas productivas, y las capacidades y calidades de los responsables de aplicarlos, así como para garantizar la continuidad de las acciones operativas.
- Contar con organizaciones estables, confiables, que puedan garantizar la integración de la información así como la calidad, la continuidad, el control, la aplicación de los planes y programas operativos de manejo integrado y sustentable acordes con los largos períodos de tiempo de los procesos naturales e inducidos de los Ecosistemas Forestales.

Ya este último punto vamos a dedicarle mas atención, ya que creemos que para lograr una real vinculación es el mayor reto, al que se enfrentan los tres países, muy especialmente, si se quiere lograr la integración y trabajar juntos.

Retos Para la Integracion de los Tres Paises

Es ampliamente estudiado y reconocido que el desarrollo tecnológico ha rebasado las capacidades que tienen los gobiernos para aprovecharlo a través de sus estructuras, no es extraño por ello que hayan proliferado las organizaciones no gubernamentales. Sin embargo, se requiere que la sociedad cree nuevas estructuras de organización controladas por ella misma, con participación de los gobiernos, por cierto, los acuerdos de cooperación signados por Canadá y Estados Unidos con México, no lo prohiben, sino que incluso lo estimulan, estas organizaciones deben ser una respuesta a lo que se necesita para contar con:

- Sistemas de producción integrados, sustentables, flexibles que respondan con rapidez, oportunidad y variedad de productos capaces de competir con las economías de producción orientadas por la demanda de los mercados y la sociedad sin dañar de manera irreversible nuestros Ecosistemas Forestales.
- Una estructura organizacional y ocupacional confiable, ágil, flexible y versátil que garantice continuidad de acciones a través de largos períodos de tiempo, basada en la estructura de redes, de equipos multidisciplinarios de trabajo y en la ingeniería de sistemas capaz de aprovechar las organizaciones y tecnologías existentes, así como de aportar soluciones creativas e inteligentes a los problemas ligados con los sistemas de producción de los Ecosistemas Forestales.
- Una estrategia de mejora continua que demuestre habilidad y capacidad para participar en la identificación, análisis, y solución de problemas que mermen la calidad y la productividad de los sistemas de producción impidiendo la sustentabilidad.

El mayor reto de la integración es que la sociedad requiere crear nuevas estructuras de organización que:

- Tengan la capacidad de generar información suficiente, confiable, y oportuna. Sin olvidar que una información deficiente afecta:
  1. La planeación, ejecución y evaluación.
  2. La asignación de recursos.
  3. La programación.
  4. La toma de decisiones.
  5. La validación y la transferencia de tecnología.
- Sepan más acerca de las relaciones de los Ecosistemas Forestales con la sociedad, ya que seguirán siendo destruidos, por lo menos en México, hasta que logremos que los dueños y productores reciban ingresos por los bienes y servicios que producen, de tal manera que les convenzan de que les son mas útiles en pie, que destruidos.
- Procuren que el diseño del manejo de la información realmente contribuya al logro del manejo integrado de los sistemas de producción de los Ecosistemas Forestales y a que el conocimiento que se genere y se aplique sea integrador (Ver Fig. 2), considerando las diferentes repercusiones en los Ecosistemas Forestales, la política, la economía, la sociedad y otros sistemas de producción colaterales.
- Jerarquicen la información relativa al conocimiento y las tecnologías para los diferentes niveles que la requieren, desde un investigador a mayor detalle, hasta el nivel nacional que debe estar referido a grandes hechos y estadísticas.
- Contribuya a entender los sistemas de producción de los Ecosistemas Forestales especialmente en lo que se refiere a los excedentes, tanto los que retornan para mantener el ecosistema en equilibrio (Ver Fig. 3) como los que pueden ser retirados como excedentes del sistema sin causarle daños irreversibles (Ver Fig. 4) introduciendo otros componentes que permitan aumentar la producción.
- Den respuesta al gran reto de integrar los conocimientos en información útil, para que realmente sea el factor más importante de la producción. Es cada vez mas aceptado que el conocimiento y la tecnología son los componentes más importantes de la producción, ya que pueden contribuir positivamente al desarrollo de los mercados (Fig. 5).

Todo lo anterior debe hacerse de tal forma que no olvidemos que solo es posible vivir en armonía con la naturaleza en la medida que más nos integremos a ella o sea en la medida que mejor la imitemos y para eso debemos conocerla integralmente. Hay sobrados ejemplos en el mundo de los precios tan altos que estamos pagando, por no hacerlo. Requerimos integrar mucha mas información acerca de los procesos naturales a corto, mediano y sobre todo a largo plazo.

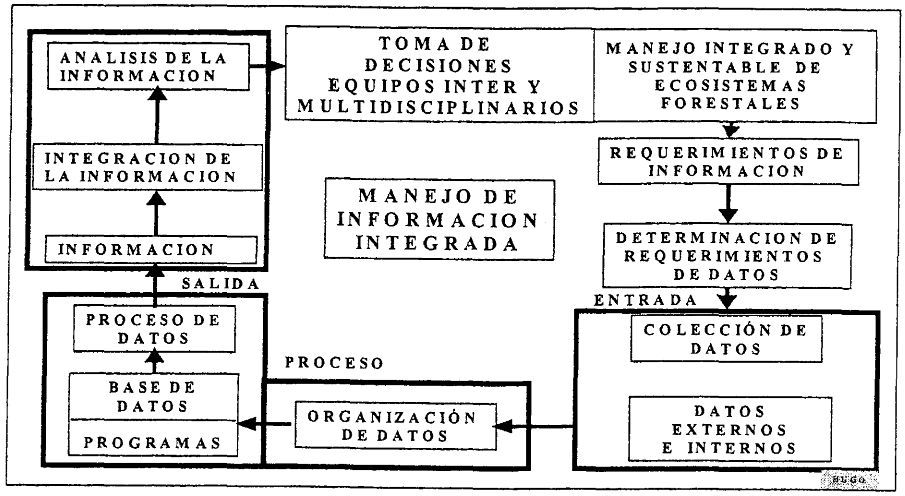

Figura 2.— Manejo de Información Integrada

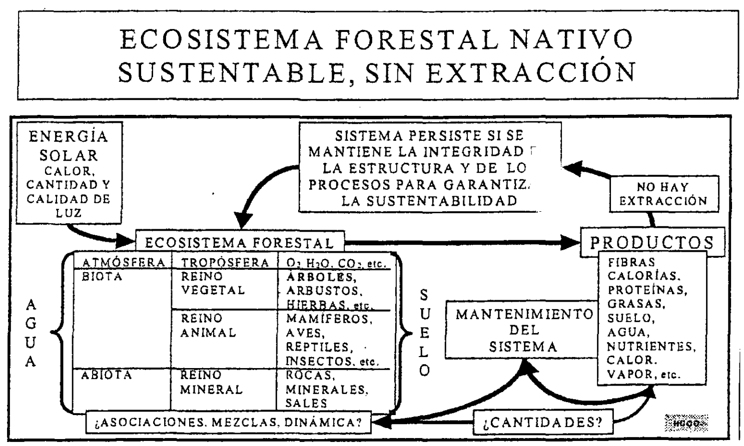

Figura 3.— Ecosistema Forestal sin aprovechamiento.

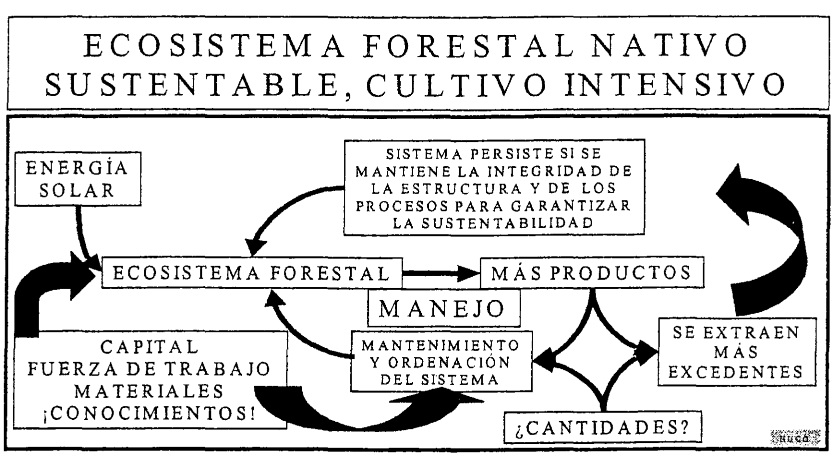

Figura 4.— Ecosistema Forestal bajo cultivo intensivo

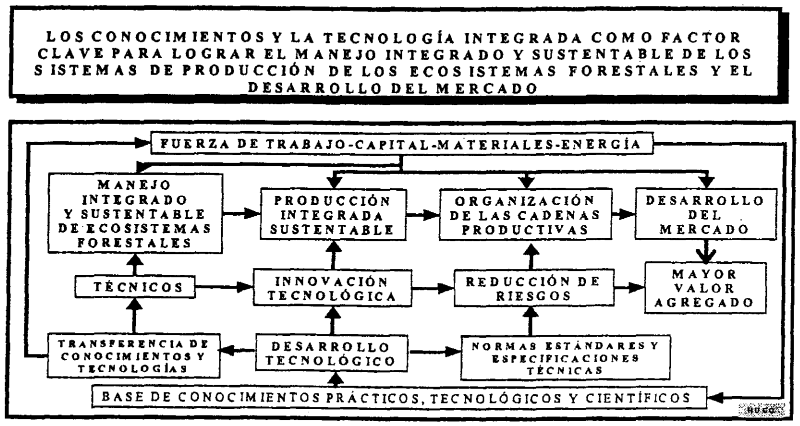

Figura 5.— Los conocimientos prácticos, tecnológicos y científicos.

Recomendacion

Por ello insistimos en la urgente necesidad de la creación de una organización civil integradora por parte de cada país, fuertemente vinculada a sus realidades políticas, económicas, ecológicas y sociales, que tenga capacidad para generar, adaptar, transferir, aplicar conocimientos y tecnologías así como administrar, comercializar, educar, culturizar, capacitar y asesorar en todo lo relativo, a los sistemas de producción de los Ecosistemas Forestales.

Es muy rara la institución pública, organización política o de gobierno que quiera apostar mas allá de su período de influencia y si lo hace, el gobierno entrante, la organización política o el jefe entrante con mayor influencia, se encarga de corregir ese error, de querer influir dentro de su período de poder, cancelando ese tipo de trabajos. Los dueños, comerciantes o industriales buscan también recuperar su inversión en el menor tiempo posible como también hemos visto. Sin embargo por organizaciones como estas, integradoras, que van a contribuir a resolver problemas vitales para la sociedad y qué se vuelven autofinanciables, estoy seguro de que si hay quien apueste e invierta por ellas.

Finalmente con ánimo de contribuir a este apasionado tema de retos para lograr la integración, quisiera agregar las siguientes reflexiones. Debemos procurar que nuestros esfuerzos eviten que sigamos generando información fragmentada, difícil de recopilar sino más bien deben ser dirigidos a integrar en un todo nuestros conocimientos, buscando entender mejor los procesos naturales y sus interrelaciones con las actividades humanas. La sociedad esta demandando gentes u organizaciones activas, que no solo se ocupen de filosofar, criticar, hacer planes, o entregar resultados aislados, sino que se arremanguen las mangas y se pongan a trabajar hasta que se resuelvan los problemas, que la constituyan gentes que se esfuercen mas allá del mínimo requerido, que vean mas allá de sus escritorios, que sepan como la tecnología funciona de una manera integrada, en conjunto y sea capaz de tener una visión de la organización que se requiere en su totalidad para aprovechar integrada y sustentablemente los sistemas de producción de los Ecosistemas Forestales.

Challenges and Opportunities for Integrating Inventory and Monitoring Into the Work of a Land Management Agency[1]

Douglas S. Powell[2]

Abstract—Inventorying and monitoring the forest ecosystems of the United States are important missions of the U.S. Forest Service in order for it to know if it is meeting its management objectives, to determine the best adjustments to make to management, and to meet the public's needs for resource information. Despite the agency's long history and substantial investments in inventorying and monitoring, the Forest Service still faces many challenges and opportunities. New and increasing demands for information by both the agency and the public; agency culture, organization and procedures; and the need for perpetual, continuous forest ecosystem inventorying and monitoring contribute to these challenges. This paper explores these challenges and offers some approaches for dealing with them. The challenges are organized into eight categories: (1) information management, (2) indicator development and selection, (3) inventory and monitoring methods, (4) scale issues, (5) adaptive management, (6) science, research, and development, (7) organizational constraints, and (8) coordination with others. Each section contains a description and rationale for the category, a discussion of the major challenges to integration of inventorying and monitoring for the Forest Service, and some suggestions for overcoming these obstacles and barriers. The paper presents a Forest Service perspective. However, since these challenges are not unique to the Forest Service or to the United States, the paper has the potential for much broader application.

Inventorying and monitoring the forest ecosystems of the United States are important missions of the U.S. Forest Service in order for it to know if it is meeting its management objectives, to determine the best adjustments to make to management, and to meet the public's needs for resource information. The agency has a long history and has made substantial investments in design and implementation of inventory and monitoring systems. Despite this experience, the Forest Service faces numerous challenges and opportunities. These are attributable to a variety of causes, such as new and increasing demands for information or agency organization and procedures. Others are perpetual features of inventory and monitoring forest ecosystems that must be addressed continually. This paper will explore these challenges and offer some approaches for dealing with them. While the paper is presented from an agency's perspective, it has broader application in that these challenges are not unique to the Forest Service or to the United States. Other agencies, organizations, and countries that conduct inventories and monitoring will recognize similar issues, concerns, and opportunities.

Information Management

Information management is a structured process to bring quality information in the right form to the right people at the right time to support sound and deliberate decisions, and to generate ideas (USDA Forest Service 1992). It encompasses practically every aspect of inventory and monitoring, including planning, data collection, compilation, analysis, interpretation, storing, reporting, display, accessing, and archiving. Most of the people engaged in inventory and monitoring are resource specialists with little formal training or expertise in information management. This has exacerbated the situation. But there is reason for optimism due to the blossoming field of information management, increased agency emphasis and support, and continual improvements in computer systems.

The Forest Service's information environment consists of hundreds of databases, applications, and standards that, because of their functional development, are not well linked. This results in redundant data; inconsistent, incompatible information; duplication with high retrieval and analysis costs; systems that are unable to share data electronically; and "islands" of information in unconnected databases and systems (USDA Forest Service 1992).

Other more specific challenges include:

- A workforce that can meet information management needs, such as people with relational database and metadata skills;
- More demand for raw data without knowing how to use it properly;
- Use of ecoregions instead of political boundaries—and there are many systems to choose from;
- Demand for different data (greater ecological focus) on a more frequent basis (annual vs. every ten years);
- Overwhelming volume of data, especially for large areas;
- Great emphasis on data collection often with comparatively little attention paid to other aspects of information management;
- Poor documentation;
- Too little attention to quality assurance and control; and
- The design of database management and information systems so that data quality is assured, efficiency is optimized, and data are protected.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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In 1992 the Forest Service mounted an agency-wide effort to address these challenges consistently. The resulting framework document (USDA Forest Service 1992) outlined a vision for the future where:

- People who develop and manage information are stewards, not owners;
- Data are captured at their source as a natural course of conducting Forest Service business;
- Data are entered once and used often;
- A shared data environment consists of integratable databases coordinated through modern data management technology;
- Widely used, commonly understood, and persistent data, information, and processes are standardized; and
- Data are shared with external cooperators and the public.
- Since then the agency has moved closer to this vision by:
- Developing a consistent core of data elements and quality assurance protocols for the national Forest Inventory and Analysis program;
- Developing a Forest Health Monitoring program information management system that assures high quality data, maintains records of all changes to the data, and assures timely and user-friendly access to data;
- Developing corporate databases and applications for vegetation, soils, geology, climate, air, and water resources;
- Documenting monitoring results and evaluation findings and improving accessibility;
- Making inventory data available via Internet (such as at this website: www.srsfia.usfs.msstate.edu/scripts/ew.htm); and
- Developing appropriate interagency metadata standards so that data collected by one group of scientists may be utilized by other scientists and organizations effectively and appropriately.

Indicator Development and Selection

Indicators can be defined in a number of ways, but they are basically quantitative or qualitative variables that can be measured or described and, when observed periodically, demonstrate trends (Santiago Declaration. 1995). They form the basic information building blocks for inventory and monitoring. There are two basic challenges: (1) the proliferation of indicators in use can make sharing of information difficult, and (2) there is often little logic to support selection of indicators.

The multiplicity of indicators is due not only to the highly complex ecosystems that we are attempting to inventory and monitor but also to the different objectives and purposes of the myriad inventory and monitoring systems in existence. The solution is to standardize indicators or variables where it is appropriate to do so. The creation of corporate databases mentioned above is one attempt to introduce standardization into a very decentralized organization. Another major effort to report common indicators is occurring at the international level—the criteria and indicators for sustainable forest management (C&I). It is widely recognized that for countries to assess their progress in sustainably managing their forests, indicators need to be monitored over time. There are several indicator development processes underway. One for temperate and boreal forests known as the Santiago Declaration (1995) involves 10 countries including Canada, United States, and Mexico. It has identified 67 different indicators that these countries have agreed they will use in common to assess sustainability. The Forest Service is actively engaged in implementing the Santiago Declaration for the United States.

Several efforts have recognized the need to provide clear exposition of the logic and rationale that underlie the selection of the environmental attributes (indicators) to be measured. The Northwest Forest Plan monitoring work in Washington, Oregon, and California emphasizes identifying candidate indicators that reflect underlying ecological processes and changes in stressor levels, represent the larger resource of which they are a structural or compositional component, and are measurable (Noon 1997). The list can be further refined by using indicators with these properties:

- Their dynamics parallel those of the larger environmental component or system of ultimate interest;
- They each show a short-term but persistent response to change in the status of the environment;
- They can be accurately and precisely estimated (that is, have a high signal-to-noise ratio);
- The likelihood of detecting a change in their magnitude is high, given a change in the status of the system being monitored;
- Each demonstrates low natural variability, or additive variation, and changes in their values can readily be distinguished from background variation; and
- The costs of measurement are not prohibitive.

The Forest Health Monitoring program of the Forest Service, which began in 1989, has been gradually adding indicators as funding and personnel resources have allowed. Their indicator development process includes these steps:

1. Identify relevant environmental or societal values of concern,
2. Formulate key questions relating to those values,
3. Review the scientific literature and available databases,
4. Note gaps in their conceptual model and select new candidate indicators,
5. Test indicators in pilot and demonstration studies,
6. Formulate plot-level indices, and
7. Review indicators by partners (participating agencies and organizations), external scientists, and interested individuals.

Inventory and Monitoring Methods

Once indicators have been selected, the next step in inventory and monitoring is to find the most efficient and cost-effective method of obtaining the necessary measurements or estimates. Techniques development in this area has generally been conducted by biometrics research and development experts or by technologists specializing in inventory and monitoring.

Anyone conducting research in inventory and monitoring methods can list a variety of challenges worthy of attention. Rather than try to list these definitively, I'll mention two that seem particularly important from my perspective. One is the integration of remote sensing (spatial) and sample-based inventories. This has been recognized nationally as a critical need in a Federal-wide effort to integrate inventory, monitoring, and research (Environmental Monitoring Team 1997). The Forest Service has inventories that are spatial and that are designed to meet managers needs at a fine scale. We also have strategic inventories that are sample-based for large areas, such as states and regions. There are discussions and research underway to bring these two types of inventories together to capitalize on the advantages of each. The Forest Service Inventory and Monitoring Institute is working closely with the Northern Region (Montana and northern Idaho) to see how the spatial needs of national forests may be met at various scales by the strategic, sample-based Forest Inventory and Analysis inventories (personal communication, Thomas Hoekstra). Moisen and others (1998) are exploring various statistical methods for merging forest inventory data with satellite-based information to improve the efficiency of estimates of forest population totals, to produce regional maps of forest class and structure, and to explore ecological relationships.

The other type of challenge relates to technical issues of remote sensing. As the technology rapidly evolves, a host of needs arise, such as coordinated acquisition of data from multiple sensors; highly automated data acquisition, archiving, retrieval, preprocessing, and distribution; global DEM (digital elevation models), especially for microwave data; robust mosaicing methods; highly automated yet interactive image classification; and validation procedures (personal communication, Frank Ahern). Solutions for these needs are being developed and tested in agencies, universities, and elsewhere in the private sector, but this will be a continual effort because the challenge is so dynamic.

Scale Issues

In any discussion of inventory and monitoring, the first thing that must be commonly understood by participants is the scale of the activity. Inventory and monitoring occur at spatial scales from global to forest stand and at temporal scales from centuries to days. Not only do costs vary as scale changes, but so too does the utility of the information to answer certain questions. Several challenges confront us. We need to identify the loss or gain of information as one changes scale as well as the temporal and spatial resolution necessary to identify patterns and change. Methods for extrapolation from fine to broad spatial scales and from short- to long-term temporal scales need to be developed. And in some instances, strategies must be flexible to meet local needs while attentive to requirements at higher levels.

To resolve scale issues, the best starting point is to identify the scale that is appropriate to the level of analysis. We must match the spatial and temporal monitoring scale to the question being asked or the issue being addressed. For example, the Forest Inventory and Analysis program is developing annual monitoring and evaluation approaches so that it can meet the needs of customers in areas where land use and timber volume changes are occurring rapidly. Ecosystem management demands resource information for broad areas, and this has resulted in the Forest Service and its partners conducting large-area assessments to gain understanding of forest ecosystems at that scale. Inventory and monitoring data and information are vital inputs to these assessments.

Adaptive Management And Decision Making

Adaptive management is a continuing process of action-based planning, monitoring, researching, and adjusting with the objective of improving implementation and achieving desired goals and objectives (Lessard 1998). Monitoring and evaluation are key aspects of adaptive management to provide the feedback to decision-makers or land managers to make necessary adjustments or improvements.

A major challenge is that there is currently little connection between monitoring and evaluation and decision making. Tied to this, we rarely identify "trigger points" in our monitoring systems, that is thresholds or limits for indicators that when they are reached they trigger a management response or decision. Monitoring and evaluation requirements often are not based on clear objectives and do not address key management questions or issues. Monitoring for monitoring's sake is unacceptable. We must evaluate the results and put them to use in adaptive management.

We find ourselves with a general inability to answer key questions about forests, such as:

- Are we managing our forests sustainably?
- How much and at what rate is deforestation or conversion occurring?
- How much of each forest ecoregion is protected and how representative are protected areas?
- Where is forest restoration most needed and achievable? and
- How can terrestrial and aquatic conservation goals be integrated?

Inventory and monitoring, in an adaptive management framework, can not only answer these questions but can also be used to correct undesirable situations that have been detected.

To practice adaptive management requires a commitment by land management agencies. It may call for a change in agency culture such that management objectives are couched as experiments and that failure is acceptable. As a result, it also requires the support and approval of Congress and our partners as well as a comprehensive educational program for the public. But even without a full commitment to manage adaptively, we can take steps that will improve our inventory and monitoring systems. Examples include:

- Monitoring needs to be designed to help managers understand the dynamics of forests and the underlying causes so that when decisions are made, they will have the desired effect to move the system toward the desired condition;
- Provide a clear statement of why the monitoring program has value (such as how it ties to management goals and objectives), what information it will provide, and

how the interpretation of that information will lead to a more responsible management response or tie to decision processes;

- Realize that there are many types of monitoring (e.g., baseline, compliance, effectiveness, and validation) so tailor monitoring designs appropriately;
- Statistical precision must match manager's needs; i.e., sampling must address detecting a given magnitude of change and the likelihood of detecting this change should it occur;
- Apply the appropriate design and quality standards to meet the monitoring objective, e.g., scientific rigor is not always needed;
- Determine threshold indicator values that will trigger a management response; and
- Use research natural areas, which are protected from harvesting, as reference monitoring sites to facilitate understanding of the effects that such management has on forests versus natural dynamics.

Science, Research and Development, Theory

If inventory and monitoring are going to be truly effective in describing forest resource conditions and in improving land management decisions, then they should be based on the best science and research available. There is widespread agreement that science and research play a vital role in integrating monitoring information (Environmental Monitoring Team 1997). Monitoring ecosystems to draw reliable inferences about system integrity before irreversible degradation occurs is daunting, given that these ecosystems are poorly understood, complex systems subject to stochastic variation and unpredictable behaviors. This calls for close involvement by research in the monitoring process.

The challenges are worthy of any research organization. This list of "gnarly" problems in monitoring ecological resources, such as forests, provides a flavor of the daunting task before us (personal communication, Barry Noon):

- Predicting across temporal and spatial scales;
- Estimating "normal" rates of change of ecosystem processes;
- Defining the expected "range of variation" in natural processes;
- Identifying threshold regions of change that trigger management responses;
- Defining a "desired future condition" for dynamic systems;
- Detecting causation when there are time lags and synergistic effects;
- Linking physical and biological process in the form of predictive models; and
- Drawing inferences to the population of interest from non-probability based samples.

Other challenges include:

- Appropriate scientific methods frequently are not used in conducting monitoring and evaluation;
- Minimal foundation in ecological theory or knowledge;
- Monitoring single species or simple systems is more straightforward and easier than assessing integrity of entire ecosystems, which may be the real need; and
- How to best integrate the human, biological, and physical dimensions of forests into inventory and monitoring systems.

The first step in integrating science with inventory and monitoring is conceptually simple but often difficult in practice: get scientists and land managers to work together for the common good. Each group provides essential pieces of this puzzle and for either one to attempt to solve it independently is doomed to failure. Researchers, scientists, and land managers need to bring their different perspectives, training, and experiences together to collaborate in the various aspects of inventory and monitoring. One positive step the Forest Service has taken is to create a monitoring and evaluation coordinator position that is funded equally by the research and national forest system branches of the agency. Since much of the inventory and monitoring theory is already well developed, another useful step is to synthesize and interpret the theory for land managers and personnel who are tasked to develop inventory and monitoring systems. If the resulting systems are solidly grounded in sound theory they will be much more efficient and useful in the short- and long-term.

Here are a couple of other suggestions. Inventory and monitoring designers can establish the relation (pathway) between those factors that may compromise the management goals (stressors) and their ecological effects. This is another way of saying that they should develop a conceptual model of how forests work. Designers can also provide a mechanism for adopting, adapting, or developing new technology or applications (e.g., remote sensing, sampling equipment, computer models and information systems) to maintain a state-of-the-art monitoring system.

Organizational/Institutional Constraints

Even if an agency can overcome all the previously described challenges to integrating inventory and monitoring, success will not be achieved unless and until organizational and institutional constraints are satisfactorily dealt with. The human resources that make up an agency form the vital connection between a well designed monitoring system and a monitoring system that is actually implemented and achieving the desired outcomes. This is not an area of scientific or technical solutions but rather an area of administrative and personnel management solutions.

The Forest Service faces numerous institutional challenges though many of these are common to other agencies as well. Monitoring and evaluation techniques, methodologies, and philosophies vary widely resulting in inconsistent findings and reporting methods that affect our credibility. Our decentralized organizational structure has encouraged and exacerbated this situation. There is a lack of integration and interdisciplinary approach in monitoring and evaluation activities resulting in duplication of efforts and redundant or inconsistent data. Functional staffs do not promote integration among disciplines. Land managers and researchers, who must work cooperatively, often do not understand each other's needs and approaches, which breeds mistrust. There is no incentive for doing monitoring and evaluation and little or no perceived risk for not doing it. Line officers and staff differ in their understanding of what monitoring is, how it works, what its value and benefits are, and how to implement it. Legal challenges to agency monitoring are mounting. There is also a reluctance to cooperate and share, i.e., public data and information are often considered as proprietary. Inventory and monitoring can be very expensive and yet financial resources have been steadily decreasing for these activities.

The Forest Service is working on solutions to these challenges on several fronts. We recently created the Inventory and Monitoring Institute to facilitate and support the collection, management, and analysis of compatible, scientifically reliable social and ecological information at the national, regional, state, and national forest levels to support ecosystem management. A strategic plan or framework is under development that will describe all of the various inventory and monitoring efforts and their relationships as well identify critical gaps and duplications of efforts. The Forest Inventory and Analysis program is working closely with the National Forest System inventories in order to fulfill its mandate of reporting on forest lands of all ownerships. A National Resource Information System (NRIS) is being developed and implemented across the agency to standardize and integrate inventories conducted at the forest and district level. Since line officers play a critical role to implement inventory and monitoring, the agency is emphasizing the benefits of monitoring and institutionalizing accountability to encourage them to be more powerful and committed advocates. But all levels of the organization must be involved, so we are pursuing a combination of "top-down" and "bottom-up" approaches. We are encouraging the use of interdisciplinary teams in designing monitoring systems so that these systems are integrated and cost-effective. Monitoring takes commitment of human and financial resources, more often than not in short supply as government continues to follow the corporate model of downsizing. These resources need to be explicitly obligated at the initiation of projects rather than added on at the end as an afterthought. Guidance has been issued to develop realistic and practical inventory and monitoring goals so that we can avoid committing to do work that we are unlikely to be able to do.

Coordination, Partnerships, Volunteers

Finally, the Forest Service, despite its talented workforce, realizes that trying to integrate inventory and monitoring in isolation from other agencies, organizations, stakeholders, and publics is not only inefficient but often counter productive. Our agency does not have a monopoly on forest resource issues, ideas, and approaches, and so our inventory and monitoring systems must be integrated with similar systems used elsewhere.

Challenges for inventory and monitoring collaboration are varied. A major one is simply lack of information on what inventory and monitoring work is being conducted elsewhere that may be useful and helpful. Once such information is obtained, another major challenge is how to adapt and/or adopt different yet related inventory and monitoring systems with ones already in use. Another one is the not uncommon view that if someone else is doing inventory and monitoring it cannot be applicable to my situation. This is known as the "not invented here" syndrome, and it is a real barrier to working cooperatively. Part of this concern, however, arises from the lack of control over the quality and timeliness of the data, and thus can be valid. Volunteers or other assistants may not have adequate training to conduct inventories and monitoring. Working with others can slow inventory and monitoring progress and thus be an impediment to timely release of resource data and information. So while coordination, cooperation, and collaboration sound worthy, they are not easily implemented.

The Forest Service is actively engaged in a variety of efforts to work with others in the inventory and monitoring of forest ecosystems. Guidance and direction have been issued for specialists not to design a system in isolation, i.e., find out what others are doing and adapt as appropriate. Also, before collecting your own data, search for comparable data from other sources. We are working to involve partners (including the public) in all phases of system design and implementation. The Black Hills National Forest in South Dakota, for instance, has invited the public to see its monitoring work in action and to participate in it themselves. The Forest Service participated in the framework to integrate environmental monitoring and research (Environmental Monitoring Team 1997) and is active in collaboratively designing and conducting the necessary inventory and monitoring for the national report card on the health of forest ecosystems. The Forest Inventory and Analysis and Forest Health Monitoring programs work very closely with State Foresters and their respective agencies, especially in the area of intensifying the sample to improve the resolution of the data and estimates. The agency also organized a roundtable discussion with many other partner agencies and organizations on approaches to use criteria and indicators to monitor progress toward sustainable forest management. We have worked with other agencies and organizations in Washington, DC to create a forest and grassland inventory and monitoring forum where interested parties meet regularly to share information and approaches to common problems. This forum resulted in a website (www.mp1-pwrc.usgs.gov/fgim/index.htm) that permits anyone in the world to link with a host of inventory and monitoring activities and information. And finally, through meetings like this symposium, we are striving to reach across international boundaries to work with our counterparts in other countries to develop forest inventory and monitoring systems that are compatible and integrated and that will yield information efficiently at the continental and global scale.

Conclusions

The challenges of properly integrating inventory and monitoring into the work of a land management agency are myriad and complex. They touch on topics such as information management, indicator selection and development, methods, scale, adaptive management, decision making, science, research and development, organizational constraints, and coordination with others. In the face of such obstacles and barriers, it would be tempting to despair. But we understand the critical importance of inventory and monitoring information to sound forest management, and so we have been addressing and confronting these challenges on a wide front for a number of years. We are making progress both internally and in cooperation with many other agencies and organizations. Momentum is building to focus more attention and resources on inventory and monitoring issues, and this can only accelerate transforming these challenges into opportunities that we can take advantage of. The "information age" demands the natural resource management agencies to provide complete information about the resources under their responsibility in a manner that can be easily accessed through modern delivery mechanisms. The Forest Service is positioning itself, in partnership with others, to be a major provider of high quality, timely, and useful forest ecosystem information. It is well worth the effort to do so.

Literature Cited

Environmental Monitoring Team. 1997. Integrating the nation's environmental monitoring and research networks and programs: a proposed framework. Committee on Environment and Natural Resources, National Science and Technology Council. Washington, DC. 102 p.

Lessard, Gene. 1998. An adaptive approach to planning and decision-making. Landscape and Urban Planning 40: 81-87.

Moisen, G. G., Edwards, T. C., Jr., and Van Hooser, D. 1998. Merging regional forest inventory data with satellite-based information through nonlinear regression methods. *In:* Ranchin, Thierry and Wald, Lucien, eds., proceedings of the Second International Conference on the Fusion of Earth Data, Sophia Antipolis, France, January 1998. p. 123-128.

Noon, Barry R. 1997. Scientific framework for effectiveness monitoring of the Northwest Forest Plan. *In:* Mulder, Barry S., Noon, Barry R., Spies, Thomas A., Raphael, Martin G., Olsen, Anthony R., Palmer, Craig J., Reeves, Gordon H., and Hart, Hartwell H., The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan. Final Report. Regional Ecosystem Office, Portland, OR. p. 40-56.

Santiago Declaration. 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. J. Forestry 93(4): 18-21.

USDA Forest Service. 1992. Information management: a framework for the future. Washington, DC. 17 p.

Some Insights Based on the Canadian Experience[1]

Hague Vaughan[2]
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Abstract—Integration within monitoring programs requires scientists from different disciplines to work together at the monitoring sites. Responsibility and expertise in these disciplines usually reside in different agencies and government departments. This creates a series of barriers to success. Scientists encounter barriers in communicating advanced concepts and results among disciplines. Integrating results from many disciplines into an ecological study is very challenging and is almost becoming a scientific discipline in itself. Scientists can be very uncomfortable in applying the results from one discipline to another—yet that is precisely what is needed in an ecological study.

Inter-organizational cooperation always presents significant barriers often because agency mandates, objectives and budget priorities may conflict—preservation versus exploitation for example. However, the scientific expertise needed for ecological studies requires interagency cooperation.

The global nature of the current environmental issues, such as atmospheric change, require cooperation among national governments—adding another dimension to the barriers to integration.

We should also mention integration within government processes. By that we mean that monitoring, however perfectly done, must ensure that its ability to alter, the character of its interpretations, the basis for its conclusions and the nature of its products are such as to respond to and feed into the needs of its supporting agencies. Since most such work is performed by, or no response to , government, relating monitoring programs and products to regulatory or policy needs should be recognized as a priority.

Scientists must take the lead role in explaining the needs and benefits of integration and must also be aware of the coordinating processes available to help the work—such as interdepartmental arrangements and International Conventions and Protocols.

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Integrating Ecological Data Over Space and Time: Challenges for the Future[1]

Robert B. Waide[2]

Abstract—Most ecological data are collected with the intent of examining specific hypotheses or questions. These questions are often framed in a way to permit the collection of data at small-scales and over short periods of time, in part because our academic and governmental institutions provide strong positive feedback for studies that are completed and published quickly. However, the extrapolation of results from these small-scale, short-term studies to larger areas or longer time frames can lead to misleading or erroneous conclusions. Results from the Long-Term Ecological Research Network in the United States suggest that some observed patterns in ecological data may be scale dependent and that examining the same data set at different scales of focus may lead to completely opposite conclusions. Matching patterns observed in the field with theory must be done cautiously to insure that purported causal factors operate at the same scale as the collection of data. Data collected at different scales may be compared, but only when observed patterns are scale-invariant. These problems make the integration of ecological data collected for different purposes and in different ways an important challenge that must be addressed in order to develop appropriate monitoring protocols.

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Hacia una Valoración Total e Integral de los Recursos Forestales[1]

Carlos Mallén-Rivera[2]
Edmundo García-Moya[3]

La vista de los campos recuerda al viajero que aquel suelo da de comer a quien lo cultiva, y que la verdadera prosperidad del pueblo mexicano no depende ni de las vicisitudes del comercio exterior, ni de la política inquieta de la Europa.

Alejandro de Humboldt (París, 1822).
Ensayo Político sobre el Reino de la Nueva España

Resumen—La economía clásica ha producido los modelos para cuantificar los recursos naturales tradicionalmente explotables, empero, la acelerada degradación social y del medio, el mediano avance en el conocimiento biológico y la pertinaz globalización de las estructuras políticas, demandan una revaloración de lo que ecológica y humanamente significan estos recursos. En México, las valoraciones políticas y económicas aun no consideran bienes y servicios colaterales, ni como potencialidades ni como necesidades, esto en el momento en que el desarrollo científico y el manejo del medio a nivel mundial se empeña desde el aprecio a los acervos genéticos, las funciones hidrológicas y el propio ciclo de carbón, hasta el costo de productos tangibles e intangibles altamente codiciados y el aprecio rural y urbano de los recursos forestales. La repetición parcial de los índices macroeconómicos considera un país en grave desventaja, su extrapolación para el caso norteamericano representan una disparidad cercana al dramatismo: Miles de hectáreas de bosques incendiadas ineficiencia, el desbalance productivo maderable, además de la contribución al producto interno bruto (PIB) nos coloca en una posición por demás vulnerable. Los usos y costumbres no son más que fragmentos de cultura popular para determinados sectores, alejados de los agentes de económicos que están considerando, no precisamente lo más valioso, genuino y original de las potencialidades bióticas y productivas. En las decisiones de cúpula se han priorizado en México los campos de mayor homogeneidad y representación para el intercambio comerciales, dejando fuera elementos como la diversidad biológica y cultural.

Se requiere de una estimación de los costos y los dividendos, al mismo tiempo de un análisis de las funciones básicas y los procesos productivos de los que depende la existencia de millones de habitantes de las áreas naturales. El útil concepto de Valor Económico Total (VET) puede dirigirse, con base en un Valor Ecológico Total, hacia un Valor Humano Total. Consideración de existencias forestales que incluyan tanto productos (bienes y servicios), tanto como productores y consumidores. Recreación, regulación climática, aprecio escénico son responsabilidad de una integración económica y legal, que también representa tradición y supervivencia. La Ecuación misma del VET como resultado de diversos valores (directos, indirectos, opcionales e intrínsecos), es factible en los terrenos de la investigación social y demanda los instrumentos de la ciencia ecológica y silvícola. El valor de los productos derivados pueden exceder el valor que se asignado a la madera comercial, y no solo al considerar las existencias reales de los bosques mexicanos, sino también el cálculo en términos de las oportunidades y el costo de las perturbaciones ambientales, y el servicio sobre el medio global.

Dado que la Teoría Económica inspiró los supuestos ecológicos, los instrumentos económicos pueden apoyar el entendimiento sobre el valor humano y ambiental de los bosques. Valoración compleja si consideramos la estructura de bosques y sociedades. Debemos pugnar por una valoración que integre los términos de la propia economía ecológica: Ecosistemas funcionales, usos múltiples, el carácter de bien público y beneficios globales. En este sentido el trabajo realizado sobre los indicadores del medio y sus relaciones con la pobreza, la riqueza y el desarrollo humano pueden ser muy valiosos, de manera similar, los estudios sobre las cuentas nacionales y el comercio internacional con base en la diversidad cultural en el extranjero.

Objetivo

Exponer, en el marco del **Simposio Norteamericano**, una reflexión en torno a las posibilidades económicas, sociales y ecológicas para una valoración integral de los recursos naturales y el medio cultural.

Cuenta de la Riqueza

Los problemas ambientales son diferentes para los ricos y para los pobres, pero surgen tanto de la pobreza como de la riqueza. Los países ricos reducen su desarrollo debido a la descontrolada demanda de recursos y la contaminación de su producción. En las naciones pobres (tercermundistas, en vías de desarrolló y ahora de economía emergente), las necesidades de alimentos y combustible por parte de las crecientes poblaciones provocan deforestación, erosión y el agotamiento de las reservas de agua. Los pobres no sólo contribuyen a la degradación del medio sino son también quienes más sufren por ello. Las relaciones entre pobreza, impartición de justicia, educación y degradación del ambiente son estrechas y directamente relacionadas, aun buena parte de las alternativas como la agroforestería aun queda fuera de quien carece de tierra y recursos (Arnold 1997). Ante esto se debe prever de una contabilidad de lo factible como provisión de productos esenciales para la subsistencia y la calidad de vida, además de considerar los elementos para garantizar el sostenimiento de estos propios recursos y medios.

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La geografía e historia ubican a México entre los más complejos sistemas económicos, que en los últimos años ha generado una enorme cantidad de pobres (50 millones). Con acuerdos comerciales con las dos potencias económicas del Norte, compartiendo económica y culturalmente muy poco, y con el desconocimiento de países hispanos de la misma línea espiritual y productiva. En esta ambivalencia no se alcanza a delimitar las trayectorias, ni los fines de la economía, la cultura y la el pacto social mexicano. El pronunciamiento de Antonio Challenger (1998), ante el estudio de los ecosistemas terrestres mexicanos, se expresa en términos comprometedores:

> A pesar de sus muchos problemas económicos, sociales, políticos y ambientales, México es quizá una de las pocas naciones de este planeta dotado de recursos bióticos, humanos, espirituales, materiales, tecnológicos y económicos suficientes como para ir a la vanguardia de lo que se refiere a apartarse del paradigma industrial convencional del desarrollo y encaminarse hacia un desarrollo más humano y ecológicamente sustentable.

Por otro lado, existen trascendentales trabajos como el de Ramamoorthy, que resume buena parte del conocimiento generado por científicos mexicanos y extranjeros:

> Aunque México, con 1,972,544 km^2, es el decimocuarto país más grande del mundo, se clasifica como el tercero con diversidad biológica, resultado de la variada historia biogeográfica sobre una clasificación de climas, abarcando un reino Neártico desde el norte y uno Neotropical en el sur, abrigando aproximadamente 30 mil especies de plantas, de las cuales más de 21,600, de aproximadamente 2,500 géneros, son plantas con flores. Más de 300 géneros y 50-60% de las especies son endémicas del país. Los árboles de coníferas dominan vastos sistemas del territorio con alrededor de 15 géneros y más de 150 especies. Existen 900 a mil especies de helechos y 2,300 especies de briofitas, además de ser excepcionalmente rico en especies de hongos y algas (Mittermeier 1988; Ramamoorthy 1993; Ramamoorthy & Lorence 1987; Styles 1988; Riba 1993; Delgadillo 1993) citados en Ramamoorhy et al. 1993.

Así mismo, se ahonda en las especificaciones de la vida que ha generado la geografía:

> Dos veces y media más pequeño que Brasil, México contiene 449 especies de mamíferos, 142 son endémicos en comparación, más de mil especies de aves habitan el territorio nacional mexicano, 53% de los reptiles (de 693 especies) y 45% de los anfibios (de 285 especies) son endémicos de México Junto con los peces que deben de existir más de dos mil especies, la cantidad de especies de insectos se enumeran en cientos o miles, de los cuales alrededor de 25 mil son lepidópteros, sugiriendo que hay más de una especie de lepidóptero por cada especie de planta con flor en el país. Solo las abejas comprenden 154 generos y 1,580 especies Brazil (Espinosa et al. 1993; Llorente 1993; McNeely et al. 1990 en Ramamoorhy et al. 1993; Escalante et al. 1993. Flores-Villela 1993; Ayala et al. 1993).

Especificando, sólo el sector forestal da pie ha una serie de comparaciones extraordinarias: Los bosques de pino-encino albergan 55 especies de pinos, la mitad del mundo (85% endémicos) y 138 de encinos (70% propias del país). Los bosques mesófilos, cubriendo únicamente el 1.4% del territorio, incluyen el 10% de las plantas del país (Programa Forestal y de suela 1995-2000).

Se señala, que esta diversidad biológica además es de importancia mundial en el panorama agrícola, en la medida que estas tierras son el origen de muchas de las plantas cultivadas históricamente y de cultivos de los cuales dependen el mercado de alimentos contemporáneo. Una gran porción de la franja genética que circula entre los Trópicos de Cáncer y Capricornio abarca México, y coincide con la distribución de centros agriculturales propuestos (Harlan 1975). La superposición de estas regiones destaca la singularidad de esta nación única como un país megadiverso y un centro de origen de cultura agrícola, coincidente con el "cinturón genético" mundial (Ramamoorthy 1993). Así se puede continuar la relación de las singularidades: De las 25 categorias de suelos clasificados por la FAO/UNESCO, en México se encuentran 23. El país tiene abiertos al cultivo alrededor de 400 mil km^2, de los cuales 300 mil son de temporal y pocos menos de 100 mil de riego (Sedesol 1992). Alrededor de los 65 cultivos más importantes en el mundo fueron domesticados en México (Harlan 1975 en Ramamoorthy 1993). A su vez el país, ha sido uno de los tres grandes centros mundiales para el origen agrícola, de tal suerte que Hernández Xolocotzin, documenta la importancia de México como un centro de plantas domesticadas. De 115 especies que crecen para la población, 60% son plantas mexicanas, 36% de los árboles frutales (44 especies) y 56 especies de las plantas ornamentales más espectaculares son nativas (Ramamoorthy 1993).

En contraposición toda esta magnitud biológica sólo es comparable a la degradación del medio en que esta se desarrolla y la subutilización de los recursos: Por año cerca de 400 mil hectáreas son perturbadas, 800 mil desforestadas y 1.5 millones transformadas (Flores y Gerez 1995). Nuestra agricultura tiene como base cuatro productos que ocupan alrededor del 62.5% de las tierras agrícolas. La pérdida de suelo por erosión es de aproximadamente tres mil ton/año/ha., de este volumen 69% se descarga en los océanos y el 31% restante se deposita en embalses naturales (Sedesol 1992). Por citar dos lugares en especial, en la región del Bajío, Guanajuato, y en el Valle de México, se registra la desaparición casi total de la vegetación original (Vázquez y Orozco 1992), mucha de esta endémica. Una sola hectárea en la selva perennifolia de los Tuxtlas, entre Veracruz y Oaxaca, fuertemente afectada en la última temporada de incendios forestales, puede contener hasta 900 especies de plantas y animales.

Contribución Tradicional

De manera general se ha ubicado y enseñado la función natural de los ecosistemas en los distintos rubros (Arnold 1997), clasificación que demandan una acotación y una superación, ya que su encasillamiento esta provocando pérdidas en cuanto a su valor agregado y oportunidad mercantil.

Alimentos y salud. Aunque no constituyen en volumen un aporte comercial significativo, los alimentos provenientes de los bosques añaden variedad, sabor y proveen vitaminas y proteínas y calorías esenciales. Durante ciertas temporadas de crisis resultan significativos para la supervivencia. También se derivan las plantas medicinales, existiendo con frecuencia fuertes vínculos culturales. Se afirman hipótesis paleoantropológicas sobre que la comida la determinaba más la cultura que la propia biología humana. En un futuro se explorarán estas fuentes alimenticias y de salud, por lo que la información genética tendrán ventajas de mercado.

Valor cultural y social primario. Reflejo de la historia, la religión y el arte de la sociedad; Sitios, plantas y animales adquieren un valor espiritual y simbólico, lo que limita su propio aprovechamiento y degradación. Control que también proporcionar productos de especial valor comercial: Alimentos reservados para las liturgias, cuyo valor no han sido estudiado en todas sus implicaciones. Países con poblaciones que se encuentran en la disposición de pagar altos precios por productos forestales excepcionales de valor cultural.

Renta y ahorro. Un gran parte de los ingresos monetarios rurales, proviene de la venta de productos forestales, y dado que las poblaciones dependen cada vez más de estos ingresos para obtener los satisfactores, no agrícolas, de a los hogares campesinos. Hasta ahora las ganancias de los productos forestales raramente representan una parte importante de la renta total, empero a menudo cubren situaciones de emergencia y estacionales. La conveniencia estriba que los bosques, ha diferencia de los campos agrícolas, funcionan permanentemente, acrecentando esta continuidad en las áreas templadas y tropicales.

La importancia de los ingresos producidos por el bosque está, normalmente, ligado al tiempo más que a su magnitud como cuota de los insumos totales. Estudios en África señalan que esto va más halla en una vinculación agrícola en que se enfrenta gastos de insumos; existe una dificultad de generalización de la dinámica forestales, en los sistemas de subsistencia, por su extensión y diversidad, así como la variación de sus relaciones. Otro elemento de consideración es que en la mayor parte de las regiones del mundo, las tierras silvestres se encuentran alteradas, fragmentadas y desconectadas. Los ecosistemas críticos han llegado a un deterioro que está a punto de convertirse en un amenaza para los sistemas regionales básicos de sostenimiento, como los ciclos del agua, la fertilidad y el clima. Ahora la pregunta no es cómo conservar el planeta sino cómo conservar todos y cada uno de sus miles de hábitats humanos y naturales, todas y cada una de sus miles de pequeñas fracciones y parcelas de tierra, cada una de las cuales, por sus características, no solamente es única e inestimable sino irremplazable (Wendall Berry,1990)

Capitalizaciones Limitadas

Los impactos ambientales y sociales, que los proyectos de crecimiento económico provocan, se originan en la naturaleza piramidal y centralizada del proceso mediante el cual se seleccionan, diseñan e implantan. La política de los bancos de desarrollo, ha sido el financiamiento mediante estructuras de administración de los gobiernos nacionales. Verbigracia, en América Latina se han creado burocracias para su planeación centralizada que absorben hasta un setenta por ciento del dinero asignado. Estas agencias responden, principalmente, a las necesidades de inversionistas y contratistas regionales y extrarregionales. Una vez que los proyectos son repartidos entre los agentes de administración, los supuestos “beneficiarios” los reciben como hechos ocurridos.

La planificación de materias primas para los procesos de producción capitalistas, ahora de manera cada vez más globalizados, lejos de girar en torno al bienestar de las poblaciones y ecosistemas locales, se enfoca hacia determinadas visiónes coyunturales dentro de las “prioridades nacionales”, las que debido al escaso nivel de participación política, con frecuencia privilegian el corto plazo y favorecen a las élites que toman las decisiones, así como a su clientela. Ello, por lo general, se traduce en infraestructura que no considera las condiciones biorregionales, con un consecuente deterioro de los recursos naturales y de la calidad de vida de las comunidades locales.

Los indicadores que los planificadores del desarrollo emplean, son bastante representativos de su estadística que parten de la noción del Producto Nacional Bruto (PNB), así como otras cifras regionales, que más que explicar, fragmentan a la nación, como los kilómetros de caminos o las toneladas de granos producidos, resultando de absoluta confusión la cuenta del mejoramiento del nivel de calidad de vida de los pobladores locales. Una mayor cantidad de kilómetros construidos pueden traducirse en mayor destrucción de la masa forestal, mayor producción de caña de azúcar puede significar menores extensiones de tierra, un PNB más elevados puede reflejar el incremento en la contaminación.

En consecuencia, los indicadores convencionales presentan un panorama parcial y distorsionado de los resultados del desarrollo económico (Night y Rodríguez 1995). El equiparar el mercado mexicano con el resto de norteamericano, como significancia ambiental resulta ocioso: Nada en diversidad biológica, ilógico en desarrollo social y dramático en cuanto a la disparidad en niveles de producción y tecnificación. La diferencia de tres naciones en nada afectaría a su propia relación y crecimiento interno, pero el marasmo que se imprimió en el sexenio del Dr. Salinas de Gortaría, cuando todos los marcos de referencia fueron olvidados, cuando no acallados, provocó un efecto aun de incalculables dimensiones. Siendo esto más que parte de una dinámica histórica que bien leida, siempre nos ha colocado en grave desventaja. Proceso que inició plenamente desde finales del siglo pasado y principios del presente en el desarrollo económico del país se inscribe en el proceso de expansión del capitalismo mundial donde México se incorpora plenamente al juego de las relaciones centroperiféricas, pero en el equipo de los neocolonizados (Bartra 1996), y ahora de los neoliberados.

Ante el alta demanda por la información cuyo precio se dispara, aun no se redimensiona con justicia el alto y depurado valor del conocimiento étnico: Los tzeltales chiapanecos son capaces de distinguir 1,200 especies de plantas, la integración de elementos ecologicos, es el caso de los chinantecos oaxaqueños que reconocen siete unidades naturales basadas en las características del suelo. En México alrededor del 50% de las plantas son usadas como alimentos y medicinas. Los mixtecos del bosque tropical deciduo de Puebla y Guerrero obtienen más de la mitad de sus plantas alimentarias de especies salvajes. Las poblaciones nahuas que habitan en los bosque de pino - encino del Este del Estado. de México, reúne 25% (28 especies) de hierbas medicinales de plantas salvajes (Bye 1993).

El valor Humano

México es uno de los países más ricos botánicamente, empero también culturalmente, con diez millones de personas hablando una de las 54 lenguas nativas. La riqueza etnobotánica es reflejada por la utilización de más de cinco mil plantas vasculares, varias familias taxonómica, y una percepción cultural que se traduce en un manejo de los recursos naturales específico. Sin embargo, es de ponderar la de degradación cultural, proveniente, principalmente, del saqueo de los recursos naturales. Si es verdad que se hablan 54 lenguas estas solo son un relicto de las 120 que se hablaban antes de la llegada de los conquistadores (Martínez 1986). Gran parte de la diversidad biológica se ha perdido, mucha de esta sin haberse ubicarse e identificado. El reconocimiento y utilidad de las plantas como se registra en los inventarios etnobotánicos nos muestra una realidad de perturbación y pérdida de alcances graves. Aunque la influencia humana en la evolución de las plantas tiene muchas facetas, resulta muy importante ahondar en su investigación sobre la impresión del género humano en la diversidad biológica, la hibridación, persistencia de plantas útiles, así como la incorporación de nuevos taxa en la flora local, y especiación acelerada en la vegetación secundaria. Todo esto de relación de competencia de biólogos, agrónomos, forestales, antropólogos, y hasta economistas, dado que las relaciones entre la riqueza biológica y cultural es difícil de determinar, México es un lugar apropiado para examinar la gran diversificación de culturas y biota, un quinto de sus sociedades indígenas registran información etnobotánica, lo que convierte al país en un autentico laboratorio natural.

Los instrumentos para alcanzar estos propósitos resultan ya disponibles, Robert Bye (1993) expresa que dado que la diversidad entobotánica no puede no ser determinada confiablemente debido a inexactitudes en las relaciones causa y efecto entre los factores culturales y biológicas; la riqueza o la variedad del componente de la interacción planta-humano puede ser la manera más práctica de evaluar la influencia humana en la diversidad de la flora mexicana. La interacción humana que parte desde la explotación irrestricta, al manejo intensivo y ahora sostenible, para el caso de las plantas vasculares mexicanas ha tenido un impacto en la diversidad de la flora, impacto por analizar, y que puede constituir una base para la proyección de los efectos y tendencias ha futuro, así como para el diseño de rutas alternas ante los riesgos de los sistemas naturales y sociales.

Estas relaciones planta - humano, producto de las percepciones del medio, son clave en el diseño de sistemas y políticas democraticas en México. Sin embargo, aunque aproximadamente de la mitad de los grupos indígenas se han publicado estudios etnobotánicos, se carece todavía de un inventario amplio de plantas importantes culturalmente, esto a pesar de que en la perturbación de los medios culturales se ven afectados los principales elementos de las sociedades, la alteración de las poblaciones de plantas, así como sus hábitats, producido cambios en la composición y estructura genética de las biodiversidad local. A pesar de que aunque las actividades humanas transgreden las barreras ecológicas de las plantas por alteración del espacio y patrones, produciéndose híbridos, algunos de los cuales son benéficos para la economía (Ramamoorthy 1993), esta dinámica esta siendo peligrosamente rebasada. Para Childe (1965) (Citado en Ramamoorthy 1993), durante el desarrollo temprano de los humanos establecieron una relación coevolutiva con la vegetación circundante, origen tanto de productos para la subsistencia, como cambios en la composición floristica. Un cambio en el proceso coevolutivo ocurre cuando los humanos desarrollaron rasgos característicos funcionales y físicos culturales que permitió la rendición de los habitats, la manipulación de los organismos deseables, como ejemplo, determino el curso de la agricultura en diferentes grupos humanos. Estos procesos y relaciones actualmente pueden poner riesgo nuestro actual sistema de existencia. Sobre todo esto escribe Efraim Hernandez Xolocotzi:

> El desarrollo cultural de los humanos ha estado polarizado por diferentes conceptos con relación a su visión cósmica y su relación con la naturaleza. En la agricultura tradicional, por ejemplo, los humanos no distinguen entre lo material y lo metafísico, no perciben una necesidad de dominar el mundo material. En contraste, la agricultura moderna esta basado en una visión cósmica con una larga distinción entre lo metafísico y lo físico, y un deseo de dominar la naturaleza. La diferencia de esta visión cósmica afecta la dirección del crecimiento cultural en los humanos

Los estudios que han pretendido identificar productos naturales para los problemas contemporáneas (sobrepoblación, estres y el deterioro del medio), confrontan que los remedios, se conformaron a lo largo de procesos evolutivos y culturales bien delimitados, sin embargo, pueden representan una guía de ubicación y preservación. Para Hernández X (1993) el desarrollo nacional se requiere dar la vuelta hacia el pasado, y afortunadamente aún hacia el presente, hacia poblaciones con un "bagaje ecológico y cultural" que ha conformado un centro de riqueza natural florística y cultural humana.

Hacia el valor Total

El razonamiento del ámbito de la economía en la ciencia ecológica se puede resumir en el caso de la contaminación ambiental, la cual es ocasionada por dos fenómenos perfectamente delimitados "la producción y el consumo", es decir, los ejes del estudio de la economía. La actual confusión económica nos impulsa hacia buscar otros rumbos más plausiblemente humanos y reales. Ajustando nuestros parámetros fuera de los sectores que cuentan con el poder político, y enfocando nuestras miras hacia la sociología y la ecología como disciplinas llamadas al acercamiento humano.

Para 1995 se produjo por el usufructúo de los bosques mexicanos una ganancia de cerca de "cuatro mil millones de dólares" esto en un sector económico caracterizado por los altibajos. Sin embargo, las valoraciones estatales aun no consideran plena o incidentalmente tanto bienes y servicios colaterales, requieriéndose una estimación apropiada de costos y dividendos de las funciones y los procesos, la ausencia de esta estimación afirman investigadores provoca una subvaloración, obstáculo para un manejo de la política económica de influencia e integración nacional (Adger et al. 1995).

Actualmente ya se esta trabajando en la sistematización y organización de los diversos rubros de componen esta economía del capital natural del país. Adger et al., (1992) proponen aplicar la ecuación de Valor Económico Total (VET) para el caso de los bosques mexicanos, definida como el monto de los recursos y expresado como la tasa que la propia sociedad otorga de acuerdo a su significado en la calidad de vida.

Valor Económico Total	**=**	**Valor de los Usos Directos**	**+**	**Valor de los Usos Indirectos**	**+**	**Valores Opcionales**	**+**	**Valor de las Existencias**

Valor de los Usos Directos. Incluye ingresos de producción maderable y no maderables. Potencial comercial considerable en tanto en su manejo se consideren las funciones ecológicas y de protección ambiental.

Valor de usos indirectos. Ciclos biogeoquímicos, agua y protección de las cuencas hidrográficas, que para nuestro país debería representa la ubicación de los sistemas de producción agrícola y desarrollo urbano.

Valores opcionales. Valor esperado de la información en los beneficios sobre un bien condicional, su preservación y uso. Verbigracia, los recursos genéticos en la industría farmaceutica.

Valor de las existencias. También expresado como Valor Intrínseco y relacionado con el valor de bienes del medio sin considerar sus usos actuales u opcionales. Lo que puede representar que el bien tenga características únicas y un significado cultural.

Por otro lado, a partir del bagaje de experiencias, sobre todo en ecología de poblaciones y comunidades, en las regiones del trópico humedo del sureste mexicano, se han formulado métodos e intentos de integrar costos sobre el medio, sus recursos y los agentes de aprovechamiento. A partir de estos se han aportado elementos, para describir y entender el conocimiento de grupos nativos sobre el entorno natural, constituyendo formalmente la disciplina de la Botánica Económica (Saruhkán 1997; en Ricker y Daly 1997), Verbigracia, M. Ricker estudio en la selva de los Tuxtlas, cuatro parcelas que en conjunto sumaban una hectárea que contenía 76 especies de árboles, de los cuales 11 producían frutos comestibles con valor comercial. Considerando únicamente cuatro especies, de las que se contaba suficiente información de mercado, además de una palma abundante de inflorescencias comestibles, se llevó acabo una serie de análisis costo-beneficio obteniendo diversos ingresos de acuerdo a la ubicación de compra y venta, y al tipo de mercado. La venta de frutos hubiera resultado en un valor presente de US$ 3,506 para el hectarea. "La especie más valiosa fue *Pouteria sapota*; un solo árbol grande de esta especie hubiera sido el responsable del 22 por ciento del valor neto de la hectárea de bosque". De las 76 especies, 19 eran de interés comercial por su calidad mederera, cuya venta del volumen hubiera significado un valor presente neto de US$ 3,357. Sin embrago, se aclara, que aunque las ganancias son similares (ligeramente mayores en el caso de los frutos), resultaba más atractivo el pago total inmediato de la madera (Ricker 1997; en Ricker y Daly 1997). Y así podemos enlistar casos como el del Hongo blanco de ocote de los bosque de Pino, del centro y sur, donde los precios por kilo, y con base en su calidad, se cotizan en el mercado internacional, sobre todo para la exportación a Japón, y que hace poco los campesino daban a sus cerdos como alimento (Mallén 1995).

Algunos de los fenómenos y procesos, humanos y ecológicas, que restan para su incorporación como componentes de valor pueden ser el secuestro de carbono, la recreación, el paisaje, la depreciación de contaminantes, el amortiguamiento del estres urbano, la diversidad biológica, la significancia ritual, el valor de especies de las denominadas "carismáticas" y que atraen la protección de otras menos atractivas, la reserva genética, la absorción de toxinas, el simbolismo, la salvaguarda de unos de los elementos más valiosos del estado como es el territorio

Los mecanismos de inventarios forestales, se enfrentan más en cuantificar lo que se encuentra, que en estimar los procesos biológicos de las existencias. Así mismo, las estimaciones de la biomasa de hábitats y ecosistemas, ha de agregar su función en la continuidad de los procesos agropecuarios e industriales. Las actividades turísticas y recreativas, atendiendo a los perfiles y al apreció de los visitantes medido en disposición de inverción, y sobre todo a la tasa de recuperación por parte de las poblaciones locales.

Los niveles de deforestación y erosión, tanto como su afectación directa a la calidad de vida y supervivencia por grupos sociales. El precio de la madera considerando la tala de bosques, la importación bioenergética y la reposición en términos de nutrimentos. El valor de la carne, agregando la porción correspondiente de la selva devastada. La energía eléctrica y su costo Kilowatt / hora y kilowatt / poblado campesino erradicado en la construcción de la hidroeléctrica. El kilo de granos y la tierra que se va con el aire o a los océanos. El cotidiano baño citadino y el precio del subsidio, de la ineficiente red de suministro y de las hectáreas sin irrigar y el cambio de ruta de los ríos. Los grados del calentamiento global, el cambio climático y los efectos invernaderos.

La oportunidad financiera de la conservación de bosques y su conversión en capital natural para su utilización ulterior, con fines incluso que apenas se vislumbran las necesidades actuales. El caso del petróleo, como el caso de la inmensa mayoría de nuestros recursos naturales, es el ejemplo, compartido prácticamente todos los países productor, donde sus dividendos se han empleado para financiar la idea que el sistema en turno tiene sobre el desarrollo más que en asegurar una solvencia económica, muy por el contrario subvenciona los errores de los gobiernos. Lo más dramático es que parte importante de los dividendos de la explotación de los recursos forestales han apoyado las propias políticas de destrucción de los recursos forestales del país. La idea de vender los bosques en pie y ponerlos a bordo del camino de la expansión transnacional para esperar pacientemente un buen precio (Ricker y Daly 1997).

Ultimas Reflexiones

La perdida de la cubierta forestal preocupa no tanto por los valores comerciales, como la madera y los frutos, resulta grave por aquellos valores no comerciales, algunos incluso que no alcanzan precio. La diversidad biológica, el ciclo hidrológico y la protección del suelo, todos consumidos y requeridos por el común de la sociedad. No se puede tratar los bienes con comerciales y no comerciales de la misma manera, por ejemplo la intervención del estado o las cotizaciones privadas. Si es verdad que de manera cada vez más acelerada se ofrecé aire puro, alimentos libres de pesticidas, o café orgánico, no es posible aún esperar que el mercado libre se encargue eficientemente de la oferta del valor integral de los bosques mexicanos. Empero también resulta comprometedor el permitir que el aprecio se concentre a lo que la economía etiquete.

Desde la óptica de nuestra sociedad se requiere un análisis integral de los costos y beneficios que ha de considerar en la valoración no-comericial. Las fronteras mismas del concepto estan siendo rebasadas, y cada vez mayores comunidades encuentran opciones de mercado y de ingresos, el problema es la dificultad de cuantificarlos de manera convincente en términos de precio para este mismo mercado.

Posiblemente el planteamiento de un "truque de valores no comerciales y términos monetarios" (Ibidem), puede dar salida al debate, asumido por conservacionistas y economistas. Vivimos una época donde el dinero es un estatus, un objetivo de vida, un instrumento de satisfacción, empero en realidad el dinero es simplemente un instrumento que se puede llamar madera, caminos, insumos, de comparación entre "el valor de la belleza del bosque no-cosechado", a través de costos de oportunidad, tal ves la oportunidad de conservar lo que nos hace excepcionales en el concierto de las naciones.

Fuentes de Consulta

Adger, W.N., Brown, K., Cervigni, R. Y Moran D., 1995. Total economic value of forest in Mexico. AMBIO. The Royal Swedish Academy of Sciences. (24)5, 286-296 p.

Arnold, M., 1997. Las dimensiones sociales de la silvicultura y su contribución al desarrollo sostenible. En: Actas del XI Congreso Forestal Mundial. Antalya, Turkia.

Bartra, A., 1996. El México Bárbaro. Plantaciones y monterias del sureste durante el porfiriato. El Atajo Ediciones. México, D.F. 516 p.

Berry. W., 1990. Commencement Addres. en Whole Earth Review, No. 66.

Bye, R., 1993. The role of humans in the diversification of plants in México. In Ramamoorthy, et al., Biological Diversity of Mexico. Oxford University Press. USA.

Challenger, R., 1998. Utilización y conservación de los ecosistemas terrestres de México. CONABIO / Sierra Madre. México. D.F.

Ejecutivo Federal, Poder, 1990. Programa Forestal y de Suelo 1995 - 2000. Secretaría del Medio Ambiente, Recursos Naturales y Pesca. México, D.F.

Flores V., O. y Gerez, P., 1994. Diversidad y conservación en México: Vertebrados, vegetación y uso del suelo. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO)/ Universidad Nacional Autónoma de México (UNAM). 2da. edición. México.

Flores V., O. 1997. In: Ramamoorthy, T. P. et al., 1993. Biological Diversity of Mexico. Oxford University Press. USA.

Hernandez Xolocotzi, E., 1993. Aspects of plant domestication in México: A personal view. In: Ramamoorthy, T. P. et al., 1993. Biological Diversity of Mexico. Oxford University Press. USA.

Mallen R., C., 1995. El hongo blanco de ocote, Tricholoma magnivelare: Análisis en la Región de Huayacocotla. Memoria del II Congreso mexicano sobre recursos forestales. Colegio de Postgraduados. México, Montecillo.

Mexico, 1992. Informe de la situación general en materia de equilibrio ecológico y protección al ambiente 1991 - 1992. Secretaría de Desarrollo Social / Instituto Nacional de Ecología. México, D.F.

Mexico, 1993. Indicadores socioeconómicos de los pueblos indígenas de México. Instituto Nacional Indigenista. México, D.F.

Ramamoorthy, T.P., 1993. Introduction. In Ramamoorthy, T.P., et al., Biological Diversity of Mexico. Oxford University Press. USA, Ney York. 812 p.

Vazquez Y., C. y Orozco S., A., 1992. La destrucción de la naturaleza. Fondo de Cultura Económica. México, D.F.

Wendall, B., 1990. "Commencement Addres, College of the Atlantic, 1988" In: Whole Earth Review, No. 66.

Richer, M. y Daly, D.C., 1997. Botánica económica en bosques tropicales. Diana. 293 p.

Subject VI

Conclusions and Recommendations

Symposium Conclusions and Recommendations[1]

Celedonio Aguirre-Bravo[2]

Executive Summary—This document proposes strategic actions for addressing the main conclusions and recommendations of the November 1998 North American Science Symposium held in Guadalajara, Mexico. Central to the syntheses delivered in this symposium was the conclusion that a fundamental improvement in the approaches currently used for inventorying and monitoring ecosystem resources is required if human civilization is to meet current and future environmental uncertainties. Symposium syntheses also revealed a strong consensus for moving toward a unified framework for inventorying and monitoring ecosystem resources in North America. Accordingly, the strategic action plan proposed here focuses on meeting these challenges through the development of practical functional mechanisms for networking across institutions and nationalities, implementation of science and technology exchange programs, and study of workable options for establishing a network of pilot study areas. As demonstrated in the Guadalajara symposium, working in partnership for supporting and carrying out the action proposals described in this document is an essential condition for achieving meaningful and successful outcomes.

Resúmen Ejecutivo—El presente documento propone acciones estratégicas para darle seguimiento a las principales conclusiones y recomendaciones del Simposio Científico Norteamericano de Noviembre de 1998 celebrado en la Ciudad de Guadalajara, Mexico. De suma importancia en las sinteses resultantes del simposio fue la conclusión de que se requiere de un mejoramiento fundamental en los planteamientos usados actualmente para inventariar y monitorear recursos de los ecosistemas forestales para que la civilización humana pueda enfrentar las incertidumbres ambientales presentes y futuras. De acuerdo a lo anterior, el plan de acciónes estratégicas propuesto en este documento se enfoca a enfrentar estos retos a traves del desarrollo de mecanismos funcionales de vinculación entre instituciones y nacionalidades, implementación de programas de intercambio científico y tecnológico, y estudio de opciones factibles para el establecimiento de una red de areas de estudio piloto. Como quedó demonstrado en el simposio de Guadalajara, el trabajar colaborativa y cooperativamente es una condición esencial para lograr resultados significativos y exitosos.

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

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Background

In November 1998, a group of four hundred specialists from government and nongoverment institutions of Canada, United States, and Mexico met in Guadalajara (Mexico) to confront a variety of issues concerning the advancement of monitoring science and technology for the assessment of forest ecosystem resources in North America. Many scientists from other countries also participated in this North American Science Symposium on Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources. Four plenary and fifteen workshop sessions were conducted to discuss a diversity of related subjects and provide specific conclusions and recommendations for advancing the integration of ecosystem inventory and monitoring programs across disciplinary and institutional boundaries, and continental (that is, geographic and temporal) scales. Specific recommendations were presented at the end of the symposium for review and targeted follow up. Sponsor representatives signed a non-legally binding statement in which they expressed their intent to continue working in partnership to support research and technology transfer efforts on monitoring for ecological assessment of ecosystems and the environment. This action plan proposal has been prepared for review and approval by the appropriate experts and executives of the sponsoring institutions.

The resulting conclusions and recommendations from this symposium clearly emphasize the urgent need to work in partnership across institutional and national boundaries to further advance ecosystem monitoring science and technology in North America. Although there are many ongoing inventory and monitoring programs, as well as related research efforts, the information they provide is inadequate to meet society's needs. Understanding the vulnerability of ecosystems to disparate drivers of environmental change is central to the major issues society faces. The generation of knowledge allowing this understanding constitutes a fundamental condition to ensuring the sustained productivity of ecosystems and their multiple values to society. Scientists in this symposium concurred that existing approaches to ecosystem resource inventory and monitoring must change radically if they are to help meet national and global needs.

In North America, as in other multinational systems, the sustainable availability of natural resources and the healthy condition of ecosystems are indisputably the primary foundation for economic and human development. Sustaining these ecological systems, managing and mitigating change in those that have already been damaged, and particularly anticipating the impacts of potential global change scenarios on human health, are among the most critical challenges that societies face today and into the foreseeable future.

To confront these challenges, the design of new inventory and monitoring programs needs to be based on an integrated approach to successfully provide answers to the complex questions scientists and the public need to know. While most existing inventory and monitoring programs are effective at tracking specific ecosystem resource components, the information they generate is inadequate for providing complete, scientifically defensible, environmental syntheses of how drivers of change impact or might impact natural resource and ecosystem condition at different scales of time and space resolution.

For North America, being a multinational free trade economy, it is essential to develop a common strategy for advancing existing approaches to ecosystem resource inventorying and monitoring. Though at present the North American Free Trade Agreement (NAFTA) countries do not have such an strategy in place, its development and implementation is particularly important given the geographic adjacency, and ecological, economic and socio-cultural linkages and interdependencies. Building this institutional capacity would make possible the development of comprehensive environmental syntheses to inform society about the status of ecosystem resources and the environment—and if they are changing, why and how that change is taking place. Symposium participants noted that if scientifically-credible information is not available to provide policy alternatives, the documented impacts of global change on the environment and human health will prevail, with the potential to increase the level of uncertainty.

In light of the considerable analysis that took place during this symposium, the thrust of the main conclusions and recommendations points toward strengthening and diversifying the existing network of partnerships to further advance the science and management of ecological monitoring for assessment of ecosystems in North America. This action plan proposal, therefore, constitutes an important outcome of this symposium. Specifically, it addresses the critical need for developing a common strategy for supporting ecosystem monitoring and research efforts through truly effective actions of international cooperation and collaboration that assure transfer of technology and access to scientific information.

Context for Action

The symposium conclusions and recommendations emphasize that there are many examples of the important roles that ecological monitoring and research have played in developing the understanding required to support sound policy and appropriate management actions. At the same time, it was also pointed out that many of the environmental issues that now confront us are larger in scope and of greater complexity than those previously addressed. There are compelling reasons—both scientific and economic—for moving toward the design of more integrated/comprehensive strategies for monitoring ecosystem resources and the environment. Scientifically defensible and credible information generated from such strategies is important so that society can differentiate between actual and perceived environmental issues and can act on them appropriately.

In North America, environmental protection and management agencies are currently involved in major reassessment and redirection of their ecosystem resource inventory and monitoring programs. Not only these programs differ in their rationale but also in their monitoring strategy and scales of resolution. Each institution's inventory and monitoring program has a wealth of information and experiences for further advancing ecosystem monitoring science at regional and continental scales. Complex environmental issues (i.e., climate change, primary productivity, insects and diseases, or human health) controlled by upper level systems (i.e., climate, environmental policy, or resource management decisions) cannot be properly addressed by current inventory and monitoring strategies.

Existing ecological monitoring programs have often been adequate for their intended purposes but the data and information they generate are usually not directly comparable. Primarily, the focus of these programs is often on single resources or single ecosystem resource groups. Given the necessarily circumscribed information generated by these programs, it is difficult to say much about the interactions between and among ecosystem components, at least not at different scale levels. Cooperative and collaborative networking with institutions that have relevant programs is essential to advance science and technology for inventorying and monitoring ecosystem resources in North America.

Other problems arise when the spatial and time scales of inventory and monitoring programs are substantially different. Similar conflicting situations emerge when the indicators design strategy, sampling and measurement strategies, vary between and among inventory and monitoring programs. Central to all these issues, however, is the limited availability of economic resources to support disjoint inventory and monitoring programs. Given current and future budget scenarios, moving toward a unified/integrated framework for inventorying and monitoring ecosystem resources seems to be a most cost-effective solution.

A North American Strategy for moving toward a unified framework for inventorying and monitoring ecosystem resources must take into consideration situations such as spatial and time scales, economic and human resources, and international linkages. As discussed in this symposium, these and many other related issues of common interest create a window of opportunity for addressing and putting into action several of the main recommendations presented and discussed at the North American Science Symposium.

Priority Areas for Action

I. Strengthening and Diversifying Partnership Networks

As in previous North American meetings, the participants of this symposium strongly recommended establishing functional mechanisms to foster and encourage tri-national cooperation and collaboration in order to further improve the development of ecosystem monitoring science and technology in North America. Successful actions to confront the diversity of issues addressed at the Symposium require the establishment of a functional networking strategy that guarantees cooperation and collaboration across institutional and national jurisdictions. For this networking strategy to be successfully operational, it must provide a common platform where the actors and players responsible for advancing ecosystem monitoring science and technology can address their issues in a fashion that is equal and impartial. Previous North American Science Symposia have taken place under this organizational criteria and their results have been highly successful and meaningful to society.

In response to this recommendation, therefore, it would be in the best interest of existing and future partners to establish formally a **World Ecosystem Resource Monitoring for Assessment Network (WERMAN)**. In order to serve its partners in the most effective possible manner, WERMAN's mission and goals needs to be anchored on a common ground of mutually beneficial conditions and opportunities. Taking this step, the formal establishment of WERMAN, will provide purpose and direction to all cooperative and collaborative efforts that need to be undertaken for moving toward a unified framework for inventorying and monitoring ecosystem resources in North America. Accordingly, the **"Action Proposal Statement"** signed by executives of the institutions that sponsored the North American Science Symposium provides an important foundation for supporting this specific recommendation for action.

II. Science and Technology Exchange

Central to the symposium's main conclusions and recommendations is the critical need for developing a joint cooperative and collaborative strategy for science and technology exchange on integrated approaches for inventorying and monitoring ecosystem resources. Symposium participants expressed consensus for moving toward a unified North American framework for inventorying and monitoring ecosystem resources. However, design strategies for moving toward this desirable condition should be adaptative and must recognize individual mandates and priorities of participating institutions. Consequently, improving and diversifying the flux of science and technology information exchange among institutions and across nationalities is an important requirement for implementing this recommendation. At present, as it was noted, there are serious differences in institutional capacity (i.e., economic, social, cultural, scientific, technological, organizational, and educational) among countries which act as major impediments for advancing ecosystem monitoring science, as well as for developing cost-effective ecosystem resource monitoring strategies. These differences, however, should not be a deterrent for cooperative action when dealing with ecological issues of regional and global significance. Cooperative training and education, therefore, are essential for advancing monitoring science and technology across institutional jurisdictions and nationalities. Specifically, the symposium participants recommended working in partnership to support scientific, technology, and educational exchange actions on the following issue areas of common interest for institutions in North America and abroad:

- Global Ecological-Economic Issues;
- Ecosystem Resource Monitoring Science;
- Ecological and Economic Indicators;
- Integrated Statistical Sampling Designs;
- Site Measurement Protocols and Metadata Standards;
- Quality Assurance and Quality Control Strategies;
- Data and Information Management Systems;
- Statistical Data Analysis Processes;
- Development of Integrated Environmental Syntheses;
- Remote Sensing and GIS Technology Applications;
- Effective Information Communication Strategies.

III. Network of Pilot Study Areas

Symposium participants also proposed the establishment of pilot study areas to serve as learning/educational centers for advancing ecosystem resource monitoring science and technology applications. For this purpose, processes for establishing pilot study areas should take into account the value of existing inventory and monitoring networks. Building upon existing networks has a number of scientific and technical, organizational, logistical, economic, and operational advantages. While conducting the science and technology exchange activities referred to above, partner institutions participating in this process may commit themselves to study viable strategies for establishing pilot study areas for addressing specific inventory and monitoring questions. Through this adaptive process, proposed actions for establishing pilot study areas not only will have better technical and scientific foundations, but also stronger political and organizational support from partner institutions. Under this rationale, partner institutions involved in these processes will experience a smoother transition moving toward higher levels of integration in their inventorying and monitoring programs.

Action Proposals

Proposal I

To establish the World Ecosystem Resource Monitoring for Assessment Network (WERMAN).

Action—Meet with executives from sponsoring institutions to discuss strategies for the establishment of WERMAN, its goals and objectives, scope, function, organization and coordination, and funding considerations.

Proposal II

To carry out a series of educational/training workshops on the specific issue areas referred to above. As continuous annual programs, these workshops will constitute the main vehicle for science and technology exchange between and among institutions in North America.

Action—Meet with executives from sponsoring institutions to discuss the proposal, and if there is consensus, then to define strategies for funding support and implementation.

Proposal III

To develop a design strategy for the establishment of "Pilot Study Areas for Ecosystem Resource Inventory and Monitoring" that can be used as a prototype model for implementing similar initiatives elsewhere in North America or other countries.

Action—Meet with executives from sponsoring institutions to discuss current efforts in a pilot study area in northern Mexico, define strategies for continuing supporting this project, and decide if it could be used as an option for the purpose of implementing this proposal.

Approach

Hold a two-days meeting with executives from the sponsoring institutions to discuss and decide on the specific proposals and actions described in this document. Preliminary reviews of this document will be conducted previous to meeting. Also, executives will be contacted to determine date and location for this meeting. Basically, the meeting's agenda will primarily focus on action items described in this proposal.

Appendix: Conclusions and Recommendations by Issue Area

Remote Sensing Applications

Recognizing that remote sensing, using various tools from Landsat to sketch mapping, serves an important function in forest inventory and monitoring across our three nations, and that it also has limitations that must be recognized (Workshop Session Chairs: Mr. Harry Hirvonen, Science Advisor, Canadian Forest Service, Natural Resources Canada, Canada and Dr. José L. Palacio Prieto, Director, Instituto de Geografía, UNAM, Mexico):

- It is recommended that mechanisms be established to facilitate exchange of both research and monitoring results and information among the three countries;
- It is recommended that joint mechanism for quality control and quality assurance be established among the three countries to allow comparability and applicability of remote sensing tools;
- It is recommended that a priority for joint research be to determine the appropriate linkages between interpretation from remote sensing and ground plots and surveys for validation.

Data Management and Analysis Support Systems

Forest inventory data are key to decision-making. Using portable data recorders allows the data to be error checked in the field where it is best corrected, plus the data feed easily and quickly into a data base management system. This system should be designed with inventory data in mind, should have sufficient metadata to describe the data, and should make it easy to retrieve. Analysis software should make it easy to generate almost any combination of the data that the analyst wants, and should produce estimates of reliability. The data should provide the necessary inputs to projection models to assist in decision-making.

Knowledge bases can be combined with the data to further refine the decision-making process. Concepts and uses of metadata in ecosystem monitoring can be extended to knowledge bases that provide formal logical specifications for interpretation of monitoring data. Knowledge bases in general provide three significant features: consistent interpretation of information, clear documentation of the reasoning that produces an interpretation, and fast, easy access to the logical basis for conclusions. The EMDS system in particular is noteworthy for its abilities to reason with incomplete information, prioritize missing information, and provide a logic framework for integrating numerous and diverse types of monitoring data (Workshop Session Chair: Dr. Douglas S. Powell, National Monitoring Coordinator, USDA Forest Service, Washington, DC, USA).

Forest Inventory Case Studies (Mexico)

Most of Mexico's forest inventories are biased toward the timber resource commercial component for management purposes. Required by Mexican Law for authorizing forest resource management plans, these inventories are conducted by forestry technicians from Units for Conservation and Forest Development (UAF/UCODEFO) or other Consulting Forestry Companies. As specific programs, they are quite divergent in their rationale (i.e., purpose, goals, objectives) and design strategies (i.e., sampling design, criteria and indicators, integration and linkages, comprehensiveness, field measurement protocols, quality assurance and quality control, information management systems, data analysis systems, syntheses, and reporting). Many of these strategies which are critical for generating scientifically-defensible and -credible information are often not documented when designing these programs. While the information of these inventories is primarily used for timber management purposes, its utility for assessing the state and condition of forests for management planning purposes is questionable. Landowners participation in processes of designing forest resource inventories is critical to insure the social significance, technical credibility, management utility, and long-term scientific value of the data and information generated through these programs. To a large extent, these problems are brought about by the lack of a coherent/integrated/comprehensive/interoperable national framework for inventorying and monitoring forest ecosystem resources. Therefore, it is recommended to develop and implement a systematic/adaptive strategy for moving toward a unified framework for inventorying and monitoring ecosystem resources. Working in partnership for the development of such a framework constitutes an important condition for achieving successful results. (Workshop Session Chair: Dr. Miguel Caballero Deloya, Jefe del Area de Capacitacion, Programa de Proyección Externa, Centro de Agricultura Trópical de Investigación y Ensenanza (CATIE), Turrialba, Costa Rica).

Science and Policy

In light of a considerable theoretical basisCand with strong empirical evidenceCfor global environmental change phenomena and their occurrence, and in recognition that Humankind's activities contribute to such change, we recommend that (Workshop Session Chair: Dr. Sidney Draggan, Senior Science Advisor, US Environmental Protection Agency, Washington, DC, USA):

- Ecological system-based, watershed-scale approaches are needed to identify, study, assess and manage options for dealing with such global environmental change;
- Identifying, studying and acting on global environmental change phenomena requires frameworks that incorporate the scientific, social, cultural, economic and political dimensions of the phenomena through wide stakeholder participation; and
- Planning and implementation of research and assessment, and planning and implementation of management actions and decisions must be based on clear communication among stakeholders;
- Researchers planning and implementing monitoring, inventory or other observational activities must seek and must have clear understanding of the questions expected to inform the positions of either managers and decision makers or other stakeholders;

- Environmental management actions or decisions need to derive from a stakeholder-inclusive process or framework for identifying, measuring, assessing and characterizing the nature of a problem or issue. Also, such processes or frameworks are needed to disclose appropriately the options for resolution or management of the problem or issue. That is, there must be acceptance of the notion of procedural justice; and
- Researchers, managers and decision makers need to recognize the substantial role for sound science in the decision process by providing appropriate support for such processes as quality assurance and independent peer review in the generation of science intended to underlie actions or decisions.

Evolving Complexity

Canada, U.S., and Mexico each has a variety of forest inventory and monitoring programs, many with long histories. Complexity has certainly evolved and accelerated (Plenary Session Chair: Dr. Robert Lewis, Research and Development, Director, USDA Forest Service, Washington, DC, USA). Some examples include:

Timber inventory -> multi-resource inventory -> integrated inventory;

- Local -> global;
- Political boundaries -> ecosystems;
- Periodic inventories -> annual inventories;
- Technology: walking with paper -> satellite with digital recording;
- File cabinets -> sophisticated databases, metadata, GIS;
- Paper table/graph reports -> publish on Internet;
- Little public interest -> great public involvement;
- Little political influence -> great political influence (particularly in Mexico);
- Status of resource -> changes and trends -> projections;
- Working in isolation -> collaboration, partners, networks;
- Timber supply -> invasive species, threatened and endangered species, disturbance, restoration, water quality, wildlife habitat, needs of local communities, other forest products, human dimension.

In light of the above, the following is recommended:

- Recognize this change in complexity;
- Understand that such change will continue;
- Keep inventory and monitoring systems as simple as possible to get job done;
- Use adaptive management in inventory and monitoring design to deal with evolving complexity.

Specific Resource Inventory and Monitoring

Unified frameworks for inventory and monitoring must recognize and provide opportunities for specific and detailed case studies to provide information on both local/ regional ecosystem processes and as a source of new technologies for extensive monitoring programs. There are a host of new measurements that will be required to address emerging global change issues. An integrated framework should anticipate and embrace new measures as they come off of the testing bench. New tools and approaches to data modeling will make possible a degree of analysis and information generation not previously anticipated. It is recommended that acceptance of some of these techniques, wether designated sample units or spatial analysis procedures, need to be considered as common standards for acceptance in an integrated North American framework (Workshop Session Chair: Mr. Bruce Pendrel, Canadian Forest Service, Natural Resources Canada, Canada).

Multiresource Inventory and Monitoring

A main conclusion in our session was that annualized inventories are an exciting new development in the US, of considerable utility to industry, environmentalists, and government. As in several instances, it shows the tremendous potential for pay-off if the 3 countries (and others such as Argentina too) could work together on such issues. Another issue raised in our session was that we cannot make good progress on aquatic inventories until good questions are raised. Until then we cannot resolve issues well of how closely terrestrial and aquatic inventories need to be done together. The US is now investigating how to integrate the two national natural resources inventories, the NRI of the Natural Resources Conservation Service and the FIA of the USFS, both agencies in the US Department of Agriculture. Several pilot studies on this are planned in Minnesota at this time. In Canada, the national forest inventory information continues to be integrated with the National Ecozone/ Ecoregion Framework. Ed Wiken suggests integrated monitoring and state of the environment reporting by the 3 countries. Why is this important? As an example noted by Ed Wiken: forestry and land practices in the mountainous regions of Mexico could affect the numbers of Monarch butterflies summering in southern Ontario in Canada (Workshop Session Chair: Dr. Hans Schreuder, Scientist, RMRS, USDA Forest Service).

Biodiversity Inventory and Monitoring

Protecting biodiversity is internationally recognized as a high priority in forest ecosystem management. The purpose of this workshop was to address questions and issues regarding how biodiversity is defined, measured, inventoried, and monitored to assess the impacts of human activities against a backdrop of natural environmental change. We review key points and comments that summarize the workshop talks and the questions and comments from the audience. There were several underlying similarities in the talks presented in the session. First, the governments and land management agencies of our three countries have responded to growing public demands for preserving native species of plant and animals as well as providing sustainable forest products. Second, most speakers recognized that current information on biodiversity is woefully inadequate. High resolution maps of hot spots of diversity, rare and endangered species, and critical habitats are not available in Canada, the USA, or Mexico. Third, there are few standardized protocols for collecting information on multiple biological groups and associated habitat characteristics at local, regional, national, and international scales. Lastly, cooperative efforts have been lagging on technology transfer and information management among agencies within and between countries. It is against this common backdrop that the speakers and the audience sensed both urgency and opportunity.

Judy Loo reported that Canada lacked a coordinated vegetation monitoring system. Although the Canadian Forest Service is characterizing and modeling some plant and animal distributions, and provinces are assessing endangered species, much more work is needed to provide timely information to land managers. Thomas Stohlgren showed how multi-scale sampling techniques are used to rapidly assess hot spots of biodiversity and areas of unique species assemblages with an emphasis on reducing the impacts of invasive exotic species. Maintaining natural disturbance regimes and monitoring key indicators of multiple stresses to biodiversity were noted as important components for preservation.

James Comiskey demonstrated the use of multi-scale sampling techniques to identify hot spots of biodiversity in the Urubamba Region in southeastern Peru. In combination with the Smithsonian Institution, and other forest monitoring programs, these methods provide an integrated approach to ecological assessments.

Jose Delgado provided a comprehensive review of the status of biodiversity in Mexico with a disturbing evaluation of the loss of rare and critical habitats, combined with increasing demands for forest products, especially lumber and firewood. The introduction of exotic species, over-exploitation of natural resources, and illegal trade of rare species all threaten forest biodiversity. Gilberto Chavez-Leon echoed these concerns with an example of decreasing bird diversity due to non-sustainable land use effects in Michocan, Mexico. Raul Rosenberg focused on the need to define critical habitat and to understand the spatial and temporal variation of habitats and animals for conservation. J. Jimenez recommended inventory methods to evaluate the vertical and horizontal stand structure of uneven-aged forests. One key feature of the method was the assessment of a suite of indicators of species and structural diversity. Ubaldo Zaragoza wrapped up the formal presentations with a report on organic matter accumulation and decay in mangrove forests ? a subtle reminder that the ecological processes that maintain forest structure also maintain patterns of biodiversity.

Michael Huston summarized the main points of the presentations in the context of understanding ecological theory as a basis for planning inventory and monitoring. Theories on the energetics and dynamics of populations can provide important insights on the distributions of species and patterns of heterogeneity. He called for the integration of GIS-based models based on remotely sensed and field data with process-based biophysical models.

Most questions and subsequent discussions focused on needs common to everyone in attendance. Greater financial support is needed from government agencies and non-government agencies to rapidly acquire detailed information on patterns of biodiversity, the status of rare species and habitats, and trends in populations of concern relative to human activities. A second commonality was the need to increase the sharing of techniques and technology, including jointly-sponsored, international inventory and monitoring programs. The third common need, which was also a goal of the conference itself, was to increase communication among scientists and land managers among our countries.

We sensed a feeling of optimism, fueled by promises of cooperation and sharing. We have much to learn, and even more to accomplish in the urgent protection of the biodiversity in North America. There is no shortage of enthusiasm (Workshop Session Chairs: Thomas J. Stohlgren, Midcontinent Ecological Science Center, U.S. Geological Survey, Fort Collins, Colorado, USA; Judy Loo, Canadian Forest Service, Natural Resources Canada, New Brunswick, Canada; Jose Concepcion Boyas Delgado, Forestry Branch, CIR-Centro, INIFAP-SUGAR, Mexico; and Reporter: Michael Huston, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA).

Long-Term Ecological Research and Monitoring

The goal for the symposium was to build on the best science and technology available to assure that the data and information produced in future inventory and monitoring programs are comparable, quality assured, available, and adequate for their intended purposes, thereby providing a reliable framework for characterization, assessment, and management of forest ecosystems in North America. This provided an excellent opportunity to demonstrate how long-term research and information management provided at Long Term Ecological Research sites in Canada, U.S. and Mexico could aid the needs of forest management. Two of the sessions in the symposium where U.S. speakers presented results from LTER were Long Term Ecological Research Monitoring and Information Management Systems. The primary objectives of the Long Term Ecological Research Monitoring session addressed issues and alternatives to integrate these sites and other monitoring programs into a more comprehensive, integrated approach for monitoring forest ecosystems. In the Information Management Systems session, speakers addressed questions and issues regarding the design of information management systems for supporting the needs of integrated/comprehensive inventory and monitoring frameworks as well as research (Workshop Session Chair: James Gosz, Professor, University of New Mexico, Alburquerque, NM, USA).

The sessions also developed recommendations to be made to the general symposium. Of special note in the Long Term Ecological Research session, participants from the three countries agreed to form the North American Regional LTER Network. Initially, the sites from the U.S. LTER Network, Canadian Environmental Monitoring and Assessment Network, and proposed Mexican MEXLTER Network will make up this regional network. We anticipate, and will work for, the addition of other North American sites/networks in the future. The North American Regional Network will join with regional networks in Asia Pacific, Latin America and Central Europe and other countries in the International LTER Network (ILTER) to increase international collaboration.

The first meeting of the Regional Network will occur in late 1999 (place to be determined) and a second meeting will occur in association with the All-Scientist LTER and Ecological Society of America meeting at Snowbird, Utah in 2000. These meetings will focus on developing scientific questions and research necessary to develop regional-scale analyses, scientific exchanges/interactions and training/ education. A number of other specific recommendations for the overall symposium were made in the two sessions. For the Long Term Ecological Research session:

- Develop analyses and syntheses of existing inventory, monitoring and research data based on important scientific and management questions;
- Integrate intensive site studies with extensive site studies. Monitoring and research efforts should be linked and integrated;
- Monitoring/Inventory should be an adaptive activity. Continual evaluation and assessment are important. Monitoring/inventory activities should be a result of top-down and bottom-up considerations. National needs (management needs) and pragmatic considerations of scientific feasibility must be considered;
- Utilize the new paradigms based on current scientific understanding and incorporate into assessments of inventory, monitoring and research needs;
- Maintain a long-term view on the needs for inventory, monitoring and research (as well as satisfying short-term objectives);
- Use conceptual models (and theory) to integrate research and monitoring efforts;
- Monitoring networks and intensive research sites should evaluate methods and approaches for determining how well intensive sites provide representative information on ecosystem dynamics and the mechanisms underlying those dynamics for the surrounding region;
- Develop exploratory project(s) to address this issue;
- Interactions among scientists and sites in Mexico, U.S. and Canada are very important. Students should be involved in those interactions;
- Consider the human factor in our research and monitoring of ecosystems;.
- Develop facilities and necessary infrastructure at intensive study sites to increase opportunities for research and monitoring activities. Increased numbers of studies facilitate the development of the comprehensive understanding of the ecosystems;
- The North American Regional LTER Network should aim at providing needed input to the decision-making processes; and
- Design research/inventory/monitoring activities to understand ecosystems along the environmental gradients present in North America.

Sampling Design and Analysis Processes

We have a once-in-a-generation opportunity for North American collaboration aimed at increasing the consistency and utility of forest ecosystem inventory and monitoring programs across North America. All three countries are presently redesigning their inventory and monitoring systems (Workshop Session Chair: Andrew Gillespie, National Forest Inventory Coordinator, USDA Forest Service, Washington, DC). Thus the opportunity exists to go as far towards a common framework as we want:

- One extreme: a single North American system with a single sample design, grid, remote sensing, and linked to more intensive monitoring efforts. This is probably more extreme than is politically feasible at the moment, although there are no technical obstacles.
- A more practical approach would be a 'common database' approach, similar to the US and Canadian systems currently in place, where data are collected according to somewhat different procedures, then are amalgamated into a single database.
- The simplest, lowest risk approach would be to simply share information on an ongoing basis as we develop our systems - share copies of manuals, planning documents, exchange invitations to meetings, etc., to assure that easy opportunities for collaboration are not missed.

There are some important areas for future research, which could be taken in a collaborative fashion. Priorities include:

- Development of remote sensing tools and techniques for increasing sampling efficiency, and increasing the range of products (maps, analyses) produced by inventory programs;
- Development of modeling, estimation procedures, especially for time series data;
- Integrating data across scales, specifically for purposes of planning forest operations;
- Spatial analysis tools and techniques for analyzing and portraying data.

Criteria and Indicators

The variety of indicators reported on makes it clear that there must be ongoing collaboration and cooperation of the development and testing of these indicators by participants, nationally and internationally. A suite of indicators be tested in Mexico in 1999, or as soon as possible, similar to the process of testing in Boise, Idaho in 1998. Indicators should be tested those used in the Montreal process Indicators for Sustainable Development (Santiago Declaration) to provide a common example for several countries (Workshop Session Chair: Dr. J. Peter Hall, Canadian Forest Service, Natural Resources Canada, Canada).

Quality Assurance Systems

While it was recognized that effective Quality Assurance (QA) is being included in some forest resource monitoring programs, the participants were concerned that general application of sound quality assurance principles to forest monitoring in North America is far from adequate (Workshop Session Chair: Dr. John Lawrence, Aquatic Ecosystems Protection Branch, Director, Environment Canada, Canada). The following was recommended: **That data quality assurance be a recognized component of all forest monitoring programs in the United States, Mexico and Canada.**

While the participants recognized the value of discussing data quality assurance at workshops held at periodic intervals, it was felt that some form of ongoing effort was required to promote potential benefits of good data quality and encourage QA implementation. The following was recommended: **That the organizers build on the findings of this Symposium, and that held in Mexico City in 1995, by establishing a permanent tri-partite quality assurance working group to:**

- Promote the awareness of data quality and identify a minimum desirable level of QA;
- Establish dialogue to promote communication of QA policies and procedures;
- Select one or two parameters for a pilot tri-partite QA initiative.

Information Management Systems

The goal of our session was to foster the development of improved information management systems for forest inventory and monitoring programs in North America. Our approach was to share experiences in the development of information systems for different types of forest monitoring programs and to discuss mechanisms for the sharing of data and information between monitoring programs (Workshop Session Chair: Dr. Craig Palmer, Professor, University of Las Vegas, NV, USA).

Several participants noted that regional and continental scale forest ecosystem data for North America are not readily accessible. No directory of forest monitoring databases across North America currently exists. The utility of data that is accessible is often limited due to inadequate data descriptions (metadata). No forum currently exists to help improve the exchange of forest monitoring information across North America. Several initiatives have been proposed for the development of forest information systems at national and global scales, but these efforts are not coordinated. To address the need for improved information sharing, the participants made the following recommendations:

- That a vision for enhanced sharing of forest ecosystem information across North America be developed as soon as possible. This vision should include the development of a directory of forest data bases, agreement on metadata standards for the sharing of information and to prevent data entropy or the loss of data utility with time, the development of approaches to encourage data sharing, and the development of data access and data synthesis tools to assist users of forest data bases.
- That the organizers build on the findings of this Symposium, by establishing a permanent tri-partite information management working group to promote cooperation within and between countries for the management of forest ecosystem data. One model for this working group is the Information Managers Committee of the Long-term Ecological Research (LTER) network. The initial efforts of the work group should include a cooperative pilot study effort with the involvement of all three countries. A primary objective would be to promote communication between information managers of forest monitoring programs to encourage data sharing, capacity building and technology transfer. The ultimate goal would be the development of a Federated Information Infrastructure for forest monitoring data across North America.

Assessment and Results Application

The session had a good cross section of views from each country (i.e. Canada, USA & Mexico), from a variety of scales (i.e. local, regional, national), and from diverse types of forest assessments. Collectively, there was a great deal of consistency in the elemental parts of each presentation. In summary, the answers provided by assessments are only important if you asked the right questions at the onset (Workshop Session Chair: Dr. Ed. B. Wiken, Canadian Council on Ecological Areas, Canada). It is recommended that he three countries initiate and further develop continental wide forest assessments on concerns of common interest such as:

- Forest protected area assessments;
- Forest health assessments; and
- Biodiversity and wildlife habitat assessments.

Such assessments should be employed to enhance the use and application of forest criteria and indicators. Assessments at the national, regional and local scale should be continued and refined to address increasingly specific needs, peculiar to individual countries or regional ecosystems. Forest assessments should be promoted as an iterative and adaptive process; a process that is flexible in addressing issues, design considerations and products (Table 1).

Table 1.—Assessments and results applications: strategy design elements.

Issues— in the sense of topics	Design considerations— in the sense of	Products— in the sense of our ability to
Air pollution	Using ecosystems as a base	Produce general assessments
Land use management	Using core science principles	Meet legal obligations
Biodiversity	Players, audiences, participants, stakeholders	Meet policies
Protected areas	Temporal and spatial scales	Meet regulations
Forest health	Data selection and relevance	Deliver concise and relevant information
Decision making needs	Cost effectiveness	Produce environmental syntheses
Others...	Financial resources	Others...

"ACTION PROPOSAL STATEMENT"

Guadalajara, Jalisco, Mexico
November 5, 1998

The executives of the North American institutions who sign this non-legally binding Action Proposal Statement, as main sponsors of the North American Science Symposium, having an official mandate for the protection, conservation, and sustainable management of ecological systems and the environment:

RECOGNIZE that the "North American Ecosystem" comprises shared regional ecological systems in which the land, air, water, plant and animal biodiversity, and the human dimension are linked and interdependent;

RECOGNIZE that there are a number of critical issues concerning the sustainability of ecological systems and the biological diversity they harbor. Among these issues: the documented and potential effects of land use change, land management practices, fire suppression, urban growth, air pollution and other contaminants, climate change, and the interaction of such stresses as insects, pathogens, and exotic species;

NOTE WITH CONCERN that the ecologic-economic effects of these issues are larger in scope and of greater complexity than those addressed traditionally by resource managers and policy decision makers;

NOTE that existing inventory and monitoring programs for ecological assessment of ecological systems and the environment have often been adequate for their intended purposes, but the data and information that they generate are usually not directly comparable and of limited used for management planning and decision making;

NOTE FURTHER that because these inventory and monitoring programs have often been focused primarily on a single environmental medium or a single natural resource, little can be inferred about the linkages among air, land, water, and biodiversity, at least not at a regional/transboundary scale;

EMPHASIZE that monitoring and assessment are scientifically based approaches to understanding and reporting on the status and trends in ecosystem condition, describing emerging ecological conditions, aiding in the design of ecosystem management activities, evaluating ecosystem management programs in terms of their performance, and responding to ecological emergencies;

RECOGNIZE that the application of interoperable methodologies and approaches to inventory and monitoring of ecological systems and the environment are essential for generating scientifically credible data and information useful for understanding and confronting the complexity of ecosystem sustainability;

RECOGNIZE that this Symposium is a tangible response to the recommendations of the "North American Workshop on Monitoring for Ecological Assessment of Terrestrial and Aquatic Ecosystems" held in Mexico City on September 18-22, 1995;

RECOGNIZE that there are numerous Agreements in place between and among the federal institutions of the countries here referred to that are designed to promote and foster cooperation for confronting issues of common concern such as the ones addressed in this Symposium;

RECOGNIZE that no institution, by itself, has the expertise and financial resources for successfully implementing inventory and monitoring programs for assessment of ecosystems and the environment without the assistance of other cooperating institutions;

REAFFIRM that it is critically important to network with all key institutions concerned with the issues and challenges referred to above; and

REAFFIRM that the development of integrated, comprehensive, and interoperable approaches to inventory and monitoring of ecological systems and the environment, as emphasized in this Symposium, brings numerous direct and indirect benefits to all institutions that share a similar mission.

Therefore, the undersigned, under a non-legally binding framework, express our intent to continue working in partnership to support research and technology transfer efforts on monitoring for ecological assessment of ecosystems and the environment. For this purpose, an **Advisory Group** comprised of appropriate experts, selected by each participating institution, will be established to:

- Study recommendations resulting from the Symposium, and pursue options to act upon appropriate recommendations, recognizing individual mandates and priorities of participating institutions;

- Determine the interest and desire for a 3rd North American Science Symposium, which would build on the foundation established by this Symposium, through discussion with scientists and managers of participating institutions and others.

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RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals.

Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

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Boise, Idaho
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Missoula, Montana
Lincoln, Nebraska
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Ogden, Utah
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