Text Version

The National Park Service
Inventory and Monitoring

Monitoring Natural Resources in our National Parks

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INTRODUCTION

This web page is a compilation of information from a number of sources that may be useful to parks for designing and implementing long-term monitoring of natural resources. The intent is to make it easier for park personnel to obtain information provided by the prototype monitoring parks and other agencies and individuals.

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to protect and manage parks. National Park managers across the country are confronted with increasingly complex and challenging issues, and managers are increasingly being asked to provide scientifically-credible data to defend management actions. Many of the threats to park resources, such as invasive species and air and water pollution, come from outside of the park boundaries, requiring an ecosystem approach to understand and manage the park's natural resources. A long-term ecosystem monitoring program is necessary to enable managers to make better informed management decisions, to provide early warning of abnormal conditions in time to develop effective mitigation measures, to convince other agencies and individuals to make decisions benefiting parks, to satisfy certain legal mandates, and to provide reference data for relatively pristine sites for comparison with data collected outside of parks by other agencies. The overall purpose of monitoring is to develop broadly-based, scientifically sound information on the current status and long term trends in the composition, structure, and function of the park ecosystem. Use of monitoring information will increase confidence in manager's decisions and improve their ability to manage park resources.

The following statement from Congress was included in the appropriations language in FY 2000, the first year of the
Natural Resource Challenge:

"The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."

Legislation and Policy

National Park Service policy and recent legislation (National Parks Omnibus Management Act of 1998) requires that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources in order to fulfill the NPS mission of conserving parks unimpaired. The following laws and management policies provide the mandate for inventorying and monitoring in national parks:

The mission of the National Park Service is "*...to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is 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*" (National Park Service Organic Act, 1916).

"The Secretary shall 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. The monitoring program shall be developed in cooperation with other Federal monitoring and information collection efforts to ensure a cost-effective

approach" (National Parks Omnibus Management Act of 1998)

"*Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions*" (2001 NPS Management Policies).

2001 NPS Management Policies state that "*The Service will:*

- *Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.*
- *Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.*
- *Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.*
- *Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.*
- *Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems.*" .

The National Environmental Policy Act of 1969 requires certain knowledge of resource conditions to direct and evaluate effects of management actions.

The Forest and Rangeland Renewable Resources Planning Acts of 1974 and 1976 also express Congressional insistence on inventory and monitoring of natural resources on all public lands in the U.S.

Several other Federal laws and executive orders also provide legal direction and support for expending funds to determine the condition of natural resources in parks (e.g., Endangered Species Act 1973, amended 1982; Fish and Wildlife Coordination Acts, 1958 and 1980; Migratory Bird Treaty Act, 1974; Clean Water Act; Executive Order 11900 (Protection of Wetlands); and the Clean Air Act.

Definitions and Purpose

A natural resource **inventory** is an extensive point-in-time effort to determine location or condition of a resource, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate. Inventories contribute to a statement of park resources, which is best described in relation to a standard condition such as the natural or unimpaired state. Inventories may involve both the compilation of existing information and the acquisition of new information. They may be relative to either a particular point in space (synoptic) or time (temporal).

Monitoring differs from inventory in adding the dimension of time, and the general purpose of monitoring is to detect changes or trends in a resource. Elzinga et al. (1998) defined monitoring as "The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective". Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory.

Natural resource monitoring is conducted primarily for two purposes: (1) to detect significant changes in resource abundance, condition, population structure, or ecological processes; or (2) to evaluate the effects of some management action on population or community dynamics or ecological processes.

Monitoring should have a specific purpose, and is a prerequisite for management action, which is triggered when values reach or exceed some pre-determined threshold value. Monitoring cannot be a "I'll know it when I see it" process.

Monitoring data are most useful when the same methods are used to collect data at the same locations over a long time period (e.g. more than 10-12 years). It is important to note that cause and effect relationships usually cannot be demonstrated with monitoring data, but monitoring data might suggest a cause and effect relationship that can then be investigated with a research study. The key points in the definition of monitoring are that: (1) the same methods are used to take measurements over time; (2) monitoring is done for a specific purpose, usually to determine progress towards a management objective; and (3) some action will be taken based on the results, even if the action is to maintain the current management.

Research has the objective of understanding ecological processes and in some cases determining the cause of changes observed by monitoring. That understanding is needed for determining the appropriate management response to threats. Research is generally defined as the systematic collection of data that produces new knowledge or relationships and usually involves an experimental approach, in which a hypothesis concerning the probable cause of an observation is tested in situations with and without the specified cause. The NPS monitoring program includes a research component to design sampling protocols for various types of park resources at different locations and spatial scales.

Research is usually short term; approximately 80% of research studies last only 1-2 years, and 75% of studies involve only 1 or 2 species. An important exception to this generalization is the collaborative Long-Term Ecological Research program funded by the National Science Foundation, which is conducting long-term research on such things as pattern and control of primary production, spatial and temporal distribution of selected populations, and patterns of nutrient influx and movement through soils, groundwater and surface waters.

Protocols and standard operating procedures used by researchers are usually based on the latest technology and are often too time consuming or expensive to provide data for a long-term monitoring program. The need to publish results in peer-reviewed journals, the measure of successful research, tends to require researchers to continually develop new sampling methods and to debate alternate models and analyses.

Long-Term Programmatic Goals

To comply with legal requirements, fully implement NPS policy, and guide management activities, the Servicewide Inventory and Monitoring Program focuses on attaining the following major long-term goals:

1. Establish natural resource inventory and monitoring as a standard practice throughout the National Park system that transcends traditional program, activity, and funding boundaries.
2. Inventory the natural resources and park ecosystems under National Park Service stewardship to determine their nature and status.
3. Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments.
4. Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making.
5. Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

Attaining these long-term goals is necessary to "manage the natural resources of the National Park System to maintain and perpetuate their inherent integrity." (NPS Management Policies, Chapter 4, 1988).

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NATIONAL FRAMEWORK FOR INVENTORY AND MONITORING

Many units of the National Park System are being subjected to a wide variety of natural and man-induced impacts and alterations. left unchecked, these factors could threaten the existence of many natural systems and biotic communities within the parks. To cope with these diverse changes, park managers and superintendents must have at their disposal comprehensive inventory information about the types and status of natural resources in the park as well as monitoring information which provides insights into how the condition of those systems and communities are changing over time.

The National Park Service has implemented a strategy designed to institutionalize natural resource inventory and monitoring on a programmatic basis throughout the agency. The effort was undertaken to ensure that the approximately 270 park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. The national strategy consists of a framework having three major components: (1) completion of basic resource inventories upon which monitoring efforts can be based; (2) creation of experimental Prototype Monitoring Programs to evaluate alternative monitoring designs and strategies; and (3) implementation of operational monitoring of critical parameters (i.e. "vital signs") in all natural resource parks.

National and Regional Oversight

Natural resource inventory and monitoring activities by the National Park Service are carried out under the direction of the Associate Director for Natural Resource Stewardship and Science. National level program coordination and management is provided by a National Inventory and Monitoring Program Manager and support staff, who are aligned administratively with the Natural Resource Information Division. A 15-member National Inventory and Monitoring Advisory Committee, consisting of superintendents, park-based natural resource managers, central office personnel, and research scientists provides programmatic and technical recommendations.

Program coordination and oversight at the regional level is provided by a full-time Regional Inventory and Monitoring Coordinator who reports to the region's senior natural resource staff member or other regional staff person designated by the Regional Director. Regional Inventory and Monitoring Coordinators are responsible for providing day-to-day coordination between parks, the regional office, and the National Inventory and Monitoring Program.

Basic Resource Inventories

All natural resource parks must posses at least a minimal compliment of resource inventory information in order to be able to effectively manage resources. The minimal inventory information required by all parks has been defined in terms of 12 data sets that include a variety of biotic and abiotic ecosystem components. The 12 data sets are as follows:

- Natural resource bibliography
- Base cartographic data
- Geology map

- Soils map
- Weather data
- Air quality
- Location of air quality monitoring stations
- Water body location and classification
- Water quality data
- Vegetation map
- Documented species list of vertebrates and vascular plants
- Species distribution and status of vertebrates and vascular plants

Prototype Monitoring Programs

The second component of the NPS national inventory and monitoring framework is a network of experimental or "prototype" long-term ecological monitoring (LTEM) programs. The tremendous variability among parks in ecological conditions, sizes, and management capabilities represent significant problems for any attempt to institutionalize ecological monitoring throughout the Service. To develop monitoring expertise throughout this range of ecological and managerial diversity, natural resource park units were grouped into 10 major biogeographic areas or biomes, and one park unit from each major biome was then selected to serve as a prototype LTEM program for that biome. To address the needs of small parks, three of the prototype programs were designed as "cluster" programs, i.e. a grouping of 4-6 small parks, each of which lacked the full range of staff and resident expertise needed to conduct a long-range monitoring program on its own. Design and testing of monitoring protocols at most of the parks is being led by scientists with the Biological Resources Division (BRD) of the U.S. Geological Survey.

Within the new network approach towards implementing vital signs monitoring throughout the NPS, the prototype parks play two special roles:

- **Centers of Excellence** - Prototype LTEM programs were established primarily in an attempt to learn how to design scientifically credible and cost-effective monitoring programs in ecological settings of major importance to a number of NPS units. The level of monitoring conducted by prototype programs is both more comprehensive and more intensive than what other parks will be able to undertake. For that reason, a major role of the prototypes will be to serve as "centers of excellence" for other parks in the system. Prototype LTEM programs will be responsible for assisting in the design, development, and testing of monitoring protocols and methods and for providing instruction in the use of those products to other parks occupying similar ecological settings.
- **Mentoring** - Prototype LTEM programs possess a wealth of experience and expertise related to the development and implementation of ecological monitoring that can greatly benefit other parks throughout the Service. Therefore, the prototype programs are required to provide mentoring assistance to other parks undertaking long-term ecological monitoring. Personnel from prototype LTEM programs will be expected to advise and provide technical assistance to staff from other parks on a wide variety of technical issues related to monitoring, including conceptual design, database management, data integration and analysis, and reporting of monitoring findings.

Detailed information on the National I&M Program and progress being made by the prototype monitoring parks is available from the Annual Reports of the Inventory and Monitoring Program, and at the NPS Inventory & Monitoring Web Site. A brief description of the monitoring programs for the first seven prototype park programs to be funded and the four newly-funded prototypes is as follows:

The Long-term Ecological Monitoring (LTEM) program at **Channel Islands National Park** has four goals: (1) identify and measure ecological vital signs of the park to determine present and future ecosystem health; (2) establish empirically normal limits of resource variation; (3) provide early diagnosis of abnormal conditions; and (4) identify potential agents of abnormal change. Threats to park resources that helped shape the design of the LTEM program include unsustainable uses, such as fishing, grazing, and disturbance by visitors; habitat fragmentation; air and water pollution; invasions by alien species; and loss of soil and vegetation. The LTEM program focuses primarily on population dynamics and monitors species populations based on a broad array of ecological roles, trophic levels and life forms, with special consideration to species with special legal status, endemics, aliens, charismatic species, and common species. Specific indicators and sampling protocols used to monitor park ecosystems are listed below. Details of the prototype monitoring program are available on the Channel Islands NP Monitoring Web Site.

Great Smoky Mountains National Park is world renowned for the diversity of its plant and animal resources, and it is the most visited national park in the National Park System. Maintenance of biodiversity is the primary natural resource goal of park management. The park's I&M program has a strong ecological basis that includes components at multiple scales from landscape to species. Objectives of the program are to (1) measure change over time in the condition of selected key populations, communities and systems; (2) provide managers with practical information to help them preserve park natural resources; (3) provide information in an accessible data management system that will encourage research in the park; and (4) provide information to help other parks develop monitoring programs. Sampling protocols are being developed to address specific management issues such as bear and deer management, effects of balsam woolly adelgid and other exotic pests, and changes in forest structure due to acidification, fire suppression, and other factors. Now that specific protocols have been designed and tested, the park is beginning to design a park-wide, ecosystem monitoring program to serve as a model for the deciduous forest biome.

Shenandoah National Park's Natural Resource Inventory and Long-term Ecological Monitoring System is the backbone of the park's natural resources management program. It provides the fundamental understanding of natural resources and processes that is essential to the development of management and mitigating actions. Objectives of the program are to (1) obtain and maintain a scientifically-based understanding of the type, abundance, and distribution of natural resources; (2) monitor resource condition and changes through time; and (3) monitor natural processes and anthropogenic influences that maintain or affect ecosystem health. Specific protocols that have been developed and tested in the park include threatened and endangered plants; forest vegetation; meadow vegetation; aquatic macroinvertebrates; stream fish; amphibians; land birds (breeding bird survey routes and MAPS stations); white-tailed deer; and black bear. Details of these monitoring protocols are presented below.

Denali National Park and Preserve has developed a monitoring program to serve as a model for other Alaska parks. Denali's mission is to understand the ecosystem, so that the ecosystem can be preserved and so that this understanding can be communicated to visitors. The Denali LTEM program supports the mission of the National Park Service and the park by the development of broadly based, scientifically sound information on the current status and trends of the physical and biological resources of the park's ecosystem. The program has a single goal of helping park managers protect park resources by providing the ecological context for resource preservation decisions. Having a single goal provides the necessary basis for prioritizing monitoring work. This goal is met through a management focus objective, targeting early warning of adverse changes, and through an ecological focus objective, targeted at ecosystem understanding. Monitoring protocols have been developed that contribute different types of information toward the management focus and ecological focus objectives. This includes vegetation, weather, glaciers, air quality, small mammals, golden eagles, stream invertebrates, avian populations, caribou & wolf interactions, hydrology and stream water chemistry. Details of the prototype monitoring program at

Denali are available on the Denali NPP Monitoring Website.

Cape Cod National Seashore is the prototype monitoring park for the Atlantic and Gulf Coast biogeographic region. The monitoring program is based on our best understanding of processes and component interactions governing the coastal ecosystem, and focuses on addressing management issues that confront coastal parks. An ecosystem-based, issues-oriented program is being developed to detect ecosystem changes, examine contributing factors and consequences of ecosystem changes, and to inform park management of the salient issues that such ecosystem changes represent. The goal of the program is to (1) detect changes in particular attributes of the coastal ecosystem and determine if those changes are within the bounds of natural or historic variability; (2) predict how those changes relate to natural processes and human influences; and (3) understand how such changes, ultimately, affect the condition of the coastal ecosystem. Monitoring data will provide a scientific basis for management decisions leading to effective protection and restoration of coastal ecosystems. Protocols are being developed to monitor estuarine nutrient enrichment, estuarine nekton (fish and decapod crustaceans), sediment and benthic fauna contaminants, shoreline change, water quality, groundwater hydrology, freshwater fish, aquatic invertebrates, amphibians, waterbirds, landbirds, and red foxes and coyotes. A report is available on the Conceptual Framework for development of monitoring protocols at Cape Cod NS.

The **Great Plains Prairie Cluster** was the first prototype monitoring effort to address monitoring in small parks. The program involves a team of resource specialists based in one park (Wilson's Creek National Battlefield), who collect monitoring data in six different small prairie parks (Agate Fossil Beds NM, Homestead NM, Scott's Bluff NM; Effigy Mounds NM; Pipestone NM; and Wilson's Creek NB). Overall goals of the monitoring program are to assess the effectiveness of resource management and to detect any degradation of park natural resources from external threats. Sampling protocols address three high-priority management issues: (1) sustainability of small remnant and restored prairie ecosystems, (2) the effects of external land use and watersheds on small prairie preserves, and (3) the effects of fragmentation on biological diversity in small prairie parks. Protocols are being developed to monitor prairie plant communities (following methods used at the Konza Prairie Long-term Ecological Monitoring Site), rare plants, stream macroinvertebrates, butterflies, grassland birds, black-tailed prairie dogs, and weather. Protocol design and development has been funded primarily by USGS-BRD scientists with the Northern Prairie Wildlife Research Center. An excellent Overview of the Prairie Cluster prototype LTEM program has been written to describe the conceptual framework, monitoring components, and implementation of this long-term ecological monitoring program. The Data Management Plan for the Prairie Cluster prototype is also available. Staff from the Great Plains Prairie Cluster prototype have lead the early planning for inventory and monitoring in the Heartland Network.

The **Virgin Islands-Southern Florida Cluster** includes Virgin Island NP and Buck Island Reef NM in the Greater Antilles, and Dry Tortugas NP in Florida. Development of protocols by USGS-BRD scientists at Virgin Islands is focusing on monitoring of coral reefs with digital video cameras, and on reef fishes. Protocols have been completed for monitoring water quality and sea turtles. Scientists are testing a sophisticated underwater positioning system which will allow a statistically rigorous sampling design for the coral monitoring work (download publications on Monitoring Coral Reefs with Videography and Sonar, and a Comparison of Surveys using Chain Transect and Videography). The overall monitoring program is designed to address effects of development and increased visitation on terrestrial and marine ecosystems; effects of hurricanes, droughts, and other natural stresses on marine and terrestrial resources; effects of fishing on fish assemblages and associated reef systems; effects of soil erosion; and status of rare, endangered and endemic species. Primary emphasis is on monitoring of reef ecosystems, sea turtles, and water quality.

Mammoth Cave National Park is the prototype park for the Caves biogeographic region. The design of this prototype program will begin in 2001.

Olympic National Park is the prototype park for the Coniferous Forest biogeographic region. The design of this prototype program will begin in 2001.

North Cascades National Park Service Complex is the prototype park for the Rivers and Lakes biogeographic region. The design of this prototype program will begin in 2001, although work already done with funding from other sources is summarized at their North Cascades Monitoring Website.

The **Northern Colorado Plateau Cluster** is the prototype park for the Arid Lands biogeographic region. The design of this prototype program will begin in 2001.

Vital Signs Monitoring Networks

The third component of the NPS national framework for inventory and monitoring consists of networks of parks that will conduct long-term ecological monitoring for selected critical parameters, or "vital signs". Unlike the prototype LTEM programs, the goal of this monitoring is to be able to assess the basic health or integrity of park ecosystems and to be able to formulate management actions whenever necessary to maintain the integrity of those ecosystems. As of October 1, 2000, approximately 270 park units organized into 32 networks will participate in vital signs monitoring.

View the Map of the 32 networks and the parks in each network.

Download a list of parks in each network.

The network strategy for implementing vital signs monitoring was adopted because it is currently unrealistic to expect that all parks will be able to obtain new funding and positions to allow monitoring at the scale and intensity being conducted at the prototype parks, and yet monitoring needs to be initiated as soon as possible in all parks with natural resources to meet service goals and Congressional mandates. A monitoring program requires professional-level staff who can analyze data, interpret data, prepare reports, and provide the information in a useable format to park managers, scientists, and the other interested parties. However, it is not realistic at this time for every park to have a full professional staff including a botanist, wildlife biologist, hydrologist, geologist, soil scientist, data manager, etc. Thus, the compromise position is to provide consistent funding and as many as 8 or 9 new positions to each network to develop a core program and identify what specialists it needs, allowing each network to then leverage these core resources with other resources and partnerships to build an integrated monitoring program that works best for that network of parks.

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DEVELOPMENT OF MONITORING PROGRAMS

Introduction

Americans expect the National Park Service to preserve the nation's heritage, including living and non-living features of ecosystems in all units of the National Park System. Knowing the condition of natural resources in national parks is fundamental to the Service's ability to protect and manage parks. National Park managers across the country are confronted with increasingly complex and challenging issues, and managers are increasingly being asked to provide scientifically credible information to defend management actions. The National Parks Omnibus Management Act of 1998 includes a Congressional mandate to provide information on the long-term trends in the condition of National Park System resources.

Management of the national parks is an extremely complicated and difficult task. Many of the threats to park resources, such as invasive species and air and water pollution, come from outside of a park's boundaries, requiring an ecosystem approach to understand and manage the park's natural resources. Managers must be capable of determining whether the changes they are observing in park ecosystems are the result of natural variability or human activities. If the latter, then park managers must understand park ecosystem processes and mechanisms well enough to know what actions are needed to restore natural conditions. Such knowledge can only be gained through long-term research and monitoring. Short-term, parochial investigations provide a useful beginning but cannot by themselves provide the needed knowledge and understanding. In the words of Ralph Waldo Emerson, "*The years teach much which the days will never know*".

The overall purpose for monitoring is to protect park resources. The **Servicewide Goals of Vital Signs Monitoring** are as follows:

- Determine 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.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

An effective long-term ecosystem monitoring program will:

1. Enable managers to make better informed management decisions;
2. Provide early warning of abnormal conditions in time to develop effective mitigation measures;
3. Provide data to convince other agencies and individuals to make decisions benefiting parks;
4. Satisfy certain legal mandates; and
5. Provide reference data for comparison with more disturbed sites.

Characteristics of Successful Long-term Monitoring Programs

Few examples of successful long-term monitoring programs exist. A few that are considered successful are the Breeding Bird Survey, Salmon Escapement monitoring, Waterfowl Harvest Surveys, the USDA Forest Service's Forest Health Monitoring Program, and Agricultural Production monitoring.

Some characteristics of successful long-term monitoring programs, as summarized by Dr. Lyman McDonald, are as follows:

- Monitoring data had some commercial or management value.
- Inferences can be made to a larger population or region.
- Indicator variables are easily understood.
- Sampling protocols are relatively cheap and easy to use.
- Sampling protocols are not changed unless there is an overlap between methods for several years.
- There is no expectation for cause and effect relationships.
- The monitoring program was someone's pet project until data had been collected for enough years

that others saw its value.

- Monitoring data show a trend or change; at least 10-12 years of data are often required to demonstrate a trend in biological monitoring data.
- The program is periodically reviewed by experts from both within and outside the program.
- Reports are issued on time at regular intervals.

These characteristics should be taken into consideration during the design of a network monitoring program.

What are Vital Signs?

Vital Signs are key elements that indicate the health of an ecosystem. Vital signs may occur at any level of organization including landscape, community, population, or genetic levels. They may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes). Vital signs can be any measurable feature of the environment that provides insights into the state of the ecosystem. The term is synonymous with "ecological indicator", but use of the term and the analogy to an individual's health helps the NPS to explain the need for monitoring to managers, Congress, and the public.

The National Park Service needs a clear simple way to account for how it is preserving the nation's natural heritage. The Service needs to identify and monitor the vital signs of environmental health in parks, just as physicians monitor their patients' vital signs, as a means of sustaining the health of park resources, diagnosing threats to their well being, and mitigating those threats. Monitoring park vital signs provides the foundation for this accountability by evaluating efficacy of restoration and other management actions and by warning of impending threats to parks. The concept of ecosystem health is not dissimilar to that for individual health. A healthy individual's vital signs remain within a normal, dynamic range and return to a nominal level quickly after disturbance. Damage to structural elements, when promptly and accurately diagnosed, is quickly and effectively repaired to sustain normal functions (restoration and maintenance). Infections (alien species) can be eliminated or contained when their nature and extent are identified in a timely manner. The same attributes pertain to wild populations, communities, and ecosystems in parks. While vital signs for these higher levels of ecological organization are not yet known with certainty, experience in many parks indicates that basic measures of physical and chemical environmental factors and population dynamics of selected species serve this role well. Just as early physicians discovered the value of body temperature, respiratory rate, and blood pressure in assessing patient health by measuring them in many patients, today's park managers need to begin measuring dynamic ecosystem parameters to identify environmental 'vital signs' for parks and to establish their normal variation.

The monitoring of vital signs is an important component of the Service's need to maintain ecological integrity of park ecosystems. Ecosystems with high ecological integrity continue to express the evolutionary and biogeographic processes that gave rise to the current biota, and they have a species composition, diversity, and functional organization expected from natural habitats of the region. Systems with ecological integrity are resilient to environmental disturbance within a natural range of variability. Thus, an ecological system has integrity when it maintains its characteristic compositions, structures, and processes against a background of anthropogenic disturbance.

Downloadable Documents Relevent to Designing a Park Monitoring Program

The following documents deal specifically with designing long-term monitoring in national parks and are made available here in .pdf (portable document format) How to read .pdf documents with the free Acrobat Reader:

PDF Download NPS-75 NPS-75 Natural Resource Inventory and Monitoring Guidelines (currently under revision)

PDF Download Davis 1997 Davis, G. E. 1997. General ecological monitoring program design, implementation, and applications: a case study from Channel Islands National Park, California In: J. K. Reaser and F. Dallmeier (eds.) Measuring and monitoring biodiversity for conservation science and adaptive management. Smithsonian Institution, Washington, D.C.

PDF Download Silsbee and Peterson 1991 Silsbee, D. G. and D. L. Peterson. 1991. Designing and implementing comprehensive long-term inventory and monitoring programs for National Park System lands. National Park Service, Natural Resources Report NPS/NRUW/NRR-91/04.

PDF Download Peterson et al. 1995 Peterson, D. L., D. G. Silsbee, and D. L. Schmoldt. 1995. A planning approach for developing inventory and monitoring programs in national parks. National Park Service, Natural Resources Report NPS/NRUW/NRR-95/16.

PDF Download Roman and Barrett 1999 Roman, C. T. and N. E. Barrett. 1999. Conceptual framework for the development of long-term monitoring protocols at Cape Cod National Seashore. USGS Patuxent Wildlife Research Center, Coop. National Park Studies Unit, University of Rhode Island.

PDF Download Noon et al. 1999 Noon et al. 1999. Conceptual basis for designing an effectiveness monitoring program. Chpt. 2 in The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. USDA Forest Service Gen. Tech. Rept. PNW-GTR-437.

PDF Download McDonald et al. 1998 McDonald, L., T. McDonald, and D. Robertson. 1998. Review of the Denali National Park and Preserve (DENA) long-term ecological monitoring program (LTEM). WEST Tech. Rept. 98-7.

Initial Steps in Designing a Monitoring Program

Design of such diagnostic monitoring programs is a multi-step process that will involve partnerships with neighboring agencies and local universities. The design of a monitoring program will require considerable thought and effort before field data collection efforts begins, and experience from the prototype monitoring program and other agencies demonstrates that developing an effective monitoring program is not a trivial matter. Information from monitoring is needed to address not only today's resource problems, but also to anticipate and define future resource problems, and yet our understanding of park ecosystems and the effects of human activities on park resources is relatively poor. The amount of funding and personnel currently available will allow parks to address only their most critical monitoring needs, and difficult decisions must be made regarding prioritization and the potential benefits and costs of various alternatives. The value of monitoring data comes from being able to compare data over time, and it is important not to make major changes in design or methodology once data collection begins. It has been said that designing a monitoring program is like getting a tattoo: you want to get it right the first time, because making major changes later will be painful and difficult. For that reason, the Servicewide I&M Program has adopted a "go slow and do it right" approach to designing a monitoring program, and considerable technical assistance from within and outside of the NPS will be available to park networks as the Service gains more experience in designing monitoring programs.

Each network of parks will design an integrated monitoring program that best meets the high-priority monitoring needs of the parks in that network. Although there will be considerable variability among networks in the final design, the basic approach to designing a monitoring program should follow four basic steps:

- Establish Monitoring Goals and Objectives;
- Compile/summarize existing data and understanding of park ecosystem;
- Develop conceptual models;
- Select indicators for monitoring and determine the appropriate sampling design and protocols.

The recommended sequence of steps involved in designing an integrated monitoring program for a network is described in the Recommended Approach for Developing a Network Monitoring Program.

To assist parks with designing an integrated monitoring program, the Natural Resource Program Center is developing a "Handbook for Monitoring Vital Signs in National Parks" that will provide guidance and recommendations for monitoring air resources, water resources, geological resources, exotic species, threatened and endangered species, and other fauna and flora. Subject experts from each of the NRPC divisions, and the Regional I&M Coordinators, are available to assist parks with the design of their monitoring program.

Draft outline for a Network Monitoring Plan

Establishing Monitoring Goals and Objectives

The overall goal 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. To be effective, the monitoring program must be relevant to current management issues as well as anticipate future issues based on current and potential threats to park resources. The program must be scientifically credible, produce data of known quality that are accessible to managers and researchers in a timely manner, and be linked explicitly to management decision-making processes.

The first step in developing a long-term monitoring program is to articulate clearly the management goals and objectives of the parks and the network of parks in concert with regional and Servicewide goals and objectives. Park-specific goals and objectives will be based on factors such as the park's enabling legislation, legal mandates for monitoring endangered species and other resources, planning documents such as the General Management Plan or Resource Management Plan, and input from park managers and scientists regarding important park resources and the stressors affecting those resources. The information needed to formulate these goals and objectives will be obtained through the steps outlined in the Recommended Approach for Developing a Network Monitoring Program.

Monitoring objectives, to be effective, should be realistic, specific, unambiguous, and measurable. This goes back to the statement that monitoring should not be an "I'll know it when I see it" process. Monitoring objectives should include six components to be complete (Elzinga et al. 1998:41): the indicator or "vital sign" to be monitored, the location or geographical area, the attribute of the indicator to be measured (e.g., population size, density, percent cover), the intended management action (increase, decrease, maintain), the measurable state or degree of change for the attribute, and the time frame. Specific monitoring objectives have not been documented by most parks, but objectives must be explicitly stated in order to design an effective monitoring program and to determine if management objectives are being met.

As described by Elzinga et al. (1998:46), management objectives can usually be classified as one of two types: (1) target/threshold objectives (e.g., increase the population size of Species A to 5000 individuals; maintain a population of a rare plant Species B at 2500 individuals or greater; keep Site C free of invasive weeds X and Y); or (2) change/trend objectives (e.g., increase mean density of Species A by 20%; decrease frequency of invasive weed X by 30% at Site C).

Examples of management objectives:

- Manually remove overstory trees at the Goat Prairie Unit to reduce combined mean density for Sugar Maple, Bigtooth Aspen, American Basswood, Red Elm and White Ash to 370 trees/ha before FY2001.
- Maintain percent cover of less than 5% for all exotic species combined at Manley Woodland from 1999 to 2008.
- Increase family richness of aquatic macroinvertebrates in Wilson's Creek by 20% between 1999 and 2004.
- Decrease population size of Rainbow Trout in Eagle Creek by 50% between 1999 and 2004.

Developing Conceptual Models of Relevant Ecosystem Components

A conceptual model is a visual or narrative summary that describes the important components of the ecosystem and the interactions among them. Development of a conceptual model helps in understanding how the diverse components of a monitoring program interact, and promotes integration and communication among scientists and managers from different disciplines. Conceptual model diagrams often take the form of a "boxes and arrows" diagram, whereby mutually exclusive components are shown in boxes and interactions among the components are shown with arrows, but many conceptual models include tables, matrices, sentences or paragraphs to summarize and communicate our understanding of the system.

From "Lisa Thomas - based on experiences in developing conceptual models for the Prairie Cluster prototype LTEM program": Conceptual models are useful throughout the monitoring process because they:

- Formalize our current understanding of the context and scope of the natural processes and anthropogenic stressors affecting ecological integrity; and
- Help expand our consideration across traditional discipline boundaries.

Most importantly, clear, simple models facilitate communication among:

- scientists from different disciplines;
- researchers and managers;
- managers and the public.

From "EMAP program Olsen et al. 1992. The indicator development strategy for the environmental monitoring and assessment program. EPA/600/3-91/023":

- Conceptual models define the linkages between environmental values, ecological endpoints, stressors, and important ecosystem components and processes.

- Conceptual models explicitly define the framework for indicator interpretation; for example, how the response indicators relate to the assessment endpoints ... and how they will be used to assess that status.
- One purpose of the models is to promote an integrated program and facilitate coordination.
- Conceptual models are important representations of scientific understanding of the ecological resource for monitoring purposes. They must be descriptive and should clearly demonstrate linkages between the indicators and the environmental values being monitored.

Aspects to consider as conceptual models are developed (from Barber 1994 EMAP program):

- Identify the structural components of the resource, interactions between components, inputs and outputs to surrounding resources, and important factors and stresses that determine the resource's ecological operation and sustainability.
- Consider the temporal and spatial dynamics of the resource at multiple scales because information from different scales can result in different conclusions about resource condition.
- Identify how major stressors of the resource are expected to impact its structure and function.

From Chapter 3 of "Margoluis, R. and N. Salafsky. 1998. Measures of success: designing, managing and monitoring conservation and development projects. Island Press, Washington D.C. 363 pp."
"Drawing a Conceptual Model is as much an art as it is a science. You first need to get good and reliable information (the science) that you'll arrange in a diagram (the art) to represent your interpretation of the situation at your site. Like a big puzzle, the easy part is getting your hands on the pieces (the information]. The difficult part is putting these pieces together in some semblance of order. [Unlike a puzzle] ... a Conceptual Model can have multiple correct arrangements. Furthermore, the model is only a best guess - one that must be changed and revised as you get more information and develop new insights."

"A good Conceptual Model does not attempt to explain all possible relationships or contain all possible factors that influence the target condition but instead tries to simplify reality by containing only the information most relevant to the model builder. One of the difficulties in building models is to include enough information to explain what influences the target condition without containing so much information that the most critical factors or relationships are hidden. Too much information can conceal important aspects of the model, while too little information in the model leads to oversimplification which in turn leads to a higher likelihood that the portrayal is not accurate."

From Comprehensive Everglades Restoration Plan:. "An essential step in the Applied Science Strategy is the creation of a set of conceptual ecological models of the major wetland physiographic regions in south Florida. These simple, nonquantitative models are an effective means for developing a consensus regarding a set of causal hypotheses, which explain the affects that the major anthropogenic stressors have on the wetland ecosystems. Each model identifies the attributes in the natural systems that are the best indicators of the changes which have occurred as a result of the stressors. Each model also delineates the ecological linkages between the stressors and the attributes and the most appropriate measures for each of the attributes. The development of a consensus regarding the components and linkages in the conceptual models is the first step in the process of reaching agreement on specific hydrological, ecological, and biological measures of restoration success, and for designing a regional, performance-based ecological monitoring program."

From Development of an ecosystem monitoring plan for the Sierra Nevada. "A detailed conceptual model of the system to be monitored is recognized as an essential component of a scientifically credible monitoring strategy. A conceptual model expresses ideas about components and processes deemed to be important in a system, along with some preliminary thoughts on how the components and processes are connected. It is a statement about system form and function."

More from Monitoring ecosystems in the Sierra Nevada. "The challenges of managing large areas for multiple objectives can only be met with efficient and informative monitoring strategies. However, monitoring can not be conducted without a framework for understanding the relationships between the components and processes of an ecosystem, and the human activities that affect them. We created a conceptual model to serve as such a framework to monitor the integrity of ecosystems in the Sierra Nevada mountains of California. The conceptual model was necessary to allow our multidisciplinary scientific team to share a common view of the dynamics of ecosystems and to build an objective, structured, and hierarchical process to select specific biological, physical, and cultural attributes to monitor. The model, which we refer to as the EPC Model, is centered on ecosystem processes, considers humans as part of the ecosystem, and has direct application to monitoring."

"We built a conceptual model to serve as the ecological foundation of a monitoring strategy. The conceptual model serves as a foundation by providing: (1) all members of the multidisciplinary scientific team with a common view of the dynamics of all aspects of the ecosystem across scales; and (2) an objective, structured, and hierarchical framework by which we can select specific attributes (indicators) to monitor."

See also the 1999 report for the Sierra Nevada program, especially chapter 3 on Key Processes and their Prospectuses.

Some **Examples of Conceptual Model diagrams** are shown for estuarine and aquatic/riparian ecosystems, old growth forest, Northern Spotted Owls, and Marbled Murrelet programs.

Examples of conceptual models developed by Prototype Monitoring Parks and other parks:

- Prairie Cluster Conceptual Framework.
- Cape Cod National Seashore Conceptual Model.
- Desert Manager's Group Conceptual Modelling Presentation (from Kris Heister).
- Denali NPP Conceptual Model.

Other examples of the use of conceptual models as part of designing a monitoring program:

- Bighorn Canyon NRA Conceptual Model development . (working draft 03/20/2002)
- Comprehensive Everglades Restoration Plan.
- Conceptual model for Biscayne Bay.
- The Nature Conservancy: Ecological Models for various systems.
- Conceptual Model for Corpus Christi Bay Estuary.

Paul Geissler of USGS-BRD has developed a web page describing development of conceptual models for park Inventory and Monitoring Paul Geissler's Site on Conceptual Models.

Download Chpt. 3 of Margoluis and Salafsky 1998 **(7.18 MB)**

Two chapters from textbooks that describe the basics of how to develop conceptual models can be downloaded here.

Download Jorgensen 1988 Chpt. 4 on Conceptual modeling from Jorgensen, S. E. 1988. Fundamentals of ecological modelling. Developments in Environmental Modeling 9. Elsevier Publishers. Call No. QH

541.15.S5J67 **(5.48 MB)** concmodel1.ppt

Download Grant et al. 1997. Conceptual model formulation. Chpt. 3 in Ecology and Natural Resource Management, systems analysis and simulation. Call No. QH 541.15.S5G73 **(3.24 MB)** concmodel2.ppt

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Selecting Indicators - What Should be Monitored?

The selection of a set of vital signs or indicators that best meet the goals and objectives for monitoring is one of the most difficult steps in designing a long-term monitoring program. It is impossible, and unnecessary, to sample all natural resources and ecosystem processes in a park, so how does one select indicators from the long list of candidates?

The largest, most expensive, and probably most scrutinized environmental monitoring program to date has been the EPA's EMAP (Environmental Monitoring and Assessment Program). The goal of EMAP is very similar to that of national park monitoring: "To monitor the condition of the Nation's ecological resources to evaluate the cumulative success of current policies and programs and to identify emerging problems before they become widespread or irreversible." The EPA, U.S. Forest Service, and other agencies have spent many millions of dollars developing and testing various indicators for monitoring ecosystems, and still there is little consensus on which indicators are best or how best to quantify them.

Noon et al. (1999) clarified some of the terminology used in environmental monitoring as he described what an indicator is: "An attribute is simply some aspect of the environment which is measurable. When an attribute is measured it takes on a (usually) numeric value. Since the exact value of an attribute is seldom known with certainty, and may change through time, it is properly considered a variable. If the value of this attribute is indicative of environmental conditions that extend beyond its own measurement, it can be considered an indicator. Not all indicators are equally informative -- one of the key challenges to a monitoring program is to select for measurement those attributes whose values (or trends) best reflect the status and dynamics of the larger system."

In their review of EPA's EMAP program, the National Research Council (NRC 1995) discussed the relative merits of retrospective monitoring, EMAP's basic monitoring approach, versus predictive or stressor-oriented monitoring. Retrospective, or effects-oriented monitoring, seeks to find effects by detecting changes in the status or condition of some organism, population, or community. This includes most of the monitoring in national parks, such as measuring changes in foliage condition of trees, size or trends in animal populations, or diversity of aquatic macroinvertebrates in streams, and it takes advantage of the fact that biological indicators integrate conditions over time. In contrast, predictive, or stressor-oriented monitoring seeks to detect the cause of an undesirable effect (a stressor) before the effect occurs or becomes serious. Stressor-oriented monitoring will increase the probability of detecting meaningful ecological changes, but it is necessary to know the cause-effect relationship so that if the cause can be detected early, the effect can be predicted before it occurs. Examples of predictive monitoring include monitoring animal tissues for presence of carcinogens, and using a canary to monitor toxic gas levels in a mine. Predictive monitoring is not commonly used in national parks because our knowledge of ecosystem processes is still poor and cause-effect relationships have often not been established. The NRC concluded that in cases where the cost of failing to detect an effect early is high, use of predictive monitoring and modeling is preferred over retrospective monitoring. They concluded that traditional retrospective monitoring was inappropriate for environmental threats such as acid precipitation, exotic species effects, ozone depletion, and biological extinctions, because of the large time lag required for mitigation, and recommended that EPA investigate new indicators for monitoring these threats.

The initial list of environmental vital signs selected for monitoring is expected to vary among networks depending on the monitoring goals and objectives and the priorities among parks in each network. The potential list of vital signs can be placed in three categories: (1) those vital signs or indicators that are required to be included in the monitoring program for legal reasons (e.g., T&E species or items included in a park's enabling legislation); (2) those that are required for Performance Management reporting purposes or because funding was provided for a specific purpose (e.g., impaired waters monitoring); and (3) those selected by networks from a list of recommended vital signs or identified as a priority by the network. Each park can identify its own top-priority monitoring needs, and it is not necessary for all parks in a network to monitor the same vital signs. Staff from the NRPC divisions of Air Resources, Biological Resource Management, Geological Resources, Natural Resource Information, and Water Resources are developing a "Handbook for Monitoring Vital Signs in National Parks" and various guidelines, reference materials, and information management tools to assist networks in the development of their monitoring programs. NRPC staff will also provide technical support to networks throughout the planning process, and Regional I&M coordinators from each region will be available to share information and assist networks in other regions as they develop their monitoring programs. Project funding at Cooperative Park Ecosystem Studies Units can also support technical assistance with monitoring protocols and implementation.

Many different criteria have been recommended for selecting indicators to monitor park resources, and these are mentioned in the documents listed above and in the article 'Challenges in the development and use of ecological indicators'. The EPA's Indicator Evaluation Guidelines may be useful as a guide for evaluating alternative indicators for monitoring. These guidelines were published in the August 2001 issue of the journal Ecological Indicators. The Ecological Monitoring and Assessment Network (EMAN) in Canada has put considerable effort into developing a suite of core variables that will be used to monitor the condition of natural resources across Canada and provide early warning of ecosystem change. Download the document describing the Selection of Core Variables for Providing Early Warning of Ecosystem Change in Canada, which includes the criteria they used to evaluate potential indicators.

Another good set of indicator-selection criteria came out of an April 1998 workshop for Lake Mead National Recreation Area:

Desirable characteristics of indicators:

- have dynamics that parallel those of the ecosystem or component of interest
- are sensitive enough to provide an early warning of change
- have low natural variability
- provide continuous assessment over a wide range of stress
- have dynamics that are easily attributed to either natural cycles or anthropogenic stressors
- are distributed over a wide geographical area and/or are very numerous
- are harvested, endemic, alien, species of special interest, or have protected status
- can be accurately and precisely estimated
- have costs of measurement that are not prohibitive
- have monitoring results that can be interpreted and explained
- are low impact to measure
- have measurable results that are repeatable with different personnel

Sampling Design Considerations; Where and When to Sample

The NPS recognizes the importance of collecting data in a scientifically credible manner so that they can be used to address current and future management issues. All parks and their contractors and cooperators should use certain "good sampling practices" so that data meet the purpose for which they were collected and withstand scrutiny by critics. Sample sizes will almost always be limited by shortages of funding and personnel, and it is critical to be able to make inferences to larger areas from data collected at relatively few sampling locations.

In February 2000, a panel of statisticians developed guidance for designing a sampling framework for monitoring natural resources in parks. Recommendations of this panel are presented in the following two documents:

Download Guidance for the Design of Sampling Schemes for Inventory and Monitoring in National Parks
Download Examples of Park Sampling Designs
Download "Examples Illustrating the Design and Analysis of Monitoring Surveys in National Parks" by Dr. Paul Geissler

See also the Summary of a Statistical Workshop at Olympic NP

A summary of key elements of the recommendations for designing a sampling scheme are as follows:

1. Some sort of probability sample should always be taken to avoid bias. Conceptually, the target population (usually the entire park) is divided into sampling units such that every point in the park is included in a sampling unit, but not in more than one. The sampling design is used to select a probabilistic sample of the sampling units. As a result, statistical estimates of population attributes can be produced with an estimate of their reliability. Probability samples occur when each unit in the target population has a known, non-zero probability of being included in the sample, and always include a random component (such as a systematic sample with a random start). The credibility of data that are not collected using these principles is easily undermined.
2. Statistical, design based inferences can only be made to areas that have a chance of being included in the sample. If study plots are chosen to be close to roads, design-based inferences can only be made to areas near roads. Since the NPS's mission is to protect resources in the entire park, sampling should be designed so that robust inferences can be made to the entire park and not some easily accessible portion of it. Model based inferences and professional judgement can be used to infer values in portions of a park that had no probability of being included in the sample. However, accuracy of model based inferences and professional judgement is only as good as the model and the decision making process of the individual providing the professional judgement, and models and judgement-based information can often be easily discredited by critics. Areas of the park that are too inaccessible or unsafe to sample can be simply excluded from the program, but then no inference can be made about resources in these areas.
3. Judgement sampling, using "representative" sites selected by experts, should be avoided. If there is no controversy, judgement sampling sounds good at the beginning, but "representative" sites may come back to haunt you in the future because they are easily discredited by critics and may produce biased, unreliable information.
4. Panel members supported a general framework of first spreading samples out over the entire park or target population, and then increasing the sampling intensity in areas of special interest. Simple random sampling is not recommended because you may select a sample that is not spatially balanced, and because we are often interested in species or other park resources that occur in limited areas and we want to make sure we include adequate samples in those areas. Samples can be spread out over the area of interest by using some sort of grid or cell design or a tesselation procedure. Within this overall design, areas of special interest such as rare habitats can be sampled with higher frequencies using either stratification or the more general approach of defining the

cells corresponding to the areas of interest and varying their selection probabilities (the unequal selection probability approach). In either case, the areas are then sampled disproportionate to their availability so that adequate samples are taken from each. This unequal sampling probability approach accomplishes most of the advantages of stratification, but avoids some of the problems of stratification that are mentioned below. An overall framework based on this design that allows for including site-specific studies and legacy data is presented below.

5. A design based on stratification of the park by "habitats" derived from vegetation maps is not recommended because stratum boundaries will change over time, and unless you fix the stratum boundaries forever there will be problems in the future with data analysis and incorporating new information into the design. A vegetation map is a model based on remote sensing data and data collected on the ground at a series of plots; the map boundaries will change as the classification models change 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.
6. 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.
7. 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.
8. An important step in developing a sampling design for a park is determining the sample size needed to significantly reduce the uncertainty of guessing about the status or trend of a resource and consequently reduce the costs of stewardship. Taking too few samples may increase the costs of stewardship and put resources at risk because important changes are missed or detected too late for management to be effective, whereas taking too many samples will waste time and resources. The sample size that is needed to meet a sampling objective is largely a function of the effect size, which is the amount of change in the resource from one point in time to the next that the manager seeks to detect, and the variability of the resource across space and time. For a statistician to be able to estimate the sample size needed for a particular program, the park manager needs to be able to specify how much change they need to be able to detect, and with what certainty, to affect their management strategies and practices or to confront and mitigate threats to the park in legal and political arenas. For planning purposes, sample size calculations in most statistical texts can be used to obtain a rough idea of the magnitude of the sample needed to produce a confidence interval of a specified width for a particular variable. If a statistical comparison is to be made between two samples, a "rule of thumb" minimum sample size is 6 measurements in each sample. It is useful to think about sampling over space when allocating samples.
9. Be sensitive to spatial integrity of the sample! These data will be used for many purposes, and an initial view of the sample on a map will help to clarify the use and limitations of the sample. When a sample is allocated, it is probably a good idea to display the sample on a GIS to ensure that adequate coverage occurs for areas of interest.
10. When repeated measurements of the same site are made to determine trend, remember that the precision will increase as the number of years of sampling increases. [The sample size of comparisons is usually the number of plots, which will not increase. However, the precision will increase because the means for each plot become less variable (var=s2/n.)]. There may be considerable intra-year variability in a measure because of small sample sizes, sampling errors and spatial variation, all of which increase needed sample sizes, and yet you may still be able to identify a trend as you increase the number of years of data.
11. When designing a monitoring program, remember that it is not necessary to visit all of the selected sites every year. Sampling designs exist that allow for increased spatial coverage though "rotating panel" designs, where each site is sampled every five years, for example, but five times as many sites can be sampled because only 1/5 of them are visited each year. Data from a complex

rotating panel design with multiple strata can be difficult, so data analysis needs to be considered when the design is put together.

12. Collocation of samples is recommended to allow comparisons among components. For example, in the same stream segments you might sample water quality, aquatic macroinvertebrates, amphibians, and fish. Another example would be to monitor changes in vegetation, birds, mammals, and certain invertebrates at sites that are close to each other.

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Protocols Used in National Parks and by Other Agencies; How to Sample

Any successful long-term monitoring program must survive turnovers in personnel (as people change jobs or retire) and technology. In almost all cases measurements over time will be taken by different people. Several important conclusions follow from these facts: (1) sampling protocols must be fully documented, with great enough detail that different people can take measurements in exactly the same way; (2) protocols must include quality control/quality assurance measures, so that it can be demonstrated that any changes in measurements are actually occurring in nature, and not simply a result of measurements being taken by different people or in slightly different ways; and (3) protocols should not rely on the latest instrumentation or technology that may change in a few years, such that measurements cannot be repeated.

Recommendations for what should be included in a monitoring protocol, and a recommended protocol format, can be downloaded here: Characteristics of a Good Monitoring Protocol.

Protocol development requires a research effort. Sampling protocols must be field tested, and experiments must be conducted to determine when and how often a site should be sampled. It has been estimated that the federal government spends $640 million per year to monitor the environment. The EPA, USDA Forest Service, and Natural Resource Conservation Service alone have spent tens of millions of dollars developing and testing sampling protocols. The National Park Service, whenever possible, should take advantage of these efforts by other agencies by using well-tested, standardized sampling protocols developed by other agencies if they meet park objectives. If other agencies are using well-established protocols to sample certain components outside of the park boundaries, it not only makes fiscal and political sense to use them (or at least adapt them to specific park needs), but also allows the park to put it's monitoring data in context by making comparisons with areas outside the park. Many biological data sets require 10 years or more of data before trends can be clearly established. Use of standardized protocols that are in use by others outside the park adds a spatial dimension to the monitoring program that may allow the park to see problems much earlier, and therefore to act much sooner than if only the temporal component is available.

Information on various sampling protocols being used or developed by the prototype monitoring parks is provided below. I also include information on indicators and protocols included in the USDA Forest Inventory and Analysis (FIA) Program, and particularly methods used in the Phase 3 subset of plots that were formerly known as the Forest Health Monitoring Program. The FIA and FHM programs have developed protocols to sample understory diversity, exotic plant species, down woody debris, and fuel loading that may be particularly interesting to parks. See the following Overview of Forest Monitoring Protocols, with information on how to get further information.

For Water Quality sampling, the Water Resources Division of NPS is developing guidance for designing and conducting water quality monitoring that is compatible with efforts outside of national parks. The latest water quality sampling guidance can be found in the "Handbook for Monitoring Vital Signs in National Parks".

The Resources Inventory Branch of the British Columbia Ministry of Environment, Lands and Parks has developed inventory and monitoring methods for birds, mammals, and herptiles, as well as general guidance for sampling vertebrate populations. Most of their Species Inventory Manuals can be viewed or downloaded from their website. Each manual presents standard methods for inventory at three levels of inventory intensity: presence/not detected, relative abundance, and absolute abundance for groups of species with similar inventory requirements. The manual "Species Inventory Fundamentals" includes a discussion of sampling design, sampling techniques, and statistical analyses. A good sampling protocol for terrestrial vegetation was developed in Canada as one of a number of good sampling protocols recommended by the Ecological Monitoring and Assessment Network.

EPA's EMAP - Surface Waters group has funded development of a set of standardized protocols for sampling various components of lakes, including water quality parameters, fish, benthic invertebrates, and birds. Protocols are described in the 1997 report "Environmental Monitoring and Assessment Program Surface Waters: Field Operations Manual for Lakes", EPA/620/R-97/001. Protocols can be downloaded in .pdf format from their EPA Website. Links to other sites concerning aquatic macroinvertebrates and other aquatic monitoring are found at EPA's Biological Monitoring Resources site.

Widely-used protocols for monitoring stream fish, benthic invertebrates, and stream habitat as part of the USGS NAWQA program (National Water-Quality Assessment) are found at NAWQA Website.

Coral Reef Monitoring protocols and assessment methods can be viewed at NOAA's Coral Health and Monitoring Program website.

Protocols being used or developed in the prototype monitoring parks, or that are widely used by other agencies, are described in the following **Protocol Database**.

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QUALITY ASSURANCE/QUALITY CONTROL

Every park monitoring effort should include and document Quality Assurance and Quality Control (QA/QC) measures into their program. Quality Assurance (QA) ensures that data meet defined standards of quality with a stated level of confidence. This is necessary for the program to be credible, so that data stand up to external review. Quality Assurance refers to the overall management system which includes the organization, planning, data collection, documentation, metadata, evaluation, and reporting activities of the program. QA provides the information needed to ascertain the quality of the data and whether it meets program requirements. Quality Control (QC) refers to the technical procedures involved in controlling errors, such as personnel training, calibration of equipment, replicate water samples, repeated measuring to determine differences among observers and the repeatability of measurements by the same person, and exercises to identify the level of error during data recording and data entry.

The EPA requires that QA/QC be included and documented in all of its projects. The agency is often taken to court, and learned that QA/QC was needed for data sets to stand up to scrutiny and to demonstrate that environmental changes were real and not an artifact of sampling and recording errors. The USDA Forest Service was required to include QA/QC in it's Forest Health Monitoring program because it was initially funded by the EPA as the forest component of EMAP. However, when the EPA stopped funding the program in 1995, the Forest Service continued the QA/QC component because they had found that it was well worth the cost to be able to document the quality of the data. An overview and recommendations for Quality Assurance in National Parks is presented in Peterson et al. 1995, which can be viewed or downloaded above. QA/QC measures are also available in Appendix C of the Channel Islands National Park Data Management Plan.

The participation of subject experts in the planning and design of a long-term monitoring program and the sampling protocols used, and periodic review of the program by experts from both within and outside of the program, are critical components of a successful program.

DATA MANAGEMENT AND REPORTING

Sound data management practices are the key to having a credible monitoring program that provides useful data to managers. The experience of the prototype monitoring parks is that at least 30% of total funding for a monitoring program should be used for data management and reporting. Only by maintaining consistency in the collection, analysis, and management of long-term datasets can we accurately detect trends in ecosystem conditions. The major objectives of data management are to ensure that data are stored and transferred accurately, secured from loss or damage, and made available to decisionmakers in a timely and understandable manner. Data Management Guidelines are currently being developed for the NPS, but while they are being developed, the draft Data Management Guidelines may be helpful to NPS units as they develop comprehensive data management programs. An example of a data management plan for the Prairie Cluster prototype LTEM Program can be downloaded here. Parks that are developing a relational database in MS Access for their natural resource information may find this document on Converting legacy data to a relational database helpful.

Information Management Tools

A priority of the inventory and monitoring effort is to make information more useable for management, research, and education and integrating natural resource information with park operations such as interpretation and maintenance. The following information management tools are being developed to assist parks and networks in making information more readily available to managers, scientists and the public:

Synthesis is an information management system for efficiently locating, organizing, integrating, and disseminating data and information. Synthesis presents the user with a simple, graphical user interface that functions as a gateway to information that may be stored on local computers, networks, intranets, or the Internet. From this single gateway, a user may view and integrate many types of information including text-based documents, photographic libraries, databases, spreadsheets, presentation graphics, geographic information system (GIS) data, bibliographies, Internet-based information, and decision support systems. All of the databases listed below, including the NPBib, NPSpecies, Dataset Catalog, GIS Theme Manager, and the Natural Resource Database Template, will operate as stand-alone applications or can be accessed through Synthesis.

The **GIS Theme Manager** is a GIS application in Arcview that makes natural resource information more available and useful to managers, interpreters, resource specialists, maintenance personnel, and others. The Theme Manager can be used as a standalone application, or can be launched from within Synthesis. It can also be used in conjunction with the NR database template as a means of organizing and displaying integrated natural resource information. The Theme Manager has the full functionality and spatial data analysis capabilities of ArcView for those who routinely use GIS, but can also be used by someone with only a few hours of training to display integrated natural resource information for planning, park operations, and decision-making. The Arcview extension and documentation for this tool can be downloaded from the GIS Theme Manager Website.

The **Natural Resource Database Template** is a flexible, relational database in MS Access for storing inventory and vital signs monitoring data (including raw data collected during field studies). This relational Access database can be used as a standalone database or in conjunction with the GIS Theme Manager to enter, store, retrieve, and otherwise manage natural resource information. The template has a core database structure that can be modified and built upon by different parks and networks depending on the components of their inventory and monitoring program and the specific sampling protocols they use. Additional information can be obtained from the Database Template Website.

The **Dataset Catalog** is a tool for keeping an inventory and providing abbreviated metadata or "Metadata light" about a variety of natural resource data sets, from physical files and photographs to digital scientific and spatial data. The one-page input and report forms provide a straightforward way to document all types of resource data that may or may not have met formal metadata standards. As with other NRPC applications, the master version of the Dataset Catalog will be available through a website and will be linked to NPSpecies (the NPSpecies database) and the NatureBib bibliography, and it will also be possible to download a version in MS Access from the website.

NatureBib is the master database for natural resource bibliographic references that merges a number of previously separate databases such as NRBib, GeoBib, and others. As with NPSpecies, it will be possible to download data from the master web-based version into an MS Access version that can be used locally on computers without an internet connection. The data structure of NatureBib makes it possible to import/export records with ProCite software. The web-based version of NatureBib is linked to other databases such as NPSpecies and the NPS Online Permitting system.

Reporting the Results of Monitoring Activities

Monitoring data must be analyzed, interpreted, and provided to managers and other decision-makers and interested parties in a useable form at regular intervals if a monitoring program is to be successful. Different types of reports are needed to provide information to multiple audiences. Examples of the Types of Reports, Purpose, and Intended Audience are listed here.

Metadata

Metadata are "data about data": information that describes the content, quality, and other characteristics of a dataset, such as the temporal and spatial scale, location where data were collected, methods used to collect the data, name of people involved in the data collection and when it was collected, etc. Metadata should be complete enough that someone can learn enough about a dataset to determine whether it is of interest to them or will meet their data requirements.

For geospatial data, a standard metadata set is required for all products produced with federal funds as a result of an Executive Order. The Federal Geographic Data Committee is responsible for developing this Content Standard for Digital Geospatial Metadata. These standards are now being adapted to specify metadata content for the full range of biological resources data and information, including data resulting from laboratory- and field-based research, field notes, and specimen collections. Software such as METAMAKER is available to create FGDC-compliant metadata. Information is available on Documenting Geospatial and Biological Data with Metamaker and proposed standards for Biological Data Profiles.

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LITERATURE CITED AND SELECTED PUBLICATIONS AND REPORTS

View the Extended Bibliography of Selected Monitoring References

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Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and management of animal populations. Academic Press: New York.

Other Links and Documents:

Vital Signs Monitoring meeting, Phoenix, AZ August 21-23, 2001

Vital Signs Monitoring meeting, Denver, CO August 13-16, 2002

NPS Data Management Meeting, Las Vegas, NV March 11-15, 2002

Workshop to develop framework for Inventory and Monitoring of Invasive Plants, Fort Collins, CO June 4-6, 2002

List of vital signs coordinators

Inventory and Monitoring Websites You Should Know About
Geologic Resource Monitoring in National Parks
Recommendations for Inventorying and Monitoring Birds in National Parks
Download Guidelines for Biological Inventories
Download Overview of Biological Inventories effort
Download Guidance for the Design of Sampling Schemes for Inventory and Monitoring in National Parks
Download Examples of Park Sampling Designs
Download "Examples Illustrating the Design and Analysis of Monitoring Surveys in National Parks" by Dr. Paul Geissler
How to Plan for and Hold a Vital Signs Scoping Workshop - The Lake Mead NRA example
Download the Dataset Catalog software for inventorying existing data
Download Gibbs et al. 1999 Gibbs, J. P., H. L. Snell and C. E. Causton. 1999. Effective monitoring for adaptive wildlife management: lessons from the Galapagos Islands. J. Wildl. Manage. 63:1055-1065.
Download Johnson 1999 Johnson, D. H. 1999. The insignificance of statistical significance testing. J. Wildl. Manage. 63:763-772.
Download Dale and Beyeler 2001 Dale, V. H. and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1:3-10.
Download Kurtz et al. 2001 Kurtz, J. C., L. E. Jackson and W. S. Fisher. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators 1:49-60.

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Monitoring Intranet

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Steve Fancy's CV

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