CHAPTER 1
Introduction to Monitoring

Thelypodium repandum
Wavy-leaf Thelypody
Endemic to Challis volcanic soils in east-central Idaho
Artist: Glenn A. Elzinga

The root of the word *monitoring* means "to warn," and one essential purpose of monitoring is to raise a warning flag that the current course of action is not working. Monitoring is a powerful tool for identifying problems in the early stages, before they become dramatically obvious crises and while cost-effective solutions remain available. For example, an invasive species that threatens a rare plant or animal population is much easier to control at the initial stages of invasion, compared with eradicating it once it is well established at a site. Monitoring is also critical for measuring management success. Effective monitoring can demonstrate that the current management approach is working and can provide evidence supporting the continuation of current management.

For monitoring to function as a warning system or a measure of success, we must understand what monitoring is, as well as the close relationship between monitoring and improved natural resource management decision making.

DEFINITION OF MONITORING

In this handbook we define monitoring as the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective. Good objectives are critical to successful monitoring. What is measured, how well it is measured, and how often it is measured are design features that are defined by how an objective is articulated. The objective describes the desired condition. Management is designed to meet the objective. Monitoring is designed to determine if the objective is met. Management is changed if monitoring reveals a failure to meet the objective. Objectives form the foundation of the entire monitoring project.

Monitoring is only initiated if opportunities for change in management exist. If no alternative management options are available, expending resources to measure a trend in a species population is futile. What can you do if a population is declining other than document its demise? Because monitoring resources are limited, they should be directed toward species for which management solutions are available. Fortunately, for most species there are management options available, although some may be politically difficult or very expensive to implement.

The management framework in which monitoring functions has been termed "adaptive management." In this framework, monitoring measures progress toward or success at meeting an objective and provides the evidence for management change or continuation (Holling 1978; Ringold et al. 1996). Because the term "adaptive management" has been adopted as a buzzword, its definition and meaning have become muddied by widespread use. In this handbook we define adaptive management as a process in which management activities are implemented in spite of uncertainty about their effects, the effects of management are measured and evaluated, and the results are applied to future decisions (Nyberg 1998).

Adaptive management is "learning by doing" (Lee 1999). It is a way of thinking about and implementing natural resource management that recognizes our understanding of ecosystems (even simple ones at small scales) is very incomplete and that any management we impose on the system is essentially an experiment (Gunderson 1999; Walters and Green 1997). There are three goals of adaptive management: 1) manage currently to the best of our knowledge, 2) learn from management, and 3) improve management in the future. In adaptive management, learning is as important as doing — monitoring is as important as management.

The adaptive management cycle is illustrated in Figures 1.1 and 1.2. In the first figure, monitoring successfully completes the adaptive management cycle. In the second figure, because the monitoring data are inconclusive, the cycle is incomplete and the management response is unknown. The monitoring effort is ineffective.

A successful adaptive management cycle involves the following steps:

1. A model of the system or species is developed. Models range from complex computer models designed to describe a complex system to simple doodling on a sheet of paper.

All are simply tools to help summarize, think about, and communicate with others concerning the system. We use only very simple models in this handbook, but encourage their use to help you think about your system and problem.

2. An objective is developed to describe the desired condition. We stress simplification and careful selection of one or a few objectives for each problem or species.
3. Management is designed and implemented to meet the objective.[1]
4. The resource is monitored. Monitoring techniques selected depend on the objectives. For example, if the objective is to increase cover of *Primula alcalina*, the technique selected would be one of those available to measure cover, not density or population size.
5. Monitoring data are analyzed to determine if objectives are reached. These results are summarized in a form accessible to decision-makers and stakeholders.
6. Management is adapted (changed) if objectives are not reached. We recommend identifying the proposed alternative management before monitoring is initiated, so that all parties understand how the monitoring data will be used to adapt management. If monitoring data provide new insights into the species or problem, the model is improved and new objectives are developed.

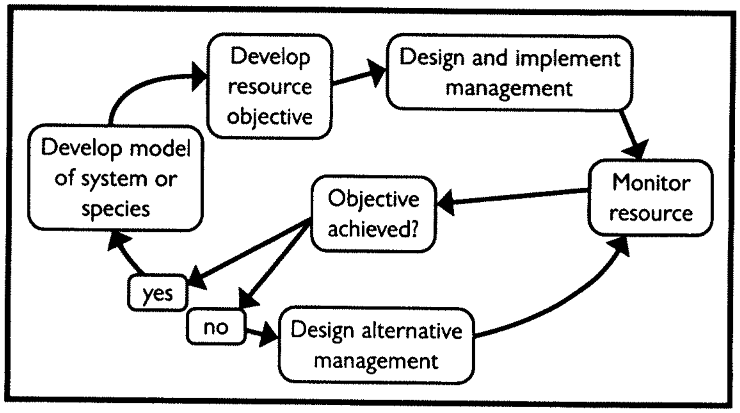

Figure 1.1. Diagram of a successful adaptive management cycle. Note that monitoring provides the critical link between objectives and adaptive (alternative) management.

Adaptive management has been promoted as a valuable tool for addressing large-scale, complex, natural resource management issues. Many authors further define adaptive management in terms of experimentation, in which the design of the management and monitoring incorporate a statistical design (research design) that allows changes to be attributed to (shown to be caused by) management (Lee 1993; Lee 1999; Nyberg 1998; Walters and Holling 1990). In this handbook, we focus on the simplest type of adaptive management: observational studies of single variables. Some authors classify this approach as the "monitor and modify" method, rather than true adaptive management (Johnson 1999). Rather than quibbling over terms, we contend that observational monitoring can be most effectively applied in an adaptive management framework. We also suggest that, realistically, given the technical skills available to most natural resource managers and the local scale of many management actions, observational studies will be the most common type of monitoring used.

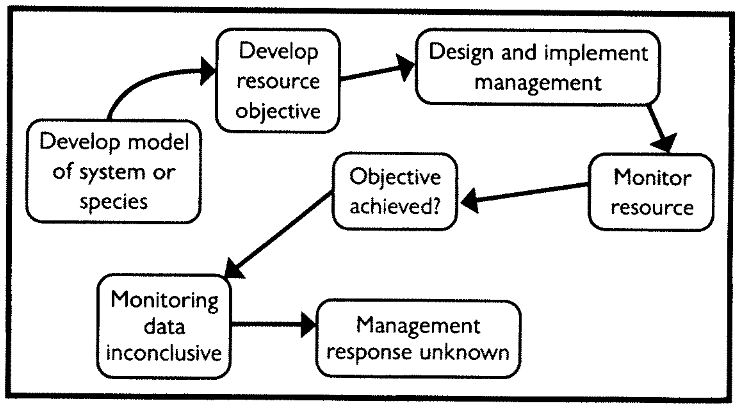

Figure 1.2. Diagram of monitoring that fails to close the adaptive management cycle. Because monitoring data are inconclusive, the management response is unknown and the cycle is unsuccessful.

---

[1]*Most descriptions of adaptive management recommend that management be designed not only to meet a resource objective, but also to learn more about the system, i.e., design management as an experiment. In this handbook, we focus on observational studies rather than experiments.*

What is the difference between an observational study and research? Both are information-gathering activities, and the field techniques used may be quite similar; the difference really is more one of degree than kind. Because of this, confusion exists about the difference between an observational study (especially one that applies sampling design and statistical analysis) and research.

Observational monitoring and research are ends of a continuum (Fig. 1.3). The confidence of attributing a change to a particular cause increases along the continuum, but the cost of acquiring the needed data also increases. Statistical significance is often erroneously equated with cause. In Figure 1.3, statistically significant differences were found in several scenarios, but only

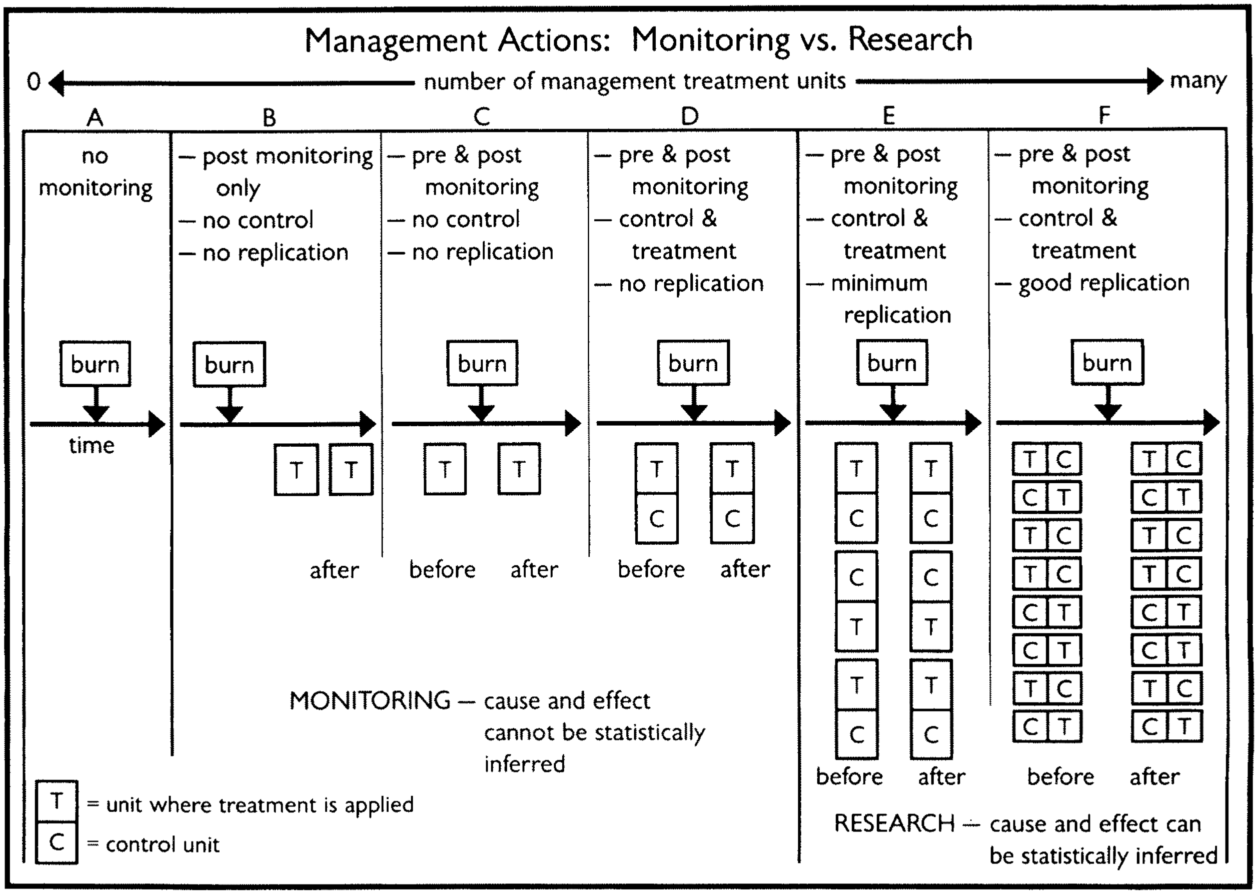

Figure 1.3. A comparison of monitoring and research approaches for detecting a treatment effect from a prescribed burn. For each of the scenarios shown in columns B-F above, statistical comparisons can be made between different time periods and a decision can be made as to whether or not a statistically significant difference occurred. However, the interpretation of that difference can be confounded by factors that are independent of the treatment itself. The diagram and the following examples illustrate a continuum of increasing confidence in determining likely causation as you move from left to right in the diagram. In column B, there is no pre-treatment measurement but you may see differences between years one and two after the burn. There is no way of knowing the conditions prior to treatment, and changes may be due to the burn, or they may be the result of some other factor such as lower precipitation. In column C, where data was gathered both before and after the burn, you still don't know if changes were due to the burn or some other factor that differed between the two time periods. In column D, there is a single treatment unit and a single control unit. Perhaps you see a change occur in the burned area but not the control area. The change could be caused by the burn or there may be some other factor that differentially affects the treatment area compared to the control. The burn unit, for example, could have a slightly lower water table than the control unit, a factor independent of the burn but not apparent. Other factors such as disease, insect infestation, and herbivory often occur in concentrations, affecting one area but not adjacent areas. Any of these factors could be the cause of observed differences. In the last two columns, the treatment and control are replicated in space; thus there is a possibility of attributing differences to the treatment. Since ecological systems are variable, the example in column E with three replicates may have inadequate statistical power to detect differences. The differences due to the treatment may be hidden by differences that occur due to other factors. The larger number of replicates in column F greatly increases the likelihood of detecting treatment differences due to the higher statistical power associated with 8 replicates as compared to 3 replicates.

*the term "significant" means that a statistical test was carried out and the difference was significant according to the test.

for the last two scenarios (Columns E and F) can you attribute significant differences to a cause. Observational monitoring data are usually of limited value in determining causes of change, and you must be careful to not misrepresent monitoring data as information on cause and effect. For example, if one were to simply note a decline in a species population after logging, this would support the hypothesis that logging negatively impacts the species, but it does not prove that logging is the cause of the decline. The decline has to be consistently found at several logging sites and not found in uncut areas to confidently determine logging activities as the cause of the decline. Only with several replications of treatment and control can you confidently attribute changes to a treatment or cause. Your design must incorporate control (minimize the differences between the treatment and nontreatment areas except for the treatment itself) and replication (measure the difference between treatment and nontreatment consistently over several-to-many independent units).

Natural resource managers must decide during the development of a project whether proving causal relationships is important. If demonstrating causality is required, the cost of obtaining that information must be evaluated. In many cases of resource management, a research approach may not be feasible. Some typical problems with incorporating a research design are the complexity of the system, the nonlinear response of organisms to causal mechanisms, and the lack of available replicates because only one "treatment" area is available (Thomas et al. 1981).

Box 1.1. *COMMON FAILURES IN MONITORING PROGRAMS*

TECHNICAL PROBLEMS

1. *Poor design leads to inconclusive results.*
2. *The use of multiple observers or unreliable data collectors complicates interpretation of results.*
3. *Data are lost, either physically (because of poor documentation or storage) or institutionally (because no one can decipher the data sheets).*
4. *Data are not analyzed because the biologist lacks the skills or the will to do so.*
5. *Natural system fluctuation obscures change caused by management.*

INSTITUTIONAL PROBLEMS

1. *Lack of institutional support results in premature termination of monitoring because of the loss of the project advocate (usually the biologist), budget decreases, changes in priorities, or increased politicization of the situation.*
2. *Lack of institutional support limits resources needed to implement monitoring as planned. Often data are collected, but inadequate resources are allocated to analyze, interpret, and communicate results.*
3. *Managers refuse to use monitoring data to make decisions because internal (other staff specialists) or external (stakeholders) antagonists question the data.*
4. *Failure to place monitoring within a management framework encourages the perception that the data are interesting but not directly applicable to a management decision.*

This handbook is not designed as a guide for developing research projects. Good design is essential to the success of a research project and often requires specialized skills. We suggest you consult with a statistician who is well versed in sampling design, especially if the treatments are expensive (such as eradication of a predator or prescribed burns). Underwood (1997), Hairston (1989), and Manly (1992) all provide an excellent introduction to good, effective research designs in ecology.

WHY DOES MONITORING OFTEN FAIL?

Biologists and botanists are often frustrated because their monitoring efforts fail to result in management changes or improvement in the resources they are concerned about. Box 1.1 lists common reasons why monitoring projects fail. Generally, these can be classified as technical failures (poor data collection methods, loss of data) and social and institutional failures (ending the monitoring program prematurely because of new crises or lack of support). All of these are linked to a fundamental problem: the failure to place monitoring within the context of a management framework. Successful monitoring is much more than counting plants and animals in plots over time.

MONITORING SPECIES, HABITATS, AND THREATS

We can monitor a species directly through counts or measures of performance, such as cover or reproductive output, or we can monitor some indicator of species success, such as habitat indicators, another species whose success is related to the success of the species of interest, threats to the species, and, for animals, indirect indices of abundance. Often monitoring a species directly is quite difficult and indicators may be much more easily measured (MacDonald and Smart 1993). For example, annual plant populations are difficult to monitor directly because so much of the population exists in a cryptic form as seeds stored in the soil. Similarly, many animals are secretive and difficult to observe directly. An indicator may be the only reasonable way to monitor such species. For some species such as very short-lived species with fluctuating populations or very long-lived populations that exhibit change slowly, monitoring an indicator may be more sensitive to detecting undesirable change than monitoring the species directly.

When management efforts designed to conserve a species are focused primarily on improving habitat conditions for the species, monitoring habitat indicators may be a more direct measure of management success than monitoring the population. For example, we may know that successful reproduction of woodcock (*Scolopax minor*), a small earthworm-eating game bird, requires (among other things) meadow openings in forested areas as courtship grounds. We may also know that fire suppression has resulted in a reduction in size and quality of these meadows on a preserve that we manage. We plan to introduce prescribed burning into this preserve to improve these meadows for use by the woodcock. A reasonable monitoring strategy is measuring the change in structure of the meadows (size, number, quality), with perhaps some corollary qualitative observations on use of the meadows by the bird, rather than trying to monitor the response of the woodcock population itself to our management action. Because population size may be affected by a number of factors, monitoring the woodcock population is not only more difficult and expensive than monitoring the meadows, but the data probably will not provide much feedback on whether our prescribed burning activity was beneficial.[2]

---

[2]*Monitoring that incorporates a research design may allow you to determine if prescribed burning actually did benefit the population, but this approach may not be affordable. In many management situations, a research design may not even be possible. It is unlikely in this example that you could isolate the effects of burning on the population within the habitat area because of the movement of the birds and the lack of a large enough area to implement independent treatment and control sites.*

Monitoring the change in extent or intensity of a threat may also be a more direct measure of the effectiveness of management than measuring the species itself (Salafsky and Margoluis 1999). For example, you may know that a riparian plant species disseminates nondormant seed in the fall (does not store seed in the soil) and that herbivory by cattle of the seed stalks can reach up to 80% within a particular population. Changing the grazing and monitoring the success of the grazing management by monitoring stubble height of riparian vegetation may be less expensive but just as effective as monitoring herbivory on seedstalks or measuring overall population change. Salafsky and Margoluis (1999) argue that monitoring changes in threats can often be done effectively through a qualitative rating assessment completed by those involved in the management project without special data collection activities.

Two final benefits of monitoring of habitat and threats are that data are often more immediately forthcoming and may be gathered using techniques already familiar to many resource managers. In the woodcock example above, population response may lag several years behind the management action. Assessing changes in threats, especially when using a qualitative approach like that of Salafsky and Margoluis (1999), can often be done on an annual basis (or even more often), whereas measuring the response of habitats or populations to a change in threat may take several years. Monitoring populations using habitat or threat indicators often relies on methods that are relatively familiar such as vegetation measurements, while monitoring the populations themselves may require more elaborate and unfamiliar techniques such as mark/recapture methods for animals or demographic monitoring for plants. People with the specialized skills needed for these techniques may not be available.

In exchange for ease, low cost, and immediacy, one must accept limitations and risks. A serious criticism of monitoring habitats or threats as indicators of species condition is that your selected indicator may not really be indicative of changes in the species population. Habitat monitoring is most effective when research has demonstrated a relationship between a habitat parameter and the condition of a species, but for most plant and animal populations, these data are lacking, and the relationship between a habitat parameter and a species must be inferred from hypothesized and known ecological relationships. You may have chosen an indicator that is not well correlated with species success or one that is correlated in an unexpected way. Some indicators, for example, are fairly robustly correlated with population changes at low densities, but become less sensitive as the population reaches higher densities.

Because monitoring an indicator may give a false sense of security, one must examine these trade-offs explicitly and design the monitoring project based on available monitoring resources and with an awareness of the risks of being wrong. For these reasons, when threats, habitat attributes, indicator species, or abiotic variables are used as surrogates for tracking individual populations, it is advisable to periodically assess the population itself to ensure the validity of the surrogate relationship.

These risks should not deter use of indicators, however. The risk of being wrong exists even when monitoring populations directly. As discussed earlier, without a research design, we do not know if changes in a population are the result of management or if they result from changes in weather patterns, insect infestations, rates of herbivory or predation, prey base or nutrient levels, incidence of disease, or other factors. All monitoring data should be interpreted with caution, recognizing sources of uncertainty. Using indicators, however, introduces the additional source of uncertainty in the assumed relationships between the indicator and the species. This risk must be assessed against the benefits of using indicators for monitoring.

MONITORING COMMUNITIES

Habitat monitoring is closely allied with monitoring of communities, and those who are interested in monitoring communities will benefit from many of the concepts described in this handbook. Appendix 1 provides additional information specific to community monitoring.

RELATED ACTIVITIES

The term "monitoring" has been applied to a variety of data-gathering activities. We have defined monitoring in this handbook as driven by objectives and implemented within a management context. This differs from many activities described below that are often implemented under the general term "monitoring." While we know that many of these activities will benefit from applying the technical concepts described in later chapters, throughout this handbook we will maintain our narrower definition of monitoring as objective-based.

Inventories are point-in-time measurements typically used to determine location or condition. Inventories may be designed for the following purposes:

- Locate populations of a species.
- Determine the total number of individuals of a species.
- Assess ages, sizes, and conditions of individuals within a population.
- Locate all populations of a species within a specific area (often a project area).
- Locate all species (or species of a certain type such as listed species) occurring within a specific area (project area, habitat type).
- Assess and describe the habitat of a species (e.g., associated species, soils, aspect, elevation).
- Assess existing and potential threats to a population.

Data collected during an inventory may be similar to those collected during monitoring. For example, the number of individuals in each population may be counted during an inventory. Similarly, a monitoring project may require counts of a single or several populations every year for several years.

Information collected during an inventory is most useful in developing models of the species of interest and in generating reasonable objectives. Inventory data may provide a baseline, or the first measurement, for a monitoring study, but do not assume that information collected during inventory will always be directly useful for monitoring the specific objective you develop. The following is a typical example:

During inventory for the rare mustard *Physaria didymocarpa* var. *lyrata*, qualitative estimates of population size and various habitat parameters were noted. Exhaustive inventory, however, only identified four populations. All are over 500 individuals, but all are restricted to small areas of extremely steep scree slopes. Management conflicts are severe at all four sites. Because of the demonstrated rarity of the species and conflicting uses, public and agency concern over management is intense. Qualitative estimates of population size are considered inadequate for monitoring this species, and quantitative objectives and monitoring are recommended.

Natural history studies investigate basic ecological questions. For animals, these questions may concern food habits; breeding, resting, and foraging sites; timing of reproduction; mortality and reproductive rates; home range; dispersal and migration behavior; predators; and disease. For plants, these questions concern pollination ecology, life history, seed viability, seed-bank longevity, herbivory, and seed predation. These questions often must be answered before effective monitoring can be designed, but such studies are not monitoring.

Implementation monitoring assesses whether the activities are carried out as designed. For example: Was the fence built in the right location according to specifications so it will effectively protect the plant population from deer? Was the off-highway vehicle (OHV) closure maintained? Were the cows moved on the right date to allow the rare plant to successfully produce seed? While such monitoring does not measure a population, it does provide critical feedback on whether the planned management is being implemented. Implementation monitoring can also identify which variables are most likely to be causing a change in the resource and thus will help eliminate from consideration some hypothetical causes of change. This type of monitoring, although critical to successful management, is not discussed further in this handbook.

Measuring change over time is a main characteristic of monitoring, but simply measuring change does not meet the definition of monitoring in this handbook. Studies that measure change can be implemented in the absence of an identified need for decision making. In contrast, monitoring is characterized primarily by objectives and by being part of an adaptive management cycle in which monitoring data are used to evaluate management and make decisions (Perry et al. 1987).

Studies measuring change in the absence of a management context have been collectively termed "surveillance" (Perry et al. 1987), but three types are recognized and described here: *trend studies, baseline studies, and long-term ecological studies*. The distinction among the types is blurred, and resource managers have frequently used the terms interchangeably.

Trend studies are designed to learn how the resource is changing over time (some authors call this "baseline monitoring" — see next section). An example of a study objective for measuring trend is as follows:

Study objective: Determine if the density of *Primula alcalina* is increasing, decreasing, or remaining stable at the Texas Creek Population over the next 5 years.

While this is important information, the trend study could be placed into a management framework by developing this study objective into a management objective:

> *Management objective*: Allow a decrease of no more than 20% from the current density of *Primula alcalina* at the Texas Creek population over the next 5 years.
>
> *Management response* (if cause is unknown): If *Primula* density declines by more than 20% over the 5-year period, more intensive monitoring or research will be initiated to determine the cause of the decline; or
>
> *Management response* (if cause is suspected): If *Primula* density declines by more than 20% over the next 5 years, grazing at the site will be limited to late fall to allow seed set and dissemination.

A subtle but fundamental difference exists between monitoring for trend and monitoring for management, even though the actual measurements and analysis may be the same. The second approach places the measurements within the adaptive management cycle and identifies the changes in management that will occur if the monitoring has a certain result. At the time the study begins, we do not know whether the population is stable, declining, or increasing. By conducting the study within the framework of an objective and a management response, the course of action at the end of 5 years is known before monitoring begins. If monitoring shows the population is increasing or stable, current management may continue. If populations are declining, an alternative management approach is outlined. If the study is done simply to detect change, the course of action at the end of the 5 years will be unclear. What will likely occur is continuation of existing management and the trend study to determine if the decline of the rare plant continues.

Biologists and ecologists are often hesitant to develop objectives and management responses because of a lack of information on the desired condition of the population and the relationship of management to that condition. At a minimum, however, an objective to maintain the current condition can be established and a commitment made to respond with more extensive monitoring, study, or research if a decline is measured.

Baseline monitoring is another type of activity implemented as monitoring. This is the assessment of existing conditions to provide a standard, or "baseline," against which future change is measured. Commonly, many variables are measured in hopes of capturing within the baseline dataset the ones that turn out to be important later. Baseline monitoring is sometimes termed "inventory monitoring" (MacDonald et al. 1991) because it often involves the collection of data to describe the current condition of a resource. Measurement again at a later date may be intended, but a commitment or plan for periodic measurement is usually lacking. Periodic measurement is integral to a monitoring study. The problem with baseline studies, and using inventory data as baseline data, is that the design of the study may be inadequate to detect changes. This inadequacy usually results from including too many variables and using too small of a sample size.

If the study is implemented with scheduled periodic measurements, a baseline study may be termed a *long-term ecological study*. The most common goal of these studies is to learn about the natural range of temporal variability of the resource by documenting the rates and types of changes that occur in response to natural processes such as succession and disturbance. The term "long-term ecological monitoring" usually is used to describe the measurement of community variables to determine change over the long term, 50 to 200 years or more. In most studies, many variables are measured on a few, large, permanent plots (usually greater than 0.1 hectare). Commonly measured variables include cover or density of all plant species, demographic parameters of important species, soil surface conditions, fuel loads, and animal signs (Greene 1984, 1993; Dennis 1993; Jensen et al. 1994; Schreuder and Geissler 1999; Scott et al. 1999; Stohlgren 1999). To add confusion to our classification, the term "baseline monitoring" is also sometimes used for this activity.

Two key differences exist between baseline and long-term ecological studies and the monitoring described in this handbook:

1. Baseline and long-term ecological studies do not specifically evaluate current management nor result in a management decision, although they may provide important information for management direction in the future by describing system functions and fluctuations (Perry et al. 1987). In monitoring, the application of the data to management is identified before the measurements are taken because monitoring is part of the adaptive management cycle.
2. These studies often attempt to maximize the number of characteristics and species measured because those most sensitive for measuring change are not known. In contrast, in this handbook, we advocate the explicit selection of one or a few measurable variables to be monitored.

One type of monitoring explicitly involves the measurement of a "baseline" and is sometimes termed "baseline monitoring." In this monitoring design a series of measurements are taken prior to the initiation of a management activity and are used for comparison (a "baseline") with the series of measurements taken afterward (Green 1979; MacDonald et al. 1991). This type of situation is common in water-quality monitoring. For example, measurements of water column sediment in a river may be taken for 5 years prior to the construction of a power plant and then for 5 years afterward to determine the background, or baseline, level of sediment and to determine whether the pollution controls of the plant are adequate to prevent elevated sediment levels. When measurements are made at both treatment and control areas, this type of monitoring design is termed the before-after, control-impact (BACI) design (Bernstein and Zalinski 1983; Faith et al. 1995; Long et al. 1996; Schwarz 1998). It is unusual in resource management to have several years' notice before initiating an activity during which a baseline can be measured, but if the opportunity arose, such a monitoring design can be very effective.

MANAGEMENT IMPLICATIONS

Monitoring must be placed in the context of a management framework to effectively improve or validate management. This framework, called adaptive management, involves 1) developing a model of the system; 2) describing the desired condition of the resources with an objective; 3) monitoring the response of the resource; 4) analyzing monitoring data; and 5) adapting management based on the monitoring information. Objectives are the foundation of the monitoring process. These may be based on the species itself (e.g., population size, reproductive success) or on a change in a habitat attribute or a threat. This objective-based character of monitoring differentiates it from other data-gathering activities such as inventory and survey studies, natural history investigations, and long-term ecological studies.