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Monitoring the Condition of Natural Resources in US National Parks

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Abstract The National Park Service has developed a long-term ecological monitoring program for 32 ecoregional networks containing more than 270 parks with significant natural resources. The monitoring program assists park managers in developing a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public for the long-term protection of park ecosystems. We found that the basic steps involved in planning and designing a long-term ecological monitoring program were the same for a range of ecological systems including coral reefs, deserts, arctic tundra, prairie grasslands, caves, and tropical rainforests. These steps involve (1) clearly defining goals and objectives, (2) compiling and summarizing existing information, (3) developing conceptual models, (4) prioritizing and selecting indicators, (5) developing an overall sampling design, (6) developing monitoring protocols, and (7) establishing data management, analysis, and reporting procedures. The broad-based, scientifically sound information obtained through this systems-based monitoring program will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources. When combined with an effective education program, monitoring results can contribute not only to park issues, but also to larger quality-of-life issues that affect surrounding communities and can contribute significantly to the environmental health of the nation.

Keywords Ecological monitoring • Environmental monitoring • Monitoring design • Indicator • National park • Protected areas • Protocol • Sampling design • Vital signs

Introduction

Knowing the condition of natural resources in national parks, which protect many of the nation's most pristine and intact ecosystems, is fundamental to the National Park Service's (NPS) mission to manage park resources "unimpaired for the enjoyment of future generations." Park managers are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public for the long-term protection of park ecosystems. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Roman and Barrett 1999; Vaughan et al. 2001; Busch and Trexler 2003).

The overall purpose of natural resource monitoring in parks is to develop scientifically sound information on the current status and long term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. Use of monitoring information will increase confidence in manager's decisions and improve their ability to manage park resources, and will allow managers to confront and mitigate threats to the park and operate more effectively in legal and political arenas. National parks also play an important role as natural laboratories and locations for developing ecological baselines against which data from more disturbed areas can be compared. When combined with an effective education program, monitoring results can contribute not only to park issues, but also to larger quality-of-life issues that affect surrounding communities and can contribute significantly to the environmental health of the nation (Soukup 2007).

The National Park Service has initiated a long-term ecological monitoring program, known as "Vital Signs Monitoring", to provide the minimum infrastructure to allow more than 270 national park system units to identify and implement long-term monitoring of their highest-priority measurements of resource condition. The NPS has used the term "vital signs monitoring" since the early 1980s (Davis 1989, 2005) to refer to a relatively small set of information-rich attributes that are used to track the overall condition or "health" of park natural resources and to provide early warning of situations that require intervention. We define vital signs as a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The broad-based, scientifically sound information obtained through this systems-based monitoring program will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources. In this paper, we describe the goals and implementation strategy for the vital signs monitoring program, and summarize the planning and design steps that were successfully used to develop long-term ecological monitoring programs for more than 270 parks organized into 32 ecoregional networks.

Policy and Management Context

The 1916 National Park Service Organic Act is the core of park service authority and the definitive statement of the purposes of the parks and of the National Park Service mission. The act establishes the purpose of national parks: "…. To conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." NPS Management Policies (NPS 2006) state that "*The Service will also strive to ensure that park resources and values are passed on to future generations in a condition that is as good as, or better than, the conditions that exist today*", and that *"Decision makers and planners will use the best available scientific and technical information and scholarly analysis to identify appropriate management actions for protection and use of park resources"*. In the National Parks Omnibus Management Act of 1998, Congress specifically directed the NPS to "undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources".

Program Goals and Implementation Strategy

The common programmatic goals of Vital Signs Monitoring for the 32 networks are as follows:

1. Determine the status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress towards performance goals.

Three factors were key in the development of the vision, goals, and implementation strategy of the NPS vital signs monitoring program: (1) An analysis of the targeted audiences and primary uses of the monitoring results; (2) Recognition of the need to leverage the limited resources available to the program through partnerships with parks, other NPS programs, and other agencies; and (3) Recognition that the "information rich" attributes that best characterized park ecosystems differed greatly across the wide range of ecological systems represented in the national park system.

The primary audience and users of the monitoring results are managers, planners, natural resource specialists, interpreters, and scientists at the local, park level (Figure 1). In partnership with other NPS programs and park interpreters, monitoring results are also provided to the general public, "because it is the broader public that will decide the fate of the resources" (National Park System Advisory Board 2001), and to Congress and the Office of Management and Budget for accountability and performance management purposes.

The level of funding provided for long-term monitoring would allow each park to monitor only a few vital signs, which in most cases was inadequate to track the condition of air, water, geological, and biological resources managed by the park. There was an obvious need to leverage the program's limited resources through partnerships with others, and to maximize the use and relevance of the data for key target audiences. Most of the larger parks were already monitoring a few high-priority resources using funding from other sources, and other NPS programs and other agencies had monitoring components that provided relevant data for tracking resource condition (Figure 1). Partnerships with other NPS programs and with federal and state agencies and adjacent landowners are critical to effectively understand and manage the many resources and threats that extend beyond park boundaries. Parks are part of larger ecological systems and must be managed in that context.

A top-down, "one size fits all" approach to monitoring design would not be effective or supported in the NPS because of the tremendous variability among parks in ecological context and in park sizes and management capabilities. The National Park System, by design, includes a huge diversity of ecological systems including coral reefs, deserts, arctic tundra, prairie grasslands, caves, and tropical rainforests. We evaluated and rejected the strategy of selecting a set of core indicators that every park would measure in a similar way because the "information rich" attributes that best characterized park ecosystems differed greatly among ecological systems, very few measures were common across parks, and because partnership opportunities (and the appropriate ecological indicators and sampling methodologies associated with them) available to parks differed throughout the national park system. We instead adopted a strategy that allowed each park, working with partners and subject-matter experts, to prioritize and select their vital signs based on their most critical data needs and local partnership opportunities, with coordination and sharing of protocols and data sets facilitated by the national office.

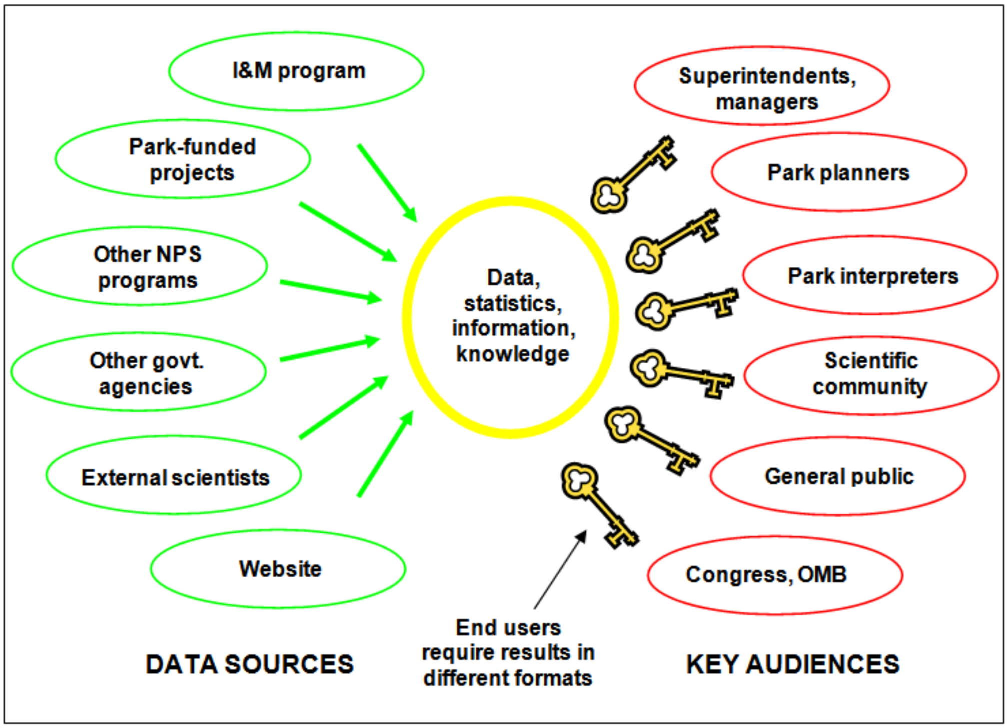

Figure 1. Scientific data for monitoring the condition of park natural resources are obtained from a number of sources, and are managed, analyzed, and distributed to key targeted audiences in various formats to maximize utility and availability of results. The I&M Program has made a large investment in information management to ensure that relevant monitoring data are managed, analyzed, and reported to key audiences.

To facilitate collaboration, information sharing, and economies of scale in inventory and monitoring (I & M), the NPS organized the more than 270 parks with significant natural resources into 32 I & M networks linked by geography and shared natural resource characteristics (Figure 2). We initially used Bailey's ecoregions (Bailey 1998) and estimates of the workload needed to manage the natural resources of each park to assign parks to each network. Parks in each network share core funding and a professional staff that are augmented by funding and staffing from park base accounts and other sources to plan, design, and implement an integrated long-term monitoring program.

Figure 2. More than 270 park units with significant natural resources have been organized into 32 ecoregional networks that share core funding and a professional staff to conduct long-term monitoring of park ecosystems.

Steps in Monitoring Design

The complex task of developing a network monitoring program requires a front-end investment in planning and design to ensure that monitoring will meet the most critical information needs of each park and produce scientifically credible data that are accessible to managers and researchers in a timely manner. The investment in planning and design also ensures that monitoring will build upon existing information and understanding of park ecosystems and make maximum use of leveraging and partnerships with other programs, agencies, and academia. We found that the following basic steps for designing a long-term ecological monitoring program worked effectively across all 32 networks. Detailed guidance, examples, monitoring plans, and sampling protocols are available on the internet (NPS 2007).

Clearly Define Goals and Objectives

One of the most critical steps in designing a complex interdisciplinary monitoring program is to clearly define the goals and objectives of the program and get agreement on them from key stakeholders. In our evaluation of "lessons learned" by other monitoring programs, we found that differences in opinion regarding the purpose of the monitoring as the program was being developed often led to significant problems later during the design and implementation phases. The 32 networks of parks all shared the same five goals of vital signs monitoring, as listed above in Section 3. The development of monitoring objectives, which provide additional focus about the purpose or desired outcome of the monitoring effort, was an iterative process that sometimes required several years to refine. Early in the design process, monitoring objectives were stated in more general terms, such as "Determine trends in the incidence of disease and infestation in selected plant communities and populations", whereas the final monitoring plan and protocols provided monitoring objectives that met the test of being realistic, specific, and measurable (e.g., "Estimate trends in the proportion, severity, and survivorship of limber pine trees infected with white pine blister rust at Craters of the Moon National Monument"; Garrett et al. 2007).

Compile and Summarize Existing Information

Another important early step in the process of developing a monitoring strategy is the task of identifying, summarizing, and evaluating existing information and understanding of park ecosystems. The I&M networks discovered and summarized existing information through a series of literature reviews, scoping workshops, and interviews and surveys with park managers and subject-matter experts. The results from these "data mining" and scoping efforts were summarized in databases and reports that were used as the basis for conceptual modeling and subsequent monitoring design work; these databases and reports are expected to have multiple future applications by park managers, planners, educators, the scientific community, and others.

Develop Conceptual Models

The development of conceptual models, which are visual or narrative summaries that describe the important components of the ecosystem and the interactions among them, are a key step in understanding how the diverse components of a monitoring program interact and in promoting integration and communication among scientists and managers from different disciplines. We found that the learning that accompanied the design, construction, and revision of the models contributed to a shared understanding of system dynamics and an appreciation of the diversity of information needed to identify an appropriate suite of ecological measurements, and the process of developing conceptual models was often more important than the model itself.

Early in the planning and design process, I&M networks developed simple models that were highly aggregated representations of ecological systems, primarily as a framework for organizing, summarizing, and communicating the large amount of information obtained from literature reviews, scoping sessions, and interviews with park managers, staff, and subject-matter experts (e.g., Figure 3). Many networks based their highest-level model on a very general ecosystem (Chapin et al. 1996), modified to include broad-scale stressors more specific to the park or ecosystems of interest (e.g., Miller 2005). Once potential indicators were identified, models became more detailed and often more mechanistic, to clearly articulate relationships between measurements and the ecological attributes they represent. The proper interpretation of indicators will be greatly facilitated by scientifically sound and defensible linkages between the indicator and the ecological function or critical resource it is intended to represent (Kurtz et al. 2001). These key linkages should be explicit in conceptual models and their articulation is essential to justifying and interpreting ecological measurements.

Conceptual models can take the form of any combination of narratives, tables, matrices of factors, box-and-arrow diagrams, and conceptual diagrams using graphical symbols, and all of these forms were used in this program. All of the networks developed a set of conceptual models that consisted of diagrams with accompanying narratives that described the model, justified functional relationships in figures, and cited sources of information and data on which the models were based. Three fundamentally different model structures, with many modifications, used by the I&M networks and other agencies are control models, stressor models (e.g., Ogden et al. 2005), and state and transition models (Westoby 1989, Bestelmeyer 2003). Figure 4 illustrates the models used by one network to meet different needs as the network matured (NPS 2008).

All conceptual models should be viewed as representing our current understanding of a systems' dynamics, and a model is just one articulation of a set of hypotheses. As data are acquired and our understanding is improved, conceptual models need to evolve to match increased knowledge (Cloern 2001).

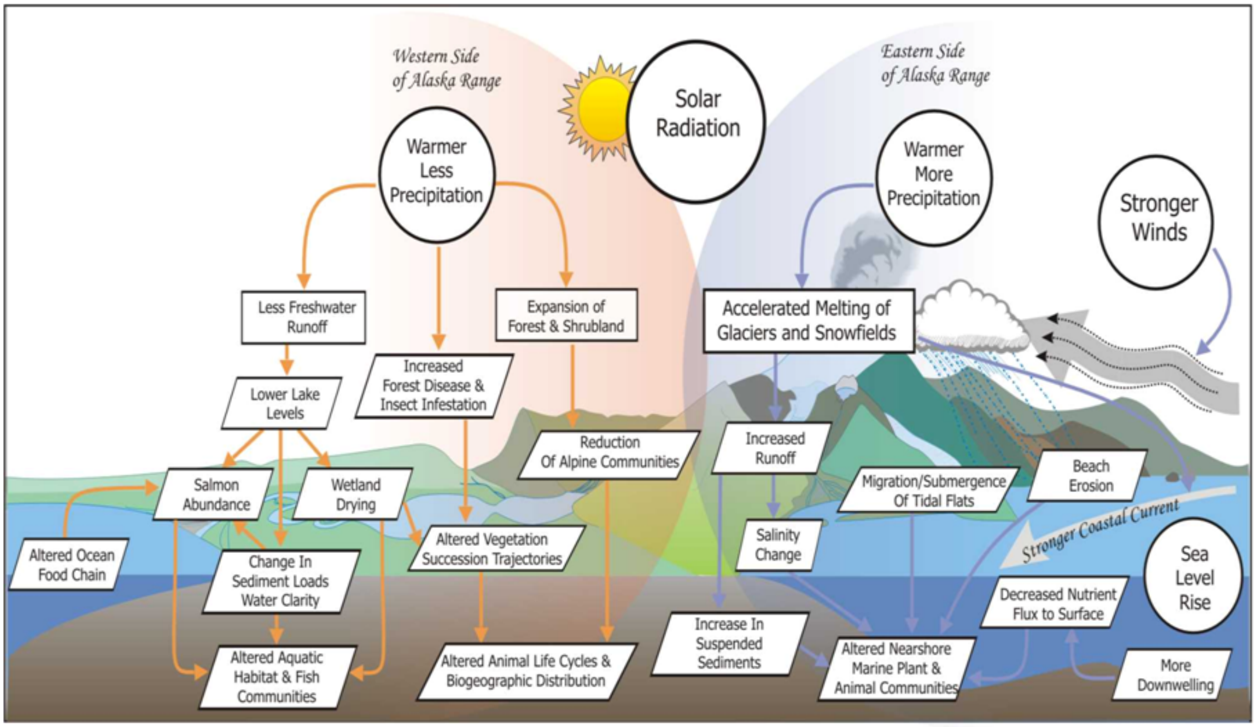

Figure 3. Example of a conceptual model summarizing expected changes from a warming climate on park ecosystems, habitats, plants, and animals in the Southwest Alaska network of parks. Warming is likely to alter the hydrologic cycle and influence processes that have created and maintained park ecosystems. Some anticipated changes include sea-level rise, greater storm intensity and frequency, altered patterns of seasonal runoff, rapid glacial retreat, and shorter duration of lake ice cover (Bennett et al. 2006).

Prioritize and Select Indicators

The task of selecting a relatively small set of long-term measurements for each national park that "represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values" is very challenging, particularly when taking into account the need to maximize the use and relevance of the data and to leverage core funding and staffing through partnerships. Most park networks followed the basic approach summarized in Figure 5 to identify and prioritize potential vital signs (NPS 2007). The scoping process identified park issues, monitoring questions, and data needs that included (1) focal resources (including ecological processes) important to each park, (2) agents of change or stressors that are known or suspected to cause changes in the focal resources over time; and (3) key properties and processes of ecosystem health (e.g., weather, soil nutrients). Conceptual models were then developed to help organize and communicate the information compiled during scoping, and to identify where cause-effect was known between some of the stressors and response variables. The scoping and conceptual modeling efforts resulted in a long list of potential vital signs, which were then prioritized using a set of criteria and a scoring system agreed upon by the parks (Table 1). We found that the process of defining vital signs and the relationships among them was critical for building shared understanding and support for the indicators that were ultimately selected (Dennison et al. 2007). The final step in the process incorporated other criteria such as efficient use of personnel, cost and logistical feasibility, partnership opportunities with other programs, and a large dose of common sense to select the initial set of vital signs for the network’s monitoring program. We obtained best results when prioritization and selection of vital signs were treated as two separate steps in the process.

We developed an Ecological Monitoring Framework (Table 2) as an organizational tool for promoting a systems-based monitoring program and for promoting communication, collaboration, and coordination with other networks, programs, and agencies involved in ecological monitoring. The framework is based on earlier work by Woodley (1993) for national parks in Canada, the European Habitat Classification System (EEA 2003), and work by Noss (1990), Grossman et al. (1998), Harwell et al. (1999), and EPA (2002). The framework has subsequently been modified and adopted by numerous agencies as part of the Natural Resource Monitoring Partnership (NRMP 2007).

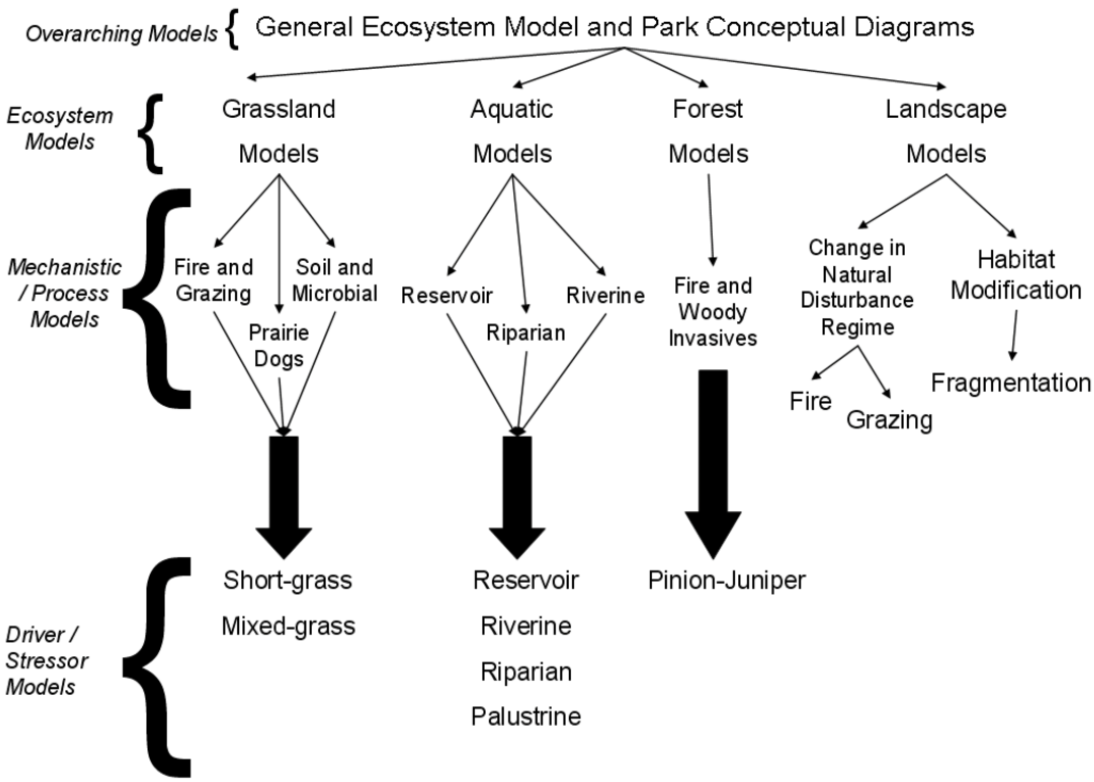

Figure 4. Conceptual models and model types used by the Southern Plains I&M Network (NPS 2008).

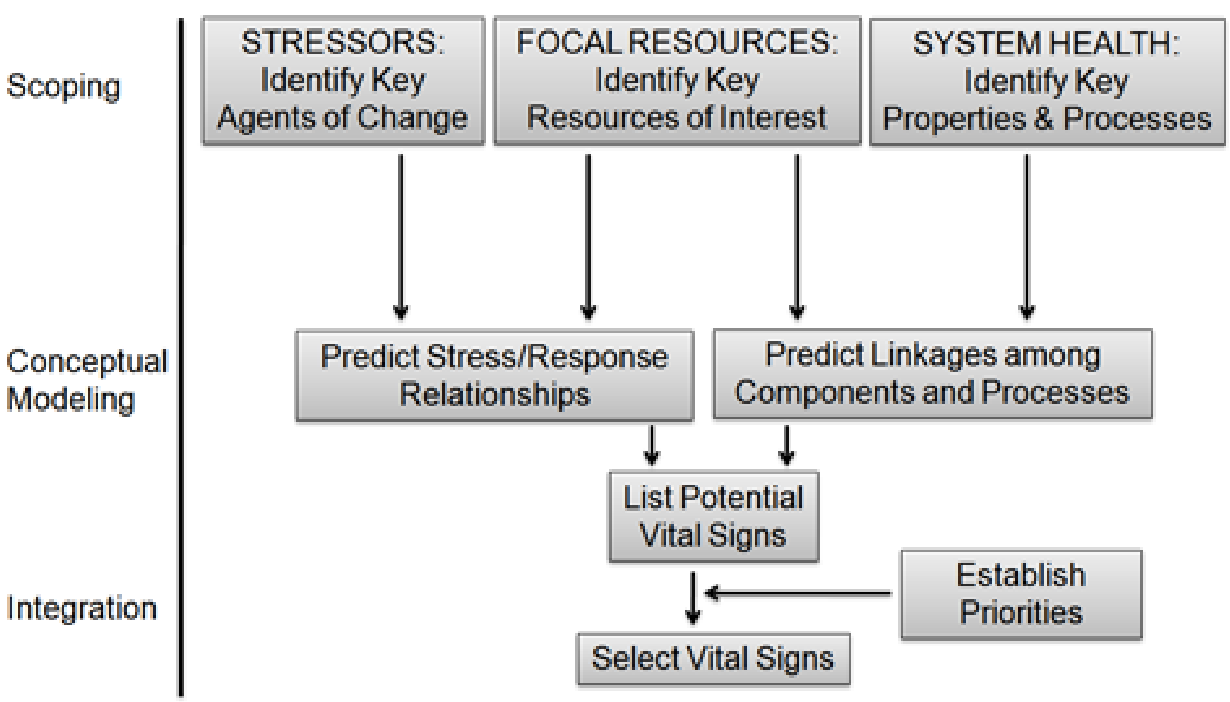

Figure 5. Basic approach to identifying and selecting vital signs for integrated monitoring of park resources (source: Kurt Jenkins, USGS Olympic Field Station).

Table 1. Criteria used to calculate priority ranks for the list of potential vital signs for monitoring resource condition.

Criterion 1: Management Significance (Weight - 40 %) - A useful ecological indicator must produce results that are clearly understood and accepted by park managers, other policy makers, research scientists, and the general public, all of whom are able to recognize the implications of the indicator's results for protecting and managing the park's natural resources. Ultimately, an indicator is useful only if it can provide information to support a management decision (including decisions by other agencies and organizations that benefit park resources) or to quantify the success of past decisions.

- There is an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management decisions.
- The measurements will produce results that are clearly understood and accepted by park managers, other policy makers, research scientists, and the general public, all of whom should be able to recognize the implications of the results for protecting and managing the park's natural resources.
- Monitoring results are likely to provide early warning of resource impairment, and will save park resources and money if a problem is discovered early.
- In cases where data will be used primarily to influence external decisions, the decisions will affect key resources in the park, and there is a great potential for the park to influence the external decisions.
- Data are of high interest to the public.
- For species-level monitoring, involves species that are harvested, endemic, alien, species of special interest, or are threatened or endangered.
- There is an obvious, direct application of the data to performance goals.
- Contributes to increased understanding that ultimately leads to better management.

Criterion 2: Ecological Significance (Weight - 40 %)

- There is a strong, defensible linkage between the indicator and the ecological function or critical resource it is intended to represent.
- The resource being represented by the indicator has high ecological importance based on the conceptual model of the system and the supporting ecological literature.
- The indicator characterizes the state of unmeasured structural and compositional resources and system processes.
- The indicator provides early warning of undesirable changes to important resources. It can signify an impending change in the ecological system.
- The indicator reflects the functional status of one or more key ecosystem processes or the status of ecosystem properties that are clearly related to these ecosystem processes. [Note: replace the term ecosystem with landscape or population, as appropriate.]
- The indicator reflects the capacity of key ecosystem processes to resist or recover from change induced by exposure to natural disturbances and/or anthropogenic stressors.

Criterion 3: Legal/Policy Mandate (Weight: 20 %) - This criterion provides additional weight to a potential vital sign if a park is directed to monitor specific resources because of some binding legal or Congressional mandate, such as specific legislation and executive orders, or park enabling legislation.

Table 2. The Ecological Monitoring Framework is a systems-based, heirarchical, organizational tool for promoting communication, collaboration, and coordination among parks, networks, programs, and agencies involved in ecological monitoring.

Level 1 Category	Level 2 Category	Level 3 Category
Air and Climate	Air Quality	Ozone
		Wet and Dry Deposition
		Visibility and Particulate Matter
		Air Contaminants
	Weather and Climate	Weather and Climate
Geology and Soils	Geomorphology	Windblown Features and Processes
		Glacial Features and Processes
		Hillslope Features and Processes
		Coastal/Oceanographic Features and Processes
		Marine Features and Processes
		Stream/River Channel Characteristics
		Lake Features and Processes
	Subsurface Geologic Processes	Geothermal Features and Processes

Level 1 Category	Level 2 Category	Level 3 Category
		Cave/Karst Features and Processes
		Volcanic Features and Processes
		Seismic Activity
	Soil Quality	Soil Function and Dynamics
	Paleontology	Paleontology
Water	Hydrology	Groundwater Dynamics
		Surface Water Dynamics
		Marine Hydrology
	Water Quality	Water Chemistry
		Nutrient Dynamics
		Toxics
		Microorganisms
		Aquatic Macroinvertebrates and Algae
Biological Integrity	Invasive Species	Invasive/Exotic Plants
		Invasive/Exotic Animals
	Infestations and Disease	Insect Pests
		Plant Diseases
		Animal Diseases
	Focal Species or Communities	Marine Communities
		Intertidal Communities
		Estuarine Communities
		Wetland Communities
		Riparian Communities
Biological Integrity		Freshwater Communities
		Sparsely Vegetated Communities
		Cave Communities
		Desert Communities
		Grassland/Herbaceous Communities
		Shrubland Communities
		Forest/Woodland Communities
		Marine Invertebrates
		Freshwater Invertebrates
		Terrestrial Invertebrates
		Fishes
		Amphibians and Reptiles
		Birds
		Mammals
		Vegetation Complex (use sparingly)
		Terrestrial Complex (use sparingly)
	At-risk Biota	T&E Species and Communities
Human Use	Point Source Human Effects	Point Source Human Effects
	Non-point Source Human Effects	Non-point Source Human Effects
	Consumptive Use	Consumptive Use
	Visitor and Recreation Use	Visitor Use
	Cultural Landscapes	Cultural Landscapes
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire and Fuel Dynamics
	Landscape Dynamics	Land Cover and Use
	Extreme Disturbance Events	Extreme Disturbance Events
	Soundscape	Soundscape
	Viewscape	Viewscape/Dark Night Sky
	Nutrient Dynamics	Nutrient Dynamics
	Energy Flow	Primary Production

A successful group decision-making process used by many of the I&M networks to prioritize vital signs involved the use of a database in a workshop setting with park managers and subject-matter experts to review and evaluate existing information and produce numerical rankings for a list of potential vital signs. Prior to holding a large, interdisciplinary workshop, a list of potential vital signs was developed based on a series of meetings, workshops, brainstorming sessions, questionnaires, literature reviews, and other information-gathering exercises to identify key monitoring questions and data needs. The list of potential vital signs was entered into a relational database that for each vital sign includes a justification statement about its importance, a draft set of monitoring questions and objectives, and other relevant information. Potential vital signs were first ranked by park managers and staff using criteria (Table 1) that are applied consistently across all parks and disciplines. The 3 criteria used by the majority of networks were Management Significance, Ecological Significance, and Legal Mandate. During the interdisciplinary workshop, subject-matter experts and managers working in teams were asked to review and improve the information in the database, and to consistently apply the criteria to rank the potential vital signs. Working with the highest-ranking vital signs, teams were then asked to develop specific measurable objectives and to identify existing protocols and partnership opportunities for each vital sign. Workshop results were documented in a report that was reviewed by all interested stakeholders, and was then used to guide park superintendents and/or technical committee members in the final step of selecting the initial set of vital signs to monitor.

Develop an Overall Sampling Design

All networks were required to develop an overall sampling design with the goals of (1) making unbiased and defensible inferences from sample observations to the intended target populations, and (2) encouraging the co-location of sampling sites and events among vital signs to improve efficiency and depth of ecological understanding. Monitoring protocols developed by each network provided more detailed descriptions of sampling design such as the size and location of sampling sites, how sites were selected, and the frequency of sampling for each vital sign.

Networks were guided by four basic principles in developing their overall sampling design:

- Wherever possible, some sort of probability design should always be used. Probability designs, where each unit in the target population has a known, non-zero probability of being included in the sample, and a random component is included in the selection of sampling sites, allow for unbiased inference from sampled sites to unsampled elements of the resource of interest (Hansen et al. 1983, McDonald 2003). Probability designs provide more reliable and defensible parameter estimates than model-based designs or convenience or judgment samples (Olsen et al. 1999, Schreuder et al. 2004), and they make it possible to provide measures of the precision of population estimates (Stevens and Olsen 2003). The most common spatially-balanced probability design is the Generalized Random Tessellation Stratified Design (GRTS; Stevens and Olsen 2003, 2004), which has been used by almost all of the park networks for a wide range of vital signs in both aquatic and terrestrial systems.
- Judgment samples that use "representative" sites selected by experts should not be used because they may produce biased, unreliable information (Olsen et al. 1999) and can often be easily discredited by critics.
- Stratification of the park using vegetation maps or other biological data or models is not recommended because stratum boundaries will change over time. A vegetation map is a model based on remote sensing and field data, and map boundaries will change as classification models are modified or as additional ground-truthing data becomes available. Using these units to define strata will limit (and greatly complicate) long-term uses of the data by restricting future park managers' abilities to include new information into the sampling framework. It is legitimate, and better, to delineate areas of special interest such as riparian or alpine areas based on physical characteristics such as terrain, and use these to judiciously define either strata or areas to sample with higher probability.
- Permanent plots that are revisited over time are recommended for monitoring, because the objective is to detect changes over time. Revisiting the same plots removes plot to plot differences from the change estimates, increasing the precision.

Develop Monitoring Protocols

A monitoring protocol is a detailed study plan that describes how data are to be collected, managed, analyzed, and reported, and is a key component of quality assurance for natural resource monitoring programs (Oakley et al. 2003). To be able to demonstrate that any changes in measurements are actually occurring in nature, and are not simply a result of measurements being taken by different people or in slightly different ways, long-term monitoring protocols require a large up-front investment in planning and design and must be fully documented, peer reviewed, and tested so that different people can take measurements in exactly the same way. Protocols should not rely on the latest instrumentation or technology that may change in a few years, such that measurements cannot be repeated.

Protocol development is an expensive, time-consuming process involving a research component. To promote consistency and data comparability and to reduce costs, existing protocols developed by other programs and agencies should be adopted or modified whenever monitoring objectives are similar. Monitoring protocols developed by our program are available on the internet in the NPS Protocol Database (NPS 2007). We also partner with the Association of Fish and Wildlife Agencies and numerous other federal and State agencies and private organizations to share protocols and monitoring project information through the Natural Resource Monitoring Partnership (NRMP 2007).

Establish Data Management, Analysis, and Reporting Procedures

Data and information are the primary products of ecological monitoring. As part of the Service's efforts to improve park management through greater reliance on scientific knowledge, a primary purpose of the monitoring program is to acquire, organize, and make available natural resource data and to contribute to the Service's institutional knowledge by facilitating the transformation of data into information and knowledge through analysis, synthesis, and modeling. A well-designed and well-documented data management system is particularly important for the success of long-term programs where the lifespan of a data set will extend across the careers of many scientists, and numerous changes in technology are to be expected.

Each network has developed a detailed plan for managing, analyzing, and reporting monitoring results (NPS 2007). Based on our evaluation of other long-term monitoring programs, all networks are expected to invest at least a third of their available resources in data management, analysis, and reporting to ensure that data are adequately entered into databases, quality-checked, analyzed, reported, archived, and made available to others for management decision-making, research, and education. All networks produce routine data summary reports, resource briefs, and occasional trend analysis and synthesis reports that are distributed in several formats to key audiences. Websites developed and maintained by each network are a key outlet for delivering monitoring results to park managers, planners, interpreters, the scientific community, and the general public.

Application of Monitoring Results to Natural Resource Stewardship

Natural resource monitoring provides site-specific information for understanding and identifying meaningful change in natural systems characterized by complexity, variability, and surprises. Monitoring results help managers determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. The improved understanding of the status and trend in resource condition and "how park systems work" will be used by park managers to adjust management practices that sustain or improve the health of park resources, such as reallocating funding and staffing to achieve desired outcomes, initiating or modifying restoration activities, or working with State or federal partners to achieve desired outcomes. The I&M program has infused NPS with an increased scientific capacity to evaluate and interpret monitoring data. Staff dedicated to environmental monitoring have been added to parks and, as a result, on-the-ground management actions and stewardship planning activities are better informed.

In addition to providing information for management decision-making, monitoring results will be used for various park planning efforts (e.g., comparing estimates of current condition for key resources with desired conditions as part of developing management strategies), and for informing policy makers and the general public about the status and trend in key resources. The detailed, complex scientific data and information depicted as the lower levels of the information pyramid in Figure 6 must be aggregated and translated through data synthesis, modeling, and resource assessments to produce information products that effectively communicate monitoring results to policy makers and the general public. The networks are working with science communication specialists and interpreters to develop more effective summary reports and graphics for presenting monitoring results.

Summary and Future Challenges

The National Park Service has completed the first steps in developing a long-term ecological monitoring program to provide information on the status and trends of selected park resources as a basis for making decisions and working with other agencies and the public for the long-term protection of park ecosystems. We found that the basic steps involved in planning and designing a long-term ecological monitoring program were the same for a diverse range of ecological systems. The process of building the program seemed to be as important as the final result in terms of building a shared understanding between scientists and managers of what the priorities are for obtaining status and trend information, and why. Key benefits of our approach are that (1) the program is park-based, with a clear link between management needs and the monitoring information being provided; (2) it builds on and leverages current monitoring investments by NPS and other partners; and (3) it provides the basic information needed by a variety of other stewardship programs in the National Park Service. These benefits are key to the relevance and long-term sustainability of the monitoring program.

Key challenges for the many scientists, data managers, park staff, and collaborators involved with this long-term program are the need to develop integrated information products through data synthesis and modeling from the data sets and reports produced for individual vital signs, and the need to aggregate and translate the large amount of complex, scientific data to decision makers, policy makers, and the general public. With the limited staff and funding we have available, we must balance the need for collecting and analyzing new data with the need to better utilize and integrate existing data so that we can provide park managers, educators, and others with useful information products.

It is becoming increasingly accepted that parks must be managed as parts of larger ecological systems, and that scientific information must form the foundation for natural resource stewardship efforts to meet the NPS mission. The day-to-day tasks involved in managing a park's natural resources have become much more technically and politically complex. The National Park Service Advisory Board (2001) stated that "A sophisticated knowledge of resources and their condition is essential. The Service

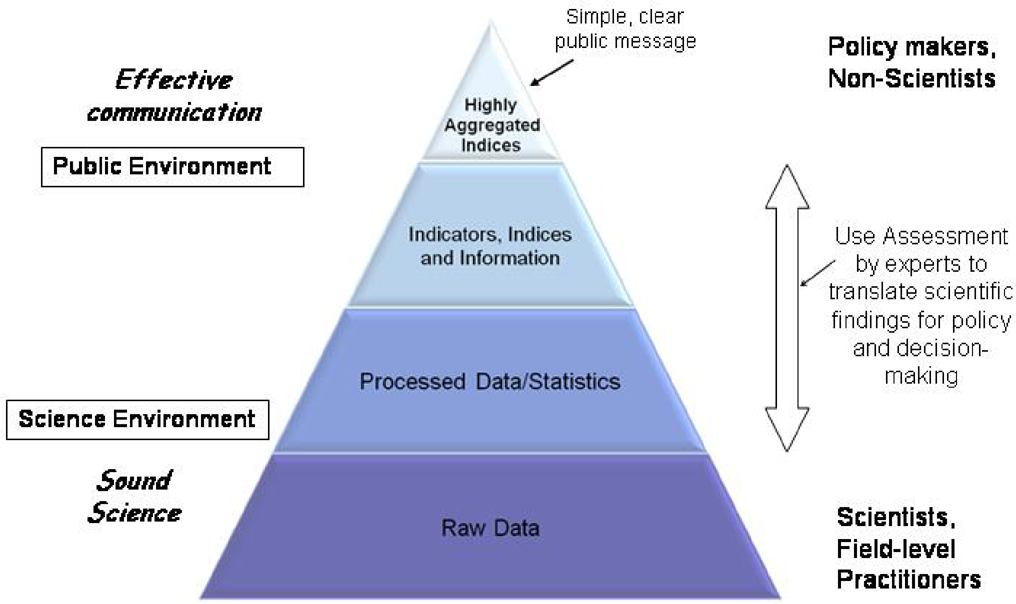

Figure 6. The information pyramid. The amount of detail and scale of analysis of scientific data will differ depending on the intended audience for the various reports and presentations. National-level reporting to policy makers and the general public will involve assessments by experts and presentations of data using highly aggregated indices and simple graphical messages. Results must be supported by a large amount of detailed, complex scientific data that is available at the park and network level.

must gain this knowledge through extensive collaboration with other agencies and academia, and its findings must be communicated to the public, for it is the broader public that will decide the fate of these resources." As the National Park Service approaches its 100th anniversary, the establishment of this long-term monitoring program is an important step towards developing the sophisticated knowledge of resources and their condition that is needed to preserve parks unimpaired for the enjoyment, education, and inspiration of this and future generations.

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