DESIGN ELEMENTS OF MONITORING PROGRAMS: THE NECESSARY INGREDIENTS FOR SUCCESS

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Abstract. Natural resource managers must know the condition of resources entrusted to their stewardship so that they can maintain unimpaired resources and know when to restore impaired ecosystems. Resource monitoring programs should be designed to provide indications of ecosystem health, define limits of normal variation, identify abnormal conditions, and suggest potential agents of abnormal changes. Development of a conceptual model that identifies all ecosystem components and their relationships is the first step in the design of such a diagnostic monitoring program. Design studies, with field testing on each selected system component, are required to determine the parameters to be measured and to establish monitoring protocols. The best approach to diagnostic monitoring appears to be based on the population dynamics of selected species relative to physical and chemical environmental factors. Both management and monitoring of natural ecosystems need to be recognized as experimental endeavors, and thus approached in an iterative fashion with the scientific method to reduce uncertainty and cost.

1. Introduction

Ecosystems and the natural resources that comprise them are dynamic features. They are in a constant state of flux, even if that is not evident to casual observers. Natural resource managers must acknowledge the dynamic nature of their reponsibilities and ask: 'How healthy are ecosystems?' Without management intervention, are they capable of fending off altered water supplies, human extraction of 'renewable' resources, accelerated invasions of alien species, physical impacts of intrusions, and air pollution? These issues threaten ecosystem integrity in natural areas world-wide. How do you determine when to intervene in natural resource issues, and how far should you go in your remedial actions?

2. Why Monitor?

Ecosystems are changing in ways never before seen. Lack of historical and contemporary data makes it difficult to clearly define the nature and extent of these changes (Orians, 1986). Unless we begin to gather empirical data on the health of natural area ecosystems now, the changes may become irreversible and fatal. Alternately we may unnecessarily impose constraints on human endeavors out of fear of the unknown. Politically, this kind of uncertainty tends to freeze action for fear of overreacting or changing systems perceived as naturally static (Wurman, 1990). Doubts about ecosystem dynamics range from concerns for global climate

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change to worrying about visitor disturbance of wildlife.

An adequate natural resources monitoring program can provide the information required to reduce uncertainty and address these questions. What to monitor, and an appropriate level of accuracy, varies from area to area, but the basic reasons for monitoring are the same everywhere. They are to:

- Determine present and future health of natural area ecosystems.
- Establish empirical limits of variation in natural area resources.
- Diagnose abnormal conditions to identify issues in time to develop effective mitigation, and
- Identify potential agents of abnormal change.

3. Medicine and Ecosystem Management

Natural area managers are essentially family physicians for natural areas. They monitor ecological health to identify impaired natural area resources. They treat ecological dysfunction and repair damage. They also prevent poor ecological health by reducing exposure to dangerous agents (e.g., pollutants).

A natural resource monitoring program should provide the same kinds of information to resource managers that health monitoring provides to physicians. It should show current health and predict future conditions. Monitoring should be sensitive to subtle chronic stresses, as well as identify overt lethal threats. An effective monitoring program will also help identify causes of system dysfunction and suggest effective treatments, in addition to identifying signs and symptoms.

Human activities have altered ecosystems in many natural areas. All too frequently, problems caused by these alterations are undiagnosed. Until the problems are diagnosed, and the causes at least tentatively identified, effective development and testing of treatments can not begin. Preventative actions can not start until reasonable options are identified. The ecological equivalent of setting broken bones, binding open wounds, and treating bacterial infections goes on, but monitoring is needed to develop diagnostic and prescriptive methodologies for system-threatening ‘cancers’.

Our present knowledge of ecosystem management is roughly equivalent to that of 17th century medicine, when William Harvey first discovered the true function of the heart and circulatory system. That is, we know the names of most of the major pieces of ecosystems, but we don’t really understand their functions and their relationships to all the other pieces. Long-term ecological monitoring is the first step in learning how to assess ecosystem health. It will be used to define normal limits of variation, diagnose impairment, and develop preliminary treatments.

A physician knows what vital signs of a patient to monitor, but ecological vital signs have yet to be identified. Physicians measure parameters such as pulse rate, blood pressure, temperature, and weight. From these, they can determine present health and project near-term future health. Similar measures for ecosystems are unknown. Physicians can interpret their findings because they know the normal (healthy) limits of the parameters they monitor. Long-term research and clinical observations (monitoring) of patients provided normal values and critical limits of these parameters. Normal limits of variation in ecosystems are virtually unknown. Monitoring is the quickest and surest way to find parameters that can serve as ecological "vital signs" and define the limits of their variation.

4. Natural Area Management: A Multi-Disciplinary Experiment

All members of the resource management team share a common goal: maintenance of healthy ecosystems. The care needed to achieve that goal requires a variety of professional skills, both managerial and scientific. All members of the staff play important but distinct roles in perpetuating natural resources.

Development of monitoring protocols is an experimental endeavor conducted by research scientists. No universal 'off the shelf' technologies exist to assess ecosystem health. Original research must discover what and how to monitor. Scientists need to identify the 'vital signs' of ecosystems and develop techniques to monitor them. Using the scientific method, they can then define normal conditions and develop treatments to mitigate human impacts on ecosystems. However, implementation of natural resource monitoring is a perpetual operational matter, like visitor center operations and facilities maintenance. As such, it is best managed by site managers and conducted by resource specialists, rangers, and other field personnel.

Site Managers are responsible for setting local policy and priorities. They direct and integrate the efforts of the entire staff (including research scientists) to assure perpetuation of unimpaired natural area resources. They focus attention on critical issues, and formulate strategic and tactical plans to resolve them. Finally, they control and set priorities on fiscal resources. Site managers are ultimately responsible both for knowing the condition of natural resources and for directing efforts to sustain them.

Research Scientists conduct original research to create new knowledge of ecosystems. They design monitoring protocols and develop new techniques for assessing ecosystem health. They investigate changes, and through experimental, manipulative research, determine causative agents. They develop and test new treatments to cure or relieve system dysfunction. Research scientists also help resource specialists analyze monitoring data and synthesize it in resource status reports. They verify validity of monitoring by publishing results in professional journals.

Resource Specialists implement monitoring protocols as an operational responsibility. They monitor ecosystem health through periodic sampling, and maintain complete and accurate records. They recognize symptoms, diagnose abnormal

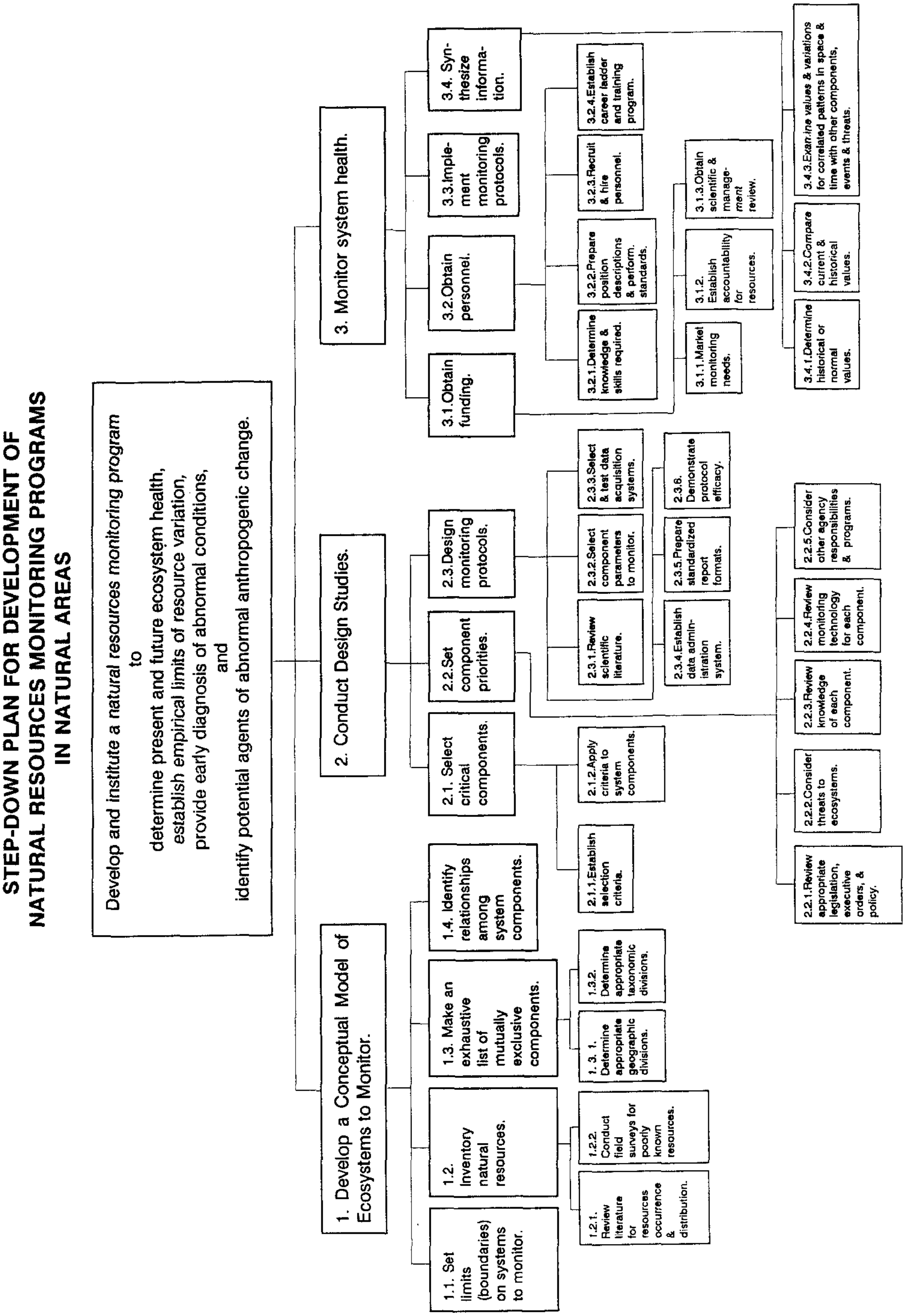
STEP-DOWN PLAN FOR DEVELOPMENT OF NATURAL RESOURCES MONITORING PROGRAMS IN NATURAL AREAS
Develop and institute a natural resources monitoring program
to
determine present and future ecosystem health,
establish empirical limits of resource variation,
provide early diagnosis of abnormal conditions,
and
identify potential agents of abnormal anthropogenic change.
1. Develop a Conceptual Model of Ecosystems to Monitor.
2. Conduct Design Studies.
3. Monitor system health.
1.1. Set limits (boundaries) on systems to monitor.
1.2. Inventory natural resources.
1.3. Make an exhaustive list of mutually exclusive components.
1.4. Identify relationships among system components.
1.2.1. Review literature for resources occurrence & distribution.
1.2.2. Conduct field surveys for poorly known resources.
1. 3. 1. Determine appropriate geographic divisions.
1.3.2. Determine appropriate taxonomic divisions.
2.1. Select critical components.
2.2. Set component priorities.
2.3. Design monitoring protocols.
2.1.1.Establish selection criteria.
2.1.2.Apply criteria to system components.
2.2.1.Review appropriate legislation, executive orders, & policy.
2.2.2.Consider threats to ecosystems.
2.2.3.Review knowledge of each component.
2.2.4.Review monitoring technology for each component.
2.2.5.Consider other agency responsibilities & programs.
2.3.1.Review scientific literature.
2.3.2.Select component parameters to monitor.
2.3.3.Select & test data acquisition systems.
2.3.4.Establish data admin-istration system.
2.3.5.Prepare standardized report formats.
2.3.6. Demonstrate protocol efficacy.
3.1.Obtain funding.
3.2.Obtain personnel.
3.3.Imple-ment monitoring protocols.
3.4. Syn-thesize informa-tion.
3.1.1.Market monitoring needs.
3.1.2. Establish accountability for resources.
3.1.3.Obtain scientific & manage-ment review.
3.2.1.Determine knowledge & skills required.
3.2.2.Prepare position descriptions & perform. standards.
3.2.3.Recruit & hire personnel.
3.2.4.Establish career ladder and training program.
3.4.1.Determine historical or normal values.
3.4.2.Compare current & historical values.
3.4.3.Examine values & variations for correlated patterns in space & time with other components, events & threats.

Fig. 1.

resource conditions, prescribe treatments, and evaluate the results of those treatments. While monitoring requires scientific training to test and improve techniques and to interpret results, it is not research. Resource specialists work closely with research scientists in analyzing and interpreting monitoring data. They work with other staff members to ensure accurate applications of data to management issues and interpretive programs. When resource specialists help with monitoring design studies, they gain an added appreciation for the strengths and weaknesses of the protocols.

Rangers identify overt threats to natural area ecosystems, such as toxic spills. They provide immediate, practical treatments to reduce acute problems and temporarily stabilize the situation. They 'hold the fort' and protect human stressed ecosystems until long-term treatments can address underlying causes. Interpretive rangers are like public health officials who prepare and distribute information about epidemics and recommend preventive actions and treatments. They interpret scientific findings about natural area ecosystems and explain their significance. They also develop ways to explain natural area values, and threats to those values, to give a wide cross section of the American public an adequate understanding of natural area issues.

Maintenance personnel not only keep equipment operating and provide transportation and other logistical support. Like rangers, they also see resource conditions firsthand, and foresee potential effects of facilities construction and rehabilitation projects. For example, they monitor site specific, or ad hoc, resource conditions, such as erosion associated with facilities, roads, and trails. They watch over public health concerns, such as potable water and sewage treatment. In doing this, they constitute an important part of an area's resource monitoring effort.

5. Monitoring Design

Design of a long-term monitoring program begins with a conceptual model of the ecosystem. This model should consist of an exhaustive list of mutually exclusive system components and a description of their relationships. From components such as birds, vascular plants, and water, representative elements (e.g., species and watersheds) are selected and tested for monitoring. The adequacy of existing resource inventories should become apparent at this stage. Certainly not all parts of the ecosystem need monitoring, but the list of components should include all biotic and abiotic resources and the processes by which they interact.

There are several legitimate ways to describe and monitor ecosystem dynamics. Among the more useful for diagnostic monitoring are assessments of pollutant and natural constituents, and measures of population dynamics and biodiversity. Perhaps the simplest approach is to consider plant and animal populations and constituents of air, water, and soil as the basic components of ecosystems. Monitoring representative elements of these components will determine the nature and extent of system dynamics sufficiently for management purposes.

Measures of population dynamics offer a good solution to monitoring the biological elements of natural area ecosystems. Parameters of populations such as abundance, distribution, age structure, reproductive effort, and growth rate are relatively easy to measure. Many of them are sensitive to subtle, chronic stress, and permit projection of future conditions. This approach is also sensitive to a wide variety of environmental conditions because organisms integrate the effects of influences like predation, competition, and pollution. They express their responses to these influences as relatively easily measured population parameters. This integration, however, prevents certain identification of causation and accurate predictions of system behavior based on monitoring observations alone. Even though population monitoring is not the quickest or surest way to determine causality, it provides an unparalleled indication of future conditions. Parameters such as age structure and reproduction permit projections of future conditions, providing early warnings of pending problems. Reduced growth and reproductive rates often reflect subtle, chronic stresses. Synthesis into system-level applications and interpretation of population parameters is relatively direct. Many management controls also operate at the population level, so application to management issues is direct and measurable.

Biodiversity is an important attribute of ecosystems. It functions at many levels: genetic, individual population, community, and even ecosystem. However, the repeated inventories required to measure and monitor biodiversity are expensive and difficult to conduct. They require highly skilled surveyors to find and identify the elements of diversity. Alone, repeated inventories do not meet the goals of diagnostic monitoring. At the species level, diversity is not very sensitive to environmental stresses and records only the past. Changes in diversity are also hard to assess, ambiguous to interpret, and difficult to apply to management issues.

Selecting chemical and geo-physical constituents, biological taxa, and processes to monitor are probably the most perplexing decisions in designing a monitoring program. The actual selections will vary among areas, but the goal is the same for all systems. It is a representative sample of elements that characterizes the structure and function of the entire ecosystem. A Delphi approach works well. Experts on each component identified in the conceptual model independently apply selection guidelines. These selections are then reviewed and modified through workshops and symposia, and finally field tested during design studies.

An effective program to monitor the dynamics of natural area ecosystems and diagnose problems will require a combination of techniques. Measurements of population dynamics in relationship to changes in physical and chemical environmental factors is the most promising. The step-down plan shown in Figure 1 outlines a generic process for developing natural resources monitoring programs in natural areas. This model is based on experience from designing a monitoring program for Channel Islands National Park, California (Davis and Halvorson, 1988; Davis, 1989). Additional information is available on design considerations and detailed monitoring protocols in Green, 1979; Conant *et al.*, 1983; Cooperider *et al.*, 1986; and Orians, 1986.

Ecosystems are dynamic. They are confusing and difficult to understand. But we can not ignore or avoid them, we are part of them. To survive, we must learn to understand the consequences of our collective actions upon them. Monitoring natural resources is the first step of a long process we must begin soon, or frozen by uncertainty about their dynamics, we will soon lose the inherent values of natural areas.

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