22 Monitoring Habitat Elements and Populations

Implementation of any stand prescription or forest management plan is done with some uncertainty that the actions will achieve the desired results. Nothing in life is certain (except death!). Following implementation, managers should expect to change plans based on measurements taken to see if the implemented plan is meeting their needs. If not, then mid-course corrections will be necessary. Many natural resource management organizations use some form of adaptive management as a way of anticipating changes to plans and continually improving them (Baker and Read 2011; McCaw et al. 2011, Westgate et al. 2013).

ADAPTIVE MANAGEMENT

Adaptive management is a process to find better ways of meeting natural resource management goals by treating management as a hypothesis (Allan and Stankey 2009). The results of the process also identify gaps in our understanding of ecosystem responses to management activities. Adaptive management incorporates learning into the process, and the data collected during monitoring provides feedback about the effectiveness of preferred or alternative management practices. The information gained from the process can help to reduce the uncertainty associated with ecosystem and human system responses to management, but successful adaptive management projects are not common (Howes et al. 2010). Westgate et al. (2013) reviewed 1336 scientific papers describing adaptive management projects, of which only 13 applied the concepts of adaptive management to the problem. Westgate et al. (2013) suggested that attempts to apply adaptive management could be improved by better collaboration between scientists and stakeholders, better risk analysis associated with not conducting adaptive management, and ensuring that projects are relevant to the management needs of the affected stakeholders.

Adaptive management has been classified as both active and passive (Walters and Holling 1990). Passive adaptive management is a process where the "best" management option and associated actions are identified, implemented, and monitored. The monitoring may or may not include unmanaged reference areas as points of comparison to the managed areas. The changes observed over time in the managed and reference areas are documented, and the information is used to alter future plans. The manager learns by managing and monitoring, but the information that is gained from the process is limited, especially if reference areas are not used. Without reference areas, we do not know if changes over time are due to management or some other exogenous factors.

Active adaptive management treats the process of management much more like a scientific experiment than passive adaptive management. Under active adaptive management, management approaches are treated as hypotheses to be tested. The hypotheses are developed specifically to identify knowledge gaps, and management actions are designed to fill those gaps. Typically, the hypotheses are developed following modeling of the system responses (e.g., using forest growth models or landscape dynamics models), to understand how the system might respond, and then use management to see if it responds as intended. Reference areas are used as controls to test responses of ecosystems, and human systems, to management. By collecting monitoring data in a more structured hypothesis-testing framework, system responses can be quantified and used to identify probabilities associated with achieving desired outcomes in the future. Whereas passive adaptive management is somewhat reactive in approach (reacting to monitoring data), active adaptive management is proactive and follows a formal experimental design.

Traditionally, adaptive management has six steps (Munks et al. 2010), but Williams (2011) described adaptive management as multiple steps having two phases (Figure 22.1). The first phase is a setup phase to engage stakeholders, set objectives, identify alternative approaches, identify models to understand likely futures, and develop a monitoring framework. The second phase is one of decision making, followed by monitoring, followed by assessment of the monitoring data, and then decision making is revisited (Williams 2011). Development of a monitoring plan is at the heart of adaptive management. Monitoring can be conducted to understand if a management plan was implemented correctly, if it was effective, or if the underlying assumptions are valid.

Implementation monitoring is conducted to see if the plan is being implemented on the ground as it is described in the plan (Roccaforte et al. 2010). Are standards and guidelines being followed? Is the appropriate number of snags, logs, and trees being left after harvest? Are harvest boundaries being respected? Are designated skid trails used? Answering these sorts of questions is important, because future stand or landscape conditions are often dependent on correct implementation of the plan. If the plan is not implemented correctly, then there is far greater likelihood that the goals of the plan will not be realized.

Effectiveness monitoring follows implementation monitoring and is designed to determine if habitat elements, populations, or processes are responding as expected and effectively achieving your management goals. Are trees growing as anticipated? Are trees and shrubs producing mast? Are focal species populations persisting and/or growing as anticipated? Answering these questions allows you to know if the management is effective, and, if not, then the results provide evidence for making changes to the plan. Deluca et al. (2010) reported that effectiveness monitoring is rarely conducted on U.S. Forest Service lands, largely due to budget constraints, and so they offered the following three integrated approaches to more efficiently conduct effectiveness monitoring: (1) pursue low-cost multiparty monitoring conducted by a collective of stakeholders, including citizens, conservation groups, timber interests, and agency personnel; (2) conduct highly detailed ecosystem monitoring on a statistically selected number of forest restoration sites by region; and (3) conduct spatial analysis of remotely sensed data as direct or proxy variables to evaluate ecosystem response

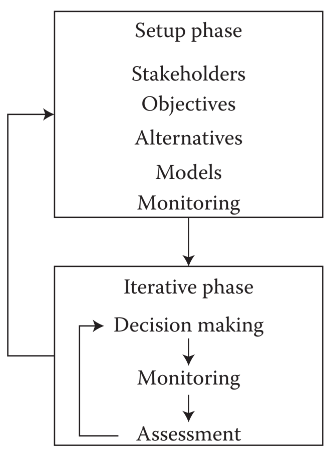

FIGURE 22.1 Traditional adaptive management cycle (above) and two-phase learning in adaptive management (below). In two-phase adaptive management, technical learning involves an iterative sequence of decision making, monitoring, and assessment. Process and institutional learning involves periodic reconsideration of the adaptive management setup. (Reprinted from *Journal of Environmental Management*, 92, Williams, B.K., Passive and active adaptive management: Approaches and an example, 1371–1378, Copyright 2011, with permission from Elsevier.)

to restoration activities. Innovative approaches such as these, along with careful selection of factors to monitor, may make adaptive management and monitoring more widely accepted.

Plans are almost always based on some assumptions. Monitoring of key processes, such as tree and shrub growth rates, population changes, or changes in animal fitness, can produce information that can be used to test assumptions (McComb et al. 2010). Validation monitoring provides the basis for reducing uncertainty associated with assumptions and provides a framework for understanding and interpreting the results of effectiveness monitoring.

With data in hand from implementation, effectiveness, and validation monitoring, the managers can periodically evaluate the responses of the system to the management actions, understand better why they are seeing certain responses, and make adjustments to their management actions in a way that increases the likelihood that they will be more effective in the future. Once these adjustments have been made, it is important to reassess the problem among involved publics to ensure that new concerns and opportunities are identified as a result of making the proposed adjustments. Then the entire process begins anew and, at least theoretically, allows managers to continually improve their ability to meet desired goals.

We may monitor habitat types, habitat elements, or populations depending on the goals of the monitoring program. Clearly, it is important to know if the habitat structure, function, and patterns are developing as expected under the plan. Managers may also want to know how populations respond to management. Monitoring populations can be critical in assessing and identifying the potential, or actual impacts of management on the persistence of a species, over some or all of its geographic range. Ideally, the monitoring should allow managers to evaluate (either directly or indirectly) the effects of management actions on factors associated with animal fitness, such as fertility, recruitment rate, survivorship, and mortality. These types of data are very expensive to acquire, so, more often, monitoring of populations is based on occurrence or abundance.

A properly designed monitoring effort allows managers and biologists to understand the long-term dependency of selected species on various habitat components. Resource availability is dynamic for all or most species. Consequently, the challenge, when developing a monitoring plan, is assessing whether changes in occurrence, abundance, or fitness in a population is independent from or related to changes in habitat availability and quality (Cody 1985). Managers will ideally want to identify and incorporate the interactions between habitat and population change in order to make informed management decisions through an adaptive management process (Barrett and Salwasser 1982). The ability to understand why populations are changing in certain directions will depend on the habitat requirements of the species and coincident monitoring of the population and the habitat. The ability to correlate animal and habitat data allows decision makers to better predict the effects of management on populations. However, monitoring plans must address two critical considerations to allow for an accurate and sound comparison of population and habitat data (Jones 1986). First, both animal and habitat data must be collected on the same sites. This allows monitoring programs to document the fluctuations in population density and distribution with respect to changes in the physical and spatial arrangement of habitat elements. Second, the level of detail identified for sampling for both species and their habitats must be determined before associations can be made. This level of sampling will ultimately depend on the objective of the monitoring program. Most monitoring programs deal with the presence/not detected data for many species of rare plants and animals; and, generally, more detailed data is collected on habitat elements in an effort to describe habitat conditions. However, if the objective of the monitoring protocol is assessing habitat quality and its influences on a species' demography, then data must be collected on a species' ability to survive and reproduce (e.g., mortality, survivorship, predation, parasitism) (Cody 1985).

DESIGNING MONITORING PLANS

Designing a monitoring program is analogous to designing a research project, and a well-designed monitoring program should be every bit as rigorous as a research project; but a monitoring program is designed to allow managers and stakeholders a chance to learn new information, as well as adapt management actions to achieve their goals. The first step in the process of developing a monitoring plan is to identify, clearly and concisely, the questions to be answered by the monitoring data. Questions can be more easily articulated if the monitoring plan is based on a conceptual framework that describes the states and processes involved in the system being monitored (Jones et al. 2009, Figure 22.2). By understanding the pieces of the system that stakeholders and managers are

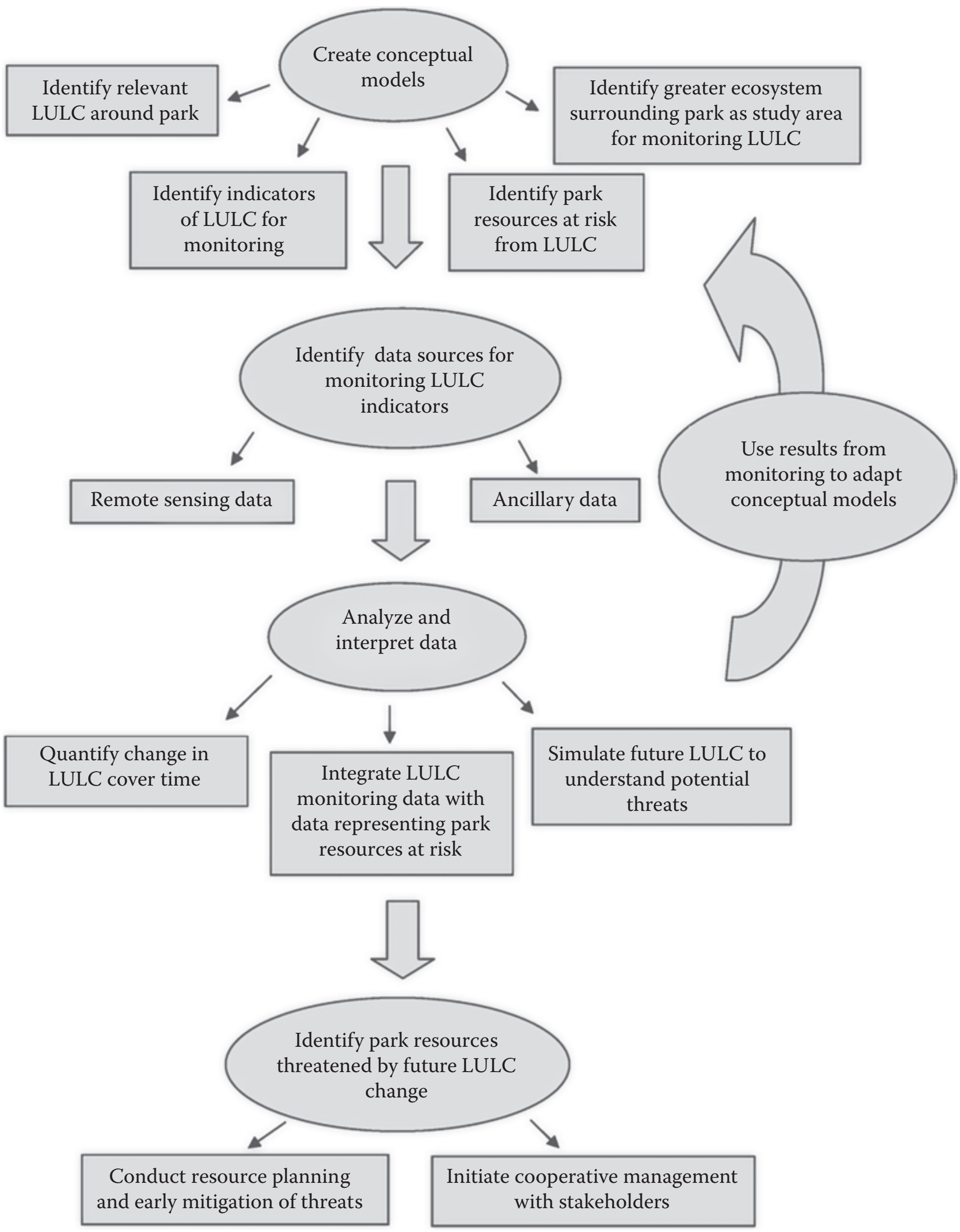

FIGURE 22.2 General steps outlining an approach for monitoring land use and cover change around parks and other protected areas. (Reprinted from *Remote Sensing of Environment*, 113, Jones, D.A. et al., Monitoring land use and cover around parks: A conceptual approach, 1346–1356, Copyright 2009, with permission from Elsevier.)

confident of, they then can focus attention on the critical aspects of the managed system that must be measured, over time, to understand if management is achieving goals. Stakeholders must be involved in this stage of developing a monitoring plan. Once each question and associated goal has been articulated, then the steps indicated in each of the following sections should be taken.

Selection of Indicators

Considering your management plan as a hypothesis, what are the indicators or response variables that you will measure? Indicators are those factors that you hypothesize are responding to the management action. Based on the conceptual framework for the system being monitored and input from stakeholders, provide the rationale for selecting specific indicators or attributes. Why was this indicator selected over others? What are the benefits associated with this indicator? What are the limitations? What are the key habitat elements and population responses that are described in your desired future condition(s) (DFCs)? Desirable characteristics of indicators include (Vesely et al. 2006; McComb et al. 2010) those that

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

Describe the Scope of Inference

The scope of inference represents the space and time over which your data can be used to assess changes in the response variable with some known level of certainty. Data must be collected in a manner that provides an unbiased estimate of your response variable from the planning area. Samples should be allocated in a randomized or stratified random manner, with points selected from a pool representing the entire scope of inference. Extrapolating data beyond the scope of inference is done with increasing uncertainty as one departs more and more from the conditions sampled from within the scope of inference. Indeed, broadcasting from the monitoring data (extrapolating to other units of space outside the scope of inference) and forecasting (predicting trends into the future from existing trends) must be done with great care because the confidence limits on the projects increase exponentially beyond the bounds of the data (Kimmins et al. 2010; Munks et al. 2010).

Oftentimes, managers wish to sample large areas so that the results of the monitoring effort can be used more efficiently, but they quickly face a tradeoff. That tradeoff is to monitor over a large spatial extent, so that results are broadly applicable, versus sampling over a small area with less variability to increase the precision of the data (and more likely detect trends). The variability in the indicator will likely increase as the spatial extent of the study increases. As the variance of the indicator increases, the probability of detecting a difference between treatments or of detecting a trend over time will decrease. Funding for the monitoring program often dictates what represents a reasonable level of sampling intensity. Generally, smaller replicated sites from a larger scope of inference can provide information that is more broadly applicable, but yet would have sufficient statistical power to detect changes.

Describe the Experimental Design

The experimental design will depend on the goals for the monitoring program and may be adapted over time to address new questions that emerge as data is analyzed (Lindenmayer and Likens 2009; Lindenmayer et al. 2011). Consider how the results of data analysis will be used. Will the analysis be used to assess occurrence, trends, patterns, or effects? Estimating occurrence may entail an estimate of the probability of occurrence at a site with an associated estimate of confidence (McComb et al. 2010). Estimating trends often involves a time-series regression, with confidence intervals to understand both the slope of the trend and the uncertainty associated with the trend based on the variability in the data (Hutto and Belote 2013). Estimating patterns may involve use of an analysis of variance (ANOVA), *t*-test, or multivariate analysis (e.g., principal components analysis) to understand if the indicator (response variable) differs between or among areas having different management actions. Estimating ecological effects or management effectiveness on an indicator typically requires a before–after, control-impact (BACI) approach so that we can understand the causes (management action) and effects (relative level of response) associated with our implemented plan (Hutto and Belote 2013).

Because monitoring data are generally collected over time to detect trends or effects, the data are often not independent from one time period to the next. The data collected at one time are related to the conditions when data were collected at a previous time, and this violates a basic assumption when using standard statistical techniques such as ANOVA or regression. This issue can lead to concluding that trends exist when they really do not, simply due to this temporal dependence because of the estimate of variance that is not accurate (too small) leading to a false conclusion (Hurlbert 1984). Repeated measures analyses are often necessary to ensure that estimates of variance between or among treatments reflect this lack of independence (Foster 2001). Similarly, when analyzing spatial data, data collected at one spot can be closely correlated with data collected at nearby sports, so spatial autocorrelation must be addressed (Zhang et al. 2012).

Sampling Intensity, Frequency, and Duration

"How many samples do I need?" "How long should I monitor?" Those are two of the most commonly asked questions when planning a monitoring program. Use of existing data, or conducting a pilot study, allows planners to conduct a power analysis to decide how many samples are needed to detect a difference or trend, with an acceptable level of confidence (Magurran et al. 2010; Danielsen et al. 2011). Because pilot study data are often collected over a limited timeframe or area, alternative approaches should be considered. Data stabilization approaches are used to assess sample size. For instance, if data on animal density were collected from 20 sites, extending out from some central location, and the variance represented in the data is plotted over number of samples, then the variance should stabilize at some number of samples. Once that asymptote in variance has been reached, then adding additional samples is not likely to influence your estimate of the inherent variability in the response variable, at least not under current conditions. It is also useful to consider how your estimate of variance might change as the plan is implemented, so that your sample intensity in the future is also adequate to address your monitoring question. A similar approach can be taken to identify the number of samples that might be needed to establish the probability of occurrence of a species at a site (Figure 22.3).

"How often should I collect data?" Some habitat elements and populations change very slowly (e.g., snags falling) over time, while others change quickly (browse biomass following a disturbance). The rates of change in the element should dictate the frequency with which monitoring data is collected. Sampling snag-fall every year for 100 years is both inefficient and unnecessary, given

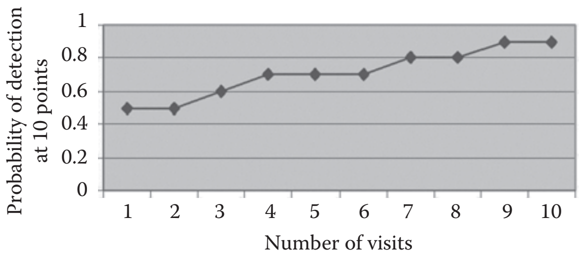

FIGURE 22.3 Hypothetical change in probability of detecting a species with increasing number of visits or samples. Note that an asymptote is reached at 9 or 10 samples. Sampling beyond this point will not likely improve the precision of your estimate.

the likely changes that would be seen from year to year, either in snags or the species that use them. Sampling every 5 or 10 years would provide useful information at a fraction of the cost.

"How long should I monitor before I can stop?" Sampling duration depends on the time that you think it would take to achieve the DFC and the time that you feel you should monitor the DFC to ensure that it is likely to persist once it is reached. By using an adaptive management approach, with continual improvements in management approaches, then monitoring may continue indefinitely with some response variables being dropped, others added, and some retained as the process continues (Lindenmayer and Likens 2009).

Monitoring Habitat Elements

If the purpose of monitoring includes understanding changes in habitat availability or quality following management, monitoring must measure and document appropriate habitat elements important to the key species, communities, or ecosystems, of concern to the managers and associated publics (see Chapter 4 for a documentation of habitat elements). These data are collected over various scales; however, the relevant scale at which to collect and interpret the data will be defined by the characteristics of the organism(s) of concern. The data should include: the organism's use of habitat, such as the geographic range; metapopulation structure; home range; resource patch selection; and ultimate resources used by each species identified in the monitoring plan.

Measurement of many habitat elements has been incorporated into existing forest monitoring programs that use ground-plot measurements to document changes in vegetation (e.g., USDA Forest Service Forest Inventory and Analysis) and may represent existing data that can be used in a monitoring program. If these data are collected at permanently marked points, then it is possible to document changes in habitat elements over time. This is especially important since the carrying capacity of habitat for a species is dynamic and depends on a number of resources that can fluctuate over time and space due to natural (e.g., floods, hurricanes) and/or anthropogenic (e.g., harvesting, forest clearing) disturbances.

Remotely sensed data are being used more frequently in association with ground-plot information to assess patterns of change over large areas. Landsat images are commonly used as the basis for assessing change in landscapes over time. The Landsat program placed satellites into orbit around the Earth to collect environmental data about the Earth's surface (Richards et al. 1999). The reflectance of various wavelengths of light is captured by sensors on the satellite and is stored as discrete numbers assigned to a place on the Earth, typically to a 30 × 30 m square or pixel, but resolution on new satellites is now down to 10 m. The values are specific to a particular place at a particular time and a spectrum of reflectance values (brightness) that are assigned to each pixel (Richards et al. 1999). The area that each pixel covers on the ground represents the resolution or grain of the information. Satellite data must be classified to be of use. Once classified, resulting maps can provide a record of change in classified elements over large areas over time. Despite increasing resolution and decreasing grain size, Landsat data are less able to provide information on changes in habitat quality, species distribution, and fine-scale disturbances. Instead, very high resolution (VHR) optical data from satellite-based optical sensors are being used more frequently (Nagendra et al. 2013). Light detection and ranging (LiDAR) and synthetic aperture radar (SAR) data, when used in combination with optical data, can even allow users to detect changes in the three-dimensional structure of habitat elements (Nagendra et al. 2013). Further, ground-plot data can be integrated with remotely sensed data to provide more detailed estimates of change in fine-scale habitat elements (Ohmann and Gregory 2002).

The accuracy of interpretation of aerial photographs and classified satellite imagery depends on "ground-truthing" (visiting spots on the ground to see if the class is accurately represented) and subsequent accuracy assessments, but the classification scheme must be designed to assess habitat for the species of interest. Indeed, Cushman et al. (2010) proposed that habitat type classifications are inconsistently applied to landscapes and that a species-specific gradient-based analysis is a more meaningful representation of habitat quality over complex landscapes. Gradient-based landscape analyses are quite likely the approach that will be used in the future, but for the past several decades, landscape analyses have been based on patch-level metrics. Biologists often use a hierarchal approach to define patches based on vegetation types, landform, soil composition, or other factors that are deemed pertinent by the managers and biologists (Kerr 1986). Once a criterion is determined for classification, the landscape can be separated into discrete units so that any additional ground samples can be stratified among vegetation types. The Resource Inventory Committee of British Columbia has outlined a good approach to vegetation stratification (Resource Inventory Branch 1998):

1. Delineate the project area boundary.
2. Conduct a literature review of the habitat requirements of the focal species. If there is enough available and accurate information on the habitat requirements of the species, then it may be possible to identify those vegetation components that relate to habitat quality. However, caution should be used when relying on habitat associations from previous studies since many studies may not be applicable to the region of study or the species of concern.
3. Develop a system of habitat stratification that you expect will coincide with species' habitat requirements.
4. Use maps, aerial photographs, or satellite imagery to review and select sample units that are reflective of the study area.
5. Evaluate the availability of each habitat strata within the study area.

It is important to keep in mind that one classification scheme will not meet the needs of identifying habitat for all species. If we (humans) classify vegetation as we see structure and composition, then those patterns may or may not relate well to the way that various species respond to patches or gradients of vegetation (Cushman et al. 2010). A classification system that is designed for each species is most likely to reasonably allow an understanding of how habitat is changing for each species over space and time.

Monitoring for Species Occurrence

Assume that you are concerned that management actions will impact a habitat element or a species that could be present in an area. How sure do you want to be that the species occurs in the proposed management area? Do you want to know with 100% confidence if a species occurs in an area proposed for management? Or can you be 95% sure; 90%? The answer to that question will dictate both the sampling design and the level of intensity with which you inventory the site to estimate presence and absence. The more rare or cryptic the species, the more samples that will be needed to assess presence; and, if the species is rare enough, then the sampling intensity can become logistically prohibitive. In that case, other indicators of occurrence may need to be considered. Consider the following possibilities when identifying the indicators of occurrence in an area (Vesely et al. 2006):

1. Direct observation of a reproducing individual (female with young)
2. Direct observation of an individual, reproductive status unknown
3. Direct observation of an active nest site
4. Observation of an active resting site or other cover
5. Observation of evidence of occurrence, such as tracks, seeds, pollen
6. Identification of habitat characteristics associated with the species

Any of the above indicators could provide evidence of occurrence and, hence, potential vulnerability to management, but the confidence placed in the results will decrease from number 1 to number 6 for most species, based on the likelihood that the fitness of individuals could be affected by the management action.

Opportunistic observations of individuals, nest sites, or habitat elements can be of some value to managers, but are often of not much use in a monitoring framework, except to provide preliminary or additional information. For instance, GPS-tracked locations of a species observed incidentally over a three-year period, could be plotted on a map, and some information could be derived from the map (known locations). The problem with using these data points in a formal monitoring protocol is that they are not collected within an experimental design. Undoubtedly, there are biases associated with where people are or are not likely to spend time, with species detectability among vegetative, hydrologic, or topographic conditions, and with varying detectability among age or sex cohorts. Consequently, this information should be maintained, but rarely would it be used as the basis for a formal monitoring design.

Monitoring Trends

Long-term monitoring of populations to establish trends is often used within monitoring programs. Such monitoring programs provide information on changes in populations or habitat availability, but they do not necessarily indicate why populations are changing. For instance, consider the changes in woodcock populations over a 27-year period (Figure 22.5). Clearly, the number of singing male woodcocks has declined markedly over this time period. This information is very important, in that it indicates that additional study is needed to understand why the changes have occurred. Are singing males simply less detectable in 1995 than they were in 1968? Are populations actually declining? If so, are the declines due to changes in habitat on the nesting grounds? Wintering grounds? Migratory flyways? Is the population being over-hunted? Are there disease, parasitism, or predator effects, which are causing these declines? Are these declines uniform over the range of the species or are there regional patterns of decline? All of these questions indicate the need to consider an adaptive monitoring approach, in which the questions asked and the indicators used can change over time in response to what is learned and what questions are raised (Lindenmayer and Likens 2009). Analysis of regional patterns indicates that the woodcock declines may not be uniform over the region (Figure 22.4). Declines are apparent in the northeastern United States but not uniformly throughout the Lake States. The Breeding Bird Survey data indicates that there are areas where declines have been significant (Sauer et al. 2012), and the work by Bruggink and Kendall (1995) indicates that the magnitude of the declines in some areas is perhaps even greater than might be indicated by the regional averages. So it would seem that causes for declines are probably driven by effects that are regional. Approaches to understanding the potential causes for change in the abundance of a species can be much more informative when considering changes to a management plan than simply examining trends. The causes for the declines would be addressed at the local scale in a manipulative manner that would allow assessment of cause and effect relationship.

FIGURE 22.4 Geographic distribution in woodcock population changes. Note that population declines are not uniformly distributed throughout the range of the species. (From Sauer, J.R. et al. 2012. The North American Breeding Bird Survey, Results and Analysis 1966–2011. Version 07.03.2013 USGS Patuxent Wildlife Research Center, Laurel, MD.)

The design of a trend-monitoring program should carefully consider the scope of inference, and if the scope of inference is large (geographic range), monitoring may necessitate coordination over large areas among multiple stakeholders. Site-specific trend analyses will probably be of limited value in many instances, because the fact that species "*x*" is declining at site "*y*" is probably not as important as knowing why the species is declining at site "*y*." Using trend monitoring to detect increases or declines in abundance is perhaps best applied to high-priority species or to allowing development of associations with regional patterns of habitat availability. These associations then allow the opportunity for a more informed development of hypotheses that can then be tested in manipulative experiments to identify causes for changes.

One aspect of trend monitoring that must be considered carefully is the sampling intensity needed to detect a change in slope over time. Consider Figure 22.5. Annual data were quite variable over the 27-year period, but a trend is still detectable because the slope was so steep. Annual variability caused by population fluctuations and sampling variance can often prevent detection of a statistically significant change in slope. This problem is exacerbated when the slope is not as dramatic as in Figure 22.5. There are several factors that must be considered carefully in the design of a trend-monitoring plan:

1. What is the spatial scale over which you wish to understand if habitat elements or populations are declining or increasing? If it is not the geographic range of a species or subspecies, then what portion will be monitored and how will the information be used?
2. Is the indicator that is selected as unbiased as possible and not likely to vary among time periods, except as would be caused by fluctuating populations?
3. Given the inherent variability in the indicator that is being used, how many samples will be needed in each time period to allow detection of a slope of at least "*x*" percent per year over time?

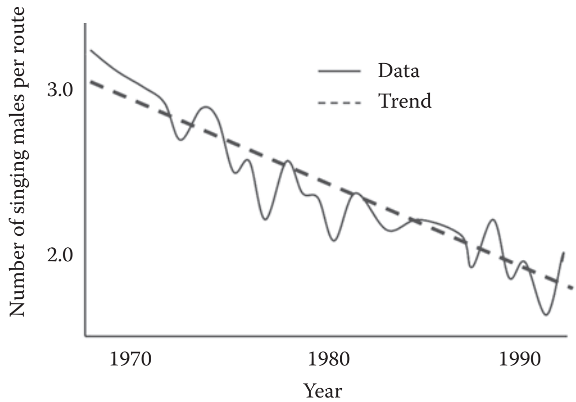

FIGURE 22.5 Trends in woodcock populations over time. Note that the annual data are variable but that the slope is sufficiently steep to allow detection of a trend. (Redrafted and adapted from Bruggink, J.G., and W.L. Kendall. 1995. *American Woodcock Harvest and Breeding Population Status*, 1995. US Fish and Wildlife Service, Laurel, Maryland, 15 pp.)

4. Given the inherent variability in the indicator that is being used, at what point in the trend is action taken to recover the species or reverse the trend? This trigger point should be well before the population reaches an undesirably low level because the manager will first have to understand why the population is declining before action can be taken, and there may be a lag time in population response to any changes in management.
5. Will the data be used to forecast results into the future? If so, recognize that the confidence intervals placed on trend lines diverge dramatically from the line beyond the bounds of the data. Forecasting even a brief period into the future is usually done with little confidence, unless the underlying causes are understood.

Finally, it is important to recognize that auto-correlation among data points is not only likely, but should be expected under traditional designs in which data are analyzed using time-series regression.

Cause and Effect Monitoring Designs

If the monitoring plan being developed is designed to understand the short- or long-term effects of some management action on a population, then the most compelling monitoring design would take advantage of an approach that would assess responses to those actions. Monitoring conducted over large landscapes or multiple sites may use a comparative mensurative approach to assess patterns and infer effects (e.g., McGarigal and McComb 1995; Martin and McComb 2002). This approach allows comparisons between areas that have received management actions and those that have not and is often analyzed using an ANOVA approach. The approach is retrospective and substitutes space for time. Alternatively, the BACI approach allows monitoring to occur on treated and untreated sites, both before and after management has occurred (e.g., Chambers et al. 1999; Bro et al. 2012).

Although the BACI design is usually considered superior to retrospective analyses, BACI designs often are not logistically feasible. On the other hand, retrospective designs—that compare treated sites to untreated sites—raise questions about how representative the untreated sites are of the treated sites prior to treatment. In a retrospective design, the investigator is substituting space (treated vs. untreated sites) for time (pre- vs. posttreatment populations). The assumption behind this approach is that the untreated sites are representative of the treated sites before they were treated. With adequate replication of randomly selected sites, this assumption can be justified, but often large-scale monitoring efforts are costly, and logistics may preclude both sufficient replication and random selection of sites. Doubt may persist regarding the actual ability to detect a cause-and-effect relationship using a retrospective approach, especially if the statistical power of the test is low.

BACI designs are more powerful and can establish cause-and-effect relationships, but they can often suffer from nonrandom assignment of treatments to sites, simply due to the logistics involved in harvest planning. Often the location and timing of management actions do not lend themselves to strict experimental protocols. Lack of random selection may limit the scope of inference only to the sites sampled. Nonetheless, with some care in matching control sites to sites that will be treated in the future, there is more that can be learned about the effects of a treatment on a population using this approach than retrospective designs (Rost et al. 2012).

ARE DATA ALREADY AVAILABLE AND SUFFICIENT?

Before embarking on collection of new data to monitor management implementation or effectiveness, or validation of assumptions, it is always prudent to ask if data already exists to address the monitoring questions. Existing data may not be better than no data at all if the data are of poor quality or have inherent biases. Consider the following questions when evaluating the adequacy of existing data to address a monitoring question:

1. *Are samples independent?* Are observations in the dataset representing units to which a treatment has been applied? Taking ten samples from one harvest unit is not the same as taking one sample from ten harvest units. In the former example, the samples are subsamples of one treatment area; in the latter example, there is one sample in each of ten replicate units (Hurlbert 1984). Further, if the species under consideration has a home-range size smaller than the average harvest-unit size, then sampling the species in harvest units probably represents reasonably independent samples. If the species under consideration has a home range that spans numerous harvest units, then the selection of harvest units to sample should be based on ensuring to the degree possible that one animal is unlikely to use more than one harvest unit.
2. *How were the data collected?* What sources of variability in the data may be caused by the sampling methodology (e.g., observer bias, inconsistencies in methods, etc.)? If sample variability is too high because of sampling error, or if an inherent bias exists (sampling along roads with and without tree cover), then the ability to detect differences or trends will decrease.
3. *Were sites selected randomly?* If not, then there may be (likely is) bias introduced into the data that should raise doubts with regard to the accuracy of the resulting relationships or differences. Although it may be possible to account for biases, interpretation of monitoring results should be conducted with caution regarding inherent bias.
4. *What effect size is reasonable?* An effect size is the difference (or slope) that you could detect given your sample size, sampling error, and the probability of making an error (as indicated by an alpha level), when rejecting a null hypothesis (that there is no difference between treatments or no trend over time). Even a well-designed study may simply not have the sample size adequate to detect a difference or relationship that is real, simply because the study was constrained by resources, rare responses, or other factors that increase the sample variance and decrease the effect size. Again, how this is dealt with depends on the question being asked. Which is more important—to detect a relationship that is real, or to say that there is no relationship when there really is none? In many instances, where monitoring is designed to detect an effect of a management action, the former is more important (especially using the precautionary principle). In that case, the alpha level may be increased (from say 0.05 to 0.10 or more) to make it more likely that an effect will be detected, but in so doing you will be proportionally more likely to say a relationship is real, when it is really not.

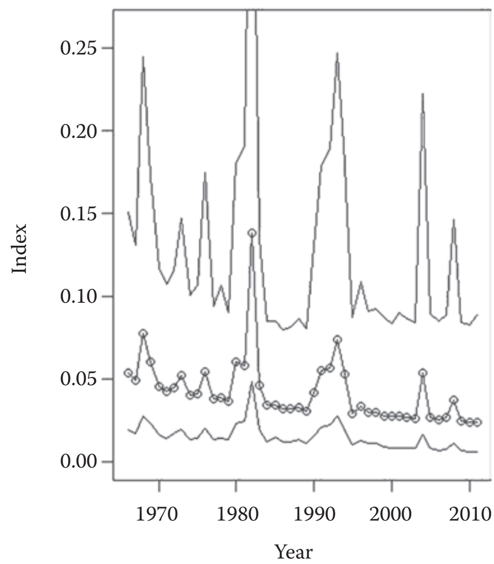

FIGURE 22.6 Changes in detections of yellow-billed cuckoos in New Hampshire 1966–2011. Limited detections, and what appears to be an outlier in the early 1980s, limits our ability to say with certainty that there is a negative trend. But using the precautionary principle, we might conclude that there is a negative trend and change management plans accordingly. (From Sauer, J.R. et al. 2012. The North American Breeding Bird Survey, Results and Analysis 1966–2011. Version 07.03.2013 USGS Patuxent Wildlife Research Center, Laurel, MD.)

5. *What is the scope of inference?* From what area were samples selected? Over what time period? Are the results of the work likely to be applicable to your area? The more different the conditions under which the data was collected from the conditions in your area, the less confidence you should place in the results.

Given the cautions indicated above, it is reasonable and correct to use data that is already available to inform and focus the questions to be asked by a monitoring protocol. For instance, results from the Breeding Bird Survey (Sauer et al. 2012) include a credibility index that flags imprecise, small sample size or otherwise questionable results. For instance, yellow-billed cuckoos have shown a significant decline in southern New England over the past 34 years (Figure 22.6), but the data are deficient when considering regional changes in abundance due to low detection levels (Sauer et al. 2012). Further, an examination of the data would indicate that the one estimate in the early 1980s may be an outlier and may have an overriding effect on the results. In this example, it would be useful to delete that datum and rerun the analyses and then determine if the declining relationship still holds.

Use of existing data and an understanding of data quality can be of value in identifying areas of a management plan that are based on weak data or assumptions. Those factors that are based on assumptions or weak data and which seem quite likely to be influencing the ability to understand management effects should become the focus of questions to be answered by the monitoring plan.

MAKING DECISIONS WITH DATA

Once you have collected data, then you need to decide what to do with it. Say that your monitoring data of population change over time under current management practices produced a chart similar to that in Figure 22.5. At what point along the *x*-axis do you decide that it is time to change your management approach—1975, 1985, 1995? Do you wait and collect more data and make a decision in 2025? At what time is a decision to change management soon enough to reduce a declining trend but not too late to make a change that may be moot? Those decisions should be clearly articulated in a management plan. We know that we cannot meet the needs of all species in the same stand or small forest at the same time; there will always be species that are increasing in abundance and others that are declining. When defining your desired future conditions, the expected changes in area of habitat, populations, or frequency of occurrence of all species of concern can be described, and then monitoring can be conducted to see if trends are progressing as expected. Deciding when to make management changes can be based on when the rates of change depart from the expected, to a degree specified in the plan. It is important to consider these decision thresholds (sometimes referred to as "trigger points") prior to implementing a management plan, rather than waiting until data have been collected and analyzed (Block et al. 2001). Nonetheless, unanticipated results may arise during monitoring, and this should trigger a reinitiation of the adaptive management process.

EXAMPLES OF APPROACHES TO MONITORING

Species respond to habitat availability and quality at multiple scales, and management occurs over a range of spatial and temporal scales. Consequently, a monitoring plan usually takes either a management-centered approach or an organism-centered approach. Regardless of the approach taken, the scope of inference from the monitoring data will be influenced by the interaction between these two approaches and their inherent scales of space and time. The scale of the management actions relative to the scale associated with populations should help identify a set of questions that can be addressed by different data types. For instance, consider the following examples based on the designs proposed by Vesely et al. (2006):

Monitoring Clonal Plants

Given our lack of knowledge of the distribution of a clonal plant species, we are concerned that timber management plans could have a direct impact on remaining populations that have not yet been identified in our district. How will we know if a timber sale will impact this species?

In this example, the plant species may have a geographic range extending well beyond the timber sale boundaries and may extend over multiple forest ownerships. The concern is that populations of this species are patchily distributed and poorly known. We may be concerned that population expansion and persistence may be highly dependent on mobility of propagules among population patches, and that additional loss of existing patches may exacerbate loss of the population over a significant portion of its range. Consequently, the primary goal of a monitoring effort should be to identify the probability of occurrence of the species in a timber sale. A survey of all (or a random sample of) impending timber sales will provide the land manager with additional information with regard to the distribution of the species. Although information may be collected that is related to fitness of the clone (size, number of propagules, etc.), the primary information needed is an estimate of the probability of occurrence of the organism, prior to and following management actions. Indeed, this survey approach also can lend itself well to development of a secondary monitoring approach, which utilizes a manipulative experiment. Identification of sites where the species occurs can provide the opportunity for random assignment of manipulations and control areas to understand the effect of management on the persistence of the species.

Monitoring the Occurrence of a Small Mammal Species

Given the uncertainty in the distribution of a species of small mammal over a forest, will a planned timber harvest have an undue impact on a large proportion of individuals of this species on this forest?

In this example, the species' geographic range extends well beyond the boundaries of the ownership, but the manager needs a context within which to understand the potential for adverse effects on the species. Based on survey information, it is clear that the species occurs in areas that are planned for harvest, but do they occur elsewhere in the ownership? We need to have an unbiased estimate of the abundance of the species over the entire planning area to understand if the proposed management activities indeed represent the potential to impact a significant portion of the population for this species. With an estimate of abundance that extends over the ownership (or forest, or watershed, etc.), one can estimate (with known levels of confidence) if the proposed management activities might affect 1% of the habitat or population for this species, or 80% of the habitat or population.

Monitoring Trends in a Salamander Subpopulation

Given the history of land management on a forest and the plans for future management, will these management actions be associated with the abundance and distribution of a subpopulation of a salamander species that we know occurs in our forest?

In this example, the species, again, has a geographic range that extends beyond the boundaries of the forest, but there is concern that a subpopulation of a relatively immobile species may occur in our forest. The concern is that the subpopulation may decline in abundance over time, as a result of the past and projected management activities on the forest. The goal is to document trends in abundance over time. Changes in abundance, or even in occurrence, may be difficult to detect at a local scale (timber harvest, road building), because individuals are patchily distributed; but, cumulatively, over space and time, impacts could become apparent. Consequently, this *trends*-monitoring approach should extend over that portion of the forest where the species is known or likely to occur and provide an estimate of abundance of the species at that scale over time.

Monitoring Response of Neotropical Migrant Birds to Forest Management

Concern has been expressed for several species of neotropical migrant birds whose geographic range extends across the forest. Is the proposed stand management causing changes in the abundance of these species?

In this example, we are dealing with a species that is probably widely distributed, reasonably long-lived, and spends only a portion of its life in the area affected by proposed management. One could develop a trends-monitoring framework for this species, but the data resulting from that effort would only indicate an association (or not) with time. It would not allow the manager to understand the *cause-and-effect* relationship between populations and management actions. In this case, there are several strata that must be identified relative to the management actions. Can the forest be stratified into portions that will not receive management and others that will receive management? If so, then are the areas in each stratum sufficiently large to monitor abundance of those portions of the populations over time? Monitoring populations in both strata, prior to and following management actions, imposed within one of the strata, would allow the managers to understand if changes occur in abundance or reproductive output. For instance, if populations in both managed and unmanaged areas declined over time, then the managers might conclude that population change is independent of any management effects, and some larger pervasive factor is leading to decline (e.g., changes in habitat on wintering grounds). On the other hand, should the population in the unmanaged stratum change at a rate different from that on the managed stratum, then the difference could be caused by management actions and lead managers to change their plan.

In Figure 22.7, one of three replicate areas is shown prior to and following the management actions that included clearcut with reserves, two-story stands, and group-selection stands. A central control area can also be seen in the post-treatment photo. The results from this effort produced predictable responses, but the responses could clearly be linked to the treatments. White-crowned sparrows were not present on any of the pretreatment sites, but were clearly abundant on the clearcut

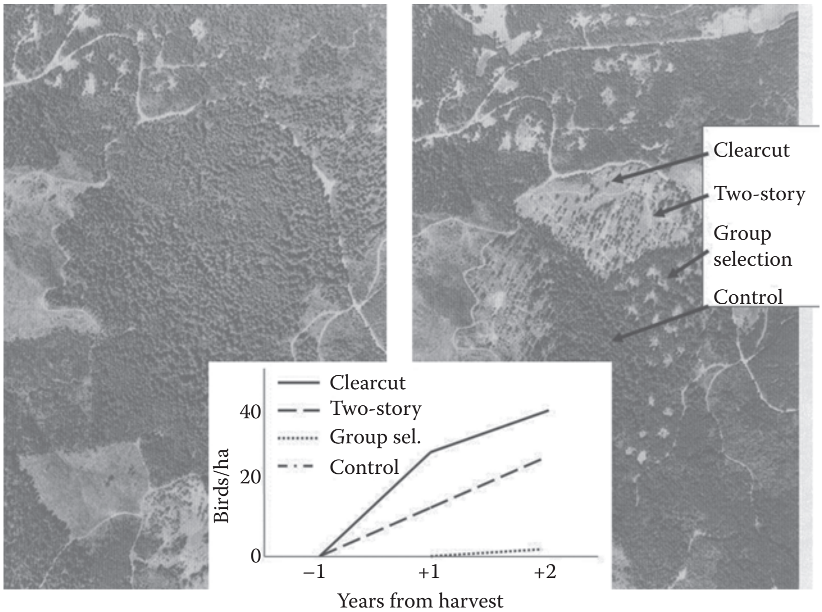

FIGURE 22.7 One of three replicate areas used to assess breeding bird response to treatments using a BACI experimental design and associated changes in white-crowned sparrow detections. (Redrafted from Chambers, C.L, W.C. McComb, and J.C. Tappeiner. 1999. *Ecological Applications* 9:171–185. With permission from the Ecological Society of America.)

and two-story stands, following treatment (Figure 22.7). The treatments caused a response in the abundance of this species.

Conversely, hermit warblers declined in abundance on these two treatments but remained fairly constant on the control- and group-selection treatments (Figure 22.8). Consequently, for this forest, we could predict, with 95% confidence, that future management actions such as these would produce comparable changes in the abundances of these two species. To fully understand why these

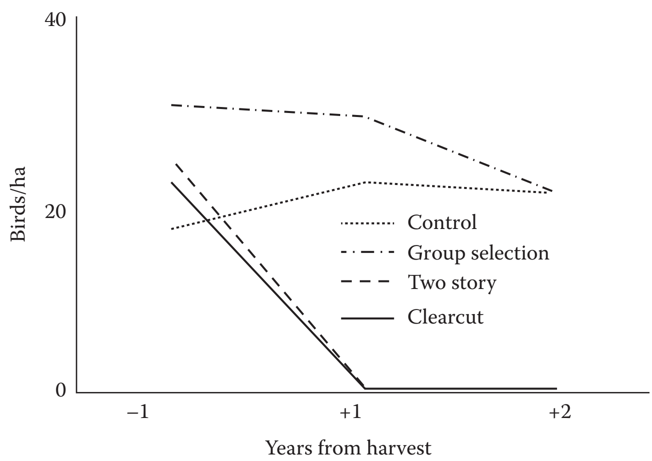

FIGURE 22.8 Changes in abundances of hermit warblers following three management actions. (Redrafted from Chambers, C.L, W.C. McComb, and J.C. Tappeiner. 1999. *Ecological Applications* 9:171–185. With permission from the Ecological Society of America.)

changes might have been observed, ancillary data on habitat elements important to these species also could be collected. If the treatments caused changes in important habitat elements, then the reasons for the effects become clearer (Chambers et al. 1999). These habitat-relationships analyses can be particularly informative when developing predictive models of changes in abundance or fitness of an organism, based on changes in habitat elements caused by management actions or natural disturbances.

Monitoring Habitat Elements

Finally, say that we believe the most likely factor affecting the change in populations of a wide-ranging raptor is change in nest-site availability. Populations are low, and the probability of detecting a change in abundance or fitness of this species over a large forest is very low. Managers may decide to monitor habitat elements that are associated with demographic characteristics of the species, rather than try to monitor the population itself. So we might ask: "How is management affecting the abundance and distribution of potential nest trees for this species?"

Ideally, monitoring of the habitat elements and the associated demographic processes can be conducted to assess cause-and-effect relationships (see above), but with rare or wide-ranging species, this may not be possible. The monitoring data needed to develop *wildlife habitat relationships* includes an unbiased estimate of the availability of key habitat elements that are assumed to be associated with a demographic characteristic of the species and an estimate of the demographic characteristics assumed to be associated with each habitat element. It is important that the monitoring framework for the vegetation component of the habitat relationships must be implemented at spatial and temporal scales consistent with those used by the species of interest.

SUMMARY

Adaptive management is a formal process of treating management plans as hypotheses, implementing the plans, and monitoring the implementation and effectiveness of the actions and validating key assumptions. The information gained from this process is then used to refine and improve future actions. Design of monitoring plans includes several key steps once goals have been identified: identify the appropriate response variables; identify the scope of inference; establish the experimental design; and estimate the appropriate sampling intensity, frequency, and duration. Monitoring of habitat elements usually includes use of both ground-based and remotely-sensed data. Monitoring of habitat element and population may be conducted to survey the probability of occurrence of species or elements, examine trends, or establish cause-and-effect relationships. Deciding how to use the information to make changes in management direction should be a key part of the description of the desired future conditions in the management plan.

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