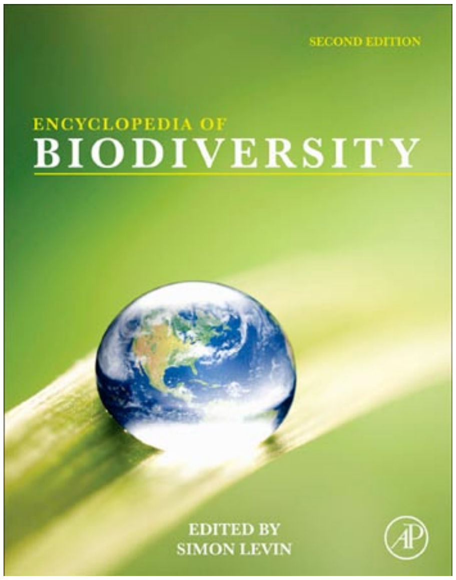

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Framework for Assessment and Monitoring of Biodiversity

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Glossary

Adaptive management A systematic, cyclical process for continually improving management policies and practices based on lessons learned from operational programs.
Analysis A process of exploring and estimating parameters of data, gathered with statistical procedures, to test previously established hypotheses.
Biodiversity assessment The identification and classification of species, habitats, and communities, within a given area or region. The overall purpose is to provide information needed to evaluate whether management is necessary to conserve biological diversity. Assessments also provide data and information that can be applied for programs of scientific inquiry.
Indicators Species or communities that enable an evaluation of environmental conditions and detect changes. Indicator species are normally surrogates of other species in the area of interest and are usually sensitive to environmental change. Environmental variables may also be used as indicators.
Monitoring The repeated collection and analysis of observations and measurements to evaluate changes in populations of species and environmental conditions. Monitoring also helps in assessing progress toward meeting a management objective. Monitoring can serve as a warning system, alerting managers that changes in biodiversity may require changes in biodiversity management regimes to ensure protection of biological resources.
Sampling Refers to the process of data collection. A protocol must be developed to direct sampling that includes sampling objectives, parameter to be measured, sample unit determination, permanent or temporary sampling, number of samples, and method of sample selection.
Uncertainty Describes the condition whereby managers have a lack of data, or unreliable, error-prone data of biodiversity that prevents them from defining the best course of management action. Uncertainty can be overcome through a well-designed adaptive management program.

Why are we interested in assessing and monitoring biodiversity? Accurate information on the status of components and processes of ecosystems is essential for the long-term maintenance of biodiversity, and its sustainable use. The selection of biotic indicators observable or linked across different spatial and temporal scales, are important to detect trends that can result in management practices (Feld *et al.*, 2009). Biodiversity assessment across spatial and temporal scales, at different levels of biological organization, and in terms of various attributes, processes, and functions of biodiversity, is critical to our understanding of ecosystem functioning and formulation of management objectives (Ash, 2009). In addition, most ecosystems are under severe pressure, either from increasing primary and secondary human impacts, or from climatic changes (Dallmeier *et al.*, 2010).

Biodiversity monitoring and assessment programs (BMAP) provide a process which collects and reports scientific information to be used for natural resource management. The first task in developing the BMAP program is to define the objectives. Then, a baseline biological assessment is often necessary to determine what kinds of species and habitats need to be considered as part of the program. After the assessment has been completed, monitoring the selected indicators to answer questions using the scientific method will provide biodiversity trends in the ecosystem. Monitoring activities leads to insights on issues such as those requiring management strategies, for example, the need for protection of threatened or endangered species, or the eradication of non-native invasive species. Monitoring is also used to assess progress made toward meeting a management objective and is an essential component of a successful adaptive management program.

Introduction

Natural resource managers and other decision makers working at the conservation and development interface confront challenging environmental issues that require science-based understanding of the status and trends of habitats and species. The primary role of the BMAP is to improve natural resource management and conservation and to build institutional knowledge. BMAPs are also designed to determine status and trend monitoring of species and habitats or baseline monitoring that is not focused on a particular management action but aims at increasing our understanding of natural processes and also acts as an early warning system. Reports and recommendations to managers based on the sampling design and data collection are the principal products of the BMAP. Sound data management is necessary to provide quality information to long-term programs. Sound BMAP programs provide information that managers need to make decisions either alerted to an impending problem, for example, early detection of invasive exotic species or pathogen, or in response to management actions that they are implementing, for example, effectiveness of invasive exotic plant management efforts, or effectiveness of restoration of degraded habitats.

BMAP Spatial and Temporal Scales

Effective BMAP frameworks require successful integration of different monitoring components to produce information that is more useful than the individual components. This integration requires spatial and temporal considerations at the ecosystem and landscape levels.

Monitoring ecosystem structure and function at the landscape level requires careful consideration for the selection of appropriate indicators. The monitoring strategy will utilize several individual indicators that collectively will measure the status and changes within the entire ecosystem. An ecosystem can be very large and most monitoring programs, depending on their design, can only make inferences to the areas that are considered as part of the sampling strategy. Results may be representative of larger areas but must be used cautiously. Often a suite of indicators is selected at various hierarchical levels of ecological organization, such as community, population, genetic levels (Noss, 1990) or from species or habitats of conservation concern and of value to society. Integration of spatial information requires the establishment of measurements made at different areas and scales within the study areas. This strategy requires understanding of spatial sampling design frameworks.

Timelines for sampling indicators also need to be considered based on the characteristics and temporal variations that these indicators may show. For example, monitoring forest dynamics and regeneration often requires 5-year measurements of tree size classes and their distribution in permanent plots, whereas water quality may require continuous measurements. The integration of monitoring programmatic activities requires coordination and communication among BMAP management organizations and other stakeholders to promote wide participation in the use of the resulting information.

BMAP Goals and Objectives

The purpose of BMAP is to develop science-based information on the current status and trends in the composition, structure, and function of habitats and species, and to link that information to management practices and policy decisions. Scientifically based information from BMAP increases the confidence level of a manager in predicting the outcome of his decisions and to operate more effectively. The overall goals of the BMAP are site specific and related to the issues and concerns addressed by the program.

Overall goals and objectives of BMAP include:

- Assess species and habitats to determine presence and relative abundance.
- Select the species and habitats that will be used as surrogates for the area under study.
- Establish the status and trends of selected species and habitat indicators to allow managers to work more effectively to minimize potential impacts on the resource and provide adaptive management strategies.
- Provide early warnings on the condition of species and habitats to help management in developing mitigation strategies.
- Monitor selected species and habitats to understand their natural and human-induced dynamics and conditions. First assessment should serve as a baseline reference to determine desired state.
- Integrate the BMAP in an adaptive management cycle for planning, management, and decision making.
- Provide data-driven information to understand the dynamics of species and habitats through comparison with similar natural and human-managed systems.
- Generate information to meet regional, national, and international environmental laws and regulations.
- Provide timelines and deliverables toward achieving the specific goals of the BMAP.
- Disseminate information generated by the program to multiple stakeholders to engage them in management and conservation efforts.

Based on these goals, it is important to develop a conceptual ecosystem model to define the study areas, identify geographical issues, habitats and species, and describe the ecosystem structure. Designing the assessment and monitoring programs requires the selection of indicators to monitor, and the development of the monitoring protocol. The final components are the implementation of the protocols, synthesizing information, and the application of recommendations as part of the adaptive management process (**Figure 1**).

The BMAP is based on the scope of the project, specifications to meet the established goals and contain variables that can be measured so that the information collected addresses questions and hypothesis. Managing objectives provides the appropriate focus to address the change/trend objective, for example, to increase the density of Species A by 30% or decrease the frequency of invasive species by 30% at a particular location (Elzinga *et al.*, 1998).

Sampling strategy is based on the sampling objectives of the BMAP that will address the monitoring questions. These questions may be formulated as part of the process and lead to other projects using experimental design to test hypotheses. They include levels of precision and magnitude of variation expected to be detected by the BMAP (see the BMAP protocol design section). The BMAP objectives provide additional details about the monitoring program or sampling protocol and the limits of the program. For example, are the objectives measureable and achievable? Is the monitoring and sampling location specific enough? Are the species and habitats being monitored, clearly selected, and specified? Will the data and information user be able to anticipate what the data and information will look like? **Table 1** provides some specific examples of monitoring objectives for BMAP sampling protocols.

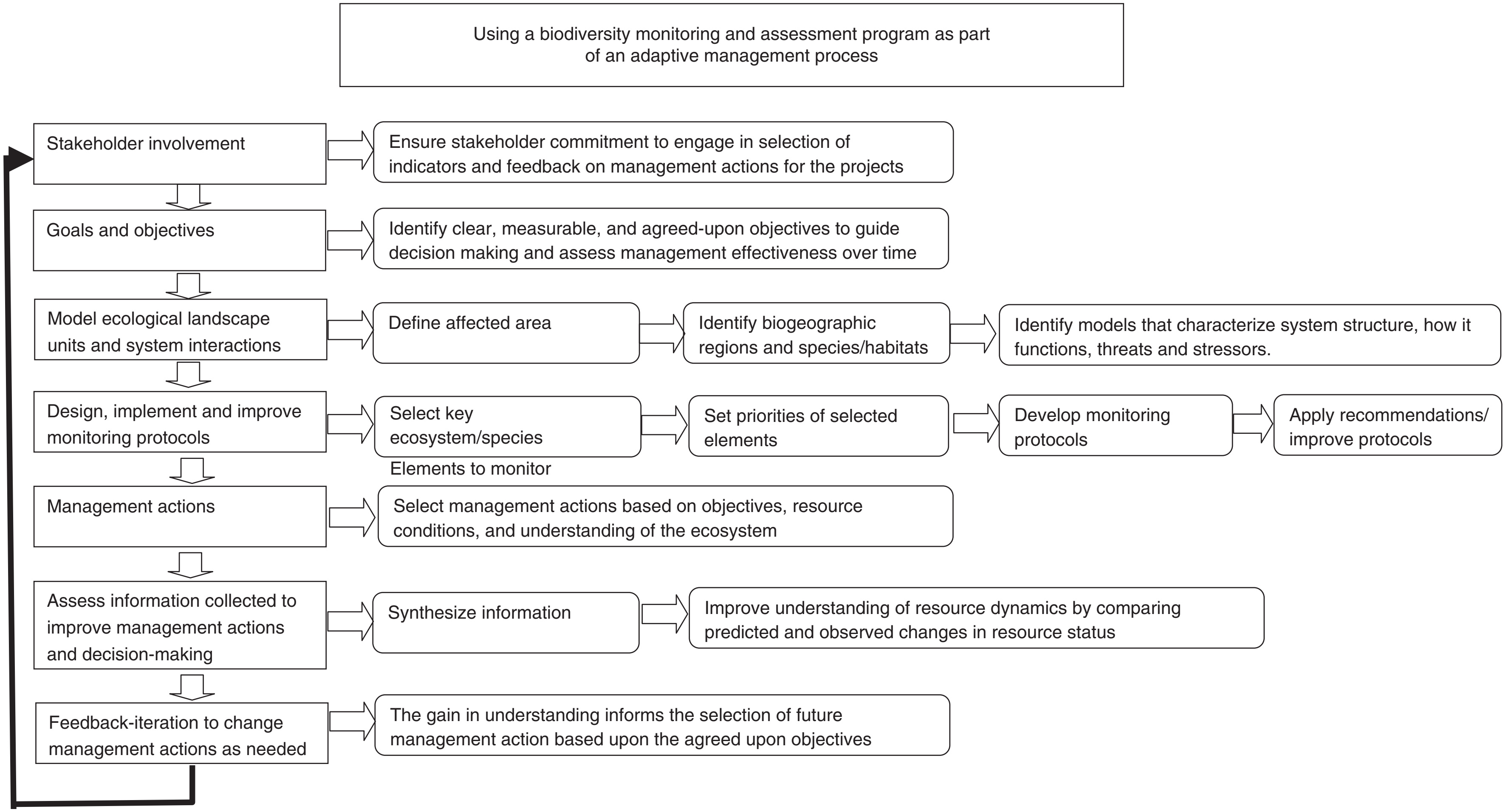

Figure 1 Biodiversity monitoring and assessment program as part of an adaptive management process.

Table 1 Examples of BMAP monitoring objectives

BMAP protocols	*Measurable objectives*
Wetland vegetation	1. Determine if species composition and abundance is different in areas up-stream and down-stream from park road. 2. Determine if species composition and abundance is the same in areas around the road where road improvements were made.
Fishes	1. Determine fish species diversity, composition and abundance in high altitude freshwater lagoons. 2. Associate these parameters to water quality in areas close and far from access roads. 3. Determine trends in the distribution and abundance of native species of fishes in areas where exotic species are introduced.
Birds	1. Determine annual status and trends in territory occupancy of cloud forest birds in areas near and far from the human development. 2. Determine annual status and trends in nest success of endemic species of birds in areas near and far from the human development.
Bats	1. Determine the distribution and abundance of desert bat species in the coastal pacific desert area of a National Park. 2. Determine short- and long-term trends in the presence of bat species and flower and fruit production by cacti species in the area.
Squamata	1. Determine the species of lizards that are found in the area of influence of new road and infrastructure development. 2. Determine the distribution and abundance of lizards in the area of new road and infrastructure development. 3. Evaluate the mitigation measures and the short and long-term trends of the distribution and abundance of lizards in the restored right of way of new road and infrastructure development and in areas control.
Amphibians	1. Determine the species of amphibians that are found in the area of influence of new development. 2. Determine the distribution and abundance of amphibians in water bodies that are close and far away from the new development. 3. Evaluate the presence of the chytrid fungus in the populations of amphibians close and far away from the new development. 4. Determine the short and long-term trends of the distribution and abundance of the chytrid fungus.
Grasslands bio-restoration	1. Determine the composition and abundance of grassland communities. 2. Monitor short and long-term trends in species composition and abundance of grass land species in areas that have been restored to reduce road erosion.
Endemic tree species	1. Determine the distribution and abundance of the endemic tree species with respect to the area of influence of development. 2. Determine the short- and long-term trends in annual recruitment.
Benthic marine community	1. Determine short- and long-term trends in percent cover of sessile marine benthic invertebrates and algae around a new jetty. 2. Determine short- and long-term trends of non-native marine communities that may have been brought by incoming boats.
Marine fish	1. Determine long-term trends in the composition and abundance of fish species of importance to the local communities in areas close to a newly constructed jetty and its area of impact.

BMAP Guiding Principles

The BMAP is based on the following guiding principles: (1) science-based, (2) peer reviewed protocols, (3) biological sampling, (4) link species/habitat to management objectives, (5) focus on species/habitats of conservation concern, (6) comply with national and international regulatory frameworks, and (7) communicate findings and implement recommendations. A small suite of indicators (Simberloff, 1998; Zacharias and Roff, 2001) are part of the basic measures of the BMAP, including biological (e.g., key species abundance and distribution), physical, and chemical elements and processes (e.g., precipitation, water temperature and pH) that represent the entire array of ecosystem features. These features, when measured over time, reflect temporal and spatial changes in habitat and species related to ecosystem structure and function. They also serve as 'leading indicators' of system integrity, stability, and capacity for self-renewal.

Choosing Appropriate Indicators

According to the U.S. National Academy of Sciences (2000, p. 1) the purpose of indicators and monitoring is succinctly described as:

> Developing indicators and monitoring them over time can help to determine whether problems are developing, whether any action is desirable or necessary, what action might yield the best results, and how successful past actions have been. To develop and implement sound environmental policies, data are needed that capture the essence of the dynamics of environmental systems and changes in their functioning.

Sampling all components of biodiversity in a given area is generally an impractical and costly task, but biodiversity surrogates enable monitoring of ecosystem functions (Noss, 1990, 1999). The concept of 'biodiversity indicators' is widespread and a key component of most biodiversity inventory and monitoring systems (Lee *et al.*, 2005). As examples, one might choose an oak tree species affected by gypsy moth defoliation, or a species whose recruitment and mortality is impacted by extended droughts. During the planning stage, it is recommended to identify potential indicator species. Important criteria in selecting indicator species include the following:

(i) The species, populations, or observed physical or chemical phenomena should be good measures of questions that the monitoring program was designed to answer.
(ii) The indicators should be able to detect a condition in advance to assist in solving the problem or else they may have a limited role in achieving the monitoring goals.
(iii) Whenever possible, indicators should be selected for which experimented controls are present (e.g., populations under different management intensities).

(iv) It should be possible to monitor the indicators within realistic budgets.
(v) The species should be selected based on their potential for impacting management decisions (e.g., charismatic species are more likely to facilitate management changes than less-attractive species).

Several considerations play a role in meeting these criteria. First, keystone species are those on which many other species may rely at some point in their life cycles. In tropical regions, for example, nectar-feeding bats are considered as a keystone species because the reproductive success of many plant species through pollination depends on them. Key common species are those that are wide-ranging, easily observed and studied, long-lived, and generally occurring at high-population densities (e.g., oak species in the eastern United States). A sudden increase, decline, or disappearance of these species in certain habitats serves as a warning that may require management attention.

Next, species or taxonomic groups that have sensitive life histories may be good indicators for biodiversity monitoring. Amphibians depend on water for reproduction and will be affected by drought or water pollution. Information on amphibian numbers, diversity, sex ratio, age, and size structure will indicate changes that may affect other components of biodiversity. And, monitoring the abundance and diversity of selected tropical frog populations can provide valuable data on the health of those populations, and hence the habitat, from one year to the next.

Finally, key habitats may also be important indicators. For example, the aspen and wet meadow habitats of the Colorado Rocky Mountains in the United States are good indicator habitats because of the species that depend on them.

Legal and Institutional Framework

The BMAP needs to provide full compliance with applicable legal requirements and project commitments (i.e., government, corporate, lenders, stakeholders, others). The principal requirements and commitments relating to biodiversity and monitoring are embodied in the international, national, state and local laws and regulations, specific project, environmental and social impact assessment (ESIA) and environmental and social management plans (ESMP), Ecological Management Plans, Biodiversity Action Plans, International Performance Standards on Social and Environmental Sustainability, and other national and international conventions, standards, and policies.

Conceptual Ecosystem Model to Support the BMAP

Conceptual ecosystem and landscape models provide an important framework to integrate current information and knowledge of an area to identify the important elements of the system, species, processes, dynamics, and conservation issues, facilitate the communication of complex subjects, and demonstrate connections within the ecological system (Gross, 2003). Models play an important role in virtually all applications of structured decision making, whether adaptive or otherwise, by linking potential management actions to ecological consequences (McGowan, 2011; Moore and McCarthy, 2010). To make informed decisions, it is important to compare and contrast management alternatives in terms of their costs, benefits, and resource consequences. Models typically express benefits and costs in terms of management inputs, outputs, and outcomes through time. Importantly, they allow one to forecast the resource impacts of management.

Development of conceptual models is recommended before initiating the assessment and monitoring programs. This process improves the collective understanding of the system and the models are important throughout the formulation of the BMAP as they provide the scientific framework for the selection of the elements to monitor. Conceptual models are a combination of diagrams and narratives that communicate interactions among ecosystem processes and dynamics, identify links among system stressors and system responses, assist in the selection of assessment and monitoring variables, and communicate the processes to diverse audiences (**Table 2**).

The recommended process (Gross, 2003) to develop project specific conceptual models includes the following activities:

- Goal setting. The primary goal of the model is to provide a synthesis of the ecosystem dynamics that will help identify the species, habitats, and other indicators that will be monitored. It will also show the relationship between indicators and ecosystem variables. The model also facilitates communication among professional and technical personal and external stakeholders.
- Set boundaries of the system. The model clearly defines the boundaries of the system illustrating the special and temporal issues for monitoring and management. It includes the variations of habitats to be assessed and monitored such as altitudinal variations, forest, grasslands, wetlands, and rivers.
- Identify system stressors. Natural and human-induced stressors, such as pollution, road construction, water use, poaching, logging, land-use changes, and many others, impact ecological systems with different intensity. Stressors are these natural or anthropogenic physical, chemical, or biological impacts to a system that are applied to the system at extreme or deficient levels (Barrett *et al.*, 1976). It is important that the model communicates the relationship among stressors, environmental responses, and the characteristics of the ecosystem. During the process of evaluating this relationship it is important to record the possible assessment and monitoring questions as well, and alternative hypotheses to be considered by the program. It is also important to prioritize, at this time, the list of possible indicators for the BMAP.
- Model reviews and revisions. As new information is generated and goals change over time, the model will need to be revised and updated.

Design Monitoring Protocols for Species and Habitats

Assessment and Monitoring Components

Biodiversity assessment involves compiling inventories and providing baseline information for the selection of the

Table 2 Examples of monitoring plans and conceptual models

Monitoring Plans and Conceptual Models	*References*
Biodiversity Monitoring Strategies	Beever (2006)
	Payet *et al.* (2010)
	Regan *et al.* (2008)
	Reynolds *et al.* (in press)
	Scott *et al.* (2009) – Forests
	Watson and Novelly (2004)
Vital signs monitoring plans	Davis (2005)
	Comiskey and Callahan (2008)
	Garrett *et al.* (2007)
	Gitzen *et al.* (2010)
	Jean *et al.* (2005)
	Mau-Crimmins *et al.* (2005)
	Mitchell *et al.* (2006)
	Patterson *et al.* (2008)
	Route and Elias (2007)
Multiple species monitoring and assessment	Dallmeier *et al.* (2011)
	Ludwig *et al.* (1997, Ludwig and Tongway (2000)) – Rangelands
	Manley *et al.* (2000) – Forests & rangelands
	McKelvey *et al.* (2009)
	Noon *et al.* (1999)
Mammals	Wilson *et al.* (1996)
Birds	Ralph *et al.* (1993)
	Welsh (1995)
Reptiles and Amphibians	Dodd (2003) – Amphibians
	Heyer (1994) – Amphibians
	Mattfeldt and Grant (2007) – Salamanders
	Patton *et al.* (2003) – Pond breeding amphibians
	Zylstra *et al.* (2010) – Desert Tortoise
Fish	Isaak *et al.* (2009) – Bull Trout
Plants	Dallmeier and Comiskey (1998, 1999)
	Comiskey *et al.* (2009) – Forest Monitoring
	Elzinga *et al.* (1998)
	Woodward and Beever (2010)
Arthropods	Bowser and Morton (2009)
Impacts	Abbott and Le Maitre (2010) – Climate change
	Lutes *et al.* (2006) – Fire
	Knutson *et al.* (1999) – Fragmentation
	Martin and Murray (2010) – Invasive Species
	Randolph *et al.* (2009) – Disease
Sustainability and Integrity	Aguirre-Bravo *et al.* (2006)
	Harwell *et al.* (1999)
Uncertainty Modelling	Rodríguez *et al.* (2007)

elements to monitor. These assessments can be comprehensive for multiple species and habitats or selective to target individual or group of species and habitats. The assessment can aid in identifying species, habitats, and communities that are important due to their rarity or those that could be used as biological indicators, or those that are important to local human communities. This helps determine species and areas that require conservation or restoration actions. The assessment process includes literature reviews, field surveys, stakeholder consultation, and inventories to gather data relevant to the site-specific monitoring program, and to identify knowledge gaps and target indicator variables (Fancy *et al.*, 2009).

Before monitoring or management activities are implemented, an assessment process should be conducted. The assessment consists of an inventory of species and resources in the area of interest, as well as an evaluation of the priorities and threats to those resources. For example, acid deposition is a stressor that can influence both terrestrial and aquatic systems in the mid-Atlantic region of North America and land-use change can increase fragmentation and alter ecosystem processes in the lowland rainforests of eastern Brazil. Without an understanding of the potential effects of stressors, it is difficult to evaluate the best management options and define the indicators that we need to monitor. Stakeholder consultation from subject matter experts is integral to this process to ensure clear understanding of effects, processes, and potential outcomes.

Assessment objectives generally include information on the location, the taxonomic groups, species or indicator to be recorded, attributes to be measured, the desired state of the species or habitat, and any measures on the status to be evaluated. Monitoring objectives also include the management action, threshold values, levels of change occurring before management activities occur, the measurable quantity, direction and degree of change expected from the management, and a time frame for the monitoring activity. As the sampling design is developed, a sample objective is stated that includes specifics such as the size of the change you aim to detect and levels of precision. Before objectives are finalized, stakeholders should be consulted and a thorough review of relevant literature and background knowledge of the study ecosystem and processes should be completed.

Selecting the elements to assess and monitor can be complex and challenging. The evaluation process requires the identification of the reliable measurements that will generate the best species and habitat information for the least cost. It will also require identifying the measures that will be essential to provide early warnings of conditions that require management intervention. The conceptual model described above helps to break down these diverse and complex elements of the system into categories to simplify the task and assure that all critical elements are considerate. The study area may be divided into an exhaustive list of mutually exclusive categories geographically, climatically, ecologically (life zones), or by scientific disciplines (geology, hydrology, climatology, biology). More commonly, most of the monitoring programs are organized around scientific disciplines as practical and cost effective approach to engage experts and trained specialists to implement the BMAP (see Table 2).

BMAP Selection Criteria

Selection criteria of habitats and species and associated parameters to be measured for each are essential first steps after the development of the conceptual model. The selection criteria include: (1) a broad array of species representing a wide array of ecological roles; vegetation, herbivores, long-lived and short-lived species, and mobile grazers and predators; (2) species and habitats representative of common and dominant ecosystems; (3) species and habitats of conservator concern and special legal status such as threatened or endangered species, endemic species, invasive or alien species and species of social, economical and cultural importance; and (4) abiotic parameters, such as sea temperature, precipitation, and meteorological measures are also complementary important criteria to the biotic system. Based on the information from the baseline assessments, the selection criteria for the BMAP is often based on site-specific priorities such as landscape changes; habitat destruction, overhunting, overgrazing, soil compaction, erosion, degradation of water quality, and the conservation status of certain species and habitats.

BMAP Protocols Design

A key component of a credible monitoring program is the protocols for data collection (Holthausen *et al.*, 2005). A protocol establishes how data are to be collected at each sample point. Protocols are detailed plans for each stage of the monitoring process and should be developed based on the management and monitoring objectives (Atkinson *et al.*, 2004; Oakley *et al.*, 2003; Szaro *et al.*, 1999a). Protocols are necessary to ensure that changes detected from the monitoring data reflect actual changes in the environment and are not just a result of measurements taken by different observers using slightly different methods or approaches. Well-designed protocols allow comparisons of data between organizations and localities, and lend credibility to your program during peer-review processes. Protocols should be developed for all steps of the monitoring project, including sampling design, field methods, personnel training, data management, quality assurance and quality control, data analysis, interpretation, and reporting. The US National Park service has an online database of existing protocols that are available for download: http://science.nature.nps.gov/im/monitor/VitalSigns/BrowseProtocol.aspx.

Monitoring and assessment protocols are designed to frequently collect and analyze observations of selective elements of the system to evaluate the status and changes of these elements and the resource and to measure progress toward meeting the goals and objectives of the BMAP (Oakley *et al.*, 2003; Elzinga *et al.*, 1998). Precise monitoring and assessment protocols are necessary to measure variables and observations in time by different individuals. Protocols often include quality assurance and quality control measures to ensure that they are being implemented correctly and to provide the levels of confidence for the credibility of the program, which allows comparisons of data across space and time sampling intervals.

It is often useful to pose the following questions related to the variables to measure: Are the results of each specific technique well integrated with the overall program? Do the methods that are used ensure reliable, timely, and effective data analysis? Are the collected data subject to the appropriate techniques for data management and analysis? Could the data gathered be coupled with new technologies for analysis and management? What mechanisms exist or can be developed to allow timely transfer of data and information to managers and decision makers?

Oakley *et al.* (2003) provides the guidelines for the preparation of long-term monitoring protocols that include the Standard Operating Procedures that specifically describe how all the components of the monitoring program will be carried out. Periodical formal reviews of individual protocols and the monitoring program are an important component of the overall quality assurance of the program.

Developing the Sampling Design

Fundamentals

Sound sampling designs provide guidelines for the most cost-efficient and effective way to gather and analyze data while maintaining high quality control standards (Smyth and James, 2004). The sampling design should address the following questions: (1) What do researchers need to know about the study area (e.g., data on forest composition, structure, and diversity as well as site-specific information such as the effects of acid deposition, drought, fires, or other disturbances)? (2) How will data from the program be used (managerial and scientific uses)? (3) Is the site representative of the habitat of interest? (4) Will the design be sensitive enough to detect changes? (5) What limits of change are expected and are important to detect (e.g., mortality rates of forest stands should not exceed 3–5% per year)? (6) What is the degree of confidence expected from the results? (7) Will the sampling design produce results that will be representative of what is happening in the entire study area?

Sampling Objectives

Sampling objectives should be developed in conjunction with management objectives (Elzinga *et al.*, 1998). Sampling (or statistical) objectives specify information such as target levels of precision, power, and the magnitude of change that one wants to detect. Precision is a measure of repeatability, or how close two repeated measurements are to each other, and is frequently obtained by calculating the standard deviation of the estimated mean from which confidence limits are calculated. Sampling objectives also identify the level of change to be detected and the risk of missing a real change or, alternatively, detecting a false change. These factors are related to the variability of the population and the number of samples used, all of which will determine the power of the sampling approach. The sampling objective should also define the population of interest. This target population consists of the complete group of sample units (e.g., individual animals and quadrats), about which inferences are to be made. It is important to distinguish the target population from the population actually sampled (the sample population). Statistical inferences can only be made about individuals and areas that have a chance of being sampled. For example, the target population may be all individuals of a specific ant species within a reserve. However, if sampling to the roadside is limited, then the ants in areas close to roads become the sample population and inferences can only be made about ants inhabiting areas close to roads. In some cases, it may be necessary to define a new sample population for logistical reasons, but this can be done in such a way that the inference is not reduced. For example, if the target population covers a very large geographic area, sample sites need to be randomly placed within the target population and sampling should be done only within these. As the sample sites have been randomly placed within the target population, inference still extends to the entire target population.

Defining Spatial and Temporal Scales

Identifying the spatial and temporal scale of the study is essential at the planning stage because it has important implications in defining effective sampling design and resource requirements. The scale often depends on the scientific goals of the program or on the managerial regions under study. Often, the scale for assessment and monitoring is based on the geographical boundaries of the protected area or conservation unit, or on subsets of such areas. Biodiversity assessment and monitoring at local and regional levels can provide decision makers with high-quality data and cost-effective choices. At local levels, studies usually concentrate on specific communities, and are chosen because of the degree of threat, because of species' locations, or due to organizations' legislative boundaries; but the results may not be representative of the landscape-level biodiversity. Monitoring populations at the landscape level provides broader information sets, but often requires sampling under different land management conditions, and may call for special permits and a large budget. The time frame depends on the biology of the species (e.g., short-lived species will respond more quickly than long-lived ones), the intensity of management (intense management produces rapid changes), and the level of specified change (the smaller the change, the sooner it will be detected). Short-term responses may benefit from more frequent evaluation of the management objectives, and results can be presented relatively fast. Nevertheless, sufficient time must be allocated to detect changes as many impacts may not be detected until as much as a decade after the initial activity. Conclusions were obtained only after a few years indicating that no effects of management could be deceptive. In some cases, monitoring objectives may be best met by focusing on more than one scale. One approach for answering multiscale questions is to select indicators at multiple hierarchical levels of ecological organization (e.g., genetic, individual, population, community, and landscape). Using multiple indicators can also increase knowledge gained as each indicator may respond differently to the same stressor or management activity. Integration of these levels will often require nesting of more intensive and frequent sampling within the context of less-frequent sampling. Objectives with multiple time frames also benefit from frequent assessment of monitoring directions and protocols within the context of long-term goals.

Parameters and Sampling Unit

- *Choice of parameter*: A parameter is a measurable attribute such as plant height or animal mortality. The parameter should be sufficiently sensitive in detecting the desired level of change and capable of distinguishing between natural fluctuations and human-induced change. The change registered by the parameter should be biologically meaningful and lead to a logical management response. The variability in observer error inherent in measuring the parameter should be minimal. In addition, the cost of measuring the variable must be within the budget, and it is necessary to identify the expertise and technical ability needed to measure the parameter. Some of these issues may be addressed by conducting pilot studies.
- *What is a sample unit?* A sample unit is often determined by the choice of parameter. For example, if the parameter is a plant part such as the number of flowers per plant, then your sample unit will be the individual plant. If your parameter is plant density, a quadrat will be the appropriate sample unit choice. Important considerations in choosing sample units include independence from each other, randomization in sample unit selection, and sufficient replication (sample size) of units (Elzinga *et al.*, 1998). When this is the case, statistical estimates of your parameter can be produced along with a reliability estimate. Randomization of the selection process is imperative to produce unbiased information with inference to the population as a whole. Selectors of sample units, based on judgments of 'representative' areas, are often heavily biased.
- *Sampling unit size and shape*: Some sample units have predetermined unit sizes (e.g., individual lizards), and thus the unit sizes and shapes are not factors in the design. Others, such as pitfall traps, could be set at any unit size or shape that the design dictates, and are thus determined by the researcher. As increasing sample sizes (i.e., the number of samples) increases the power to detect changes, smaller sample units may be advantageous by allowing the sampling of more units. However, if the units are too small, the sample will be highly variable, reducing the precision of the estimates. Conversely, in very large plots, the variability among units will be low, but there may be too few plots to compare. This is also dependent on the inherent variability in the community or population being monitored. If the variability in your sample is low, then you may be able to achieve the same power to detect changes with fewer and smaller sample units, than if the variability is high. In plot-based sampling, the shape of the plot must also be determined. Rectangular plots have a greater "spread" over the area than square or circular plots, and are thus more likely to incorporate individuals if they are clumped or aggregated. This decreases the variation among the plots and increases the precision of the estimates.
- *Sampling unit locations*: Positioning of sample units within the population should be done in such a way as to (1) incorporate a random component to the selection process and (2) achieve good interspersion of units across the population. There are a number of different types of sampling methods that can be used; the most common ones being the following:
  a. Simple random sampling can be employed for relatively small study areas with homogenous habitats. This type of sampling keeps analysis simple, but it may lead to some areas within the target population being underrepresented. It tends to be an inefficient design for clustered populations, and it can be logistically difficult

as it can result in considerable travel time between sample units in larger study areas.

b. Stratified random sampling is useful when the parameter of interest is influenced differently across some variables such as habitat or climatic differences. A simple random sample is taken within each stratum, and the number of sample units within each stratum does not need to be equal. For example, if the strata are of differing sizes, the number of units per stratum may be proportional to the size of the strata. If there is a strong influence on the parameter by the strata variable, this design can result in more efficient population estimates than simple random sampling.
c. Systematic random sampling, when samples are placed in a grid or regular pattern, is useful for most sampling situations, except when the number of possible samples is low. It provides good interspersion of sample units and is an efficient design for data collection. Two necessary components of this design are (1) a randomly selected starting point and (2) units that are far enough from each other to be considered independent. Another approach, generalized random tessellation stratified (GRTS) sampling, combines random and systematic sampling in a spatially balanced design allowing for addition or subtraction of sample sites/units in the future while still maintaining spatial balance.
d. Restricted random sampling is setup by determining the number of sampling units that are needed (n), and then dividing the population into n equal-sized segments. A single sample unit is randomly positioned or selected within each segment. This method provides good interspersion across the population and is an alternative to systematic sampling if the number of potential samples is low. When the potential number of samples is 425–430, systematic sampling is more efficient and should be chosen instead.
e. Cluster sampling is used when it is difficult to take a random sample from the population. Clusters of units are identified, and then clusters are randomly chosen instead of randomly choosing from the units themselves. Every unit within the cluster is then measured. This is a cost-efficient design but more complex calculations are required.
f. Two-stage sampling can be used in place of cluster sampling if there is a large number of units within each cluster. In two-stage sampling, a second sample of units is taken within each cluster, instead of sampling all the units in the cluster. Cluster sampling and two-stage sampling are generally the only efficient methods for estimating a parameter associated with individual plants.
g. Should permanent or temporary sample units be used? As monitoring occurs over time, it is necessary to decide whether to measure the same sample units at each time period, or to randomly reselect sites at each time period. This decision partially depends on whether the aim of the project is to estimate the status or the trend. If the main goal of the program is to determine the status of a population, selecting a new sample is appropriate. Conversely, if the objective is to estimate the change or trend in a population, it is best to use permanent units. Permanent units outperform temporary ones for trend assessments, as statistical tests for detecting change between one time period and the next are more powerful when based on permanent units owing to the removal of variation between different plots. However, permanent units are often more costly as units need to be marked for relocating at later time periods, and marking may be infeasible and difficult (e.g., sand dune systems). As monitoring programs often aim to determine statuses and trends, an option is to incorporate both aspects into the design. For example, an augmented rotating panel design includes some units that are resampled every year and others that are reselected on a rotating basis. Another option is the augmented serially alternating design in which some units are always sampled and the others are sampled on a rotating basis. However, data analysis becomes more complex with these designs, and this fact should be taken into account during the planning stage.
h. How many sample units do we need? A sufficient sample size gives you the power to assess whether your management objective has been achieved. However, as costs increase with your sample size, a balance needs to be met. There are a number of issues involved in determining the appropriate sample size. The initial consideration is the level of precision stated in the objectives. For example, if the objective is to increase the population abundance of a species by 20%, a sample size with sufficient precision to detect a change of that magnitude is needed. It is important to keep in mind that the increase in precision is not proportionate to the increase in sample size. The statistical benefits of increasing sample size generally diminish after a certain sample size has been achieved. There are a number of power analysis equations that can be used to determine sample size, and, for these calculations information (such as variability in the measurements) needs to be gathered during a pilot study. Researchers need to be familiar with the assumptions of these formulas and the effects they have on the calculations before proceeding. Assumptions include random selection of sampling units, an infinite population, and an approximately normal distribution of sample means.

Data Analysis

Once the scientific questions are defined and the objectives of the monitoring established, the methodology for the data analysis needs to be considered. Each monitoring protocol contains detailed information on analytical tools and approaches for data analysis and interpretation, including the rationale for a particular approach, and advantages and limitations of each procedure. A number of graphical methods are used to reveal patterns in the data that are not evident by calculating summary statistics such as means and standard deviations (Ellison, 2001). The type of data analysis that is most appropriate should be determined during the planning stage of the project. Analysis will depend on the objectives and design.

Exploring Data

The first important step in data analysis is to do an initial exploration of the data. This is very important when assessing pilot studies as it will help in understanding the variability in the data as well as whether the assumptions of the parametric tests apply to the data (*see* Parameter Estimation and Significance Tests). There are a number of graphical methods that reveal patterns in the data that are not evident by calculating summary statistics such as means and standard deviations (Ellison, 2001). A normal probability plot allows you to assess how closely the data fits a normal distribution. The observed values are plotted against the values that would be expected if the data came from a normal distribution. A plot showing a straight line indicates normality. Density plots such as histograms are useful for displaying the distribution of data and thus can reveal issues such as data skewness. However, histograms have the disadvantage of grouping the data into arbitrarily determined bars or bins. The number and width of these bins can alter the shape of the histogram. Dit plots are similar to histograms, where all data points are presented. Box plots are another commonly used form of data exploration. This plot displays more information about the data than a histogram. The median, 25th and 75th percentiles, data spread, and outliers are represented.

Parameter Estimation and Significance Tests

The type of data analysis that is most appropriate should be determined during the planning stage of the project. Analysis will depend on the objectives and design. For example, parameter estimation is generally needed for a monitoring project with target/threshold objectives, and significance tests are often used in projects with change/trend objectives. Parameter estimation involves generating a sample statistic such as a mean or total that estimates the true population value. An associated confidence interval is also calculated. This provides an estimate of precision around the sample statistic that specifies the likelihood that the interval includes the true value. The sample statistic can then be compared with the target or threshold value to assess whether the objective has been reached or if further management activity is necessary. For example, the management objective is to maintain a population of at least 5000 individuals of a certain species in a reserve over a period of 10 years. If the lower bound of the confidence interval is above this threshold, there is confidence that the objective has been achieved (based on the desired confidence level). Conversely, if the upper bound of the confidence interval is below the threshold of 5000, there is confidence that the objective has not been achieved. The results are less clear when the confidence interval overlaps the threshold. In these cases, management decisions are often based on the perceived level of risk associated with implementing or not implementing further action. Tests of significance are used to assess whether there has been a change in the parameter of interest between the time periods of the monitoring program. In the same way, they can also be used to compare specific parameters in different spatial areas. These tests produce a probability estimate of whether a change seen is real or simply due to random variation from different samples. The next step is to test for significance and thus a null hypothesis needs to be expressed. This usually asserts that there has been no change in the parameter of interest. The hypothesis will be rejected if the significance test concludes (with a desired level of confidence) that there has been a change in the parameter between the sampling periods. The null hypothesis is evaluated by calculating a test statistic that quantifies the difference between the samples. The confidence level is important as this determines, on a probabilistic basis, how large the test statistic should be before the null hypothesis is rejected. There are two types of errors that can be made in arriving at a decision regarding the null hypothesis. The first, Type I error, involves rejecting the hypothesis when it is actually true. The larger the predetermined confidence level, the more likely it is that the null hypothesis will be falsely rejected. The second, Type II error, involves failing to reject the null hypothesis when it is actually false. Type II error is related to the power of your test. The most commonly used significance tests for monitoring questions are *t*-tests (when comparing two samples), analysis of variance tests (when comparing more than two samples), and w2 tests (when comparing proportions). The first two tests here are parametric tests as they estimate population parameters such as means or totals. Parametric testing requires several assumptions to be met for the results of the test to be valid: (1) The population must follow a normal distribution. (2) The variances must be relatively similar between the samples. (3) The sample must be randomly selected from the population. There are tests that evaluate departures from assumptions 1 and 2, but in most cases graphical review of data is the best method. If deviations from these assumptions are found, increasing sample size or transforming data may resolve the issue and allow you to proceed. If not, there are alternate methods (nonparametric statistics and resampling methods) that do not require these assumptions to be met.

Nonparametric Statistics

When the assumptions of parametric tests cannot be met, or due to the nature of the objectives and data, nonparametric statistics may be an appropriate tool for data analysis. Many nonparametric tests focus on the order or ranking of data, not on the numerical values themselves. Other nonparametric tests are useful for data for which ordering is not possible, such as categorical data. These tests generally focus on the differences between samples in medians instead of their means, as seen in parametric tests. Nonparametric tests commonly used for monitoring questions are w2 tests, Mann–Whitney *U*-test, Wilcoxon's signed rank test, and McNemar's test. The advantages of nonparametric tests are (1) they may be the only alternative when sample sizes are very small, unless the population distribution is known exactly, (2) they make fewer assumptions about the data, (3) they are useful in analyzing data that are inherently in ranks or categories, and (4) they often have simpler computations and interpretations than parametric tests. The main disadvantage of nonparametric tests is that they are generally less powerful than their parametric analogs.

Data and information management goes hand in hand with data collection. The raw data are the basis for the analysis, synthesis, and modelling of the monitored species and habitats that will generate the interpretation for decision making. For these reasons, data need to be properly recorded, analyzed, reported, archived, documented, and catalogued using a proper information management system. Data management within the information management system needs to ensure that the data are readily available, unverified data are not released, data distributed is accompanied by metadata, sensitive data (i.e., potential commercial value of plant species) are identified and protected from unauthorized access, and data dissemination records are maintained.

Decision Making

Analysis and evaluation elicit answers to the questions underlying the project's objectives, thus allowing for the generation of management recommendations and the calibration of the program. In addition, it allows an evaluation of the process. It is often useful to pose the following questions: Are the results of each specific technique well integrated with the overall BMAP? Do the methods used ensure reliable, timely, and effective data analysis? Are the collected data subject to the appropriate techniques for data management and analysis? Could the data gathered be coupled with new technologies for analysis and management? What mechanisms exist or can be developed to allow timely transfer of data and information to managers and decision makers? Management approaches should be viewed as a means to reach operational goals. Through evaluation of the monitoring data, managers receive timely feedbacks as hypotheses are tested. Thus, evaluations are the tools for improving management by checking on management actions and providing guidelines for improvement. For example, when a predetermined degree of change is detected, appropriate action is taken and the results are evaluated. All the preceding steps lead to decision making regarding the need or lack, thereof, to adjust the management practices and monitoring program. If the findings determine that biodiversity trends are within the expected values, monitoring will continue without substantial alterations. If significant changes in the trends are observed, managers or decision makers need to design the most appropriate response in an adaptive management framework. The reasons for monitoring can be evaluated at this stage. Is the monitoring still required, and, if so, do the objectives still remain the same? Inconclusive results require adjustment of the objectives and sampling approaches to increase the degree of precision. Therefore, careful planning and design of the monitoring program can reduce the risk of inconclusive information.

Data and Information Management

Analysis of the data generated by the BMAP will support the program objectives, the sampling design, and the information for management and stakeholders. There are several levels of data analysis generated by assessment and monitoring protocols: (1) descriptive summaries of basic statistical analysis; (2) baseline descriptive information on status of the monitored resource; (3) trends and condition of the monitored resource; and (4) statistical synthesis of resource trends along spatial and temporal scales. Often descriptive analyses are performed at any time following data collection and input to calibrate sampling methodologies and detect early variations. One approach is to ensure that results are reported on a regular basis – may be annual or less frequent depending on the protocol. The idea is that data is put out in some form to stakeholders. These more frequent reports are low level data summaries. Status and trends reports go into more depth and involve more review, but are less frequent. A long-term trend information synthesis is subject to scientific peer review as appropriate.

The US National Park Service (2008) has provided Data Management Guidelines for Inventory and Monitoring Networks: http://science.nature.nps.gov/im/datamgmt/standards/data_standards_summary_20100610.pdf. In addition, national (NPS, 2008) and network data management plans (e.g., Callahan and Wakamiya, 2008) are developed and made available. The strategy for data and information management for BMAP includes: describing the long-term data and information management for the BMAP with the overall BMAP goals and strategies; defining the specific procedures and work practices for effective data management; training the BMAP personal in sound data management practices; encouraging effective data management practices as a part of project management so that all data are available and usable for management decisions at all times; and promoting data sharing, software development, applications and analyses. The products that are often part of the data and information management system include:

- Compiled data – GIS information, maps, species lists, data files, and analyzed records.
- Documents – BMAP protocols and protocol updates, metadata, information on reference collections and photographs.
- Reports – Periodical or final reports and publications.
- Management and administrative records – BMAP contracts and agreements, BMAP operational timelines, research permits, and memorandum of understandings.

Information Management Goals

The information management goals for the BMAP are: (1) to confirm that the BMAP personnel leading the protocols, data collection and data management, and collaborators understand the essentials of data and information management; (2) to implement effective data management practices by integrating quality control procedures throughout the project; (3) to generate communication protocols to reach multiple stakeholders; and (4) to develop a framework to integrate the monitoring information into recommendations that can be implemented by adaptive management.

Communications

Communicating the BMAP results is essential to disseminate knowledge about the resource and its management, and to keep stakeholders informed of the activities performed by the program. There are many approaches to develop communication plans including the establishing of mechanisms and timing for information dissemination, developing the information and tools to convey the messages to specific audiences, creating timelines for knowledge and information dissemination, assessing the cost to implement the communication plan, and defining the messages to be communicated to each audience.

BMAP and the Adaptive Management Approach

Adaptive management is a systematic and iterative approach for improving resource management by emphasizing learning from management outcomes (Holling, 1978; Bormann *et al.*, 2007). The underlying assumption is that adaptive management is not simply changing management direction in the face of failed policies but is a planned approach to reliably learn how to improve policies or management practices over time in the face of uncertainty (Bormann *et al.*, 2006, 2007; Burgman, 2005). Adaptive management is not an end in itself, but a means to more effective decisions and enhanced benefits through monitoring the impacts of management practices at achieving the desired outcome. A fundamental premise of adaptive management is that complete knowledge of species and ecological systems is not only incomplete but almost impossible to fully determine (Stankey *et al.*, 2005). As a result, there is a growing realization that decisions need to be made without complete understanding and that expanding knowledge through traditional scientific inquiry will always be limited by resources and time. Adaptive management is one way that understanding and learning can directly inform decision-making and policy processes. In the case of biological resources, the desired outcome is to maintain biodiversity in an optimally functioning state. Human activities can have drastic impacts on biodiversity, impacts that often are irreversible or require long and costly periods of recovery. Managing biodiversity conservation through the adaptive management process can help to avoid or mitigate those impacts.

Adaptive management can be described as a cycle of iterative activities, where each step builds on the learning experiences of previous steps, as the calibration of the goals and objectives is conducted through a feedback process determined by assessing and analyzing monitoring data (**Figure 1**). Each step is calibrated periodically to assure that the appropriate information feeds the next level. The cyclical nature of the process is very important in validating the results of the separate steps. One useful way to describe the implementation of adaptive management is in terms of a setup or planning phase in which its key components are put in place, and an iterative phase in which they are linked together in a sequential decision process (Williams *et al.*, 2009). The iterative phase utilizes the elements of the setup phase in an ongoing cycle of learning about system structure and function, and managing based on what is learned.

Stakeholder Involvement

Project definition, development, and implementation require continuous stakeholder involvement and feedback. Stakeholders are individuals representing local, regional, national, and international communities, agencies, nongovernmental organizations (NGOs), industry, and any other organization with an interest in the project or responsibility within the area of the project's influence. Consulting stakeholders throughout different stages of the project is very important. Of particular importance is the participation of stakeholders in assessing the resource problem and reaching agreement about its scope, objectives, and potential management actions (recognizing that differences of opinion about system responses may exist even with consensus on these issues). By defining the operating environment of a project, stakeholders directly influence both decision-making and the opportunity to learn. The breadth and extent of stakeholder involvement can vary greatly among projects, and both are influenced by the scale and complexity of the intended project. Stakeholder participation in some cases will be restricted to an internal process when the organizations' goals are driven by legal requirements and institutional/organizational policies.

Management Objectives as Related to the BMAP Objectives

Objectives, resource status, and learning all influence the choice of management interventions in adaptive management. Objectives also play a crucial role in evaluating performance, reducing uncertainty, and improving management through time. It is especially important to have clear, measurable, and agreed-on management objectives at the outset, to guide decision making and assess progress in achieving management success. It is often the case in adaptive decision making that there are multiple objectives. In such a situation it is important to weigh different objectives in terms of their perceived importance, so as to facilitate the comparison and prioritization of management alternatives (Burgman, 2005). Initially, management objectives are formed to frame the question and goal.

Management Actions

Like any iterative decision process, adaptive decision making involves the selection of an appropriate management action at each decision point, given the status of the resources being managed at that time. Resource managers and stakeholders, typically working with scientists, have the responsibility of identifying the set of potential actions from which this selection is made.

The management alternatives in an adaptive management project constitute a key element in its operating environment, and they can strongly influence strategy selection. Just as the choices made in daily life depend on one's available options, so are strategy choices in an adaptive management project constrained by the set of available options. If these options fail to span a reasonable range of management activities or fail to produce recognizable and distinct patterns in system responses, adaptive management will be unable to produce effective and informative strategies. This argues for careful thinking about the potential actions to be included in a project.

Decision-Making

At each decision point, an action is chosen from the set of available management alternatives. Management objectives are used to guide this selection, given the state of the system and the level of understanding when the selection is made. The appropriate action is likely to change through time, as understanding evolves and the resource system responds to environmental conditions and management actions. That is, management is adjusted in response to both changing resource status and learning. It is the influence of reduced uncertainty (or increased understanding) on decision making that renders the decision process adaptive.

Follow-up monitoring

Monitoring is used to track system behavior, and in particular to track the responses to management through time. In the context of adaptive management, monitoring is seen as an ongoing activity, producing data to evaluate management interventions, update measures of model confidence, and prioritize management options in the next time period.

Evaluation, Decision-Making, and Feedback

At any given time, the gain in understanding from monitoring and assessment is used to inform the selection of management actions (Szaro *et al*., 1999b). As understanding evolves, so too does the decision making that is influenced by improved understanding. In this way, the iterative cycle of decision making, monitoring, and assessment leads gradually to improved management as a consequence of improved understanding.

Management approaches should be viewed as a means to reach operational goals. Through evaluation of the monitoring data, managers receive timely feedback as hypotheses are tested. Thus, evaluations are the tools for improving management by checking on management actions and providing guidelines for improvement. For example, when a predetermined degree of change is detected, appropriate action is taken and the results are evaluated.

The need to better understand and characterize the process elements of adaptive management often becomes more pressing as adaptive management rolls forward through time. Thus, stakeholder perspectives and values can shift as the adaptive process unfolds, and previously unanticipated patterns in resource dynamics can arise that require an adjustment of objectives, alternatives, and other elements of the process. In this sense, learning focuses on changes in institutional arrangements and stakeholder values as well as changes in the resource system.

All the preceding steps lead to decision making regarding the need, or lack thereof, to adjust the management practices and monitoring program. If the findings determine that biodiversity trends are within the expected values, monitoring will continue without substantial alterations. If significant changes in the trends are observed, managers or decision makers need to design the most appropriate response in an adaptive management framework. The reasons for monitoring can be evaluated at this stage. Is the monitoring still required, and, if so, do the objectives still remain the same?

Inconclusive results require adjustment of the objectives and sampling approaches to increase the degree of precision. Therefore, careful planning and design of the monitoring program can reduce the risk of inconclusive information.

Learning from Experience

The explicit hypotheses about the relationships between strategies and objectives and the emphasis on learning are some of the basic elements of adaptive management (Price and Daust, 2009). Assessment and monitoring programs are widespread in conservation organizations, agencies, and industry as a means to improve understanding and future management. Many have had mixed results, suffering from problems that may have been foreseen if other approaches and programs had been reviewed (Stem *et al*., 2005; Reid, 2001). Although each monitoring program has differing objectives and thus needs to be tailored individually, there is much to be learned from previous projects. Common issues include: poorly defined monitoring questions and objectives, poorly trained field crews, incomplete baseline information and assessments, sampling plans that are not designed to meet objectives, delays in analyzing data, inadequate monitoring durations, poor data management and interpretation, and lack of integration of the monitoring results into management. In many cases, utilizing management in an experimental context, such as that implemented in adaptive management, may be the only feasible way to gain the system understanding needed to improve that management.

All these can be overcome by paying greater initial attention in identification of specific monitoring questions, goal development, and project planning. Strict development of protocols for each step of the process increases quality control and allows the identification of potential issues at the outset. A more integrated approach to biodiversity management across sectors, administrative boundaries and at landscape and seascape scales would be an important step forward in conservation (European Environment Agency, 2010). To accomplish this, there is a need for greater collaboration within the conservation community to promote learning from experience, reduce duplication of efforts, and strengthen projects by combining resources.

See also: Ecosystem, Concept of. Ecosystem Function Measurement, Aquatic and Marine Communities. Ecosystem Function, Principles of. Population Viability Analysis

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