An Evaluation of Resource Inventory and Monitoring Program Used in National Forest Planning

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ABSTRACT / The National Forest Management Act (1976) specifies that multiresource inventories be conducted to provide baseline data for development and, later, monitoring of national forest management plans. This mandate entails the most ambitious and complex resource planning effort ever attempted. In this paper we evaluate the structure and use of current inventory-monitoring programs and recommend a framework for gathering data to improve national forest planning. Current national guidelines are general and provide only basic directions to forest-level planners. Forest inventories have traditionally concentrated on timber. Although these inventories are often well designed, the questions we are now asking about forest resources have outgrown these methods. Forest management is impeded by general confusion over definitions of resources and the interactions among them. We outline a simple classification scheme that centers on identification of basic ecosystem elements that can be readily measured. Furthermore, spatial and temporal scales must be considered in the design of inventory-monitoring programs. The concept of ecological indicators is reviewed, and caution is advised in their use. Inventory-monitoring programs should be goal-directed and based on as rigorous a statistical design as possible. We also review fundamental issues of variable selection, validation, and sampling bias. We conclude by developing a flexible inventory-monitoring program that is designed to provide information on individual characteristics of the environment, rather than being based on fixed definitions of resources.

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), as amended by the National Forest Management Act of 1976 (NFMA), specifies that forest-level inventories be developed and analyzed by interdisciplinary teams to develop integrated forest land and resource management plans (forest plans). These forest-level inventories are to provide baseline data for monitoring and provide input to the RPA assessment and program. In doing so, the inventories must reflect regional and national information needs as well as serving as a base for further project development (Lund 1984, Forest Service 1989). This mandate, as given to the US Forest Service (FS) by Congress, entails the most ambitious and complex resource planning effort ever attempted. Such a large, multifaceted program requires clear elucidation of the general philosophy, goals, and procedures to be used in meeting program requirements. Furthermore, adequate personnel, both in terms of quantity and quality, and funding must be made available to meet program requirements (Garcia 1989).

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The purpose of this paper is to evaluate the structure and use of current inventory and monitoring programs used on national forests, with emphasis on wildlife, range, and timber. We first review inventory-monitoring requirements placed on the Forest Service by legislative action, including the concepts underlying integrated, multiresource inventories. Next we review the format of current inventory-monitoring programs used by the forest service for forest planning. We then develop an alternative format for defining and analyzing resources and incorporate this format into a new framework for Forest Service inventory monitoring. We also evaluate the use of ecological indicators and the concept of biodiversity in inventory- monitoring and issues of study design and statistical analysis necessary for the development of a rigorous inventory-monitoring program.

Complete descriptions of the inventory and monitoring programs used by national forests are not provided here. Such summaries have been previously produced by other individuals (OTA 1992) as part of a review of forest planning. We used these reviews as part of our analysis and incorporate some of their conclusions with respect to current programs and future needs for Forest Service inventory and monitoring. In this paper we define monitoring as simply the repeated inventory of an item to determine its trend and status.

Mandated Goals and Requirements

The Forest Service is required to gather information on all land, soil, timber, forage, water, air, fish, wildlife, aesthetics, recreation, wilderness, and energy and mineral resources on all forests and rangelands in the United States for developing the RPA assessment and program, and subsequent regional guides and forest plans (Forest Service 1989, 1990). These inventories are conducted to: (1) determine the condition, production, potential, and amounts of key ecosystem components or processes; (2) identify a benchmark for describing the current physical and biological situation and for forecasting changes; (3) provide ecological information as bases for protection and management decisions about land and resource uses, proposed plans, or actions; (4) consider conditions or trends that either change the demand for resources or that are affected by resource decisions; and (5) refer all inventory information to specific units of land (Forest Service 1990).

The FS has approached this inventory and monitoring task in a largely decentralized way. General guidelines that direct adherence to RPA and NFMA directives have only recently been developed by Washington staff (e.g., Lund and Thomas 1989, Forest Service 1990). However, specific details of sampling design, data collection, data analysis, and forecast modeling have been left to region- and, more typically, national forest (hereafter, forest) level decision making. Guides provided from the national level are general and provide only the most basic of direction. For example, the *Resource Inventory Handbook* (Forest Service 1990) requires only that each forest "establish and maintain required RPA assessment data bases." The content, structure, and reliability of these data bases are not specified. Although "a description of the inventory objectives" and "analysis and reporting procedures" must be specified for each forest inventory, only the most general guidelines on these objectives and analytical techniques are presented.

FS conducts inventories at three scales: (1) a regional forest inventory and analysis (FIA) that uses a grid sampling design to depict conditions of general strata of forest types rather than each specific location, (2) a forest level inventory designed to assess timber growth and volume of forests, and (3) stand exams designed to provide information for developing management (timber harvest) prescriptions. These inventories are not necessarily poorly designed; they typically adhere to scientific methods and procedures of statistical sampling. The problem, however, is that the questions that we are now asking about forest resource conditions and trends have simply outgrown these methods. Initial attempts to inventory integrated conditions and trends of wildlife habitat and timber conditions, for example, have been made by the Eastern Region through their wildlife and timber management information systems (WMIS and TMIS) (R. Holthausen, personal communication). Such approaches should be applauded and expanded even further to consider broader questions of biodiversity and ecological health.

The task for inventory and monitoring as presented to the FS by Congress, and then dispersed to the various administrative levels, is complicated from both an administrative planning and technical level. Inventory and monitoring questions are not trivial. As we develop throughout this paper, there is long-term and ongoing discussion within the scientific community as to what constitutes appropriate inventory of current conditions and monitoring to assess trends. Differing approaches constitute "rigorous and proper" sampling design (for both inventory and monitoring), and many complicated statistical and mathematical techniques exist for analyzing the resultant data. Advanced academic training and extensive research experience are often necessary to design inventories and analyze inventory data and establish a monitoring program (see also Garcia 1989, Schreuder and others 1993). Within this context the FS has been asked to develop a program of inventory and monitoring of forest resources.

Integrated Inventories

RPA and NFMA legislation mandated that inventories be integrated (e.g., Munn 1988). Lund (1986) defined an integrated inventory as being designed to meet multilevel, multilocation, multiresource, or temporal needs. This integrated focus was desired to minimize duplication of data gathering and so that relations among resources could be considered in the development of forest (and any management) plans. Integration thus forms the core of the inventory program required for use in FS planning. However, the application of a statistically reliable program of integrated inventory and monitoring at all spatial scales is difficult and costly (e.g., Schreuder and others 1993).

True multiresource inventories are those designed to meet at least part of the information requirements for management of two or more resources; for example, timber and wildlife. In the broadest sense, even a timber cruise could be considered "multiresource" because some of the information gathered could be useful to wildlife-habitat analysis, for example, data on tree species composition and tree stocking density. As shown by Morrison (1983) and Morrison and others (1987), however, inventories designed solely for timber analysis are often poor predictors of wildlife density. Lund (1986) restricted the use of "multiresource" to include only those inventories in which preplanned integration was involved.

Many considerations arise in the design of multiresource inventories. Data from one or more data bases should have the potential of being aggregated to different levels of resolution for analysis. Furthermore, data could be collected from the same location to allow for analysis of potential interactions among variables, when this is of interest, and account for changes (e.g., temporal variation) in environmental conditions that will alter resource condition. Sample locations should be distributed across the ecosystem, and the inventory should serve as the baseline for monitoring change. Using existing data, adding additional information, and developing new sampling designs as needed should all be integrated into the ideal multiresource inventory (see Schreuder and others 1993).

Conceptual Framework for Development of Inventory-Monitoring Programs

In this section we present a conceptual framework for developing a scientifically rigorous program of inventory and monitoring of natural resources. We also evaluate the concepts of biodiversity and ecological indicators as they apply to inventory-monitoring.

Resources: What Are They and Why Do We Measure Them?

Inventory, monitoring, and management of what we popularly call natural resources are complicated by a general confusion concerning definitions of various resources and the interactions among them. NFMA and its implementing regulations specify only the general type of "resources" to monitor. A simple classification scheme, taken from Carey and Dennis (1984), allows us to operationalize "resources." This scheme describes an overall "wildland production system" as being comprised of three basic but interdependent subsystems. Most fundamental are the ecosystem elements consisting of air, water, minerals, soil, sunlight, flora, and fauna. Ecosystem elements provide the basic materials for satisfying many human needs (e.g., air, water) and desires (fauna, aesthetics). Whenever humans perceive opportunities to transform such basic elements into a state suitable for human use through the application of expertise and technology (i.e., through management), such elements (singularly or in combination) represent natural resources. Natural resource management produces wildland outputs in the form of commodities and amenities available or desired for human use.

Many of the items we label as natural resources are actually artificial constructs that do not have clear biological definition or justification. For example, "rangelands" or rangeland vegetation has been defined as ". . . shrublands, grasslands, and open forests where dry, sandy, saline, or wet soils; steep topography; and rocks preclude the growing of commercial and timber crops" (Heady 1975). Rangelands include, then, numerous ecosystem elements in a variety of topographic and soil conditions. Rangelands are further defined by their management for livestock and big game and the amount and distribution of forage available for animals to consume. As previously noted, the FS (and other federal agencies) is mandated to inventory and monitor this range–forage ecosystem with its attendant resources. To accomplish this task adequately, however, policy decision makers within the FS must decide which ecosystem element or combination of elements (interactions) to emphasize, including specific methods of inventory, data analysis, and model development (for forecasting). The "rangeland resource" per se cannot be inventoried and monitored in any meaningful way; it must be broken down into its component, measurable ecosystem elements. Similar arguments can be developed for each of the natural resources specified in RPA and NFMA. Similarly, resources per se are not directly impacted by natural or human-induced changes. Rather, ecosystem elements within what we term a resource are impacted, thus impacting specific human desires (outputs). Cutting a tree can alter fungi, which may or may not alter resource output at some further time; compensation by many of the other interacting elements could occur [e.g., decline in flying squirrel (*Glaucomys sabrinus*) density which results in or from a change in fungi].

Until the passage of RPA and NFMA, forest inventories concentrated primarily on the timber resource from a standpoint of maximizing timber production through stocking density, tree growth, mortality, and other production-related factors. These inventories largely ignored other attributes unlikely to influence timber production (McClure and others 1979). The inventory and monitoring programs currently in use were initially based on pre-RPA and -NFMA attitudes and a production-dominated paradigm. Current inventory and monitoring programs, which are mandated to include integrated, multiresource inventories, are largely designed by retrofitting timber-oriented programs (see papers in LaBau and Cunia 1990, especially pp. 467–543).

Thus, consideration of ecosystem elements should be clearly distinguished from resources and wildland outputs in the conceptualization and design of inventories and monitoring programs. This will facilitate appropriate selection of sampling methods, goal setting for precision and bias, and development and use of specific analytical and modeling tools.

Spatial and Temporal Considerations in Sampling

Spatial scales must be considered in the design of inventory and monitoring programs. The scale of an inventory and monitoring effort must be appropriate to the element being quantified. For example, an aggregation of stand inventories into larger units—say, a watershed—fails to address element interactions that go spatially (geographically) beyond stand boundaries. Water and wildlife move beyond stand boundaries; recreation opportunities usually cover large tracts of land. An animal may be in a stand because the stand offers some of its life requisites (e.g., nest site) or because of its juxtaposition to other stands. Knowing the specific ecosystem processes that influence the occurrence of a resource helps to determine the appropriate scale to inventory and monitor.

The temporal scale is also of primary importance in measuring and evaluating ecological systems. If we sample during the wrong period, or over too narrow a time, we may miss a critical component of an ecosystem element. For example, sampling wildlife only in the summer largely ignores habitat requirements for winter survival (e.g., Fretwell 1972, Morrison and others 1985). It may also be undesirable if the time period within which data are collected is too wide. For example, birds significantly alter their use of tree species for foraging even within one to three-week time blocks (Brennan and Morrison 1990). Thus, sampling over too wide or too narrow of a time period will miss critical factors in ecosystem (resource) assessment; different ecosystem elements will require different sampling scales and times.

Biological Diversity as the Basis for Identifying Inventory and Monitoring Elements

Biological diversity is the variety and variability of living organisms and the ecological conditions in which they occur. The concept of biological diversity, or biodiversity, thus encompass ecosystem elements and ecosystem interactions (e.g., OTA 1987, Noss 1990). Any change in an element will affect ecosystem interactions to varying degrees. Changes in elements affect our human-defined natural resources and their outputs. Although natural resources and their outputs are not the essential elements that should be inventoried and monitored, changes in their component parts—ecosystem elements—will influence the ecosystem and the resources we desire.

There is growing interest in assessing biodiversity (OTA 1987), including within the FS (Szaro and Salwasser 1990, Williams and Marcot 1991). Acknowledging the need to inventory and monitor biodiversity is simply placing the FS-mandated integrated, multiresource inventory and monitoring program into a more realistic and popular framework. It will be more realistic if inventory and monitoring of biodiversity focuses on ecosystem elements and their processes and not on resources and resource outputs. Wildland outputs should be viewed and analyzed within a context of ecosystem functioning and their effects on biodiversity.

Although the FS is now discussing biodiversity, the means to inventory and monitor its component parts and their functions and interactions are not resolved. Inventory and monitoring must address numbers and distribution of organisms and should allow assessment of long-term population viability. Inventory and monitoring should also address a variety of processes that occur within the ecosystem.

Use of Ecological Indicators: Cautions

Indicators are often used as an index of environmental conditions that are too difficult, inconvenient, or expensive to measure directly (Landres and others 1988). Some indicators are useful because, under the right circumstances, they can portray responses to cumulative effects of natural and human-caused environmental conditions when such effects are not evident when the attributes are measured alone (e.g., bioaccumulation of contaminants). Indicators are intended to function as surrogates for determining effects of management activities and resultant environmental stress (Hunsaker and Carpenter 1990).

Use of indicators assumes that the *modus tollens* form of retroductive logic operates correctly, namely, reasoning from a hypothetical proposition according to which if the consequent be denied, the antecedent is denied. In other words, if overall environmental conditions are good, then an indicator of those conditions will take on particular values; if the indicator is observed to not take on those values, then environmental conditions are not good. The fallacy of this reasoning is that the indicators can be responding to a host of factors other than those that represent environmental conditions of interest, such as factors not controllable by management, or off-site effects as with degradation or Neotropical wintering habitats for migratory songbirds. Thus, we can never be sure that the response variable directly and always reflects local conditions or direct effects of management guidelines (e.g., Morrison 1986).

For this reason, schemes that use ecological indicators to overcome the intrinsic complexity of ecosystems, including measures of biodiversity, might be inadequate and untrustworthy (see also Kelly and Harwell 1990). At the least, indicators should be selected and used with care, and examined with the use of rigorously designed evaluation studies. Indicators should not be based solely on best-guess estimates. The prevalent practice is to make "indicators" out of species that already require monitoring (e.g., threatened and endangered; game species), and to rely on existing data bases, however inadequate.

The FS now recognizes three general classes of indicators: ecological indicators, management indicator species, and most recently (Federal Register 36 CFR Part 219, Section 219.40; 15 February 1991), management indicators. Ecological indicators are elements of the biotic system that index changes in ecological conditions of an ecosystem. Management indicator species (MIS) are individual species or species groups that are selected to index population responses of another species in the ecosystem. Management indicators is a broad concept that "include[s] biological communities and special habitats rather than being limited to only individual species. This recognizes the important role of biological communities in providing diversity and the ecological contributions of various structural elements within those communities" (loc. cit.). The FS is now proposing to use "management indicators," rather than the other two concepts in Forest planning. They note (Section 219.40), however, that the concept of ecological indicators is coming under diminishing scientific support (e.g., Landres and others 1988).

Proposed changes in the use of the indicator concept should consider several key components. Ecological indicators are coming under diminishing support primarily because of their misuse both by scientists and managers, although the concept itself remains valid (e.g., Morrison 1986, Landres and others 1988). MIS is a broad concept that includes five FS-defined types of indicators; only one of these classes is an ecological indicator (Patton 1987). Endangered species, species with special habitat needs, and other classifications are included under MIS. The proposed changes should clearly address how these various types or classes of species will be handled in the future. A standard system to classify "biological communities and special habitats" should be developed. Communities should be unambiguously delineated on maps and related to management allocations and activities. Care should be taken to avoid circularity in definitions, such as: "biological communities [provide] diversity an the ecological contributions . . . within those communities" (loc. cit.). Communities themselves are largely defined by diversity and ecological elements.

In a practical sense, then, the proposed use of "communities" as indicators would not be easy to apply. The biological community must be defined—but the definition is based largely by the species present. What value will be used to summarize or describe the community? What is the community intended to indicate? What change in the community—if it can be measured—is acceptable? Clearly, much thought and research is necessary before the new management indicator concept can be considered a positive advancement.

Sampling Design and Statistical Considerations

Inventory and monitoring by the FS of ecosystem elements and conditions should be designed to test clearly stated hypotheses. There should be overall (national) guidelines on how to develop such hypotheses of ecological conditions and trends and effects of resource management on ecosystem conditions and on how to design inventory and monitoring methods to test these hypotheses. In this way, individual national forests could gather and analyze data at appropriate spatial and temporal scales in a consistent manner. The levels of acceptable error and power also are critical to identify a priori in analyzing inventory and monitoring data. Managers must know the reliability of the data they use. Unfortunately, forest plans seldom provide information on statistical analyses, if indeed any were or are to be conducted.

Improvement of FS inventory and monitoring thus begins with the development of an overall modeling environment based on the interplay between a complex environment and RPA and NFMA requirements for integrated, multiresource inventories. FS planning should not be based solely on use of existing information.

An optimal study design provides a starting point against which all other, suboptimal designs can be compared. There are four prerequisites for optimal design of any study, including inventory and monitoring (Green 1979, pp. 68–70): (1) An impact must not yet have occurred; before-impact baseline data provide a temporal control to which future data (impact or no impact) can be compared. (2) If an impact has occurred, then the type, intensity, place, and time of the impact must be known so that a sampling design appropriate to tests of hypotheses can be developed. Otherwise, one is conducting a monitoring study to detect impact, rather than an impact study to test against the null hypothesis of no change due to impact; the former is much more difficult to conduct than the latter. (3) It must be possible to obtain measurements of all relevant biotic and abiotic variables in association with the individual samples. That is, measurements for an area covering numerous samples may be adequate for general description, but are inadequate for hypothesis testing. (4) Areas that will be free from future impact must be available to serve as controls.

The first and fourth prerequisites imply that controls in both time and space are necessary. Otherwise, one cannot determine if any change is due to an impact; it may have happened anyway. An optimal design is therefore necessarily a treatment × area × time factorial design in which evidence for change is a significant area × time interaction (i.e., univariate or multivariate analysis of variance). Clear statements of null hypotheses are essential prerequisites to the determination of statistical methods.

In practice, it is difficult or impossible to meet the requirements of an optimal design, especially when monitoring landscape-scale conditions because landscapes are not replicable or controllable units. However, additional steps can be taken in the future to increase adherence to these standards. Some previously collected FS data might be suitable as baseline data for future, properly designed monitoring, but in all cases, these data and the design and methods used to collect them must be rigorously evaluated. Stating that "it's the best we have available" might compound and prolong the problem and probably would force continued collection of worthless data.

In summary, the FS must examine all existing designs and the data they generate and document the rationale (e.g., adequacy of design, methods, sample size, data analyses) for continuing their use. Furthermore, future management plans can be written that incorporate proper study design and analysis for the evaluation of project effects. It will not be possible to implement an optimal design in all cases, but attempts should be made to do so, and failures to achieve such a design explained and documented. Green (1979, Figure 3.4) summarized many possible designs for sampling and statistical analysis, and Schreuder and others (1993) reviewed sampling and analytical techniques specific to forest applications.

Validation of Inventory and Monitoring Study Designs

It is important to assess the quality of data used in inventory and monitoring with regard to sampling bias: that is, are your measurements actually sampling the proper statistical population? This concerns both the equipment and techniques used and the people doing the data collection. Included are critical spatial and temporal components: the same item may vary spatially and temporally in distribution because of natural or human-caused events. Thus, sampling in the same manner over an inappropriate time period may result in biased results (e.g., Brennan and Morrison 1990).

Several wildlife studies have clearly shown that significant bias exists among observers and that this bias can alter conclusions based on such data [e.g., see papers in Ralph and Scott (1981) and Morrison and others (1990); see also Gotfryd and Hansell (1985), Block and others (1987), Verner and Milne (1990)]. For example, Gotfryd and Hansell found significant interobserver variability for 18 of 20 univariate habitat comparisons. Training can reduce observer error to an acceptable level (e.g., see Kepler and Scott 1981; Block and others 1987). However, training must be combined with an actual analysis of this bias: the act of instruction does not necessarily result in adequately trained and qualified personnel. Furthermore, many observers will stray from acceptable levels of accuracy and precision over the course of time, and observers do not stray in the same manner. Often termed drift, such observer error can be corrected only through a continuing program of training and evaluation. Each forest should detail how training and evaluation are handled and how bias is quantified and reduced.

Bias may not be a significant problem. If a consistent sampling method is used and the independent variables measured vary in a similar manner over time or between areas (e.g., between a treatment and a control), then the conclusions might still be valid regardless of this bias (Green 1979, pp. 33–34), but this is a situation that cannot simply be assumed to exist. It must be studied and corrected as indicated.

Development of Inventory and Monitoring Program

We have reviewed the foundation required for development of a scientifically valid program of inventory and monitoring. Specific programs developed by the FS must be defensible from the standpoint of rigorous study design and analysis. Thus, inventory and monitoring activities must adhere to the principles of the scientific method. Here we suggest a program of inventory and monitoring that is founded on a basic framework for identifying ecosystem elements and that is capable of addressing both current and potential (future) questions on resources and wildland outputs.

Inventory

Inventories can be category-driven or attribute-driven. With a category-driven inventory, resources are tallied into a series of classes that are defined a priori. Category-driven inventories are thus inflexible. If the questions being asked change, then the inventory data will be unlikely to address the new question adequately. Category-driven inventories have been used historically and are currently in wide use by the FS (although newer inventories of land conditions, as from remote sensing, lend to attribute-based approaches). Regional and subregional inventories, however, that use a systematic grid rather than an optimized or category-driven design, such as forest inventory and analysis (FIA), avoid some of these problems (J. Ohmann, personal communication).

Thus, inventories should be designed to provide information on individual environmental characteristics rather than designed based on a set of fixed definitions (e.g., old growth, mixed conifer, rangeland). For example, there has been much debate over the absolute amount of old growth remaining in the Pacific Northwest, largely due to differences in definitions and sampling error (Marcot and others 1991). This is a fundamental question of study design, the answer to which must be based on sound ecological principles. The basic building blocks of what we term "natural resources" are the individual ecosystem elements. By basing an inventory and monitoring system on these building blocks, we allow much flexibility in assessing status and trend in variously defined resources. Thus, as our definitions of resources change—for a host of ecological, economical, and sociological reasons—an inventory based on elements can still provide useful data on the abundance, distribution, and condition of resources. In attribute-driven inventories, resources and the elements that comprise them can be assembled at various spatial and temporal scales depending upon the questions being asked.

Monitoring

To monitor resources requires a survey or sampling design that results in specified accuracy and precision; inventory is often driven by the requirements of monitoring. Thus, inventory and monitoring in the context of long-term land management are necessarily complementary.

It is beyond the scope of our paper to describe specific inventory-monitoring programs for each ecosystem element, and thus each resource, of concern to the public. Study designs necessary for sampling these elements must be based on the purpose and spatial–temporal context of the element. What the FS must do is determine which elements are of primary concern and then use the most appropriate sampling methods to gather data on the proper elements.

A two-tiered approach can be used to inventory and monitor ecosystem elements on forests: (1) national and regional scales can define the specific resources that require a general or overall view, and (2) forest- and district-specific resources and conditions based on localized management concerns. The attribute-based system outlined above can address both of these levels of inquiry. Both of these levels must state their questions explicitly and develop a clear study design.

Monitoring can be classified into three simple categories: (1) implementation monitoring—determines if management operations are actually being conducted as prescribed; are established guidelines being followed? (2) effectiveness monitoring—are goals of management activities actually being met; is the management activity having the desired effect? (3) Validation monitoring—are the basic assumptions and foundations used for developing forest management guides sound and correct? These categories are not mutually exclusive, but should be incorporated into the design of any inventory and monitoring program.

Use of Ecological Indicators

The FS should seriously consider moving away from the current management indicator species (MIS) concept and delay implementation of the proposed management indicator concept. The FS would be better served by developing a system to answer specific, key questions about the environment by selecting ecosystem element indicators that will answer those questions, rather than forcing environmental questions a posteriori into the MIS or other systems. The FS will thereby gain substantial information on ecological conditions and responses. Some good information has been gathered on specific species (especially those rare and endangered), and MIS has certainly raised the awareness of most FS personnel regarding the importance of a more holistic approach to management. If the management indicator concept is developed, we propose that a mixed team of ecologists and planners be given the charge to identify criteria and classification approaches, and necessary field validation studies, to further develop this approach as one facet of biodiversity on Forests.

Toward an Integrated Inventory

Inventory and monitoring of management activities should include tracking ecological conditions across political and administrative boundaries. Indeed, Roughgarden (1989) has suggested a national ecological survey; recent development of the USDI National Biological Survey is apparently a step in this direction. The Environmental Protection Agency (EPA) has already initiated a national program of environmental monitoring, called the Environmental Monitoring and Assessment Program (EMAP 1990). This program is a response to a 1988 recommendation by the EPA Science Advisory Board indicating that EPA should monitor ecological status and trends, as well as develop innovative methods for anticipating emerging problems before they reach crisis proportions (Hunsaker and Carpenter 1990). EMAP seeks to monitor at regional and national scales. The FS, in contrast, must expand its monitoring at local, forest levels to include broader, resource-neutral conditions of biological diversity and ecosystems. The structure outlined by EMAP, however, appears applicable to areas more localized than that envisioned by the EPA. The goal of providing statistically unbiased estimates with known confidence limits is a prerequisite to all inventory and monitoring programs. The EMAP program can aid FS in meeting these prerequisites in an expanded inventory and monitoring program. Moreover, two major existing inventory and monitoring programs already used by FS—forest health monitoring (FHM) and FIA—should be supported and expanded beyond their main focus on timber resources to depict subregional and regional biodiversity conditions and trends. Sampling frameworks for many ongoing inventories are already providing statistically valid measures of some ecosystem elements, particularly vegetation composition and structure (J. Ohmann, personal communication). Such methods and data have proven useful in many ecosystem and multiple-resource assessments (e.g., Ohmann and Mayer 1987, Ohmann 1989, 1990, papers from Workshop 2 in LaBau and Cunia 1990, Hansen and others 1991, Schreuder and others 1993, Ohmann and Cohen 1994).

We recommend that the FS establish or use existing research and development projects with the goal of developing a scientifically valid method of applying the ecological indicator concept at the forest level. If designed properly, this project could provide information to both general tiers of FS data needs: for regional and national planning, and for district and forest planning and management. Although EMAP itself will be of limited use to the FS below the regional level, its program and program officers will be a valuable source of information to the FS. Ecosystem elements and indicators of various ecosystem processes should be selected as outlined above.

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