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Institutionalizing an effective long-term monitoring program in the US National Park Service

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Introduction

The need for long-term ecological monitoring

Managers of protected areas have increasingly recognized the value and need for credible, scientific information as a basis for making management decisions and working with partners and the public to conserve natural resources. The management of public lands has become increasingly complex, both technically and politically. Managers need reliable data and information on the status and trends in the condition of key resources that they manage as a basis for conservation planning, determining whether current management practices are having the desired effect, and informing stakeholders and the general public of changes in the condition of natural resources that may be caused by stressors operating at regional or global scales.

Long-term ecological monitoring provides information needed to understand and identify change in natural systems characterized by complexity, variability, and surprises. This information can be used to help assess whether observed changes are within natural levels of variability or may be the result of unwanted human influences. Data collected in a consistent way over long periods are fundamental to conservation and management because they provide the context for interpreting observed changes, and may provide the basis for initiating new management practices or changing existing practices (Carpenter 1998, Lovett *et al.* 2007). For example, reliable and consistently collected data from long-term studies are currently in high demand for developing quantitative models to inform conservation and action plans for addressing the ecological consequences of rapid climate change.

The legacy of long-term monitoring programs

Despite the importance of reliable, relevant long-term monitoring data, the track record for initiating and sustaining effective long-term monitoring has been poor (Mulder and Palmer 1999, Reid 2001, Noon 2003, Nichols and Williams 2006, Lindenmayer and Likens 2009). Monitoring programs are often hurriedly planned and implemented in response to a short-term funding opportunity or political directive, are often insufficiently funded, and historically have been one of the first programs to be cut in times of budget reductions. Large-scale monitoring programs designed to provide inferences at a regional or national scale often do not provide sufficient information relevant to the highest priorities of land managers at the local level. For example, the number of sampling sites in a management unit may be too small to support reliable local-scale information. Therefore, on-the-ground managers are often not enthusiastic about such large-scale efforts.

The legacy of science and monitoring in the US National Park Service

The nearly 400 units managed by the US National Park Service (NPS) include many of the nation's most treasured natural landscapes and historical and cultural sites. The NPS mission, as defined by the 1916 Organic Act, is "To conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." NPS management policies state that "The Service will also strive to ensure that park resources and values are passed on to future generations in a condition that is as good as, or better than, the conditions that exist today", and that "Decision makers and planners will use the best available scientific and technical information and scholarly analysis to identify appropriate management actions for protection and use of park resources" (NPS 2006). As natural laboratories and long-term monitoring sites, NPS units can serve as reference sites and places where effects of regional and global changes may be detected without many of the smaller-scale confounding influences found on other public and private lands.

An overarching natural resource management objective for all of the parks is to pass the resources on to “future generations in a condition that is as good as, or better than, the conditions that exist today”. To address this management objective, park managers and planners clearly need reliable scientific information about the condition and trends of the natural resources for their park. However, until recently almost all of the NPS workforce and budget was focused on traditional scenery and tourism management (Sellars 1997), with relatively little attention and funding given to science as a basis for resource management. The Natural Resource Challenge, initiated in 2000 (NPS 1999), resulted in increased funding and a commitment by the NPS leadership to strengthen resource preservation and restoration through strong, science-based programs. Although funding was allocated to an ecological monitoring program, development of this program faced significant challenges due to the relatively low funding level and the agency’s decentralized organizational structure. Furthermore, the diversity of ecological systems included in the NPS (e.g., coral reefs, deserts, arctic tundra, prairie grasslands, caves, rivers, and tropical rainforests) made it difficult to design a monitoring program that would be relevant and effective to parks throughout the system.

Despite these challenges, the NPS has successfully designed a long-term ecological monitoring program that continues to gain support and acceptance as a key component of natural resource stewardship. In this chapter we share some of the key lessons learned in designing, implementing, and institutionalizing a long-term monitoring program in a natural resource management agency. At one level, we emphasize the importance of these lessons for effective implementation of a scientifically credible program. We have effectively incorporated many of the statistical recommendations made throughout this volume into the design of the program; NPS has worked with statisticians and subject-matter experts to develop and disseminate more than 100 peer-reviewed monitoring protocols applying a variety of statistical tools. However, we also provide a broader context. We emphasize that although sound statistical design and analytical approaches are an essential underpinning of the scientific credibility and reliability of any monitoring program, they are just one component of developing and institutionalizing an effective monitoring program.

Critical elements for institutionalizing a monitoring program: relevance, reliability, and commitment

The term "institutionalize" implies broad acceptance of the program as an integral part of an agency’s operation. Mere longevity does not constitute institutionalization. To be truly institutionalized, a monitoring program needs to be sufficiently and formally integrated into the key operations (e.g., decision-making and planning), such that it helps the agency achieve its mission and goals. Only a handful of large scale ecological monitoring programs have achieved relative longevity and even fewer have become institutionalized. Probably the best examples come from regulatory contexts where monitoring for compliance has a legal mandate as part of an organization’s day to day operations (e.g., water quality monitoring by state governments to address the Clean Water Act in the USA). If a monitoring program is not legally mandated, it can achieve institutionalization only if it has long-term support from all levels of an organization.

In practice, the level of integration within an organization's operations and the roles played by a monitoring program in these operations can be highly variable. All too often, the primary means of integrating scientific information into management is limited to opportunistic gleaning of information if a manager happens to be aware of potentially relevant science. If this is the primary use of information produced by monitoring, the program clearly has not been institutionalized effectively. Rather, the information gathered via the monitoring program needs to be an integral part of the planning and operations of the organization through a systematic and routine process for communication of relevant science and a decision process that enables effective consideration of that science and the potential for its incorporation into management decisions.

There are many aspects of a monitoring program that contribute to its success. There are, however, a few broad themes without which a program has virtually no chance of becoming an integral part of an organization: relevancy, reliability, and commitment (Box 22.1). The primary focus of this chapter will be to discuss those three themes. As part of this discussion, we will consider some of the trade-offs we made and how the NPS monitoring program sought, and is still seeking, to become an integral part of the planning and operations within NPS. We also discuss how quantitative topics of other chapters in this volume relate to these three themes.

Relevance of the monitoring program

The importance of clearly defining relevant goals and objectives

There is virtually universal consensus that setting realistic, clear, specific, and measurable monitoring objectives is a critical first step in developing a monitoring program (e.g. Spellerberg 1991, Elzinga *et al.* 1998; Chapters 2, 3, 18, 21, and others in this volume). Olsen *et al.* (1999) noted that "Most of the thought that goes into a monitoring program should occur at this preliminary planning stage. The objectives guide, if not completely determine, the scope of inference of the study and the data collected, both of which are crucial for attaining the stated objectives." They stated that a "clear and concise statement of monitoring objectives is essential to realize the necessary compromises, select appropriate locations for inclusion in the study, take relevant and meaningful measurements at these locations, and perform analyses that will provide a basis for the conclusions necessary for meeting the stated objectives." Chapter 2 further discusses the importance of well-defined objectives in guiding all other quantitative decisions required in the development of a monitoring program.

Recognizing these critical roles, the NPS monitoring program put considerable emphasis on the task of formulating monitoring objectives that meet the test of being realistic, specific, and measurable (Fancy *et al.* 2009). We found that there was confusion initially about the differences between goals, management objectives, monitoring objectives, and sampling objectives. Therefore, we developed guidance for writing monitoring objectives that was effective in improving the quality and consistency of objectives in monitoring plans and sampling protocols (NPS 2008a).

Management-oriented monitoring is most efficiently accomplished when clearly defined management objectives exist and are accompanied by clearly defined monitoring objectives. Relevant to the agency's overarching management objective, the NPS long-term ecological monitoring program was established to address whether natural resources in parks are being passed on to future generations in a condition that is as good as or better than the conditions that exist today. Most parks also have more specific and usually shorter-term management objectives for specific restoration projects and other management actions, but any monitoring associated with those specific management actions requires other funding sources (see *Future Research and Development* section below for further discussion of overall condition vs. effectiveness monitoring).

Box 22.1 Take-home messages for program managers

Based on our experience in designing a long-term monitoring program for the US National Park Service, there are three broad themes determining whether a monitoring program has a chance of becoming a widely accepted, integral part of an organization: *relevancy, reliability,* and *commitment.*

Relevancy

The establishment of clearly defined goals and objectives and the selection of indicators are the most critical components of making the monitoring program relevant. To ensure relevancy, the program must have a carefully structured process that allows both natural resource managers and scientists to have input into developing these objectives and selecting indicators. Understanding the information needs of an organization is an essential first step. Such a process also begins establishing what should be a long-standing partnership among scientists and managers.

Reliability

The reliability of scientific information used in management, planning, and policy decision-making partly determines the credibility of these decisions and support from stakeholders, local communities, and the general public. Key elements that contribute to the reliability of a long-term ecological monitoring program are the development of the following:

i. clear, specific, and measurable monitoring objectives;
ii. conceptual models that describe important components of the ecosystem and the interactions among them, and that help to justify and interpret the ecological measurements;
iii. well-documented, peer-reviewed protocols that describe how data are to be collected, managed, analyzed, and reported;
iv. survey designs to ensure that data collected are representative of the target populations and sufficient to allow defensible conclusions to be derived about the resources of interest; and
v. procedures that ensure that data are properly managed, routinely analyzed, and are readily available to key audiences in a usable and timely manner.

Commitment

A prerequisite for a successful long-term monitoring program is an agency's commitment and solid funding base to sustain the program. Institutional commitment is best achieved through clear demonstration of a program's value in supporting credible decisions and sound management of natural resources, and by showing that the benefits derived from the program are worth the expense. Developing a partnership between scientists and managers from the outset will help ensure that the monitoring program addresses questions that are relevant to management and policy issues, and that the monitoring can effectively answer those questions in a scientifically defensible manner. This step alone will go a long way toward gaining support at the ground level - support that is essential if the program is to become an integral part of the organization's operations.

Top down or bottom up? Trade-offs between relevancy, efficiency, and inference

There are numerous advantages for designing an agency-wide "top-down" monitoring program with an interchangeable set of indicators and sampling protocols applied to all units so that data can be "rolled up" to address questions at different geographic and/or organizational scales. The development of sampling protocols, databases, analysis routines, and reporting structures is more efficient if a consistent set of indicators and protocols is used at all sites, and there are scientific advantages in being able to provide context and better interpret the monitoring results from a site by comparing them with data from other sites.

We initially evaluated, but rejected, the strategy of selecting a core set of indicators that every park would measure in a similar way. The "information-rich" indicators that best characterized park ecosystems differed greatly among ecological systems, and very few relevant measures were common across parks. Moreover, partnership opportunities (and the appropriate ecological indicators and sampling methodologies associated with them) available to parks differed greatly throughout the National Park System (Fancy *et al.* 2009). The development of partnerships with other government agencies and nongovernmental organizations is important for developing political relevance, which in turn contributes to agency commitment. A top-down, "one size fits all" approach to monitoring design would not have been effective or supported in the NPS because of the tremendous variability among parks in ecological context and in park sizes and management capabilities, and because individual parks have very different resource issues, information needs, and partnership opportunities. Thus, in order to gain acceptance at the park level, some sacrifice of national consistency was necessary. We balanced park-specific relevance with organizational efficiency by grouping the more than 270 parks with significant natural resources into 32 Inventory and Monitoring (I&M) networks (see the map at http://science.nature.nps.gov/im/networks.cfm) that each share a professional staff and funding to conduct long-term monitoring (Fancy *et al.* 2009). Each network worked with partners and subject-matter experts to prioritize and select park-specific or network-wide indicators based on their most critical information needs and local partnership opportunities, as described in the next section. Thus, the issue of considering a top-down versus bottom-up program extends beyond gaining the acceptance of the individual parks, but also is an essential consideration for developing an efficient and cost-effective program that takes advantage of partnership and cost-leveraging opportunities.

Selecting indicators

The selection of indicators is a critical step in ensuring the relevancy and usefulness of monitoring data. Consequently, this topic has been widely addressed in the literature and has an entire journal *(Ecological Indicators)* devoted to the topic. Ecological indicators serve three primary purposes (National Research Council 2000): (i) to quantify information in such a way as to illustrate its significance, (ii) to simplify information about otherwise complex phenomena (Hammond *et al.* 1995), and (iii) to serve as a cost-effective alternative to monitoring a larger suite of species and processes (Landres 1992). In order to achieve these purposes and to maximize the relevance of the monitoring results to meeting the stated objectives, it is essential to use a careful, structured process that allows both managers and scientists to have input into the indicator selection process (Jackson *et al.* 2000).

The process for selecting indicators for each of the 32 I&M networks began with a scoping process to identify park issues, monitoring questions, and data needs. The scoping process identified focal resources (including ecological processes) important to each park; agents of change or stressors that are known or suspected to cause changes in the focal resources over time; and key properties and processes of ecosystem condition (e.g. weather, soil nutrients). Conceptual models were then developed to help organize and communicate the information compiled during scoping, and to identify known or hypothesized cause-effect relationships between some of the stressors and response variables. The scoping and conceptual modeling efforts resulted in a long list of potential indicators, which were prioritized using a set of criteria for management and ecological significance, and a scoring system agreed upon by each network (see Fancy *et al.* 2009 for details). The final step in the process incorporated other criteria such as efficient use of personnel, cost and logistical feasibility, partnership opportunities with other programs, and a large dose of common sense to select the initial set of indicators for each network's monitoring program (Table 22.1). We obtained best results when networks treated prioritization and selection of indicators as two separate steps in the process (Fancy *et al.* 2009).

Reliability of the monitoring program

Management, policy, and planning decisions based on reliable scientific data and information generate credibility and support from stakeholders, local communities, and the general public. Reliability entails all program elements that enable the user to develop an expectation of credible and available information. The key elements for the reliability of a long-term ecological monitoring program that we will emphasize here include the development of the following:

i. clear, specific, and measurable monitoring objectives;
ii. conceptual models that describe the important components of the ecosystem and the interactions among them, and that help to justify, interpret, and communicate the ecological measurements;
iii. well-documented, peer-reviewed protocols that describe how data are to be collected, managed, analyzed, and reported;
iv. survey designs to ensure that data collected are representative of the target populations and sufficient to allow defensible conclusions to be derived about the resources of interest; and

v. procedures that ensure that data are properly managed, routinely analyzed, and are readily available to key audiences in a usable and timely manner.

We discussed the development of objectives above; therefore, we focus now on each of the last four key elements. We also consider an additional challenge relevant to all of these elements - the need for adaptability over time.

Conceptual models

Conceptual models are an essential tool for framing the right questions and aiding in the selection of relevant indicators for any ecological monitoring program (Barber 1994, National Research Council 1995, Noon *et al.* 1999; see also Chapter 2). Conceptual models help us to understand the key components and processes deemed important in an ecosystem (Manley *et al.* 2000, Gross 2003). These models help us identify assumptions about how components and processes are related, and to identify gaps in our knowledge. Essentially, they are a representation of working hypotheses about system form and function (Huggett 1993, Manley *et al.* 2000). A well-constructed conceptual model will provide a scientific foundation for the monitoring program and aid in the selection of relevant indicators (Gross 2003). More narrowly, by helping identify links among attributes and important factors affecting attributes, conceptual models can help increase the ecological insights gained from monitoring and can indicate supplementary covariates that could be incorporated into eventual statistical analyses to reduce unexplained variability and increase statistical power and precision. Figure 22.1 is an example of a conceptual model that serves several of these purposes.

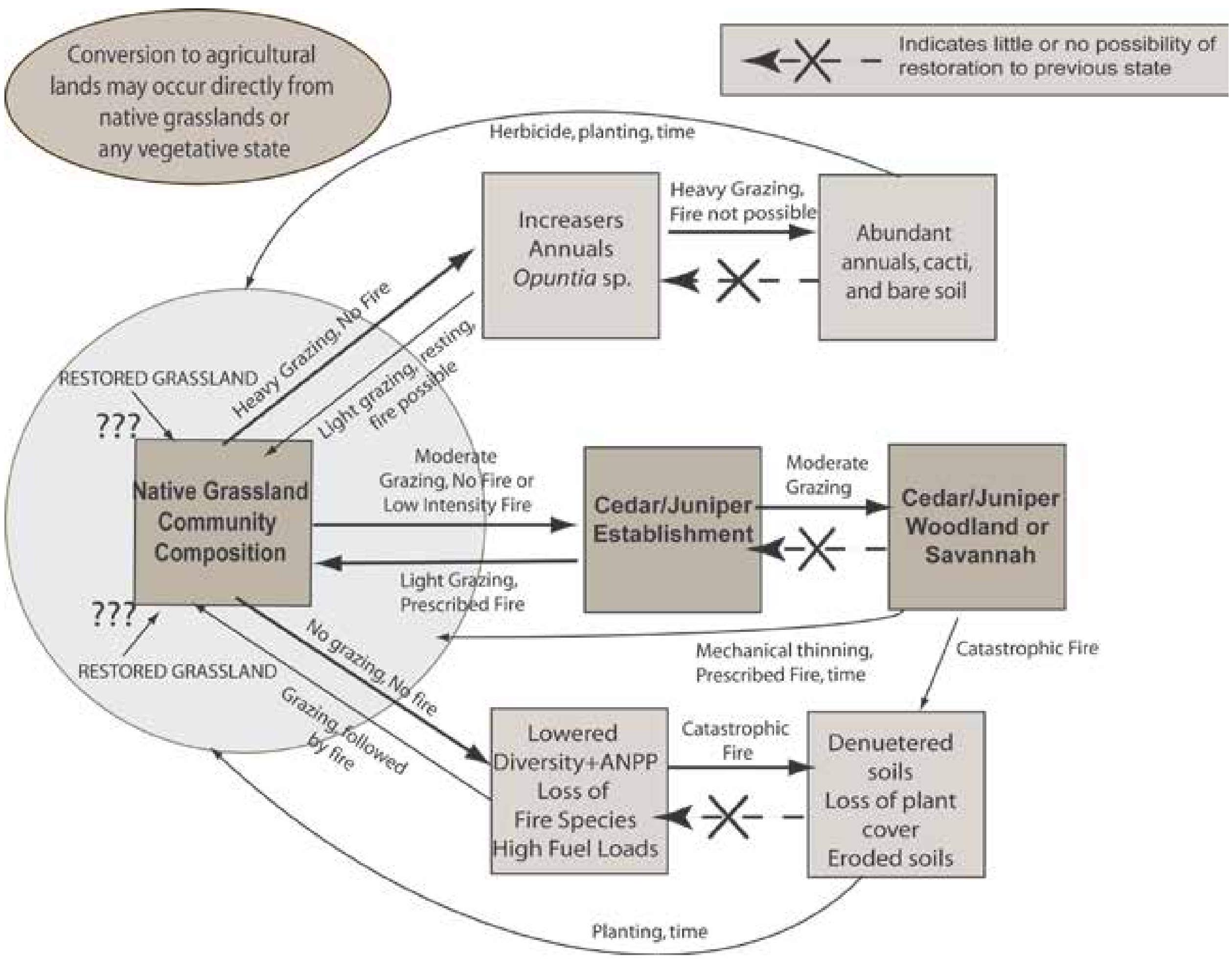


Figure 22.1. Example of conceptual model developed by the National Park Service Southern Plains Inventory and Monitoring Network (NPS 2008b) for NPS units in the Southern Great Plains region of the USA. The model depicts three potential pathways for community composition changes that result from interactions of fire and grazing, as well as a fourth pathway that results in the conversion of any grassland community to agricultural lands.

Table 22.1. Summary of the most common indicators of natural resource condition and examples of specific measures that are being monitored by the US National Park Service long-term ecological monitoring program.

Indicator Category	Example Measures	Number of Parks
Weather and climate	Temperature, precipitation, wind speed, ice on/off dates	246
Water chemistry	pH, temperature, dissolved oxygen, conductivity	211
Land cover and use	Area in each land cover and use type; patch size and pattern	203
Invasive/exotic plants	Early detection, presence/absence, area	200
Birds	Species composition, distribution, abundance	189
Surface water dynamics	Discharge/flow rates, gauge/stage height, lake elevation, spring/seep volume, sea level rise	158
Ozone	Ozone concentration, damage to sensitive vegetation	140
Wet and dry deposition	Wet deposition chemistry, sulfur dioxide concentrations	114
Visibility and particulate matter	IMPROVE network; visibility and fine particles	113
Fire and fuel dynamics	Long-term trend of fire frequency, average fire size, average burn severity, total area affected by fire	105
Vegetation complexes	Plant community diversity, relative species/guild abundance, structure/age class, incidence of disease	101
Mammals	Species composition, distribution, abundance	93
Forest/woodland communities	Community diversity, coverage and abundance, condition and vigor classes, regeneration	93
Soil function and dynamics	Soil nutrients, cover and composition of biological soil crust communities, soil aggregate stability	91
Stream/river channel characteristics	Channel width, depth, and gradient, sinuosity, channel cross-section, pool frequency and depth, particle size	89
Aquatic macroinvertebrates	Species composition and abundance	86
Threatened and endangered species and communities	Population estimates, distribution, sex and age ratios	85
Air contaminants	Concentrations of SOCs, PCBs, DDT, Hg	71
Groundwater dynamics	Flow rate, depth to ground water, withdrawal rates, recharge rates, volume in aquifer	69
Amphibians and reptiles	Species distribution and abundance, population age/size structure, species diversity, percent area occupied	54
Grassland/herb communities	Composition, structure, abundance, changes in treeline	51
Fishes	Community composition, abundance, distribution, age classes, occupancy, invasive species	50
Insect pests	Extent of insect-related mortality, distribution and extent of standing dead/stressed/diseased trees, early detection	50
Riparian communities	Species composition and percent cover, distribution and density of selected plants, canopy height	45
Nutrient dynamics	Nitrate, ammonia, DON, nitrite, orthophosphate, total K	45
Primary production	Normalized differential vegetation index (NDVI), change in length of growing season, carbon fixation	41
Wetland communities	Species composition and percent cover, distribution and density of selected plants, canopy height, aerial extent	40
Microorganisms	Fecal coliform, *E. coli*, cyanobacteria	30
Water toxics	Organic and inorganic toxics, heavy metals	30
Invasive/exotic animals	Invasive species present, distribution, vegetation types invaded, early detection at invasion points	29
Coastal/oceanographic features and processes	Rate of shoreline change, sea surface elevations, area and degree of subsidence through relative elevation data	29

Monitoring protocol development and peer review

A monitoring protocol is a detailed study plan that describes how data are to be collected, managed, analyzed, and reported. It is a key component of quality assurance for natural resource monitoring programs (Oakley *et al.* 2003). Protocols that are well-documented, peer-reviewed, and tested can demonstrate that any detected trends are actually occurring in nature, and are not simply a result of measurements being taken by different people or in slightly different ways. Protocol development is often an expensive, time-consuming process involving a research component. In order to promote consistency and data comparability and to reduce costs, a program should adopt or modify existing protocols developed by other programs and agencies whenever monitoring objectives are similar.

The survey design as a central component of scientific credibility

A carefully planned survey design seeks to ensure that the data collected are representative of the target populations and sufficient to allow defensible conclusions to be derived about the resources of interest (USEPA 2002; Chapters 2, 5-7). Sample sizes for any monitoring program will usually 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 a relatively small subset of potential sampling locations.

During the design of the NPS ecological monitoring program, the I&M networks were required to develop survey designs with the goals of (i) making unbiased and defensible inferences from sample observations to the intended target populations, and (ii) encouraging the co-location of sampling sites and events among indicators to improve efficiency and depth of ecological understanding. In the early planning and design phases, we promoted the following four basic principles for developing an overall survey design for each of the I&M networks that has been effective in the development of credible, practical approaches for selecting sampling locations and revisit designs (Fancy *et al.*2009).

- Wherever possible, a probability design should always be used for selecting sample locations. Probability designs, where each unit in the target population has a known, non-zero probability of being included in the sample, and a random component is included in the selection of sampling sites, allow for unbiased statistical inference from sampled sites to unsampled elements of the resource of interest (Hansen *et al.* 1983, McDonald 2003; Chapters 2, 5). Probability designs provide more reliable and defensible parameter estimates than convenience or judgment samples (Olsen *et al.* 1999, Schreuder *et al.* 2004), and provide measures of the precision of population estimates (Stevens and Olsen 2003). The most common probability design that has been used by almost all of the NPS I&M networks for a wide range of indicators in both aquatic and terrestrial systems is the spatially balanced Generalized Random Tessellation Stratified Design (GRTS; Stevens and Olsen 2003, 2004; Chapters 6, 10, 16).
- Judgment samples that use "representative" sites selected by experts are not recommended because they may produce biased, unreliable information (Olsen *et al.* 1999; Chapters 2, 5) and can often be easily discredited by critics.
- Stratification of the park using vegetation maps or other biological data or models is problematic because features used to establish stratum boundaries at the start of monitoring will change over time. A vegetation map is a model based on remote sensing and field data, and map boundaries will change as classification models improve 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 (e.g. estimating current status for dynamic domains or subpopulations of interest such as a vegetation cover type for which the permanently specified strata boundaries are no longer meaningful). 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 judiciously to define either strata or areas to sample with higher probability (see also Chapters 2, 3, 5).
- Permanent sampling sites, revisited over time, are recommended for monitoring, because the objective is to detect changes over time. In most situations, revisiting the same sites increases the precision of change estimates, and therefore increases power to detect temporal changes (Chapters 7-8).

Another key aspect of the survey design involves consideration of whether sufficient sample sizes can be obtained to enable distinguishing the signal of interest from the noise (background variation). Although statistical power in the ecological sciences is seldom what we would like it to be, we at least need to ensure the cost and effort we expend on data collection have a reasonable probability of producing interpretable results (Chapter 8). If we do not have confidence in our results, then we are not providing managers with the information they need to make informed decisions.

Data management, analysis, and reporting

Data and information are the primary products of an ecological monitoring program (see also Chapter 2). Efforts to provide organized, well-documented data and information to key audiences will largely determine the monitoring program's efficacy and image among critics, peers, and advocates. Monitoring information is "wasted if it is not analyzed correctly, archived well, reported timely or communicated appropriately" (Gibbs *et al.* 1999). Information is created from data as a result of processing, manipulating, synthesizing, or organizing data in a way that provides interpretation or meaning.

Therefore, a critical component of the reliability of the monitoring program is to ensure that data and information are managed and analyzed so that they can be easily found and obtained, are subjected to full quality control before release, and are accompanied by complete metadata. The program needs to provide data and information in formats that are useful to end users. Finally, sensitive data (e.g. locations of some legally protected species) need to be identified and protected from unauthorized access and distribution.

The appropriate analysis of monitoring data, which is a focus of many chapters in this volume, is directly linked to the monitoring objectives, the survey design, the intended audiences, and the management uses of the data. As emphasized in Chapter 2, analysis methods need to be considered when the objectives are identified and as the survey design is developed, rather than after data are collected. Each monitoring protocol should contain detailed information on analytical tools and approaches for data analysis and interpretation, including the rationale for a particular approach, advantages and limitations of each procedure, and Standard Operating Procedures for each prescribed analysis (Oakley *et al.* 2003). Four general levels of data analysis that typically occur with a monitoring program are: (i) descriptive and summary statistical analysis; (ii) determination of resource status; (iii) determination of trends in condition over time for a monitored resource; and (iv) synthesis of status and trend information across multiple resources over time to depict larger-scale aspects of ecosystem structure and function.

Monitoring results must be reported and communicated using a variety of products and approaches in order to effectively convey results to key audiences. Park managers sometimes complain that scientists "tend to know (and communicate) too much" (Lewis 2007: 39), and managers usually prefer the Cliff's Notes'® version of scientific reports in the form of resource briefs or other short summary documents. The short summary documents, however, must be backed up by detailed technical reports and protocol documents so that the scientific credibility and reliability of the results can be established. Therefore, to deliver monitoring results to key audiences, each of the 32 NPS I&M networks produces a suite of products including 1- or 2-page resource briefs, simple data summary reports, more detailed technical reports, journal articles, and trend analysis and synthesis reports. Internet and intranet websites are the primary outlet for delivering monitoring results to park managers, planners, the scientific community, and the public (see http://science.nature.nps.gov/im).

The need for adaptability

One of the trade-offs that will inevitably be encountered is whether to change the monitoring program, and if so, how and when. The peer-review process helps us correct initial flaws or weaknesses in our approach, but other potential changes will need to be considered. Over time, new technologies for sampling emerge, analytical approaches are advancing, and even the questions being asked can change or evolve as we gain knowledge or have shifts in priorities. A successful monitoring program needs to be able to adapt to such changes without losing the long-term integrity of the data (Lindenmayer and Likens 2009). This decision requires careful consideration of the potential trade-offs between long-term data integrity and the potential need or benefits of change (Chapter 3). Analogous to Albert Einstein's well-known portrayal of model complexity, monitoring programs should accommodate as much change as is needed, but no more.

Commitment to the monitoring program

One of the most important prerequisites for a successful long-term monitoring program is an agency's commitment and solid funding base to sustain the program (Strayer *et al.* 1986). Institutional commitment is best achieved through clear demonstration of a program's value as a means of supporting sound science-based decisions and protecting resources, and the ability to demonstrate that the benefits derived from the program are worth the expense. In the NPS monitoring program, achieving commitment and support from the individual parks largely boils down to whether or not the program provides relevant and timely information that helps managers make decisions and work with other agencies and the public for the long-term protection of the park's resources and values.

Developing a partnership between scientists and managers from the outset

Any monitoring program intended to support management decisions must first understand the information needs of the managers (Chapters 2-4 and others). It is not enough for scientists to plan the effort based on what they believe a manager should know, rather than taking the time to work with managers to determine their priority information needs. Similarly, managers often will not know how to frame questions in such a way that these questions can effectively be addressed through long-term research or monitoring (Lindenmayer and Likens 2009). Developing a partnership between scientists and managers from the outset will help ensure that the questions being asked are relevant to the management and policy issues, and that the monitoring is designed to answer those questions effectively and in a scientifically defensible manner. This step alone will go a long way toward gaining support at the ground level - support without which the program has little chance of becoming an integral part of the organization's operations.

The NPS monitoring program attempted to establish a partnership between scientists and managers from the outset. An important step for achieving this was to involve both groups in the scoping process that led to the selection of appropriate indicators, as described earlier. This partnership has continued through the use of advisory and oversight committees comprised of park superintendants and park resource managers. Through these committees, park managers and other park staff work with I&M

network scientists to provide advice and feedback on the relevancy and effectiveness of the I&M network's efforts. Another important step has been to hire regional and network program managers with a solid scientific background but who understand the importance of establishing a strong long-term partnership between scientists and managers.

With good reason, many managers may be wary of new programs that promise much, but are slow to deliver results that make their job any easier. One of the key elements for maintaining support beyond the initial acceptance is to keep expectations realistic. It is important to be clear from the outset what can be delivered, but also what cannot be delivered (Chapter 3). A common expression in the consulting arena reminds us that it is far better to under-promise and over-deliver than the reverse.

Future research and development

Based on initial program reviews of most of the 32 I&M networks, and a review by the National Academy of Public Administration (NAPA 2010), the NPS monitoring program seems to be meeting its goals of providing credible, scientific data and information to park managers and other key audiences. All organizational levels of the agency view the monitoring program as successful. Although it may be several years (especially for slowly changing resources) before parks reap the direct benefits of long-term monitoring, we are already seeing the indirect benefits of having more scientists available who are familiar with a particular park's resources and issues (e.g. involvement in park planning, helping to identify research needs, etc.). The strategic decisions made and the guidance provided in the early years of planning and designing are paying dividends, but in hindsight there are also some things we would have done differently, as well as opportunities for improvement.

Integration of the NPS monitoring effort into planning and decision processes

Although the NPS monitoring program has gained considerable acceptance throughout our organization, we still have some work ahead of us regarding full integration of the program into the planning and decision processes (NAPA 2010). The true measure of whether a monitoring program is successful is if it routinely produces reliable information that is perceived as being essential toward achieving the agency's mission and goals. Being an integral component of the planning at all organizational levels from routine park management to agency policy decisions is the best way to achieve such success. Park managers have provided many examples of how the scientific data and understanding generated by the monitoring program have already been incorporated into park operations and planning documents. However, throughout the agency there are still many challenges and opportunities for integrating monitoring data and information into the planning and decision-making operations of the organization. The NPS leadership recently decided to begin developing a State of the Park Report for each park that will summarize status and trend information for important park resources and services. This decision is an important step towards institutionalizing scientific information into routine park operations.

Effectiveness monitoring versus overall condition monitoring

The NPS monitoring program, by design, provides information on the overall condition of each park and the long-term effectiveness of management regimes based on changes in the status and trend of selected park resources. In contrast, many monitoring programs have an emphasis on monitoring the effectiveness of specific management actions, often with short-term "experiments" in an adaptive management framework (Mulder and Palmer 1999). Because of the NPS mission and its "leave unimpaired for future generations" mandate, specific management actions that are conducive to such shorter-term effectiveness monitoring are more limited in NPS units compared to those of other agencies that more actively manage natural resources to meet specific objectives. Even in the NPS, though, both types of monitoring are needed. Some of the contexts within the National Park Service that are quite amenable to an adaptive management approach, particularly when accompanied by effectiveness monitoring, are fire management, invasive plant management, and visitor management (how many, where, when, etc.).

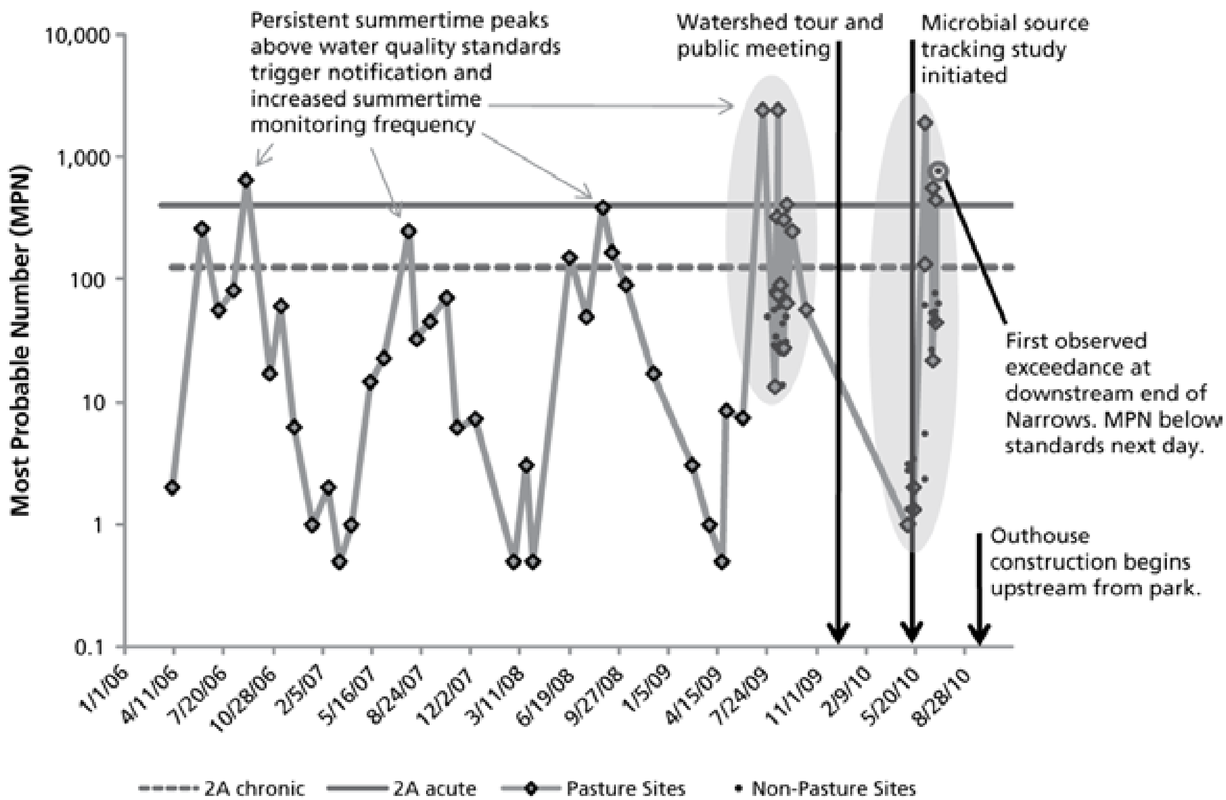
However, funding that was available for the NPS long-term monitoring program was enough to fund only one professional-level position per park, on average, plus some operating funds. We chose to focus on monitoring of long-term changes in the overall condition of park resources because it is integral to our agency's mission, and we assumed that funding from specific programs and projects would support short-term effectiveness monitoring as necessary. In retrospect, such funding has rarely materialized and this continues to be a real and unmet agency need.

If additional funding were available, the addition of a research complement to long-term monitoring would greatly facilitate our ability to use the information being generated by our monitoring efforts. Our current programmatic direction allows us to examine changes in the status and trends of resources in our parks, but without additional study does not effectively allow us to examine the causes of any changes we observe (Box 22.2). Incorporation of key covariates in our monitoring often leads to correlative results that can further lead to the development of hypotheses about such causes and effects, but to be truly effective, a complementary effort specifically designed for this purpose is needed. As important changes in status and trend of resources are observed, a complementary research effort focused on understanding the causes would greatly enhance our ability to incorporate information about such changes into sound management decisions.

Box 22.2 Common challenges: we've detected a problem

Long-term condition monitoring is designed to assess current status and trends for important resources and ecological processes, or human-caused stressors to the ecosystem. When a problem is detected, additional research studies or monitoring generally will be needed to determine likely causes of the problem. However, condition monitoring often can lead to relatively rapid and effective detection and mitigation of a problem, even when supplemental data collection is needed to assess causes of the problem. Moreover, although some benefits of a long-term monitoring program may not be realized until it has been operational for a decade or more, usually the program will almost immediately begin providing information highly relevant to managers. The following example demonstrates how water quality monitoring at Zion National Park (Utah, USA) relatively quickly confirmed the occurrence of an ongoing problem and led to management actions to try to reduce the problem.

The Northern Colorado Plateau Inventory and Monitoring network began monitoring the water quality of the North Fork Virgin River upstream from Zion National Park in 2006. Each summer for three years, the monitoring detected elevated *Escherichia coli* levels (see figure below) at a site where the river flows through irrigated pastures grazed by cattle (Van Grinsven *et al.* 2010). The results were reported to park staff. In 2009, hikers entering the Virgin River upstream of the park were issued warnings about these elevated levels. Monitoring was increased to isolate the source of contamination and help



Estimates of *Escherichia coli* population levels (Most Probable Number) for monitoring sites on the North Fork Virgin River, Utah, USA. Horizontal lines indicate water quality standards (exceedence thresholds) for the river.

determine if the problem was persistent or intermittent. The increased monitoring included a higher frequency of data collection at the original pasture site and the addition of three non-pasture sites: two sites 1-2 miles upstream, plus a heavily used visitor site at the mouth of the Zion Narrows, 16 miles downstream. Results from 2009 confirmed that the contamination source was near the pasture site, and that elevated *E. coli* levels were persistent during the summer season.

The Utah Division of Water Quality (UDWQ) subsequently hosted a public meeting with staff from NPS, the Bureau of Land Management (BLM), and the county Conservation District. The outcomes of the meeting included additional intensive monitoring and research study to determine if the source of the bacteria was human, bovine, or wildlife. Definitively identifying the source of contamination is complicated by several factors. Cattle graze the pastures adjacent to the stream in summer, but hundreds of visitors also use the stream, and there are second homes and wildlife in the watershed. After the meeting, the UDWQ provided the BLM with funds to build an outhouse at the trailhead upstream from the park, to mitigate potential bacterial inputs from park visitors. Continuing cooperation with the UDWQ, BLM, and Conservation District will help determine the source of bacteria and eventually help arrive at solutions that will involve federal and state agencies, as well as local land owners.

Summary

Managers of natural resources need reliable scientific data and information on the status and trends in the condition of key resources as a basis for conservation planning, determining whether current management practices are having the desired effect, and informing stakeholders and the general public of changes in the condition of park resources that may be caused by stressors operating at regional or global scales. Data collected in a consistent way over long periods are fundamental to conservation and management because they provide the context for interpreting observed changes, and may provide the basis for initiating new management practices or changing existing practices. Despite this need, the track record for institutionalizing long-term programs that provide such information is poor. In this chapter, we have provided examples and "key lessons learned" from our experience in planning and designing a long-term ecological monitoring program for more than 270 parks in the US National Park Service. We emphasize three critical elements for a long-term monitoring program in a resource management agency: relevance, reliability, and commitment. These elements are essential to institutionalizing a monitoring program such that it becomes an integral component in the planning and operations of the agency. The quantitative recommendations presented in this volume are an essential underpinning of the scientific credibility of any monitoring program, but they are just one component of designing, implementing, and institutionalizing a long-term ecological monitoring program.

References

Barber, M. C. 1994. Environmental monitoring and assessment program indicator development strategy. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory. Report EPA/620/R-94/022, Athens, Georgia, USA.

Carpenter, S. R. 1998. The need for large-scale experiments to assess and predict the response of ecosystems to perturbation. Pages 287-312 *in* M. L. Pace and P. M. Groffman, editors. Successes, limitations and frontiers in ecosystem science. Springer, New York, New York, USA.

Cote, M., D. Kneeshaw, L. Bouthillier, and C. Messier. 2001. Increasing partnerships between scientists and forest managers: lessons from an ongoing interdisciplinary project in Quebec. The Forestry Chronicle 77:85–89.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. Bureau of Land Management, BLM Technical Reference BLM/RS/ST-98/005+1730, Denver, Colorado, USA.

Environmental Protection Agency [EPA]. 2002. Guidance on choosing a sampling design for environmental data collection, for use in developing a quality assurance plan. Environmental Protection Agency, Report EPA QA/G-5S, Washington, D.C., USA.

Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment 151:161-174.

Gibbs, J. P., H. L. Snell, and C. E. Causton. 1999. Effective monitoring for adaptive wildlife management: Lessons from the Galapagos Islands. Journal of Wildlife Management 63:1055-1065.

Gross, J. E. 2003. Developing conceptual models for monitoring programs. <http://science.nature.nps.gov/im/monitor/docs/Conceptual_Modelling.pdf >. Accessed 5 Aug 2010.

Hammond, A., A. Adriaanse, E. Rodenburg, D. Bryant, and R. Woodward. 1995. Environmental indicators: A systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development. World Resources Institute, Washington, D.C., USA.

Hansen, M. H., W. G. Madow, and B. J. Tepping. 1983. An evaluation of model dependent and probability sampling inferences in sample surveys. Journal of American Statistical Association 78:776-793.

Huggett, R. J. 1993. Modeling the human impact on nature: systems analysis of environmental problems. Oxford University Press, New York, USA.

Jackson, L. E., J. C. Kurtz, and W. S. Fisher. 2000. Evaluation guidelines for ecological indicators. Environmental Protection Agency, Office of Research and Development, EPA/620/R-99/005, Research Triangle Park, North Carolina, USA.

Jacobson, S. K., J. K. Morris, J. S. Sanders, E. N. Wiley, M. Brooks, R. E. Bennetts, H. F. Percival, and S. Marynowski. 2006. Understanding barriers to implementation of an adaptive land management program. Conservation Biology 20:1516–1527.

Landres, P. B. 1992. Ecological indicators: panacea or liability? Pages 1295-1318 *in* D. H. McKenzie, D. E. Hyatt, and V. J. McDonald, editors. Ecological Indicators, Volume 2. Elsevier Applied Science, London and New York.

Lee, K. N. 1993. Compass and gyroscope. Island Press, Washington, D.C., USA.

Lewis, S. 2007. The role of science in National Park Service decision-making. The George Wright Forum 24:36-40.

Lindenmayer, D. B., and G. E. Likens. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology and Evolution 24:482-486.

Lovett, G. M., D. A. Burns, C. T. Driscoll, J. C. Jenkins, M. J. Mitchell, L. Rustad, J. B. Shanley, G. E Likens, and R. Haeuber. 2007. Who needs environmental monitoring? Frontiers in Ecology and the Environment 5:253–260.

Manley, P. N., W. J. Zielinski, C. M. Stuart, J. J. Keane, A. J. Lind, C. Brown, B. L. Plymale, and C. O. Napper. 2000. Monitoring ecosystems in the Sierra Nevada: the conceptual model foundation. Environmental Monitoring and Assessment 64:139–152.

McDonald, T. L. 2003. Review of environmental monitoring methods: Survey designs. Environmental Monitoring and Assessment 85:277-292.

Mulder, B. S., and C. J. Palmer. 1999. Introduction to effectiveness monitoring. Pages 1-19 *in* B. S. Mulder, B. R. Noon, T. A. Spies, R. G. Martin, C. J. Palmer, A. R. Olsen, G. H. Reeves, and H. H. Welsh, editors. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-437, Portland, Oregon, USA.

National Academy of Public Administration [NAPA]. 2010. Strengthening America's best idea: an independent review of the National Park Service's Natural Resource Stewardship and Science Directorate. http://www.napawash.org/NRSS/FINAL NPS NRSS Report 7-08-2010.pdf. Accessed 5 Aug 2010.

National Park Service [NPS]. 1999. Natural Resource Challenge: The National Park Service's action plan for preserving natural resources. <http://nature.nps.gov/challenge/assets/actionplan/NatRes2.pdf>. Accessed 5 Aug 2010.

National Park Service [NPS]. 2006. Management policies 2006. <http://www.nps.gov/policy/MP2006.pdf >. Accessed 5 Aug 2010.

National Park Service [NPS]. 2008a. Examples of specific, measurable, monitoring objectives. <http://science.nature.nps.gov/im/monitor/docs/Goals&ObjectivesGuidance.doc>. Accessed 5 Aug 2010.

National Park Service [NPS]. 2008b. Southern Plains Network Vital Signs Monitoring Plan. Natural Resource Report NPS/SOPN/NRR-2008/028. National Park Service, Fort Collins, Colorado.

National Research Council. 1995. Review of EPA's environmental monitoring and assessment program: overall evaluation. National Research Council, National Academy Press, Washington, D.C., USA.

National Research Council. 2000. Ecological indicators for the nation. The National Academies Press, Washington, D.C., USA.

Nichols, J. D., and B. K. Williams. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21:668-673.

Noon, B. R., T. A. Spies, and M.G. Raphael. 1999. Conceptual basis for designing an effectiveness monitoring program. Pages 21-48 *in* B. S. Mulder, B. R. Noon, T. A. Spies, R. G. Martin, C. J. Palmer, A. R. Olsen, G. H. Reeves, and H. H. Welsh, editors. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-437, Portland, Oregon, USA.

Noon, B. R. 2003. Conceptual issues in monitoring ecological resources. Pages 27-71 *in* E. D. Busch and J. C. Trexler, editors. Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, D.C., USA.

Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31:1000-1003.

Olsen A. R., J. Sedransk, D. Edwards, C. A. Gotway, W. Liggett, S. Rathbun, K. H. Reckhow, and L. J. Wong. 1999. Statistical issues for monitoring ecological and natural resources in the United States. Environmental Monitoring and Assessment 54:1-45.

Reid, L. M. 2001. The epidemiology of monitoring. J. Amer. Water Resources Assoc. 37:815-820.

Schreuder, H. T., R. Ernst, and H. Ramirez-Maldonado. 2004. Statistical techniques for sampling and monitoring natural resources. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-126, Fort Collins, Colorado, USA.

Sellars, R. W. 1997. Preserving nature in the national parks: a history. Yale University Press. New Haven, Connecticut, USA.

Spellerberg, I. F. 1991. Monitoring ecological change. Cambridge Press, Cambridge, UK.

Stevens, Jr., D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. Environmetrics 14:593-610.

Stevens, Jr., D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of American Statistical Association 99:262-278.

Strayer, D., J. S. Glitzenstein, C. G. Jones, J. Kolasa, G. E. Likens, M. J. McDonnell, G. G. Parker, and S. T. A. Pickett. 1986. Long-term ecological studies: an illustrated account of their design, operation, and importance to ecology. Occasional Publication of the Institute of Ecosystem Studies, Number 2. Millbrook, New York, USA.

Van Grinsven, M., M. Malick, M. Moran, and D. Thoma. 2010. Water quality monitoring in the Northern Colorado Plateau Network, 2006–2009. Natural Resource Technical Report NPS/NCPN/NRTR–2010/358. National Park Service, Fort Collins, Colorado.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2007. Adaptive management: The U.S. Department of the Interior technical guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C., USA.