Designing and Implementing Comprehensive Long-Term Inventory and Monitoring Programs for National Park System Lands

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Cover photographs: Field of lupines in Olympic Mountains in 1913 (top photo) and retake of same field in 1989 (bottom photo).

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Introduction

> Inventory: a survey of natural resources.
> Monitor: to watch, observe, or check, especially for a special purpose.
>
> *Webster's Ninth New Collegiate Dictionary* 1990

According to these definitions, inventory and monitoring activities have been conducted in national parks for many years. They have included individual projects such as species checklists, visitor counts, academic research, and weather records. Not until recently, however, has any effort been made to bring these activities together into an integrated program, to identify other needed activities, and to coordinate inventory and monitoring activities throughout the National Park System.

One objective of this heightened interest in inventory and monitoring is to develop a nationwide program capable of tracking the condition of the vast array of resources under National Park Service (NPS) stewardship. Programs outside of the National Park Service intensively monitor a wide variety of ecological parameters to identify resource trends and conditions of small areas, such as the Hubbard Brook and the H. J. Andrews experimental forests (Likens et al. 1977, McKee 1984). Other programs, such as the National Atmospheric Deposition Program, National Trends Network (NADP/NTN 1989), and the Forest Service Continuous Forest Inventory Program (Knight 1987), involve large areas or many sites networked across the United States, but these programs focus on a fairly narrow suite of measurements (e.g., precipitation chemistry) addressing specific data needs. A comprehensive NPS program would be unique among inventory and monitoring programs because it would apply a broad spectrum of ecological measurements to a large and diverse geographical area.

The ambitious nature of the NPS inventory and monitoring program and its relatively limited budget make careful design of the program critical. Effort must be strategically directed toward areas that give the most return of useful information for time and money invested. In this paper, we identify and discuss some of the major issues involved in designing an inventory and monitoring program for national parks and similar reserves. Characteristics of actual and proposed programs are used to identify trade-offs and pitfalls inherent in designing successful inventory and monitoring programs.

Objectives of Inventory and Monitoring Programs

Nearly every author who discusses the design of inventory and monitoring programs declares that the first hurdle is carefully defining program objectives (e.g., Garton 1984, Hirst 1983, Hinds 1984, Johnson and Bratton 1978, Jones 1986). Authors who do not emphasize defining objectives as a first step nevertheless state specific objectives in their discussions (e.g., Halvorson 1984, Davis 1989).
Once the basic objectives of a program are defined, the next step is to determine specific attributes that should be inventoried or monitored (Hinds 1984, Davis 1989). Choice of attributes depends to a large extent on the objectives. Developing specific monitoring protocols for selected ecosystem attributes is a relatively straightforward process, dictated by cost limitations and the intensity of sampling needed to give useful results (Hinds 1984, Hoffman 1988).

A review of the objectives of inventory and monitoring programs for natural preserves (including national parks, biosphere reserves, Nature Conservancy preserves, and Forest Service research natural areas) reveals a variety of objectives and a corresponding variety of approaches to designing the programs (Table 1). In general, the objectives fall into two categories: those that involve keeping track of the preserve resources for their own sake, and those that examine preserve resources to gain knowledge relevant to areas outside the preserve.

The most commonly stated objective is to use inventory and monitoring information to enable managers to make better informed management decisions (e.g., White and Bratton 1980, Croze 1982, Davis 1989, Jones 1986, Buttrick 1984, Quinn and van Riper 1990). For example, the impact of park visitors on vegetation can be monitored to determine whether changes in visitor management strategies are needed. To better inform managers, programs must focus their limited resources on parameters relevant to management issues, not on general monitoring of "ecosystem health" (Buttrick 1984, Jones 1986). In many cases monitoring can include studies that test specific hypotheses of change (Johnson and Bratton 1978).

A related objective is to use inventory and monitoring information to convince others to make decisions benefiting parks (Croze 1982, Johnson and Bratton 1978). Although still oriented toward informing decision makers, the area of interest changes from the effects of park management activities to the effects of activities outside the park. Consequently, inventory and monitoring under this objective concentrates on documenting specific external threats. For example, the Everglades National Park conducts extensive monitoring to document the effects of water delivery schedules from outside the park on the Everglades ecosystem. Because the objective is to convince skeptical outsiders or even more skeptical courts of law to make decisions benefiting parks, the work

must meet the highest standards of quality assurance and may require more dramatic evidence of the problem than would be necessary simply to make an intelligent management decision.

In some cases, inventory or monitoring activities are required by specific legal mandates (Davis 1989, Buttrick 1984). For example, legal mandates may require parks to inventory or monitor endangered species. In other cases, such as criteria air pollutants, legal mandates may govern monitoring methods. In either case, specific legal constraints determine to some extent what attributes a program must monitor or what protocols the monitoring must follow.

Table 1. Summary of monitoring objectives, strategies for selecting ecosystems and attributes for monitoring, and intended audience for resulting information.

Objectives	Strategies		Audience
	Ecosystem Selection	**Attributes Selection**	
Inform internal decision makers	Ecosystems involved in specific management decisions	Attributes involved in specific management decisions	NPS managers
Influence external decision makers	Ecosystems most threatened by outside activities	Attributes most likely to show effects of outside activities	External decision makers
Satisfy legal requirements	Determined by legal requirements	Determined by legal requirements	Variable
Maintain familiarity with resources	Broad spectrum, but mainly areas of suspected change	Attributes most sensitive to change	NPS personnel
Provide better understanding of resources	Broad spectrum of ecosystems	Broad spectrum of attributes	Scientists and NPS personnel
Provide background information	Broad spectrum of ecosystems	Attributes of day-to-day interest to visitors and others	Scientists, NPS personnel, visitors
Provide early warning of global or regional problems	Ecosystems most likely to be sensitive to change	Attributes most likely to show detectable change	External decision makers
Provide background data for exploited areas	Ecosystems comparable to large areas outside park	Attributes of interest in managing outside areas	External decision makers

Some authors suggest that it is important to document changes just for the sake of familiarity with the resources (Halvorson 1984, Croze 1982). The responsibility of resource managers may include being aware of changes in the resources under their stewardship even if no specific management decisions or external activities are involved. For example, a park may want to monitor vegetation succession in areas that were logged or farmed before national park establishment even if no active management of the vegetation was contemplated. Although this objective suggests that everything imaginable should be monitored, practical limits force a more narrow scope, concentrating on specific areas of suspected change (Johnson and Bratton 1978, White and Bratton 1980). Other authors (e.g., Buttrick 1984) suggest that time and money would be wasted collecting data that are not needed by managers.

A further objective of some inventory and monitoring programs is simply to gain insight into "how the system works" (Croze 1982). By gathering data over long periods of time, correlations between different attributes (such as predator and prey populations) become apparent, and a better general understanding of the ecosystem is obtained. For example, much has been learned about the nutrient dynamics of forested ecosystems by monitoring stream chemistry and hydrology at the Hubbard Brook Experimental Forest (Likens et al. 1977). If gaining a better, general understanding of the ecosystem is an important objective of a program, the program should be designed to gather a broad spectrum of data on the system of interest rather than focusing on specific changes.

An inventory and monitoring program can also provide basic background information that is always needed by researchers, public information offices, interpreters, and those wanting to know a little more about the area around them (Johnson and Bratton 1978). Regardless of whether they reveal anything of scientific or management interest, data such as basic weather information, species lists, and records of major events such as fires are useful on a day-to-day basis to those working or visiting in the park.

An additional justification for inventory and monitoring programs in parks and preserves is that by monitoring these pristine areas we can provide society with a kind of "canary in the mine" -- an early warning of the effects of human activities before they are noticeable in less pristine areas (e.g., Davis 1989, Wiersma 1984). The effects of long-range transport of air pollution, for example, are more easily recognized in a location free from local sources. To satisfy this objective, a program should look intensely at the most sensitive species or communities rather than addressing the condition of the park as a whole.

Finally, inventory and monitoring in protected areas such as national parks can provide a reference point to which less pristine areas can be compared (Wiersma 1984). A study of the effects of human land use on the water quality of streams, for example, would be difficult without including unimpacted streams in the study. To provide this kind of comparison, a program must focus intensely on species and ecosystems that are comparable to large areas outside the park, rather than those unique to the park.

Attributes Selection for Inventory and Monitoring

Selecting specific attributes for inventory and monitoring is a matter of reducing the huge number of possible ways to spend money to a manageable few. This selection must be done in the way that will provide the information most useful for meeting the objectives of the program (Johnson and Bratton 1978). The program objectives determine its specific attributes (Hinds 1984), so the following considerations have different importance in different situations.

Inventory and monitoring may be done at any level, from individual organisms to entire ecosystems (Table 2) (Hinds 1984, Davis 1989). In general, monitoring is easier and cheaper when performed at lower levels of complexity, such as individuals or populations, than at higher levels, such as communities and ecosystems (Hinds 1984). Furthermore, results are easier to interpret and explain to managers at lower levels of complexity (Davis 1989). Individual and population level effects of stress are likely to appear sooner than effects on ecosystem function, providing a better early warning of problems (Odum 1985). Conversely, broader measures of ecosystem function integrate a variety of species and processes and detect changes that may be beyond the scope of a program oriented towards specific species. Observable changes in functional characteristics of an ecosystem may also be a more definitive sign of a serious problem than would be simple changes in species composition.

Decisions must also be made on whether to focus intensively on a few species, communities, or geographical locations (White and Bratton 1980), or to examine a broad range of park resources less intensively (Hoffman 1988, Croze 1982). The intensive approach allows more thorough monitoring of the resources considered to be most important or most sensitive, but this approach may not detect important changes in other resources. The extensive approach allows broader coverage of the resources, but only dramatic changes are detectable because sampling intensity is reduced.

Several criteria have been proposed for selecting species to be monitored (Davis 1989, White and Bratton 1980). These criteria suggest choosing species that are

1. widespread, dominant, or otherwise important in controlling ecosystem function (selected because of their significance to the overall ecosystem)
2. rare, endangered, or endemic (because of their vulnerability or legal status)
3. known to be in a state of flux (to keep track of known cases of change)
4. disturbance dependent (because they are likely to be in a state of flux and may require management intervention)
5. alien, or exotic (because they are considered a threat)
6. charismatic (because of public support and understanding)

Table 2. Summary of various levels of organization in relation to designing and implementing ecological monitoring program (adapted from Hinds 1984).

Level of Organization	Ease of Interpretation	Ecological Effects	Current Understanding	Design Development	Probable Cost
Individuals (physiology and behavior)	Moderate	Unclear	High	Easy	Low
Populations (structure and dynamics)	Easy	Moderate	High	Moderate	Low
Multispecies groups (guilds and trophic transfers)	Easy	Important	Moderate	Moderate	Moderate
Communities (composition and dynamics)	Moderate	Important	Moderate	Difficult	High
Ecosystems (structure and function)	Difficult	Uniquely significant	Small	Unexplored difficulties	Unknown

More information may be obtained by choosing species representing a variety of ecological roles and life-forms than by monitoring a long list of similar species (Davis 1989). Consequently, some species may be selected as "indicators" of larger groups or specific processes rather than for their own inherent interest. Similar criteria may be applied to choices of communities and ecosystems if monitoring is being conducted at that level (White and Bratton 1980).

Another suggestion is that inventory and monitoring efforts should focus on the most significant resources in the parks (Buttrick 1984, Garton 1984, Hoffman 1988). It seems at first counter to NPS principles to relegate some communities or species within a national park to "less important" status. However, some resources are more unique, outstanding, or important to the public than others, and many parks have been established primarily to protect specific resources. Managers and scientists must have a clear idea of which resources have priority when choices are required because of funding limitations.

Inventory and Monitoring Methods Development

After specific attributes have been selected for inventory or monitoring, whether they are physiological parameters of individuals, populations of specific species or species groups, or functional ecosystem characteristics, monitoring procedures must be chosen or developed. In many cases, well-defined, widely accepted methods already exist and should be used (Davis 1989, U.S. Environmental Protection Agency (EPA) 1987).

Even where widely accepted methods exist, optimum temporal frequency and spatial intensity of sampling, plot sizes, and other details should generally be established by pilot studies or analysis of existing data (Halvorson 1984, Hinds 1984, Davis 1989). Although adequate procedures may often be used off-the-shelf (U.S. EPA 1987), a little extra effort spent evaluating and refining the program (Figure 1) will generally pay off in improved cost-effectiveness over the long term (Hinds 1984). Simplicity and economy are important at every stage of program development, because the program will have to be sustained for many years through changes in personnel and in funding priorities (Garton 1984, Halvorson 1984, Quinn and van Riper 1990).

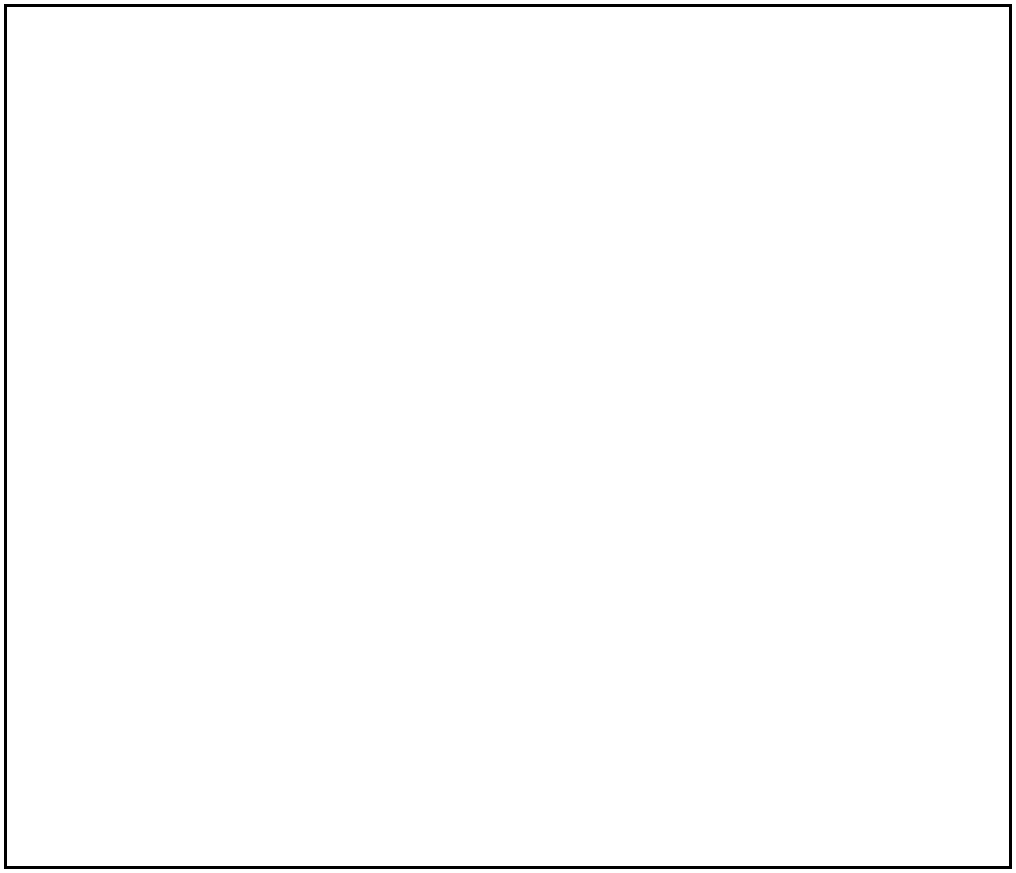

Figure 1. Evaluating ecological monitoring methods (adapted from Hinds 1984).

Simplicity and economy must not come at the expense of methodological rigor and statistical validity, however. From the outset, thought must be given to how the data will be processed, analyzed, and archived (Hinds 1984, Jones 1986). Techniques should be as insensitive as possible to differences between observers, because substantial personnel turnover is likely and because field personnel may not always be highly trained (Davis 1989). New techniques must be calibrated with respect to old techniques whenever methods are changed, and changes should be minimal (Lund 1983).

Park-to-park consistency is essential where data are to be compared between parks. Differences in methodology or even terminology can make interpark comparisons difficult or misleading (Quinn and van Riper 1990, Sauvajot et al. 1990, Robinson et al. 1990). Where inventory and monitoring programs are being developed independently by different parks and regions, using widely accepted methods and discussing methods early on with other parks may minimize inconsistencies.

Institutional Framework for Inventory and Monitoring Programs

For a long-term monitoring program to be successful, an administrative structure must be built to coordinate activities and clearly define responsibilities for data collection, analysis, reporting, and database maintenance (McKee 1984). These responsibilities must be incorporated into the organizational structure so they are tied to positions rather than individuals (Hirst 1983).

Because the National Park Service currently has little experience with large-scale inventory and monitoring programs, the programs and institutional structures to support them can best be developed incrementally. A program should start with the most basic level of information. The program may then build further as experience and feedback from field operations give a solid base for a more comprehensive program (Quinn and van Riper 1990).

To ensure continued support, inventory and monitoring programs must provide data that are both useful and widely used (Hirst 1983, Parker 1983, Greene 1984). The data must be relevant to topics of widespread interest (e.g., economically important resources or significant public issues) or specific management concern (Hirst 1983), and must be maintained for easy access by interested parties (McKee 1984). In addition, the precision and accuracy of the data must be known and stated (Parker 1983). Finally, the data must be reported and distributed on a regular basis in an easily understood and informative format (Parker 1983).

The Future of Inventory and Monitoring

As pressures on natural resources increase throughout the world, detailed and comprehensive inventory and monitoring data will become increasingly essential to effective resources management (Bromberg 1990). Unfortunately, funds for inventory and monitoring programs will likely never be sufficient to provide all the necessary data. Careful evaluation of priority data needs is the only way to ensure the most effective use of whatever funds are available.

The effects of increased human use both in and adjacent to parks, introduced species, air pollution, and a potentially changing climate are largely unknown. Because these factors are rapidly increasing in importance, it is essential that data collection activities are instituted as soon as possible. NPS inventory and monitoring activities are gearing up for what hopefully will be long-term programs. Only long-term data will provide the information that is necessary to evaluate the effects of multiple environmental stresses on park resources.

Because of organizational and financial commitment to the programs being developed, sufficient start-up time to determine clear priorities, cost-effective methods, quality assurance protocols, and rigorous analytical and reporting procedures is important. The National Park Service has the opportunity, if not the obligation, to assume a national and global leadership role in assessing the condition of natural resources. Nowhere are areas better suited to such an assessment than are national parks. Successfully developing and administering an inventory and monitoring program will provide a model for other agencies and institutions.

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