Alternative Natural Resource Monitoring Strategies in the Mexican States of Jalisco and Colima

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Abstract.—This paper presents a strategy for inventorying and monitoring the natural resources in the Mexican states of Jalisco and Colima. The strategy emphasizes a strong linkage between remote sensing with field sampling design to produce statistical summaries and spatial estimates at multiple scales and resolution levels. Outputs derived from this strategy are expected to have significant local use where policy and management decisions are most effectively made.

Through the Consortium for Advancing the Monitoring of Ecosystem Sustainability in the Americas (CAMESA), various federal agencies of Canada, the United States, and Mexico are working in partnership with the Mexican states of Jalisco and Colima to advance the science and technology of monitoring natural resource sustainability at multiple scales and resolution levels. Central to this work is the need to design and implement inventory and monitoring programs that are cost effective, technically defensible, scientifically credible, and of high social utility for multiple natural resource applications. Within the USDA Forest Service, the Rocky Mountain Research Station is currently leading this effort. In light of the successful results so far, these cooperative activities have been organized into a **Pilot Study and Learning Center** so that a variety of stakeholders (i.e., federal and State government, industry, academia, and nongovernmental organizations) can learn and benefit from the results of this experience. Should this undertaking succeed, it could then be recommended as a model for implementing similar initiatives elsewhere in Mexico and other countries in the Americas.

Vision and Mission

The vision in this cooperative undertaking is to advance the human values of environmental sustainability and the socioeconomic system by providing the resources that will enable individuals, agencies, organizations, governments, and other entities in Mexico and the Americas to effectively manage their natural resources in a way that sustains, rather than degrades, the ecosystem and enriches, rather than impoverishes, the social and cultural environment.

Goal and Objectives

The pilot study's overall goal is to develop a well-structured set of strategies that incorporates state-of-the-art science, technology, and analytical capabilities together with an Internet-based strategy for communicating program outputs. A seamless process will be created to provide all stakeholders the tools and knowledge needed to make intelligent decisions regarding the profitable and sustainable management and utilization of natural resources. Investments in this program will be directed to achieving the following specific objectives:

- Train a cadre of workers to inventory, monitor, and assess the sustainable management of natural resources.
- Create an appropriate physical infrastructure through which users may acquire, store, manage, analyze, report, and disseminate the information to inventory and monitor natural resources for their profitable and sustainable management and utilization.
- Create strategies for developing accurate and useful information about natural resources to help in decisionmaking and planning for sustainability.

If successful, this cooperative initiative will facilitate a multi-institutional capability for managing natural resources

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for their sustained use and productivity, while at the same time ensuring their vitality, diversity, and ability to provide important ecological services for the enjoyment of present and future generations.

Scope and Context

While focused on the goals described above, and using a hierarchical system of "Watershed Units" for ecological and economic accounting, the program will address a variety of critical questions regarding the information needed for assessing and managing natural resources within watersheds, at multiple scales and resolution levels. For example, what are the extent and condition of the watershed resources and processes (i.e., vegetation, soils, water, animals, landscapes, runoff, erosion, human activity, etc.)? What components of the watershed are changing and why? Why are some resources changing faster than others and where are these changes taking place (i.e., within and across watersheds)? What are the quantity, quality, and extent of services provided by watersheds, and how do human systems benefit from them? Within and across watersheds, where is mitigation/restoration of resources and processes most practical and beneficial? How are human systems sustaining the ecological integrity and societal value of watersheds? Will the current extent and condition of resources/services of watersheds meet future ecological and economic needs? How can stakeholders (i.e., landowners, federal and State government, industry, academia, and nongovernmental organizations) work together to solve the problems and issues within and across watersheds so that we can ensure the health of these systems and the well-being of present and future generations? Specific strategies will be developed and implemented to address these questions.

Study Area Significance

The Pilot Study Area comprises the Mexican southwestern states of Jalisco and Colima. The two states together cover an area of approximately 10 million hectares (25 million acres). Although Jalisco occupies 90 percent of the area, the State of Colima plays a distinctive role in the economy of the whole region and helps to diversify the Pilot Study Area. Four major ecological regions provide the natural resources and environmental conditions that make this region one of the most prosperous in Mexico. These ecoregions are the transversal neo-volcanic system, the southern Sierra Madre, the Southern and Western Pacific Coastal Plain and Hills and Canyons, and the Mexican High Plateau. Nested within these ecological regions are several important Hydrological Regions (HR) that drain to the Pacific Ocean: (HR12 Lerma-Santiago, HR13 Huicicila, HR14 Ameca, HR15 Costa de Jalisco, HR16 Armeria-Coahuayana, HR18 Balsas, and HR37 El Salado). One of the watersheds, the Lerma-Santiago Hydrological Region, is connected to Chapala Lake, the primary source of water for the City of Guadalajara.

Variables and Indicators

To maximize data versatility, the variables and indicators proposed in this pilot study either are directly parallel or are similar to those used in inventory and monitoring programs used by land management and environmental protection agencies of the United States and Canada. By adopting variables and indicators that meet Quality Assurance/Quality Control (QA/QC) requirements, the data and information collected through this program should be fully compatible or comparable with North American databases and other international programs. Local needs for more specific information for natural resource management will influence significantly the collection of additional variables and indicators. Long-term comparability of variables and indicators between and among various jurisdictions can be achieved by measuring a minimum subset of them **(Core Variables and Indicators)** at each site to address issues and problems of common concern. Some of the core variables will be standard information necessary to locate each site and define its basic physical and resource use characteristics. These variables will be measured once or remeasured occasionally. Other "Core Variables and Indicators" will also be measured to document the factors that have historically affected the status of the ecosystem. Metadata records will be kept to document these processes.

Strategy for Sampling Design

In designing an integrated multi-resource inventory and monitoring system to evaluate the condition and change of variables and indicators for sustainable natural resource management (forest, rangeland, agriculture, wildlife, water, soils, biodiversity, etc.), one needs some baseline data for comparison. Because one is generally dealing with complex systems, it may not be wise to select one or two variables for ecological monitoring. Also, analyzing these variables independently may lead to incorrect conclusions because of their interdependencies. One approach is to model the spatial relationship between key indicator variables. In natural resource management, for example, this information can be used to identify forest habitats that are either conducive or a deterrent to the presence of ecologically important plant and/or animal species. Techniques commonly used in describing spatial relationships between two or more variables include regression analysis and a variety of spatial statistical procedures that take into consideration the spatial dependency. The proposed natural resource monitoring system will rely on information collected at different spatial scales of resolution and sampling intensities to provide detailed information at the local level for natural resource planning and management (Schreuder *et al.* 2002).

Spatially Continuous Monitoring

Landsat Thematic Mapper (TM) data will be used to provide a complete and uniform census of individual Environmental Accounting Units (EAU) across jurisdictions (i.e., private lands, federal and state lands, ejidos, communities, counties, regions, etc.). This approach will provide measurements collected as a series of contiguous and simultaneous measures across land tenure units. It will also allow monitoring EAU's for changes in spectral and spatial characteristics that can be applied over a range of spatial and temporal scales appropriate for addressing specific natural resource issues.

Design-based Monitoring

The development of the sampling and plot designs is complicated by the variety of indicators to be assessed, the need to assess the natural resources at a range of scales, the need to monitor the indicators over time, and the need to do so efficiently. To meet national and State level objectives for natural resource assessments, we will develop a grid-based, traditional sampling design. For the remaining objectives involving estimation at local scales, the design will be enhanced to provide information needed to develop spatial statistical models to estimate key attributes at all locations within the sampled population (Reich and Aguirre-Bravo 2002).

Site-specific Monitoring

Because of the biological importance of certain areas in terms of threatened and endangered plant and animal species, there is a great need to initiate species- and/or site-specific research and monitoring. Detailed information should be collected at this stage through specific projects if funding is available. In addition, data should be collected that are compatible with key indicator variables collected at other monitoring levels. All data should be georeferenced to allow the integration with information collected at the different levels using spatially explicit models.

Quality Assurance/Quality Control

Quality assurance (QA) and quality control (QC) are essential to any monitoring and inventorying system. Quality Assurance builds confidence in the results of the inventory and monitoring program. Quality Control documents the quality of various program components to ensure that the components meet some minimal level of desired quality. QA/QC protocols apply to all components of the inventory program: program planning, data collection, information management and compilation, analysis and reporting, and continuous program improvement. Compatibility of QA/QC protocols across monitoring programs in the NAFTA countries is essential for this pilot study (Aguirre-Bravo and Alonso 2002).

Statistical Spatial Modeling

Detailed spatial models describing natural resources are typically limited by the spatial resolution of the data on which the models are based. For large geographical surveys, obtaining sufficient coverage further complicates the modeling process, as time and resource limitations preclude detailed sampling over large areas. Use of remotely sensed information, such as multi-spectral satellite imagery, allows one to easily derive large amounts of resource information over large areas; however, these sensors gather information at a fixed spatial resolution (e.g., 30 x 30 m for Landsat satellite imagery), and resources (such as forest structure, soil properties, etc.) may still occur at scales smaller than the resolution of the sensors with which the data were collected. Both Metzger (1997) and Joy and Reich (2002), however, were able to improve the spatial resolution of satellite-based classifications of forest structure and composition, respectively, using fine-scale field data for the classification procedure.

Modeling key indicator variables will be similar to what was done in Metzger (1997) and Joy and Reich (2002). Ordinary least squares (OLS) procedures will be used to generate trend surface models (TS) that describe the large-scale spatial variability in each of the vegetative elements measured in the field. Proportional data (basal areas by species, canopy closure, etc.) will be transformed using logistic transformation to stabilize the variance of the large and small proportions. OLS will be used twice in the model-building process —once as a preliminary means to reduce the number of independent variables used to predict the vegetative characteristics of interest, and secondly to generate the final TS model. In the preliminary analysis, independent variables with a P-value > 0.15 will be dropped. Independent variables used in the model may include slope, aspect, elevation, landform, information from Landsat bands 1-5 and 7, and land use class. Dummy variables can be added to the TS models to account for interactions between the various land use classes and the other independent variables.

Combinatorial regression will be used to determine which of the remaining independent variables best predict the dependent variable of interest. This "screening" procedure, which examines all possible combinations of independent variables in all possible orders to yield the best fit, determined by the lowest Akaike's Information Criteria (Akaike 1973), requires enormous amounts of computer memory. So it is important to eliminate unnecessary variables in the model (hence, the preliminary OLS) before running this screening procedure. The best fitting models will be used to generate a grid for each structural component of interest using ARC/INFO® (ESRI 1995). Kriging, cokriging, or regression trees will be used to describe small-scale spatial variability (i.e., error associated with the residuals from each TS model) in the landscape (Reich and Aguirre-Bravo 2002).

Project Coordination

Initially, the proposed organizational structure for coordinating this undertaking consists of a Project Technical Coordinator, a Science and Technical Committee (STC), and various Task Force Units for technical training, field implementation, data analysis, information management, and reporting. Members of the STC are senior executives/scientists from CAMESA institutional partners, as well as experts from other participating institutions and organizations. In this organization, the STC provides a mechanism to foster and coordinate technical and scientific cooperation and collaboration on matters concerning the design, planning, and execution of activities related to this project. Periodic meetings with the STC serve to analyze strategies and recommend ways to successfully implement this project. Aguirre-Bravo and Alonso (2002) provide detailed information about the coordination, organization, and implementation of this pilot study project.

Expected Products and Benefits

The pilot study creates a window of opportunity for a coordinated multinational effort to design and implement integrated approaches for inventorying and monitoring natural resources in the Mexican states of Jalisco and Colima. Salient to this undertaking is the opportunity to further improve information compatibility and procedures for use in integrating and evaluating information on the status, extent, trends, and projected changes in natural resources across jurisdictions, and at multiple scales and resolution levels. As a multinational partnership effort, it promotes the sharing of scientific and technical information and approaches to gain common understanding on a variety of issues and problems of current and future concern within and across jurisdictional boundaries and geographical scales. In addition, it addresses new approaches and methodologies for advancing the design and implementation of inventory and monitoring programs for the assessment and sustainable management of natural resources, at multiple scales and resolution levels. For the Americas, and particularly for Mexico, the pilot study serves as a learning center upon which scientists and resource managers learn and benefit from the results of working in partnership.

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Literature Cited

Aguirre-Bravo, C.; Alonso, T.L.A. 2002. Conceptual framework for inventorying and monitoring ecosystem resources at multiple scales and resolution levels. Tech. Bull. 35. PRODEFO, State Government of Jalisco, Mexico: 33–61.

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In: Petran, B.N.; Csaki, F., eds. International symposium on information theory, 2d ed. Budapest, Hungary: Akademiai Kiadi: 267–281.

ESRI. 1995. ARC/INFO® software and on-line help manual. Redlands, CA: Environmental Research Institute, Inc.

Joy, S.M.; Reich, R.M. 2002 [In review]. Modeling forest structure on the Kaibab National Forest in Arizona. Forest Science.

Metzger, K. 1997. Modeling forest stand structure to a ten meter resolution using Landsat TM data. Fort Collins, CO: Colorado State University. 123 p. M.S. thesis.

Reich, R.M.; Aguirre-Bravo, C. 2002. Spatial statistical strategy for inventorying and monitoring ecosystem resources. Tech. Bull. 35. Mexico: PRODEFO, State Government of Jalisco. 121–130.

Schreuder, H.; Williams, M.S.; Aguirre-Bravo, C.; Patterson, P.L. 2002. Statistical strategy for inventorying and monitoring the ecosystem resources of the states of Jalisco and Colima at multiple scales and resolution levels. Tech. Bull. 35. Mexico: PRODEFO, State Government of Jalisco. 87–108.