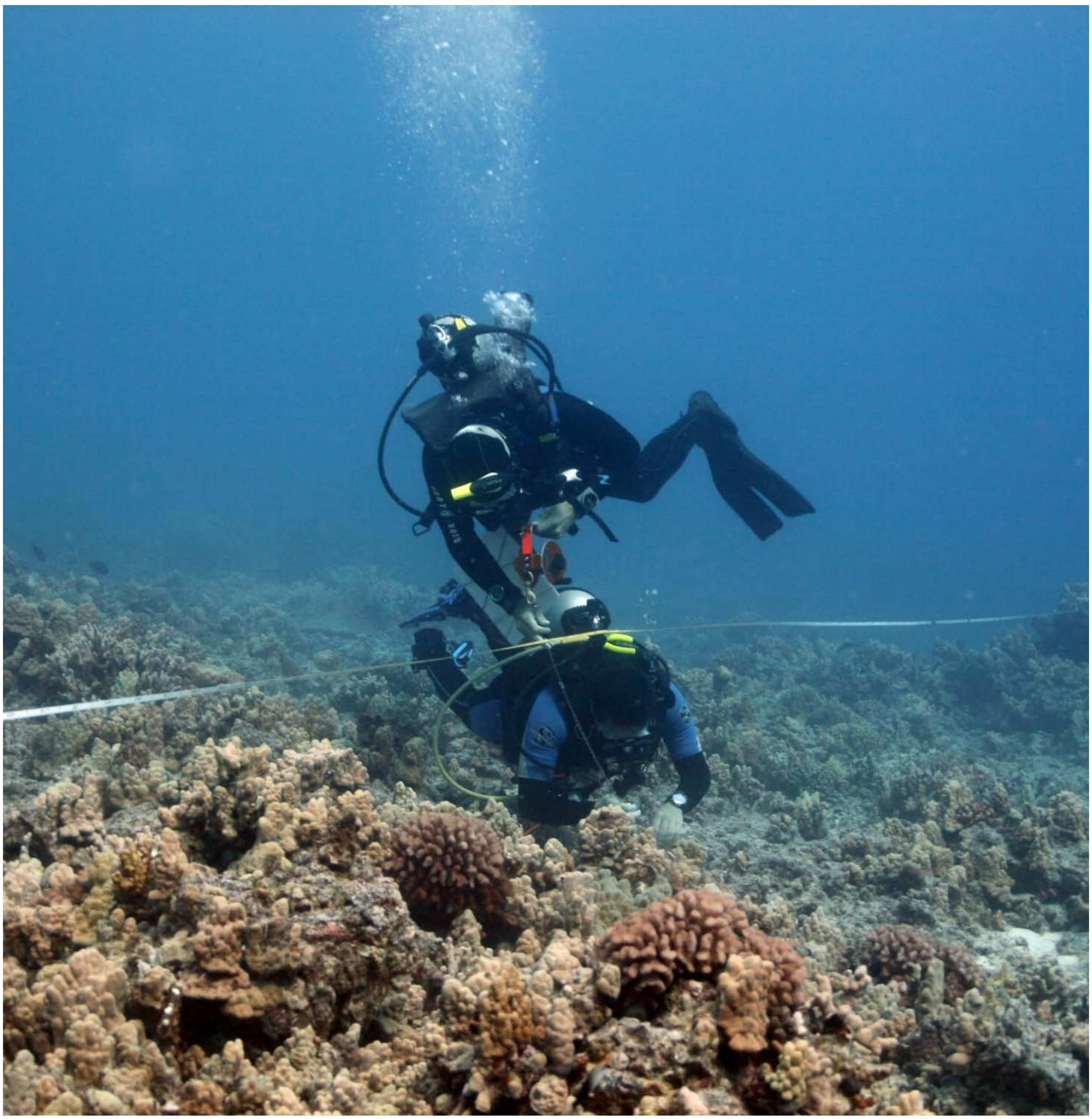
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Guidance for Designing an Integrated Monitoring Program

Natural Resource Report NPS/NRSS/NRR—2012/545



ON THE COVER
NPS ecologists Tahzay Jones and Eric Brown measuring coral reef rugosity at Kaloko-Honokohau National Historical Park on the island of Hawaii as part of the benthic marine monitoring protocol for the Pacific Island I&M Network. NPS photo.

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National Park Service

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Abstract

This document is a compilation of guidance that was developed by the National Park Service (NPS) Inventory and Monitoring (I&M) Program and was made available through NPS websites during the period of 1999 to 2012 to the 32 I&M networks, their partners, and to other agencies and organizations. The guidance summarized here has been the basis for planning, designing, and implementing what has become a very successful long-term ecological monitoring program for more than 300 units of the National Park System.

The guidance and examples that were previously presented on a series of I&M websites was consolidated into this document in 2012 once monitoring had been implemented in all 32 I&M networks, and as the I&M websites were being revised and simplified.

One of the five goals of the I&M Program is to “Share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.” It is hoped that the information and examples available in this document are helpful to others.

Introduction

Natural resource monitoring is a major component of park stewardship, and a cornerstone of the NPS Natural Resource Challenge--a program to revitalize and expand the natural resource program within the Park Service and improve park management through greater reliance on scientific knowledge. The overall purpose for natural resource monitoring is to determine the status and trend in the condition of selected park resources. Monitoring results will be used to assess the efficacy of management and restoration efforts, provide early warning of impending threats, and provide a basis for understanding and identifying meaningful change in natural systems characterized by complexity, variability, and surprises. Monitoring data may help to determine what constitutes impairment and to identify the need to initiate or change management practices.

The intent of park vital signs monitoring is to track 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 elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. In situations where natural areas have been so highly altered that physical and biological processes no longer operate (e.g., control of fires and floods in developed areas), information obtained through monitoring can help managers understand how to develop the most effective approach to restoration or, in cases where restoration is impossible, ecologically sound management. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

Justification for Integrated Natural Resource Monitoring

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to manage park resources "unimpaired for the enjoyment of future generations." National Park managers across the country 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 benefit of park resources.

For years, managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas to assess the efficacy of management practices and restoration efforts and to provide early warning of impending threats. The challenge of protecting and managing a park's natural resources requires a multi-agency, ecosystem approach because most parks are open systems, with threats such as air and water pollution, or invasive species, originating outside of the park's boundaries. An ecosystem approach is further needed because no single spatial or temporal scale is appropriate for all system components and processes; the appropriate scale for understanding and effectively managing a resource might be at the population, species, community, or landscape level, and in some cases may require a regional, national or international effort to understand and manage the resource. National parks are part of larger ecosystems and must be managed in that context.

Natural resource monitoring provides site-specific information needed to understand and identify change in complex, variable, and imperfectly understood natural systems and to determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Thus, monitoring provides a basis for understanding and identifying meaningful change in natural systems characterized by complexity, variability, and surprises. Monitoring data help to define the normal limits of natural variation in park resources and provide a basis for understanding observed changes; monitoring results may also be used to determine what constitutes impairment and to identify the need to initiate or change management practices. 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).

An effective long-term ecosystem monitoring program will:

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

Goals and Objectives

Establishing Monitoring Goals and Objectives

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. 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.

One of the most critical steps in designing a monitoring program or protocol is to clearly define the goals and objectives of the monitoring effort and to develop a consensus among key stakeholders before much time is invested in the details of the monitoring design. The development of a good set of monitoring objectives is especially important for monitoring protocols, which are detailed study plans that describe how data are to be collected, managed, analyzed, and reported. The set of monitoring objectives for a protocol should specify what the protocol will do, and the objectives should meet the test of being realistic, specific, and measurable.

The need to clearly articulate the goals and objectives of a monitoring program is emphasized in just about every "how to" guide that has ever been written about natural resource monitoring, and yet good examples of specific, measurable objectives are hard to find.

Five Goals of Vital Signs Monitoring

A goal is a concise, general statement of the overall purpose of a program. All 32 networks of parks address the following five Goals of Vital Signs Monitoring as they plan, design, and implement integrated natural resource monitoring:

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.

Monitoring Objectives

An objective is a more specific statement that provides additional focus about the purpose or desired outcome of the program. Three types of objectives that are commonly presented in the ecological monitoring literature are Management Objectives, Sampling Objectives, and Monitoring Objectives. For purposes of vital signs monitoring plans (Phase 1, 2 and 3), we are primarily concerned with Monitoring Objectives. An effective set of monitoring objectives should meet the test of being realistic, specific, and measurable.

Management objectives provide focus about the desired state or condition of the resource, and provide a measure of management success. 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). Some examples of management objectives are as follows:

- 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.

Sampling objectives are usually written as companion objectives to management or monitoring objectives. Sampling (or statistical) objectives specify information such as target levels of precision, power, acceptable Type I and II error rates, and magnitude of change you are hoping to detect. An example of a sampling objective is as follows:

- We want to be 90% certain of detecting a 40% change in bird density and we are willing to accept a 10% chance of saying a change took place when it really didn't.

Monitoring objectives provide additional detail about what the monitoring program or sampling protocol will do. In the introductory chapter of the monitoring plan, monitoring objectives should be written as more general statements to provide some additional focus to the program beyond the five monitoring goals. For purposes of a sampling protocol, however, we are looking for a set of specific, measurable objectives that meet the test of being realistic, specific, and measurable. After reading only a brief justification statement and the set of monitoring objectives, the reader should be able to anticipate what the resulting data set will look like, and should have a good sense of what measures will be included or not included. The monitoring objectives explain 'what the protocol will do', and they often put boundaries or limits on what will be included in the monitoring by specifying particular study areas, species, or measures. The following checklist of questions should be applied to the set of monitoring objectives to see if they meet the test:

- Are each of the objectives measureable?
- Are they achievable?
- Is the location or spatial bounds of the monitoring specified?
- Is the species or attribute being monitored specified?
- Will the reader be able to anticipate what the data will look like?

An effective set of monitoring objectives should meet the test of being realistic, specific, and measurable.

Examples of Monitoring Objectives

Table 1 below provides a number of examples of specific, measurable monitoring objectives for sampling protocols. If only one or two species or locations is to be monitored, the objective statement should include the names of those species or locations to make it "specific"; however, if numerous species or locations will be monitored, it is acceptable to use terms such as "for selected species" or "in selected sites" in order to make it easier to read and understand the objective statement. The protocol document itself, however, should include a list or table specifying all of the species or locations to be sampled.

Table 1. Examples of specific, measurable monitoring objectives.

Vital Sign or Protocol	Specific, Measurable Objectives
Weather/climate	▪ Determine variability and long-term trends in climate for all PACN parks through monthly and annual summaries of descriptive statistics for selected weather parameters, including air temperature, precipitation, cloud cover, and wind speed and direction. ▪ Identify and determine frequencies and patterns of extreme climatic conditions for common weather parameters.
Erosion and deposition	▪ Determine long-term trends in soil erosion rates and soil quality (e.g., organic matter, pH, infiltration, bulk density, aggregate stability, root exposure, soil crusts, etc.) at randomly selected sites in WAPA, AMME, and ALKA. ▪ Determine seasonal and long-term trends in water column turbidity at selected marine and freshwater sites. ▪ Determine seasonal and long-term trends in sedimentation rates at selected marine and freshwater sites stratified (or weighted) by degree of recreational access.
Groundwater dynamics	▪ Determine long-term trends in groundwater withdrawal and saltwater intrusion through measurement of groundwater levels, discharge rates, and salinity at selected sites.

Table 1. Examples of specific, measurable monitoring objectives (continued).

Vital Sign or Protocol	Specific, Measurable Objectives
Water quality	▪ Determine long-term trends in water temperature, pH, conductivity, dissolved oxygen, flow/stage/level, PAR, total nitrogen, total phosphorus, and chlorophyll a in selected freshwater and marine sites in PACN parks.
Non-native invasive terrestrial plants-early warning	▪ Develop and maintain a list of target species that do not currently occur in the parks, occur in localized areas of parks, or are extremely rare, but that would cause major ecological or economic problems if they were to become established. ▪ Develop and maintain a predictive "risk of occurrence" search model for target species based on life history attributes, dispersal modes, invasion corridors, vectors of spread, invasibility of areas and known locations. ▪ Detect incipient populations (i.e. small or localized) and new introductions of selected non-native plants before they become established in areas of high and moderate management significance in a rotating panel design searching 1/3 of the park each year.
Non-native invasive terrestrial plants-status and trends	▪ Determine the areal extent, distribution and abundance of selected non-native invasive plants in PACN parks at 5 year intervals. ▪ Determine the rate of spread of selected non-native invasive plants in all areas of high priority management significance at HALE and HAVO. ▪ Determine the stand structure of populations of selected non-native invasive plants within high priority management areas in order to predict potential spread.
Terrestrial plant species and communities	▪ Determine long-term trends in species composition and community structure (e.g., cover, density by height class of woody species) of selected focal plant communities. ▪ Determine long-term trends in the distribution and abundance of plant species of special management interest in selected areas of PACN parks. ▪ Determine annual variation in recruitment and mortality for selected populations of long-lived perennial plant species of special management interest.
Benthic marine community	▪ Determine long-term trends in percent cover of sessile marine benthic invertebrates (e.g., coral, sponges) and algal assemblages (including large fleshy, articulated and crustose coralline, and turf algae) at selected sites along an isobath between 10 and 20 meters depth. ▪ Determine trends in benthic rugosity at randomly selected, fixed (permanent) stations that have been stratified by reef zone (e.g., reef flat, reef slope). ▪ Determine trends in recruitment rate to uniform artificial surfaces of hard corals (as an assemblage) at selected sites on the fore reef along an isobath between 10 and 20 meters depth. ▪ Determine trends in rate of growth and survival of randomly selected coral colonies of a common, trans-Pacific species (e.g., Pocillopora damicornis, P. verrucosa) growing at similar depth. ▪ Determine long-term trends in the incidence and severity of coral and algal disease and bleaching.

Table 1. Examples of specific, measurable monitoring objectives (continued).

Vital Sign or Protocol	Specific, Measurable Objectives
Freshwater animal communities	▪ Determine long-term trends in the composition and diversity of fish and invertebrates in selected freshwater and brackish water communities. ▪ Determine trends in the distribution and abundance of fish and invertebrate populations in selected stream and lentic habitats. ▪ Improve understanding of relationships between freshwater and brackish water animal communities and their habitat by correlating physical and chemical habitat measures with changes in distribution and abundance of fish and invertebrates.
Marine fish	▪ Determine long-term trends in the abundance of key reef slope fish species at selected sites along an isobath of 10-20 m depth. ▪ Determine long-term trends in abundance and size of targeted coral reef fish species (e.g., species that are harvested) from selected sites within and outside of marine protected areas.
Forest passerine birds	▪ Determine long-term trends in species composition and abundance of native and non-native forest passerine species in selected areas of PACN parks. ▪ Improve our understanding of breeding bird - habitat relationships and the effects of management actions such as alien plant and animal control on bird populations by correlating changes in forest bird species composition and abundance with changes in specific habitat variables.
Seabirds	▪ Determine long-term trends in the number, distribution, and size of colonies of coastal-strand nesting Procellarid seabirds at HALE, HAVO, KALA, KAHO, and NPSA. ▪ Determine reproductive success of a sample of nests within colonies monitored in Objective #1. 3. Determine long-term trends in reproductive success and recruitment of Hawaiian Petrels at HALE and HAVO and Tahiti and Herald Petrels at NPSA. ▪ Determine trends in the number and distribution of booby roost sites in and adjacent to KALA, NPSA and WAPA.
Bats	▪ Determine long-term trends in the distribution and abundance of flying foxes in selected areas of WAPA and NPSA. ▪ Determine long-term trends in the distribution and abundance of Hawaiian Hoary Bats in selected areas of PACN parks in Hawaii.
RTE Plant Species	▪ Determine long-term trends in the distribution and abundance of selected rare, threatened, and endangered plant species within selected areas of PACN parks. ▪ Determine size-class distribution for selected RTE plant species in selected areas to help predict population trends. ▪ Determine long-term trends in the distribution, abundance, and stand structure of RTE plants in selected areas with and without management intervention (e.g., non-native invasive plant and animal control in Special Ecological Areas).

Table 1. Examples of specific, measurable monitoring objectives (continued).

Vital Sign or Protocol	Specific, Measurable Objectives
Fisheries harvest	▪ Determine annual composition, sizes, catch-per-unit-effort, and quantities (by weight, and numbers where possible) of park-specific targeted coral reef fishes and invertebrates (e.g., shellfish, octopus, lobster, sea urchins and palolo polychaetes) harvested in park waters.
Landscape Dynamics	▪ Determine annual status and trends in the areal extent and configuration of land-cover types on park lands. ▪ Determine annual status and trends in the areal extent and configuration of land-cover types on lands adjacent to parks. ▪ Determine long-term changes in fire frequency and extent. ▪ Determine long-term changes in frequency and extent of insect and disease outbreaks.
Peregrine Falcons	▪ Determine annual status and trends in territory occupancy of Peregrine Falcons. ▪ Determine annual status and trends in nest success of Peregrine Falcons. ▪ Determine annual status and trends in productivity of Peregrine Falcons.
Raptors	▪ Determine annual nesting success of breeding raptors at Pinnacles NM as measured by territories occupied, number of chick produced and number of chicks fledged.
Benthic Macroinvertebrates	▪ Determine trends in species composition, distribution, and abundance of benthic macrofauna assemblages in systems where tidal influence is being restored (Hatches Harbor, East Harbor) versus trends in systems with unaltered tidal hydrology.
Shoreline Change	▪ Determine where the directions of shoreline change (i.e. erosion or accretion) are persistent, where they are cyclic and near equilibrium, and where park resources are at risk.
Ozark Hellbender	▪ Determine long-term changes in the distribution of hellbenders in Ozark NSR. ▪ Determine long-term trends in the number of hellbenders in selected study areas in OZAR. ▪ In selected study areas in OZAR, determine long-term trends in the sex and age structure and rates of reproduction and survival of hellbenders.

Monitoring Program Planning and Design

Recommended Approach for Developing a Network Monitoring Program

The recommended approach that each network of parks should take to develop their strategy for monitoring natural resources involves seven steps:

1. Form a network Board of Directors and a Science Advisory committee.
2. Summarize existing data and understanding.
3. Prepare for and hold a scoping workshop.
4. Write a report on the workshop and have it widely reviewed.
5. Hold meetings to decide on priorities and implementation approaches.
6. Draft the monitoring strategy.
7. Have the monitoring strategy reviewed and approved.

Form a network Board of Directors and a Science Advisory Committee

- A Board of Directors composed of park superintendents or their designee, the regional I&M coordinator, and the network monitoring coordinator, should be formed to oversee the development of the monitoring strategy for the network. The committee will make decisions regarding the development and implementation of the monitoring strategy, including decisions on hiring, budgeting, and scheduling, and will promote accountability for the monitoring program. The committee should be chaired by one of the superintendents, and all members should have authority to make on-the-spot decisions on personnel, budgets, office space, and commitments of existing park personnel and funding to the monitoring effort. A charter should define the roles and functions of the different members and outline the process to be used to make decisions related to monitoring within the network. The charter must be signed before funding is released to the network. The network I&M coordinator should act as staff to the chair to help arrange meetings and logistics, produce agendas, and coordinate between the Board of Directors and the technical committee.
- A Science Advisory or technical committee comprised of natural resource managers and scientists, including scientists from outside of the NPS who work in the parks and are familiar with park issues, should be formed to provide technical assistance and advice to the Board of Directors. The Science Advisory committee should be chaired by the network monitoring coordinator and will be responsible for compiling and summarizing existing information about park resources and developing the materials needed at the scoping workshop, and will draft the workshop report and monitoring strategy for review and approval by the Board of Directors.

Summarize existing data and understanding

One of the most important steps in the process of developing a monitoring strategy is the task of identifying, summarizing, and evaluating existing information and understanding of park ecosystems. Much of this needs to be done before the scoping workshop is held.

To accomplish this task, it is anticipated that most networks will need to hire, assign or contract at least one or two full-time persons (e.g., a Monitoring Coordinator and data management specialist) and allow at least a year prior to the scoping workshop for this step to be accomplished.

This step will include a literature review, a review of the Resource Management Plan (RMP), General Management Plan (GMP), and other applicable plans for each park, and an inventory of existing datasets and other information on park ecosystems.

Superintendents and other park managers should be interviewed regarding the key management issues facing their park and the types of information they need from the monitoring program.

Current or historical monitoring of natural processes and resources in each park should be summarized, including data from monitoring of fire effects, T&E species, water quality, air quality, physical processes/changes, and other resources. Data sets and the sampling design used should be evaluated to determine whether the monitoring is meeting the needs of park managers and is providing reliable and credible data to help manage the park. Maps showing the locations where monitoring has occurred should be prepared.

Monitoring that is being conducted by neighboring agencies, partners, and related parks should be identified and summarized to help determine where comparable data sets and sampling protocols exist.

Where understanding exists regarding cause-effect relationships between environmental stressors and the park's natural resources, or where the linkages among ecosystem components are understood, draft conceptual models should be prepared to help summarize this understanding.

<u>Prepare for and hold a scoping workshop</u>

A scoping workshop should be held to obtain additional input and peer review of existing information and understanding of park ecosystems from park managers and subject experts from within and outside of the NPS. In preparation for the workshop, the monitoring coordinator and technical committee will be responsible for preparing handouts, maps, and presentations of the material summarized in Step #2.

The monitoring coordinator and technical committee should define the goals and preliminary objectives of the monitoring program prior to the scoping workshop. The goals and objectives should be approved by the Board of Directors. Additional material that should be developed prior to the scoping workshop include:

- Draft lists of important management issues for each park;
- Draft lists of important natural resources and focal species or processes for each park;
- Draft lists of known stressors that may cause changes in park resources;
- Draft conceptual models of portions of the park ecosystem;
- Draft list of measurable objectives for the monitoring program;
- Criteria for indicator selection.

Workshop participants will be asked to review the material prepared for the workshop and provide additional input and understanding, including additional development and modification of conceptual models. Participants will also be asked to identity and provide an initial prioritization of potential indicators to be monitored by the network. Include short-term, tactical monitoring as well as long-term monitoring needs. Participants will also indicate where appropriate sampling methodologies exist, and where there is a need to develop new sampling protocols for the high-priority indicators that are identified.

A three-day workshop with facilitated breakout sessions focusing on different components of the park ecosystem is recommended.

Write a report on the workshop and have it widely reviewed

The results of the scoping workshop should be widely circulated for additional input and comment. It should be sent to all interested parties, including persons that did not attend the scoping workshop. The additional input provided through the review process should be incorporated into the final version of the workshop report.

Hold one or more meetings to decide on priorities and implementation approaches

The Board of Directors, based on recommendations of the Science Advisory committee, should meet to make decisions regarding priorities for monitoring and how to implement the monitoring strategy within the network. The set of indicators that will be monitored by the network should be selected based on the preliminary list of indicators developed during the scoping and review process, and the availability of funding and personnel from the I&M program and other sources (e.g., base funding from parks, partnerships).

Decisions should be made on which sampling protocols are most appropriate for the network. Where protocols already exist, they may need to be adapted for the particular conditions within the network. In cases where no suitable protocol exists, the committee and managers should decide on an approach for developing these protocols through contracts or technical workshops.

Staffing issues should be addressed at this meeting. Each network will hire a number of professional-level monitoring specialists and technicians that will be shared by the network parks, and decisions should be made regarding the appropriate job series and grade level of these positions and where they should be stationed.

The Science Advisory committee and Board of Directors should discuss data management and reporting issues. Experience from the prototype monitoring parks indicates that at least 30% of the total resources should be allocated to data management and reporting. A data management plan needs to be developed before the final monitoring strategy is approved.

Draft the monitoring strategy

A report describing the monitoring strategy and the various tasks and decisions that contributed to the final selection of indicators to be monitored by the network should be written by the technical committee. This document describing the monitoring strategy should include the following:

- An overview of each park and its natural resources, including a summary of the park's enabling legislation, the park's natural resources in a regional or national context, and a summary of the important natural resources in each park;
- A summary of the management issues and scientific issues facing each park, including stressors or other agents of change that affect park resources;
- A summary of the understanding of the park ecosystem, including conceptual models developed during the scoping and review process;
- Descriptions of the indicators to be monitored by the network and the sampling protocols that will be used, including justification for why these were selected. The report should also list and describe the indicators that were considered but not selected for monitoring, and the reasons why they were not selected;
- The overall statistical sampling design for the network;
- The staffing plan;
- Data management plan, including how often reports will be generated and who will be responsible for ensuring that results are provided to managers in a timely manner.

Have the monitoring strategy reviewed and approved

The draft monitoring strategy document should undergo a peer review by the managers and scientists involved in its development and the network Board of Directors, and then be forwarded through the regional office to the Servicewide I&M Division for final review and acceptance before it is fully implemented.

The Three-phase Approach

The recommended sequence of steps described above are incorporated into a 3-phase planning and design process that has been established for the monitoring program.

Phase 1 of the process involves defining goals and objectives; beginning the process of identifying, evaluating and synthesizing existing data; developing draft conceptual models; and completing other background work that must be done before the initial selection of vital signs. Each network is required to document these tasks in a Phase 1 report, which is then peer reviewed and approved at the regional level before the network proceeds to the next phase. (The Phase 1 report is a first draft of the chapters of the final monitoring plan that present the Introduction/Background and Conceptual Models).

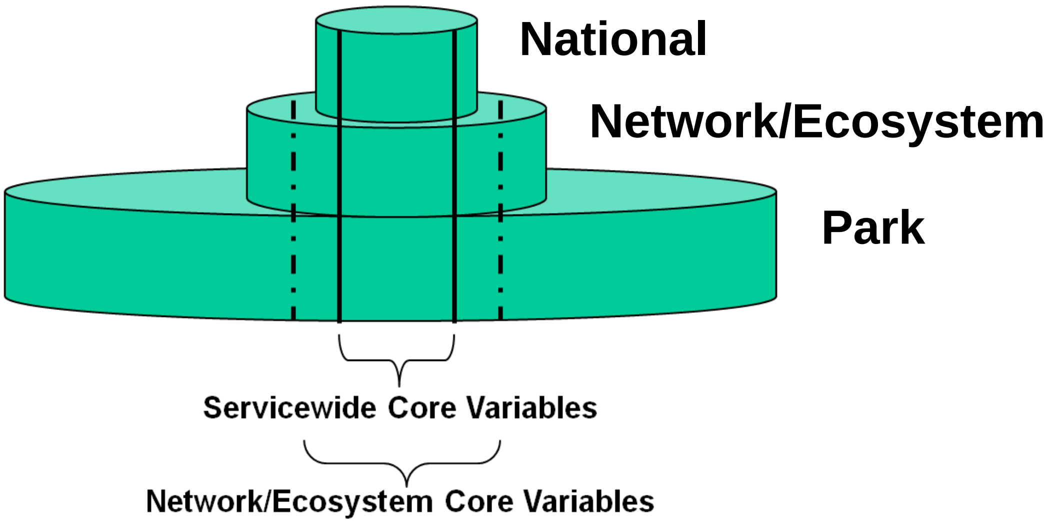
Phase 2 of the planning and design effort involves prioritizing and selecting the vital signs that will be included in the network's initial integrated monitoring program.

Phase 3 entails the detailed design work needed to implement monitoring, such as developing specific monitoring objectives for each vital sign, developing sampling protocols and a statistical sampling design, developing a plan for data management and analysis, and determining the type and content of various products of the monitoring effort such as reports and websites.

During the development of the vision for park vital signs monitoring, it was clear that a "one size fits all" approach to monitoring design would not be effective in the NPS considering the tremendous variability among parks in ecological conditions, sizes, and management capabilities. A primary purpose of vital signs monitoring is to provide park managers with the data they need to understand and manage park resources, and the data most relevant to different types of park systems should be expected to be very different. Furthermore, partnerships 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, but these partnerships (and the appropriate ecological indicators and methodologies involved) differ for parks throughout the national park system.

The amount of funding available for vital signs monitoring allows most parks to monitor only a few indicators. The NPS has adopted a strategic approach to maximize the use and relevance of the monitoring data at the park level by allowing each network of parks to determine what they will monitor based on their most critical data needs and local partnership opportunities. Parks are encouraged to use or modify standard protocols and partner with existing programs wherever possible to allow comparability and synthesis of data, and the Servicewide monitoring program will coordinate the development of standardized protocols and approaches where appropriate, but decisions on what should be monitored and the most appropriate protocols to follow are made at the network level.

The list of ecological indicators monitored throughout the National Park System is expected to follow the "wedding cake design" adopted from the USDA Forest Service and shown below, in which the majority of indicators are selected to provide site-specific data need by park managers for making decisions and working with other agencies and individuals for the benefit of park resources. Nationwide, or at the level of the park network or ecosystem, there is also a set of indicators that are monitored in a standardized way to allow comparisons and synthesis of data across larger areas.



The complicated task of developing a network monitoring program requires an initial investment in planning and design to guarantee that monitoring meets the most critical information needs of each park and produces scientifically credible results that are clearly understood and accepted by scientists, policy makers, and the public, and that are readily accessible to managers and researchers. These front-end investments also ensure that monitoring will build upon existing information and understanding of park ecosystems and make maximum use of leveraging and partnerships with other agencies and academia.

Outline for a Monitoring Plan

Each network of parks that receives funding from the Natural Resource Stewardship and Science Directorate to develop a monitoring program is required to prepare a monitoring plan describing the monitoring program and the various tasks and decisions that contributed to the final selection of indicators to be monitored. The content of the network monitoring plans is described in the Outline for a Network Monitoring Plan. Authors of the monitoring plans should also use the Checklist for Monitoring Plans to help them prepare the monitoring plan.

Vital Signs Monitoring Networks

More than 270 parks with significant natural resources have been grouped into 32 I&M networks, which have been determined based on geography and shared natural resource characteristics. The network organization facilitates collaboration among parks, information sharing, and economies of scale in natural resource inventory and monitoring. Each of the 32 networks is guided by a Board of Directors (usually composed of park superintendents, and the regional and network coordinators) which specifies desired outcomes, evaluates performance for the monitoring program, and promotes accountability. The level of funding available through the Natural Resource Challenge does not allow comprehensive monitoring in all parks, but provides a minimum infrastructure for initiating natural resource monitoring in all parks that can be built upon in the future.

Parks within each of the 32 networks work together and share funding and professional staff to plan, design, and implement an integrated long-term monitoring program. 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 is 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 agencies and academia.

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

A monitoring program requires professional-level staff who can analyze and interpret data, prepare reports, and provide the information in a useable format to park managers, scientists, and other interested parties. However, it is currently unrealistic that every park will be able to obtain funding to hire a full professional staff, including, as an example, a botanist, wildlife biologist, hydrologist, geologist, soil scientist, data manager, etc. The vision behind the vital signs monitoring program is to provide each network of parks with consistent annual funding and approximately 5 to 7 full-time staff to develop a core, long-term program. Each network leverages these core resources with existing personnel, funding from other sources, and partnerships with other agencies and organizations, to build a single, integrated monitoring program that best addresses the needs of the parks in that network.

The integrated program monitors the condition of physical and biological resources (e.g., air quality, water quality, geological resources, weather, fire effects); threatened and endangered species, exotic species, and other flora and fauna. The offices of the Natural Resource Stewardship and Science Directorate, including the divisions of Air Resources, Biological Resource Management, Geologic Resources, and Water Resources, coordinate efforts to provide funding and technical support to park networks for developing these integrated monitoring programs.

Conceptual Models

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.

The next section is condensed from more extensive guidelines for developing and preparing conceptual models.

Conceptual models are important throughout all phases of development of a monitoring program. Early in the process, simple conceptual models provide a framework that relates information in discussions and literature reviews to a broader context - it is a structure to organize information. Learning that accompanies the design, construction, and revision of the models contributes to a shared understanding of system dynamics and appreciation of the diversity of information needed to identify an appropriate suite of ecosystem indicators.

Well-designed conceptual models will:

- Formalize current understanding of system processes and dynamics
- Identify linkages of processes across disciplinary boundaries
- Identify the bounds and scope of the system of interest
- Contribute to communication:
  - Among scientists and program staff
  - Between scientists and managers
  - With the general public.

These roles are important throughout the life of a monitoring program. Once the program is underway, proper interpretation of indicators is greatly facilitated by 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, or box-and-arrow diagrams. Jorgensen (1988) discusses 10 kinds of models and evaluates their advantages and disadvantages. Most monitoring programs will use a combination of these forms, and it may occasionally be useful to combine several forms in the same figure.

Tables and matrices provide a convenient means to summarize large quantities of information, including interactions between components. However, many people find it difficult to comprehend how a system works from tabulated data, especially where the spatial context is significant.

Diagrams are usually necessary to clearly communicate linkages between systems or system components. Most monitoring programs develop a set of conceptual models that consist of diagrams and accompanying narratives. Narratives describe the diagrams, justify functional relationships in figures, and cite sources of information and data on which the models are based.

The process of constructing system diagrams almost always identifies inadequately understood or controversial model components. There isn't a single correct conceptual model, and it can be insightful to explore alternative ways to represent the system. These different representations of the system can help articulate important, and often exclusive, hypotheses about drivers, stressors, or interactions that are central to understanding how the system operates. These alternative hypotheses can form the basis of an effective adaptive management program, and it will likely be worthwhile to make the extra effort to clearly document and archive alternatives that arise during the process of model construction. Workshops to construct conceptual models are brainstorming sessions, and they provide an important opportunity to explore alternative ways to compress a complex system into a small set of variables and functions.

Most ecological systems are complex and management decisions are based on ecological, social, political, and economic considerations. To accommodate the full range of considerations, a set of models with different spatial domains and relevant subsystems will be necessary. Thus you can anticipate the need to construct different models that vary in scope, detail, spatial extent, relevant time frame, and focus. For realistic systems, it probably will not be particularly insightful or rewarding to attempt to construct a single model with all important components and interactions. An all-encompassing model will be too complex for most people to understand.

While the monitoring program does not intend to develop quantitative ecosystem models or dictate management policy, constructing a set of realistic, focused conceptual models is an important starting point for designing effective monitoring programs and for evaluating effective management policies. Monitoring programs founded on a solid conceptual model are more likely to identify key processes and indicators, and thereby contribute significantly to Parks management. The central role of models (both conceptual and quantitative) is well illustrated in the Applied Science Strategy adopted by the South Florida Ecosystem Restoration Working Group.

Creating Conceptual Models

In many cases it will be difficult to create even a single conceptual model, and the more complex the system is, the more difficult it will be to reach consensus on the elements to be included, the key interactions between elements, and the response of the system to drivers and stressors. It may require a multiple meetings to obtain general agreement on model structure and content. Keep the end in mind - you want to develop a suite of models that address the time and spatial scales of interest, at an appropriate level of detail.

Control and stressor models

Depending on the intended use of the conceptual model, two fundamentally different model structures have been used by I & M Networks and other agencies. A *control model* is a conceptualism of the actual controls, feedback, and interactions responsible for system dynamics. A control model therefore needs to represent, in a mechanistic way, the key processes, interactions, and feedbacks. Quantitative ecosystem simulation models are control models, and they vary in complexity from relatively simple to highly complex. Most groups begin by constructing a set of control models since this is the way we typically think about how systems operate. For a particular system (e.g., Park or other land) control models are typically hierarchical, with a top level, highly aggregated model and more detailed models of subsystems. In quantitative simulation models, the subsystems are usually functional units (e.g., soils, plant, fire, etc.) that overlap in space, whereas conceptual models often first decompose a larger system into more-or-less spatially distinct vegetation or habitat types. Jackson et al. (2000) describe the process of creating simple simulation models.

Stressor models are designed to articulate the relationships between stressors, ecosystem components, effects, and (sometimes) indicators. Stressor models normally do not represent feedbacks and they include only those system components that are most pertinent to the monitoring program. The intent of a stressor model is to illustrate sources of stress, ecological responses, and system attributes of most interest. These models are founded on known or hypothesized ecological relationships, frequently derived from control models, but they do not attempt a mechanistic representation of the system . The Everglades restoration program produced a comprehensive set of stressor models, and they have excellent documentation on how the models contribute to their overall management strategy (e.g., Gentile et al. 2001). The Greater Yellowstone and Northeast Coastal and Barrier Networks have developed sets of stressor models to guide their monitoring programs.

It may be necessary to develop both kinds of models, at least for some subsystems or habitats. Control models present a more complete and accurate picture of system components and their interactions. Stressor models are likely to more clearly communicate the direct linkages between stressors, ecological responses, and indicators. See the appendices to the Everglades Restoration Plan.

Steps in Constructing Conceptual Models

A systematic program that leads to a set of conceptual models will include the following tasks. These tasks are described in more detail in the documents listed below.

- Clearly state the goals of the conceptual models.
- Identify bounds of the system of interest.
- Identify key model components, subsystems, and interactions.
- Develop control models of key systems and subsystems.
- Identify natural and anthropogenic stressors
- Describe relationships of stressors, ecological factors, and responses.
- Articulate key questions or alternative approaches.
- Identify inclusive list of indicators.

- Prioritize indicators (a separate process)
- Review, revise, refine models.

These steps appear as a sequential list, but it will be necessary to at least partially address the goals of some tasks simultaneously. For example, the construction of control models (steps 3 and 4) must include substantial discussion and consideration of stressors and relationships between stressors and ecological functions (steps 5 and 6).

Execution and Network Experiences

Networks and prototypes have employed a wide variety of processes to develop conceptual models and the resulting models reflect this diversity. Here are some general observations the experience of several networks:

- It is very useful to have a general (high level) conceptual model to focus groups on linkages between submodels and to encourage model builders to conform to a common model structure.
- Hierarchical sets of models work well. At intermediate levels, submodels most commonly focus on vegetation types. The lowest-level models may focus on species, soils, or nutrients.
- It can be difficult to include animal species or animal communities in ecosystem models. Separate models may be required for a particular species or community.
- Models that address different scales are insightful, even when they focus on the same process or variables, but at different scales.
- It is very time-consuming to build useful conceptual models. Engage collaborators with appropriate disciplinary expertise as early as possible and allow time for repeated revision.
- There is a large return on investment in documenting the ecological theory that underpins a modeling approach. The underlying theory supports use of a common approach and shared vision of system processes and linkages. The Northern Colorado Plateau Network report (currently being revised) is an excellent example.
- At the lowest levels, models must include sufficient detail to link indicators to ecological processes and, where possible, to management actions. Insufficiently detailed models have limited utility. It is a substantial challenge to construct a model with just the *right* amount of detail, and to decide when to split a model into separate submodels to avoid an overly-complicated model.
- Provide definitions of key terms and phrases. Syntax is important.

Greater Yellowstone Network is using the I&M program as an opportunity to review and integrate a variety of natural resource programs. Up to July 2003, they have developed a comprehensive set of control and stressor models, and a few hybrids. The models operate on a variety of scales (e.g., they include a dry timberland model as well as a Lake Bob model).

Northern Colorado Plateau Network report has an excellent discussion of underlying ecosystem theory. They have adopted state and transition models as a structural framework for representing dynamics of many systems. In conversation, they noted that insufficient detail in early models limited their usefulness.

Mediterranean Coast Network developed an initial set of Everglades-type stressor models, but had difficulties adequately incorporating animal communities. The network is currently developing energy flow models to better represent trophic relationships.

Cape Cod Prototype implemented stressor models and tables, including excellent early work on conceptual foundation of these models (Roman and Barrett 1997).

Documents on Developing Conceptual Models for Ecological Monitoring Program

Gross, J.E. 2003. Developing conceptual models for monitoring programs. (pdf, 650 KB, DRAFT)

Gross, J.E. 2003. Developing conceptual models. Appendix IV. Figures. (pdf, 880 KB, DRAFT)

Integration and Application (IAN) Newsletters. Excellent newsletters from University of Maryland Center for Environmental Studies

Lookingbill, T., et al. 2007. Conceptual models as hypotheses in monitoring urban landscapes. (pdf, 240 KB)

Roman and Barrett 1999. Conceptual framework for the development of long-term monitoring protocols at Cape Cod National Seashore. (pdf, 900 KB)

Plumb, G. 2003. Really useful conceptual models. Paper presented at the Greater Yellowstone workshop. (pdf, 820 KB)

Haefner, J.W. 1996. Chapter 3. Qualitative model formulation. Excellent; see section 3.7 for strategies to simplify models. (pdf, 1.4 MB)

Maddox, D. et al. 1999. Evaluating management success: Using ecological models to ask the right monitoring questions. Great consideration of conceptual models in the context of monitoring. (pdf, 1.7 MB)

Grant, W.E., et al. 1997. Chapter 3 - Conceptual model formulation. (pdf, 885 KB)

Jorgensen, S.E. 1988. Conceptual models. (pdf, 1.7 MB)

Examples and Programs Using Conceptual Models

University of Maryland Center for Environmental Studies, Integration and Application Network. Comprehensive, state-of-the-art site for science communication, including use of conceptual diagrams and how to use them to reach different audiences. Developed and provide a free library to greatly facilitate production of professional-quality diagrams. http://ian.umces.edu/

Strategic Plan for the U.S. Climate Change Science Program.. This well-written document makes extensive use of very thoughtful and informative conceptual models. Many models in the report are broad-scale and they will likely be useful to illustrate drivers and impacts of climate change that are relevant to ecological monitoring programs. The IPCC reports also include many climate-specific models that can be useful to monitoring programs. http://www.climatescience.gov/Library/stratplan2003/default.htm

Wetlands, volume 25, issue 4 (December 2005) comprises a set of 14 papers on conceptual models for the

Everglades and other subtropical (mostly wetland) systems. This is a very good general reference on conceptual models.

Mark E. Miller. 2005. The structure and functioning of dryland ecosystems. Conceptual models to inform the vital-sign selection process. Link to USGS site, from which you can download the very large file. Mike L. Scott et al. 2005. The structure and functioning of riparian and aquatic ecosystems of the Colorado Plateau. Conceptual models to inform monitoring. (pdf, 3.3 MB).

Gulf of Alaska Ecosystem Monitoring (GEM) Program. Very nice treatment of conceptual models in chapters 2 & 8. Particularly good for coastal parks/networks

The Western Port Project (Victoria, Australia) This reports on a study commissioned specifically to produce conceptual models of a large marine bay. An excellent report with professional "picture" models - released October 31, 2003. http://www.coastal.crc.org.au/Publications/WesternPort.html

Healthy Waterways Conceptual Models. About 50 aesthetic models of Australian rivers, creeks, bay, and estuaries. Update February 2008: The models seem to have mostly disappeared from the site. See the Background documents for an example that remains on the site. http://www.ehmp.org/index.html

USDA NRCS state and transition models. ** see areas SD2, SD3, WP3 - only some sites have embedded models. http://www.nm.nrcs.usda.gov/technical/fotg/section-2/ESD.html

Vital Signs Prioritizing and Selection

What Should be Monitored?

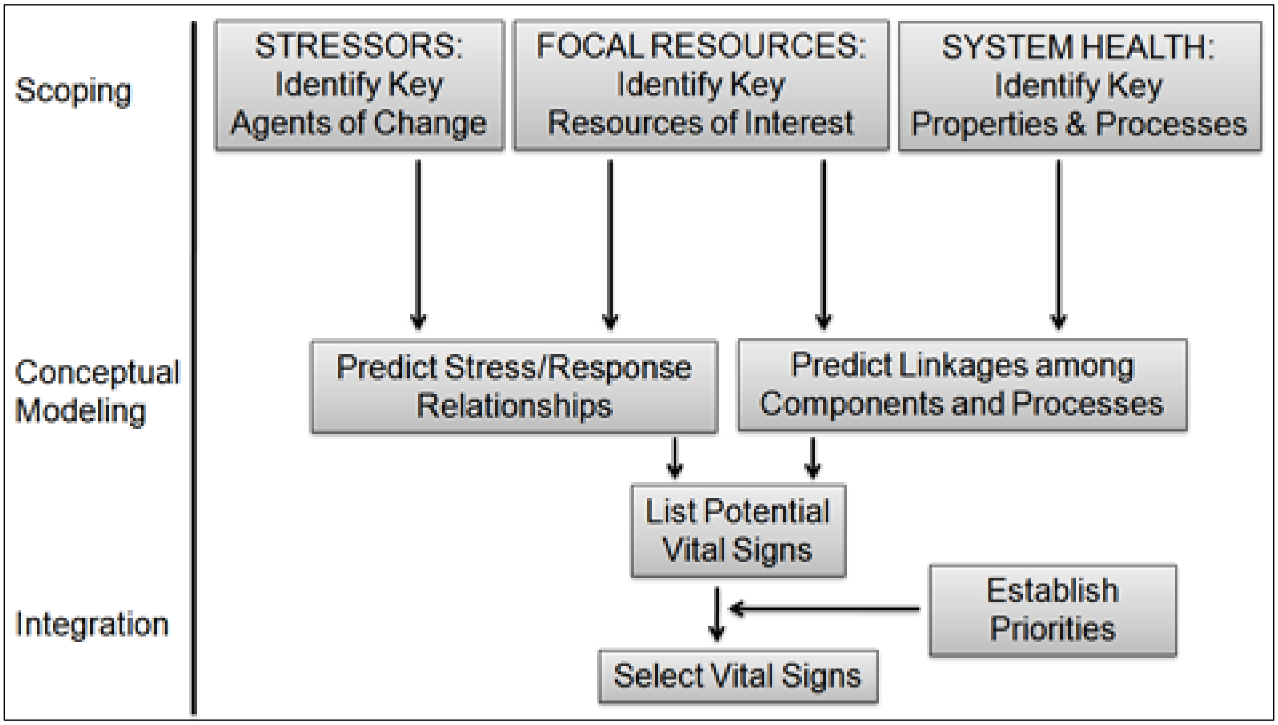
The task of selecting a relatively small set of measurements for a national park that "represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values" is not a trivial task. It is relatively easy to generate a list of potential monitoring projects or indicators to address a park's most critical data needs, but the process of paring the list down to a few "vital signs" that best represent the composition, structure, and function of the larger ecosystem is very challenging.

There is no tried and true method for developing and prioritizing a list of potential vital signs. Many different approaches for developing and evaluating potential indicators have been used by various monitoring programs, and there are numerous sets of criteria for the 'ideal indicator'. A number of these approaches have been summarized in the document Example Criteria and Methodologies for Prioritizing Indicators.

Most networks of parks are following the basic approach shown in the figure below to identify and prioritize potential vital signs. The scoping process usually involves a series of meetings, workshops, brainstorming sessions, questionnaires, literature reviews, and other information-gathering exercises to identify monitoring questions and data needs that include (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) some basic key properties and processes of ecosystem health (e.g., weather, soil nutrients). Conceptual models are then developed to help organize and communicate the information compiled during scoping, and to identify where cause-effect is known between some of the stressors and response variables. The scoping and conceptual modeling efforts will result in a list of potential vital signs, which must then be prioritized using some set of criteria agreed upon by the parks.

Many networks have generated a separate prioritized list for each park, plus a "network list" that combines the rankings from each park with the number of parks that have identified a particular vital sign as a high priority. The final step in the process is using the prioritized lists in combination with 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 <u>select</u> the set of vital signs that will be included in the initial monitoring program. Thus, it is recommended that <u>prioritization</u> and <u>selection</u> of vital signs be treated as two separate steps in the process.

The process of prioritizing the list of potential vital signs for a park network will involve a group decision that involves many different parks, individuals, and disciplines. A structured group decision-making process should be used to take all of the information and ideas available, and then produce judgments, manage conflict, and enable consensus. Several approaches to group decision-making are summarized below.



Basic approach to identifying and selecting vital signs for integrated monitoring of park resources.

Group Decision-Making Processes used to Prioritize Vital Signs

- BOGSAT (Bunch of guys/gals sitting around a table). Not Recommended. This is a term coined by Schmoldt and Peterson (2000); it is often used in workshop 'scoping meeting' settings, and is the most common and often least effective approach to group decision-making. Group deficiencies related to the BOGSAT or workshop setting have received the unenviable names of "social-loafing" and "group-think," and are often the result of member shyness or alternatively individual dominance, lack of communication skills, social pressure to conform and personality conflicts or uncooperative individuals. The consequences are often "an abundance of unfocussed and rambling discussion, which mixes judgmental and intellective issues, ... and a cost in inefficiencies of time and effort and the loss of ideas introduced in the wrong context." (Schmoldt and Peterson, 2000, p. 64). [quoted from Oliver (2002), Ecological Indicators 27:1-15.]
- Delphi. Recommended for brainstorming, but not for prioritization/selection of indicators. The Delphi approach, especially when used over the Internet, provides an ideal vehicle for rapidly and efficiently drawing together expert knowledge and opinion on complex issues faced by natural resource managers (Oliver 2002). "Delphi may be characterized as a method for structuring a group communication process, so that the process is effective in allowing a group of individuals, as a whole, to deal with complex problems."
  - Delphi is based on the premises that: (1) opinions of experts are justified as inputs to decision-making where absolute answers are unknown; and (2) a consensus of experts will provide a more accurate response to a question than a single expert. The objective of the Delphi approach is to generate many ideas, initially, in the absence of evaluation. It usually

involves questionnaires to which each expert responds anonymously. These are returned to participants for revision accompanied by feedback which summarizes all responses. This iterative process may continue until convergence of opinion is reached.

- The distinction between Delphi and other GDM processes is that the communication process operates among panel members dispersed in space and time. Also, the Delphi approach is commonly applied to large groups (30-100 individuals) that do not function well in a face-to-face environment. (see references in the document link above).

- Analytic Hierarchy Process. Recommended, as long as some 'tweaking' is allowed with the final 'short list.' The analytic hierarchy process (AHP) is a decision-making framework that uses a hierarchical structure to describe a problem and paired comparisons to rank decision alternatives with respect to importance (or preference or likelihood). This technique has been applied to a wide variety of decision problems. Schmoldt et al. (1994) describe its use for inventory and monitoring program planning and give an example. Workshop facilitators and specialized software is available. See papers by Schmoldt and Peterson 2000 and Schmoldt and Peterson 1997).
- Hybrid (simplified version of AHP). Recommended. In this approach, the park network uses some combination of BOGSAT, questionnaires, DELPHI, and scoping workshops to brainstorm and produce a list of monitoring questions and potential indicators. A smaller group of individuals (e.g., technical committee and Board of Directors) then establishes a set of criteria and subcriteria (with numerical weights) for ranking the monitoring questions or indicators, and uses a database in a group setting to prioritize the potential indicators. The 'short list' might then be adjusted based on expert opinion and 'common sense' judgment calls to produce the final set of recommended indicators.

Recommended Approach for Prioritizing and Selecting Vital Signs

The current, recommended approach for prioritizing vital signs involves the use of an MS Access database during a workshop setting as a means of focusing discussion and obtaining advice from experts. This approach was successfully implemented by the Mojave Desert Network during a May 2004 workshop, and is summarized in the Summary of Vital Signs Prioritization Process for the Mojave Desert Network , a presentation by Kris Heister, Mojave Desert Network, at the 2005 Annual I&M Meeting. The MS Access database used to evaluate and rank the potential vital signs can be downloaded here. More recently, the Northern Great Plains Network used this database approach during their September, 2005 workshop. The basic steps involved in this recommended approach are as follows:

1. During Phase 1 of the monitoring planning and design effort, the network coordinator leads a process involving a series of meetings, workshops, brainstorming sessions, questionnaires, literature reviews, and other information-gathering exercises to identify key monitoring questions and data needs. Initial conceptual models are developed to help organize existing information and knowledge and to promote communication across disciplines. This process eventually leads to a relatively long list of potential vital signs for all parks in the network.

2. The list of potential vital signs is loaded into the vital signs prioritization database, which is organized around the Ecological Monitoring Framework. For each potential vital sign, the database includes a justification statement about why the vital sign needs to be monitored, an initial set of monitoring questions and objectives, which parks the vital sign applies to, and other draft information.
3. Vital signs are consistently ranked for each park using a set of criteria that are applied equally across all parks and disciplines. The 3 criteria used by the Mojave and other networks are Management Significance, Ecological Significance, and Legal Mandate. The ranking for Management Significance for each park is done prior to the workshop by the park managers, and the ranking for Legal Mandate is usually done by the network coordinator prior to the workshop, and then reviewed by the park managers. The ranking for Ecological Significance is usually done during the workshop by the subject-matter experts.
4. During the prioritization workshop, subject-matter experts, park managers and others are divided into subject workgroups (e.g., Air and Geology; Water Resources; Plants; Animals) and are asked to review, revise, and improve the information entered into the database (e.g., justification, monitoring questions and objectives) for vital signs assigned to their workgroup.
5. As a result of applying the ranking criteria, prioritized lists are generated for each park and one list is generated for the network overall. Each workgroup is then asked to work with the highest-ranking vital signs assigned to their workgroup, and to develop a set of specific measurable objectives for each vital sign, and to identify existing protocols and partnership opportunities as well as other information.
6. The workshop results are documented in a report, which is then sent out for peer review to a larger audience. After incorporating the comments of this peer review, the results of the workshops are used by the network Board of Directors and/or Technical Committee to guide the next step, which is the SELECTION of the initial set of vital signs to be monitored by the network parks.

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 documents:

Download Guidance for the Design of Sampling Schemes for Inventory and Monitoring in National Parks (S. Fancy, March 2000)

Download Examples of Park Sampling Designs (S. Fancy, March 2000)

Download Examples Illustrating the Design and Analysis of Monitoring Surveys in National Parks (P. Geissler, May 2001)

Download Sample Designs for National Park Monitoring (P. Geissler and T. McDonald, April 2003)

Estimation of Change from Survey Data Results and Summary of a Workshop Held 11-12 March 2003 At The USGS Patuxent Wildlife Research Center, Laurel MD

A good example of how a network of parks has designed a scientifically sound, efficient sampling scheme for a variety of terrestrial and aquatic resources is presented in the Sampling Design Chapter for the Heartland Network.

See also:

Summary of a Statistical Workshop at Olympic NP (A. Woodward and K. Jenkins, April 2001)

Statistical Methods for Adaptive Management Studies This is a good manual on statistical methods by the British Columbia Ministry of Forests Research Program.

Statistical Techniques for Sampling and Monitoring Natural Resources by Schreuder et al. 2004.

Statistical/Modeling Tools for Design and Analysis of Conservation Monitoring Data.

Sampling Design Recommendations

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 judgment 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 judgment is only as good as the model and the decision making process of the individual providing the professional judgment, and models and judgment-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. Judgment sampling, using "representative" sites selected by experts, should be avoided. If there is no controversy, judgment 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. Co-location 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.

Monitoring Protocols

Required Content and Format of Monitoring Protocols

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.

The NPS I&M Division and the USGS Status and Trends Program have developed guidelines for the content and format of monitoring protocols. The guidelines, which were published in the Wildlife Society Bulletin (Oakley et al. 2003), have been adopted as the protocol standard by the NPS I&M program and the USGS Status and Trends Program. All monitoring in national parks that uses funding from the NPS I&M program MUST develop protocols that meet the Oakley et al. 2003 protocol standards.

Download the Guidelines for long-term monitoring protocols (Oakley et al. 2003).

Download Guidance for Protocol Development Summary documents

Any protocols that are developed using I&M funding should follow the steps outlined in the guidance for the Protocol Development Process. In short, parks are encouraged to adopt or modify existing protocols or portions of protocols developed by other programs and agencies to promote consistency and data comparability. In almost all cases, the first step involved in protocol development is "Do your homework": Thoroughly scope out the issues, monitoring questions, and objectives that will be addressed by the protocol. The developer must be able to answer the question, "who will use the monitoring results and how will they use the data?" Build on existing work and data: review relevant monitoring done by others, other relevant protocols or portions of protocols, and find and evaluate field data collected by others for similar situations. Field data collection, including collection of pilot data to determine variability of the measures, time/effort required for each sample, or to determine sample sizes needed to detect a certain level of change, should be one of the last steps of the protocol development process.

NPS Protocol Database

The NPS I&M Division has developed a Protocol Database to catalog and make available sampling protocols that have been developed by one of the prototype monitoring programs or networks, or that are widely used by other programs or agencies. The database currently contains many legacy protocols that do not conform to the Oakley et al. protocol standards, but over the next few years these will be replaced by more than 200 protocols currently being developed by the I&M networks. As part of the NPS Natural Resource Challenge philosophy of "Share the information widely," and because of the current high interest in NPS monitoring protocols by the States and other federal agencies, NPS staff and collaborators are encouraged to make available draft protocols, including some that have not been fully peer- reviewed and tested. The protocol database is organized following the Ecological Monitoring Framework , and a future version will include keywords and a search capability. For each protocol, the database provides a reference and a brief summary of what is included in the protocol, and makes it possible for the user to download an electronic version. For most protocols, the NPS is also developing a relational MS Access database that follows the Natural Resource Database Template scheme, and wherever possible, a stand-alone database or database components (e.g., table structure, queries, data entry forms, code for error checking, etc.) are made available along with the protocol document.

Go to the Protocol Database

Examples of Protocols used by other Programs and Agencies

Protocol development is a difficult, expensive, time-consuming process that includes a research component. Sampling protocols must be field tested, and experiments must be conducted to determine when and how often a site should be sampled. The EPA, USDA Forest Service, and Natural Resource Conservation Service alone have spent tens of millions of dollars developing and testing sampling protocols. To promote consistency, data comparability, and cost efficiency, the National Park Service should take advantage of these efforts by other agencies by using well-tested, standardized sampling protocols developed by other agencies if they address the park's monitoring objectives.

Information on various sampling protocols being used or developed by the prototype monitoring parks is provided below. Also included is 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. Included in the WRD guidance are Recommendations for Core Water Quality Monitoring Parameters, and Core Water Quality (Vital Signs) Monitoring Parameters for Marine and Coastal 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 Assessment 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.

Data Management and Analysis

See http://science.nature.nps.gov/im/datamgmt/

Reporting the Results of Monitoring

The broad-based, scientifically sound information obtained through natural resource monitoring has multiple applications for management decision-making, research, education, and promoting public understanding of park resources. The primary audience for the results of vital signs monitoring is park management: provide superintendents, park resource chiefs, and other managers with the data they need to make and defend management decisions and to work with others for the benefit of park resources. However, other key audiences for monitoring results include park planners, interpreters, researchers and other scientific collaborators, the general public, and Congress and OMB. To be most effective, monitoring data must be analyzed, interpreted, and provided at regular intervals to each of these key audiences in a format they can use, which means that the same information needs to be packaged and distributed in several different formats.

The scientific data we need to better understand how park systems work and to better manage the parks will come from many sources. In addition to new field data collected through the I&M Division, other data to help us assess and keep track of the condition of park resources will come from other park projects and programs, other agencies, and from the general scientific community (Figure 1). To the extent that staffing and funding is available, the vital signs program will collaborate and coordinate with these other data collection and analysis efforts, and will promote the integration and synthesis of data across projects, programs, and disciplines.

The vital signs monitoring program can be viewed as an information system, with each of the steps involved in designing and implementing long-term monitoring (e.g., develop monitoring objectives, design monitoring program, collect field and lab data) being like pieces of a puzzle (Figure 2). The approach for collecting, managing, analyzing, and reporting monitoring data must be planned and implemented as a package in order for the pieces to fit and the overall program to be effective. Communication, collaboration, and coordination with other projects, programs, and agencies is needed to efficiently and effectively reach the overall goal, which is to understand, protect and restore park resources. Contributions of expertise and funding from parks, other programs, and other agencies through partnerships are needed to build an integrated monitoring program. In the process of carrying out these steps, the program helps to build institutional knowledge: ensuring that the results are available for future park staff and collaborators.

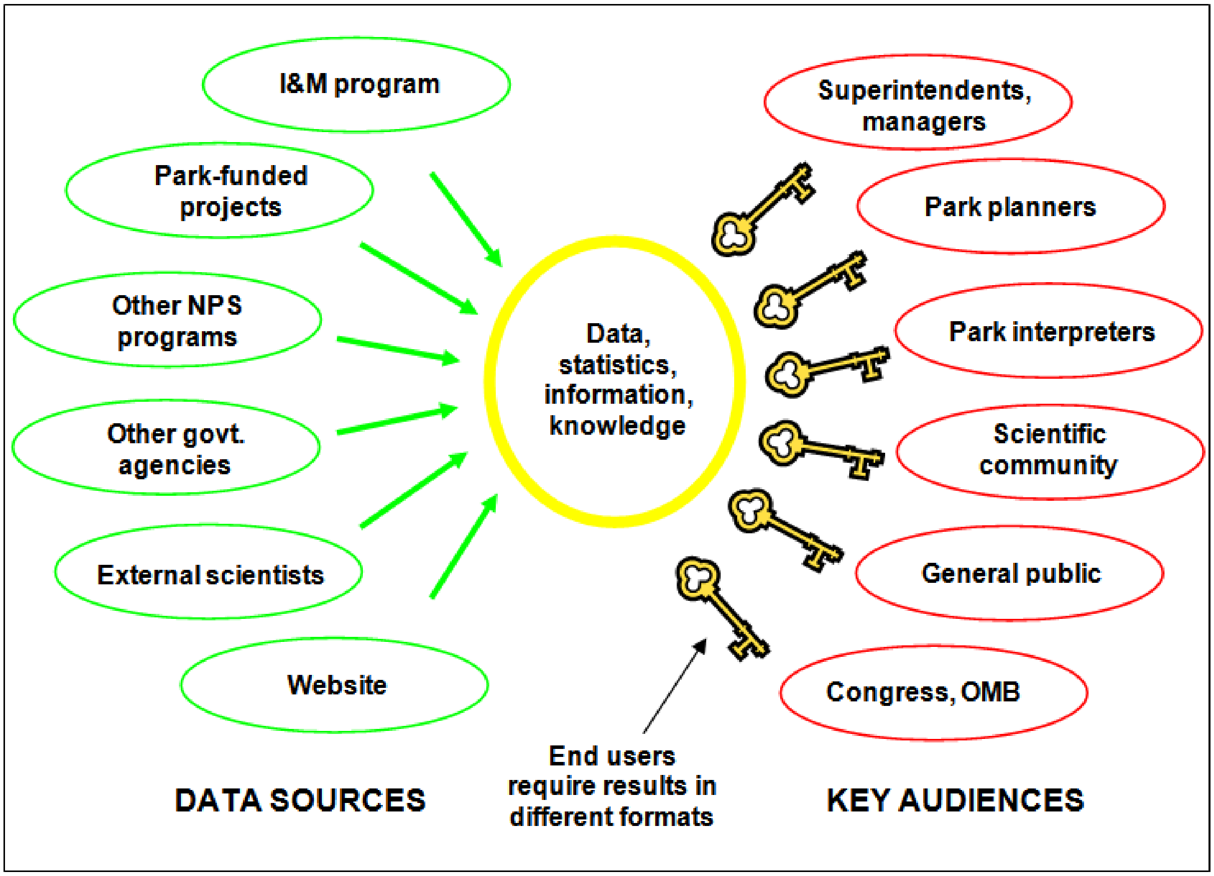


Figure 1. Scientific data for assessing and keeping track of the condition of park natural resources will come from multiple sources, and will be managed, analyzed, and distributed to multiple audiences in several different formats in order to make the results more available and useful.

The content and amount of detail included in the various products of the monitoring program will differ depending on the intended audience for each report. At the local level, park managers and natural resource staff and collaborators need to have available the detailed, complex scientific data relevant to the park's issues and resources. At the national level, however, a different scale of analysis and reporting is needed to be most effective. To report on the status and trends in the condition of natural resources in the National Park Service, the NPS is developing a Natural Resource Scorecard that will involve the integration and evaluation of detailed scientific data for each park and resource category by experts. For effective communication, the overall assessment of resource status and trends (the "highly aggregated indices" zone at the top of the information pyramid shown in Figure 3) will be presented using a simple, clear public message, but the results will be supported by the large amount of detailed, complex scientific data and information depicted as the lower levels of the information pyramid (Figure 3).

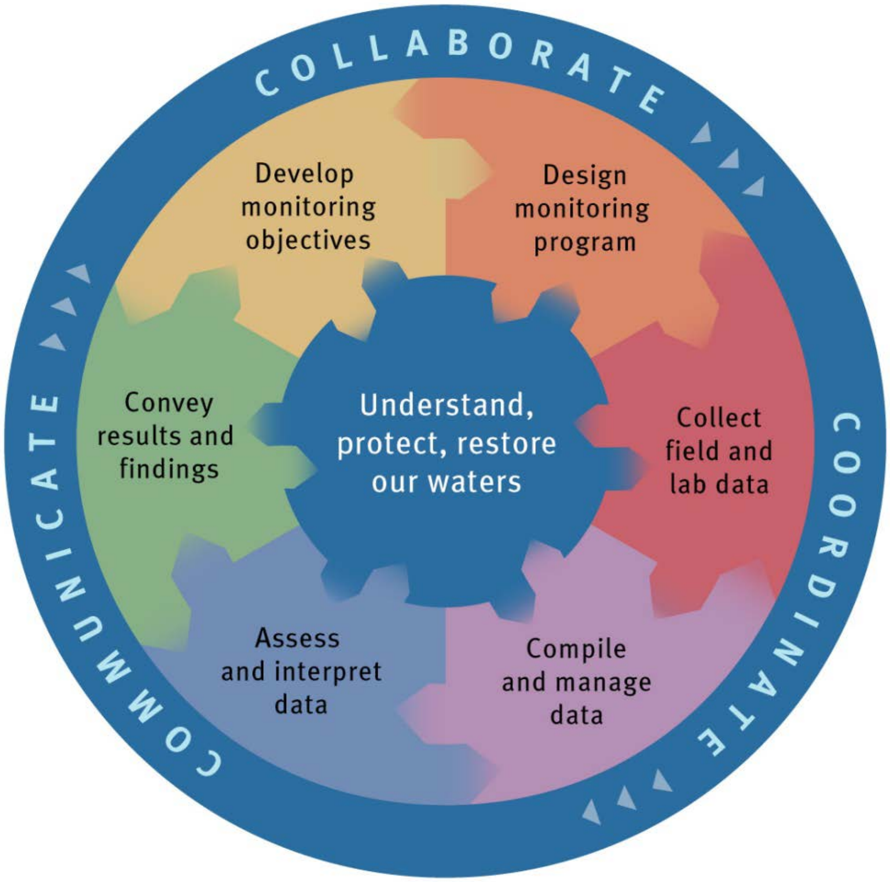


Figure 2. The monitoring program can be viewed as an information system, with the various steps seen as pieces of a puzzle that must be designed to fit together for the program to be most effective. The monitoring program promotes communication, collaboration, and coordination with other programs and agencies to reach the overall goal of understanding, protecting, and restoring park resources.

A Summary of Reports, Presentations and Websites that will be produced by the monitoring networks, along with their purpose and intended audience, are summarized here. Websites developed and maintained by each network will be a key outlet for distributing results to key audiences. In addition to the various kinds of written reports and presentations at scientific meetings and symposia, many networks will coordinate annual "Science Day" briefings targeted at park managers, where scientists from a number of programs will provide briefings to managers and other staff on key findings and potential action items for their particular project or discipline. These "Science Day" briefings will also promote integration and synthesis across programs and projects by allowing various scientists and managers to hear what is going on with other projects and programs in the park.

Download an Overview of Reporting the Results of Vital Signs Monitoring

Guidelines for publishing reports in the NRPM National Report Series

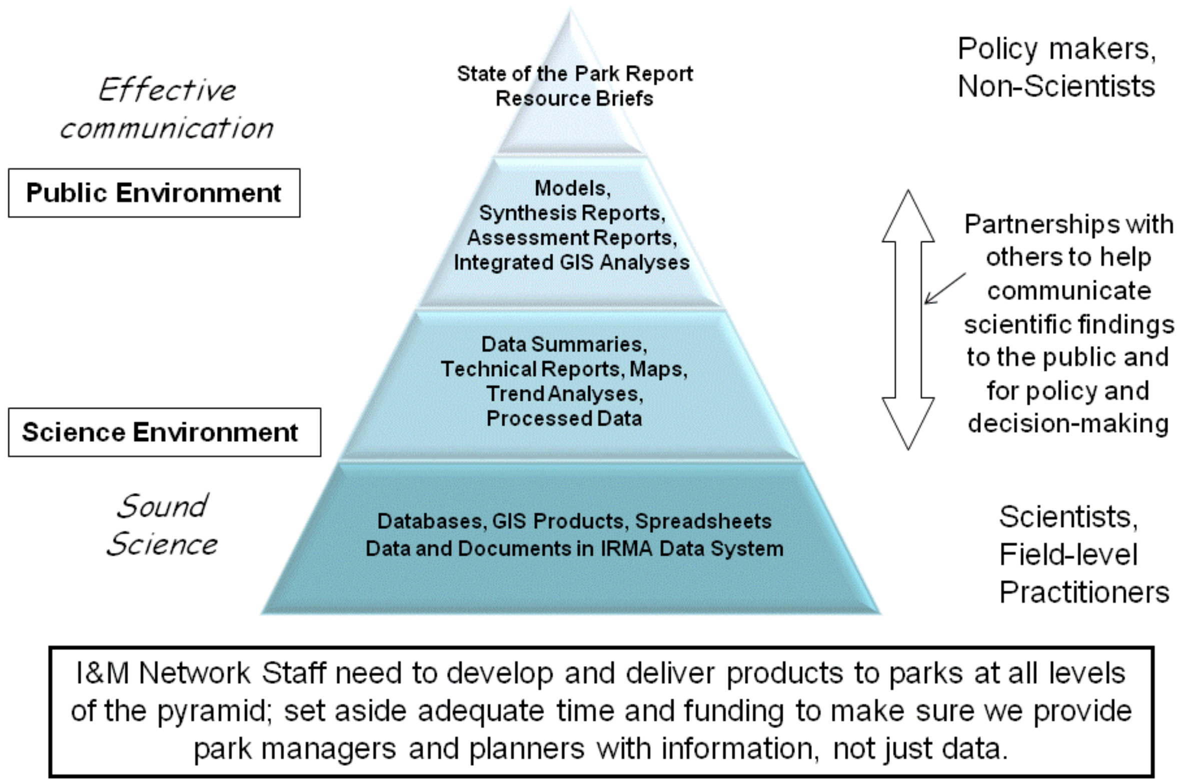


Figure 3. The information pyramid. The amount of detail and scale of analysis of scientific data will differ depending on the intended audience for the various reports and presentations. National-level reporting to the American public and to Congress will involve assessments by experts and presentations of data using simple graphical messages, but the results will be supported by a huge amount of detailed, complex scientific data that is available at the park and network level.

Glossary of Terms Used by the NPS Inventory & Monitoring Program

Adaptive Management: a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form --"active" adaptive management -- employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

Area Frame: A sampling frame that is designated by geographical boundaries within which the sampling units are defined as subareas.

Attributes: any living or nonliving feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem. The term Indicator is reserved for a subset of attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). See Indicator.

Biological Significance: An important finding from a biological point of view that may or may not pass a test of statistical significance.

Co-location: Sampling of the same physical units in multiple monitoring protocols

Conceptual Models: purposeful representations of reality that provide a mental picture of how something works to communicate that explanation to others.

Driver: The major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces or anthropogenic.

Ecological integrity: a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

Ecosystem: defined as, "a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992).

Ecosystem drivers: major external driving forces such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., earthquakes, droughts, floods) that have large scale influences on natural systems.

Ecosystem management: the process of land-use decision making and land-management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated land-use decisions.

Focal resources: park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes such as deposition rates of nitrates and sulfates in certain parks, or they may be a species that is harvested, endemic, alien, or has protected status.

Indicators: a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

Inventory: An extensive point-in-time survey to determine the presence/absence, location or condition of a biotic or abiotic resource.

Measures: specific feature(s) used to quantify an indicator, as specified in a sampling protocol. For example, pH, temperature, dissolved oxygen, and specific conductivity are all measures of water chemistry.

Metadata: Data about data. Metadata describes the content, quality, condition, and other characteristics of data. It's purpose it to help organize and maintain a organization's internal investment in spatial data, provide information about an organization's data holdings to data catalogues, clearinghouses, and brokerages, and provide information to process and interpret data received through a transfer from an external source.

Monitoring: collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (Elzinga et al. 1998). 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.

Protocols: as used by this program, are detailed study plans that explain how data are to be collected, managed, analyzed and reported and are a key component of quality assurance for natural resource monitoring programs (Oakley et al. 2003).

Stressors: physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

Trend: as used by this program, refers to directional change measured in resources by monitoring their condition over time. Trends can be measured by examining individual change (change experienced by individual sample units) or by examining net change (change in mean response of all sample units).

Vital Signs: are 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 elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and 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).

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