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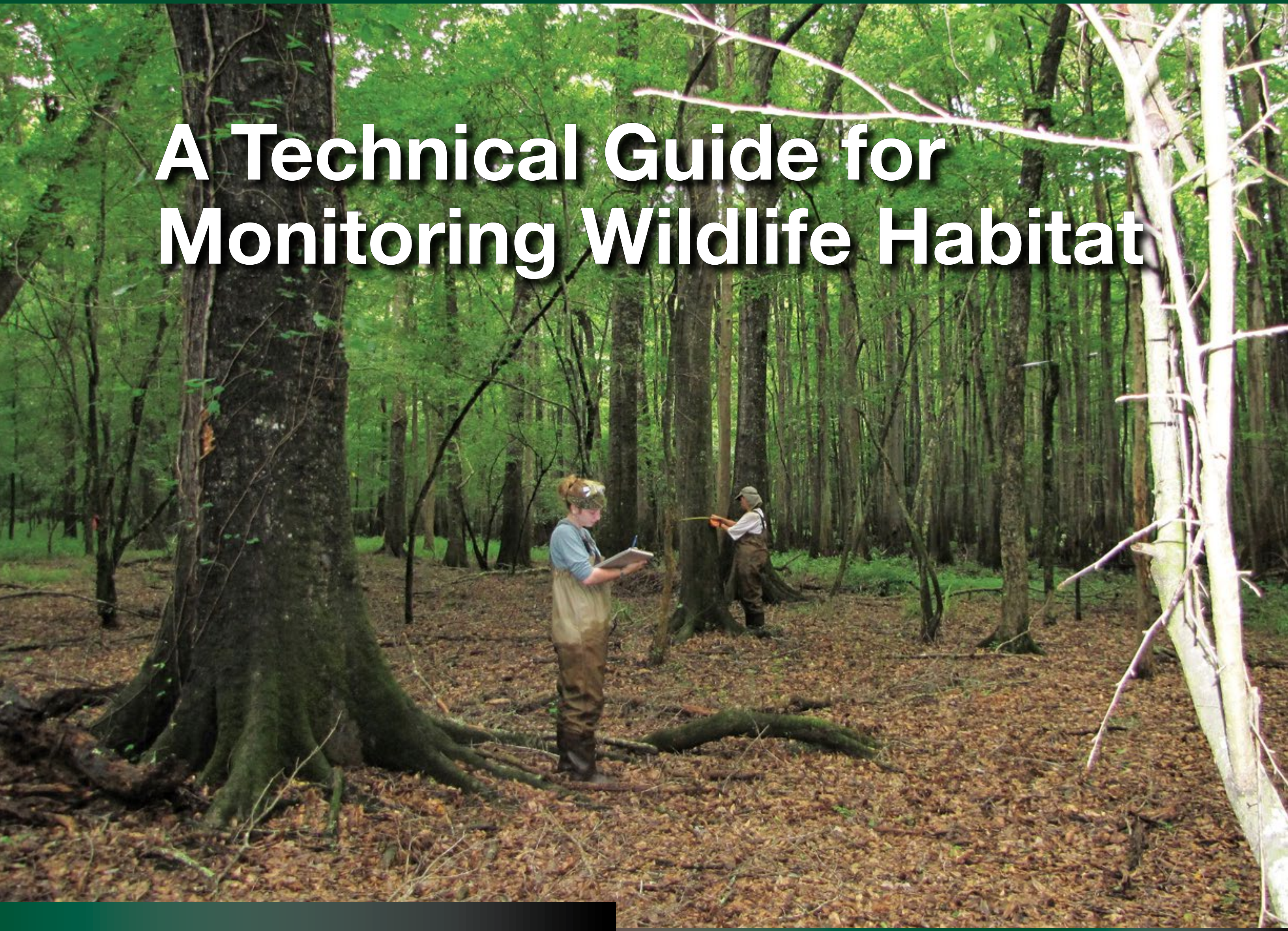
A Technical Guide for Monitoring Wildlife Habitat



Forest Service

Gen. Tech. Report WO-89

October 2013

Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	0.305	Meters
Miles (mi)	1.609	Kilometers
Acres (ac)	0.405	Hectares
Square feet (ft^2)	0.0929	Square meters
Yards (yd)	0.914	Meters
Square miles (mi^2)	2.59	Square kilometers
Pounds (lb)	0.454	Kilograms

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A Technical Guide for Monitoring Wildlife Habitat

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Cover photo: The cover images illustrate the primary sources of habitat monitoring data: field data (front cover), remote sensing data (back cover), and existing data sources (the hexagonal grid of the Forest Inventory and Analysis [FIA] program superimposed on a topographical map; back cover). The three wildlife species are those featured in the guide as case examples of habitat monitoring: American marten (*Martes americana*), greater sage-grouse (*Centrocercus urophasianus*), and marbled salamander (*Ambystoma opacum*), representing the group of mole salamanders. Photo credits: bat habitat monitoring in bottomland hardwood forest, Susan Loeb; American marten, Erwin and Peggy Bauer; greater sage-grouse, Stephen Ting; marbled salamander, Lloyd Gamble; FIA image, Randall S. Morin; person with increment borer, Michelle Gerdes; dot grid overlay, Remote Sensing Applications Center; and image of kernel estimator for the probability of salamander dispersal, Kevin McGarigal.

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Preface—Monitoring Matters

The tragedy of the commons occurs when people pursue their self-interests in using a shared resource and deplete it, thereby compromising their long-term welfare (Hardin 1968). The larger the area shared, the greater the potential for tragedy. The USDA Forest Service is a multiple-use Federal agency that seeks to balance multiple uses of public resources across the Nation while protecting those resources. The agency, facing continual pressure from the public and interest groups to use public resources, has developed a planning process that includes within its framework an important step—monitoring. Monitoring the effects of resource policies and projects on the Nation's resources is critical to maintaining the long-term health, diversity, and productivity of the public's forests and grasslands today and into the future. A well-designed monitoring program avoids the tragedy of the commons. This guide is an invaluable contribution to understanding how to monitor habitats.

Although designed to provide a unique national contribution to habitat monitoring, particularly regarding the condition of habitat and scale of analysis, it must be made clear that this guide does not present population monitoring approaches, or ways to count individuals. The objectives of habitat monitoring and population monitoring are distinctly different, and it is important to keep them separate while reading. Species require habitat to survive. As habitat conditions improve, the long-term resilience of individuals improves and populations become better able to resist perturbations to their ecosystems. As society uses or extracts resources from our forests and grasslands, monitoring the effects of those activities helps us determine if ecosystems are behaving as predicted. Therefore, carefully designed monitoring programs help us avoid ecological surprises.

Human uses place stress on ecosystems in the form of, for example, policies that control wildfire (quick response and control measures) to the permitting of roads that eliminate and fragment habitat. Controlling fire by extinguishing fire starts may eventually lead to increasing fuel loads to greater than normal levels. Elevated fuel levels could lead to catastrophic fires that destroy larger areas of forest than natural effects have destroyed in the past. Increased human access into areas containing species that are sensitive to human presence may interrupt or lower reproduction of sensitive species. Finding a balance in use of, and access to, public resources requires monitoring programs that provide information that is crucial to managers when they adjust their management actions to avoid habitat damage.

In addition to understanding localized human impacts, monitoring is also important to understand the larger, ever-present stress of climate change and its constantly varying pressure on habitats through changes in temperature and precipitation. In stable climates, managers may adjust their resource management actions with more confidence in their predicted outcome than in unstable climates. As climate becomes more variable, as

extreme events become more frequent, and as the pace of climatic change continues to trend in one direction, it becomes critical for managers to quickly adjust their policies and actions to protect public resources that are entrusted to them. Without access to the information that is gained through habitat monitoring, it is difficult at best, if not impossible, for managers to adjust their management direction and avoid major mistakes. Without good information, the probability of error increases, which, for species with sensitive habitat requirements, may be disastrous. Monitoring is fundamental to wise stewardship of public lands.

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Chapter 1. Overview

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1.1 Objective

Information about status and trend of wildlife **habitat**[1] is important for the U.S. Department of Agriculture, Forest Service to accomplish its mission and meet its legal requirements. As the steward of 193 million acres (ac) of Federal land, the Forest Service needs to evaluate the status of wildlife habitat and how it compares with desired conditions. Habitat monitoring programs provide information to meet the needs of the agency while fostering use of standardized, integrated approaches to produce robust knowledge. This technical guide provides current, scientifically credible, and practical protocols for the inventory and monitoring of terrestrial wildlife habitat. Protocols include data standards, data-collection methods, and methods for detecting and monitoring changes over time (Powell 2000).

To our knowledge, this document is the first comprehensive guide to monitoring wildlife habitats. It serves a unique role by providing protocols specifically tailored to habitat monitoring, which is especially pertinent for the Forest Service, given its role in managing landscapes that support a wide diversity of taxa across the major biomes of North America.

Protocols described in this guide address habitat monitoring for terrestrial wildlife. In the past, the term *wildlife* was used to denote all terrestrial vertebrates, especially game birds and mammals, but later was expanded to include species of conservation concern. In more recent years, the term has broadened to encompass the full array of all biota in an ecosystem (Morrison et al. 2006). In this technical guide, the term terrestrial wildlife includes terrestrial vertebrates and invertebrates, but managers may also find the protocols applicable for monitoring rare plants.

Although population monitoring is a necessary and critical complement to habitat monitoring (chapter 2, section 2.2.2), this guide does not address population monitoring per se because several excellent published resources exist on this topic. Two Forest Service technical guides describe population monitoring: (1) Manley et al. (2006) provide protocols for inventory and monitoring of populations of groups of wildlife species, using standardized Forest Service plot data to assess habitat conditions at plot sites; and

[1] Terms indicated in bold typeface are defined in the glossary in appendix B.

(2) Vesely et al. (2006) describe protocol development for monitoring populations of wildlife, fish, and rare plants. Thompson et al. (1998) and McComb et al. (2010) are also good references for monitoring wildlife populations.

The target audience for this guide is professionals (e.g., ecologists, biologists, silviculturists, and planners) charged with forest planning, project impacts analysis, and habitat monitoring at ranger district, national forest or grassland, and regional levels. This guide may also benefit other agencies and organizations that want to standardize their approaches to wildlife habitat monitoring. Protocols and process steps in this technical guide are recommendations, not agency requirements or policy. This guide follows national direction for inventory, monitoring, and assessment as described in Forest Service Manual (FSM) 1940 (USDA Forest Service 2009).

This first chapter describes the origins of the technical guide, business requirements for wildlife habitat information, key concepts of habitat monitoring, recommended roles and responsibilities of Forest Service personnel for completing and applying the protocols, the relation of habitat monitoring to other Federal inventory and monitoring programs, and information about data storage and reporting related to habitat monitoring. Chapter 2 describes selection of habitat attributes for monitoring, and chapter 3 addresses planning and design of habitat monitoring programs.

Chapters 4 through 7 provide specific guidance for monitoring selected habitat attributes (e.g., vegetation structure and composition), monitoring habitat within a landscape context, and monitoring human disturbance agents. Chapter 8 offers recommendations for data analysis, whereas chapter 9 addresses data storage and reporting. Chapter 10 provides detailed examples of habitat monitoring for two individual species and a monitoring plan for a species group.

1.2 Background and Business Requirements

1.2.1 Background

A wildlife protocol development team was established in 2001, under the auspices of the Ecosystem Management Coordination Staff in the Washington Office of the Forest Service, to identify and prioritize species or groups of species that would benefit from standardized inventory or monitoring protocols throughout the Forest Service. This team initially identified the need for population monitoring protocols, which resulted in three products: (1) a protocol for monitoring multiple species (Manley et al. 2006), (2) a set of protocols for monitoring the northern goshawk (*Accipiter gentilis*) (Woodbridge and Hargis 2006), and (3) a general guide for developing other population monitoring protocols (Vesely et al. 2006).

The Washington Office later identified the need for national protocols to address habitat monitoring in support of land management planning. When wildlife habitat is

included in a land management plan's objectives and desired conditions, habitat monitoring is a necessary component of the plan's monitoring program. Most national forests and grasslands undertake habitat monitoring and would benefit from guidance on selecting key habitat attributes for wildlife as well as standard protocols for inventory and monitoring habitat attributes at a variety of spatial scales. This technical guide provides such guidance. It represents the best available science from a broad base of published literature and from expertise of research scientists, ecologists, and statisticians who co-authored individual chapters.

1.2.2 Business Requirements

Specific business requirements of the Forest Service for standardized habitat monitoring arise from the need for information in (1) land management planning, for which structured monitoring can facilitate plan revisions or amendments; (2) recovery of threatened and endangered (T&E) species and sensitive species; and (3) environmental analyses for projects as prescribed in various laws, regulations, and policies (table 1.1). Information needs range from status and trends of ecological diversity to population trends in relation to habitat change for individual species or species groups. Integration of habitat monitoring with monitoring of other resources is critical for meeting agency information needs while ensuring efficient use of funds and staffing.

The habitat monitoring protocols described in this guide address additional business requirements of the Forest Service beyond those listed in table 1.1 and include—

- Improving consistency in monitoring species and species groups, as identified in the National Inventory and Monitoring Action Plan of 2000, across all administrative units of the Forest Service.
- Integrating habitat monitoring with other ongoing data-collection activities (e.g., Forest Inventory and Analysis [FIA] Program, intensified grid inventories, and **Common Stand Exams**) for greater efficiency.
- Ensuring that the best available science is considered in habitat monitoring through documentation of the monitoring process and consistent application and appropriate interpretation of science.
- Ensuring that effects of climate change on habitat are incorporated in monitoring programs, as appropriate, using guidance such as the Forest Service "National Roadmap for Responding to Climate Change" and climate performance scorecard (USDA Forest Service 2010a).
- Providing standardized habitat information for broad-scale assessments.
- Understanding effects of management actions on habitat, such as activities related to the Healthy Forests Initiative and the Healthy Forests Restoration Act.
- Providing standardized habitat information for other existing or emerging national and regional business requirements, such as program and budget planning and execution.

Table 1.1.—*Forest Service business requirements for habitat monitoring in relation to existing laws, rules, and policies.*

No.	Business requirement	Target group	Type of information needed	Analysis scale[a]	Type of report
1	To provide information on habitats needed to maintain viable populations of existing native and desired nonnative vertebrate and invertebrate species (NFMA 1982 reg. at 36 CFR 219.19)	Vertebrates, invertebrates, and plants whose populations are at risk	Habitat abundance, distribution, condition, and trend	Mid and broad scale: the planning area, usually a local management unit (e.g., national forest, grassland) or multiple administrative units	LRMP, AMS, annual monitoring and evaluation reports, supporting regional assessments
2	To provide information on MIS for planning and monitoring under the 1982 rule for the NFMA[b]	MIS	Habitat condition and trend as related to population change, or habitat only (depends on specific language in the LRMP)	Mid and broad scale: the planning area, usually a local management unit (e.g., national forest, grassland) or multiple administrative units	LRMP or AMS, annual monitoring and evaluation reports, supporting regional assessments
3	To aid in the recovery of species listed under the ESA (FSM 2670) (USDA Forest Service 2005a)	Federal threatened or endangered species	As indicated in recovery plans; typically habitat trends and trends in stressors	Mid, broad, and sometimes national scale: geographic range, significant portion of range, or ESU of the listed species	Annual reports of recovery plans and habitat conservation strategies; BA, BO
4	To avoid Federal listing of plant and animal species (FSM 2670, USDA DR 9500-004) (USDA Forest Service 2005a)	Plant or animal species designated “sensitive” by the Forest Service	Distribution, status, and trend of habitats	Mid, broad, and sometimes national scale	Habitat conservation strategies and agreements; progress reports; annual monitoring and evaluation reports; BA, BE, project records
5	To provide information for environmental analysis of proposed projects (NEPA)	TES, MIS, sensitive, socioeconomic species, and migratory birds	Availability of suitable habitat in the project area and larger landscape context	Base (local), mid, and broad scale: usually the project area and larger landscape context; dependent on project scope, species affected, etc.	Landscape or watershed assessment; road analysis; project EIS, EA, or CE; BE, BA, BO; post-activity monitoring reports
6	To work cooperatively with States in the conservation of selected species (as described in the Sikes Act)	Species identified for conservation through an MOU between a State and the Forest Service, including species identified in State comprehensive wildlife conservation strategies	Information as specified in the MOU or strategy	A State or the range of a species within a State	Progress reports as specified by the MOU
7	Account for the effects of global climate change on forest and rangeland conditions (Forest and Rangeland Renewable Resources Planning Act of 1974)	Vertebrates, invertebrates, and plants whose habitats may be at risk from climate change	Habitat abundance, distribution, condition, and trend	Mid and broad scale: the planning area, usually a local management unit (e.g., national forest, grassland) or multiple administrative units	LRMP, annual monitoring and evaluation reports, supporting regional assessments

AMS = analysis of the management situation. BA = biological assessment. BE = biological evaluation. BO = biological opinion. CE = categorical exclusion. CFR = Code of Federal Regulations. EA = environmental assessment. EIS = environmental impact statement. ESA = Endangered Species Act. ESU = ecologically significant unit. FSM = Forest Service Manual. LRMP = Land and Resource Management Plan. MIS = ***management indicator species****. MOU = Memorandum of Understanding. NEPA = National Environmental Policy Act. NFMA = National Forest Management Act. TES = threatened, endangered, and sensitive species.*

[a] See chapter 4, section 4.2.4, for definition of scale as used in this guide.

[b] MIS, a concept developed in the 1982 planning rule to implement the NFMA (USDA Forest Service 1991). The use of MIS is in effect for all planning units until their plans are revised under a new planning rule.

Source: Adapted from Vesely et al. (2006): table 1.1.

1.3 Key Concepts

1.3.1 Habitat

Clements and Shelford (1939) originally defined *habitat* as the physical conditions surrounding a species, a population, an assemblage of species, or a community. Hall et al. (1997: 175) further defined habitat as—

> ...the resources and conditions present in an area that produce occupancy—including survival and reproduction—by a given organism. Habitat is organism-specific; it relates the presence of a species, population, or individual (animal or plant) to an area's physical and biological characteristics. Habitat implies more than vegetation or vegetation structure; it is the sum of the specific resources that are needed by organisms. Wherever an organism is provided with resources that allow it to survive, that is habitat.

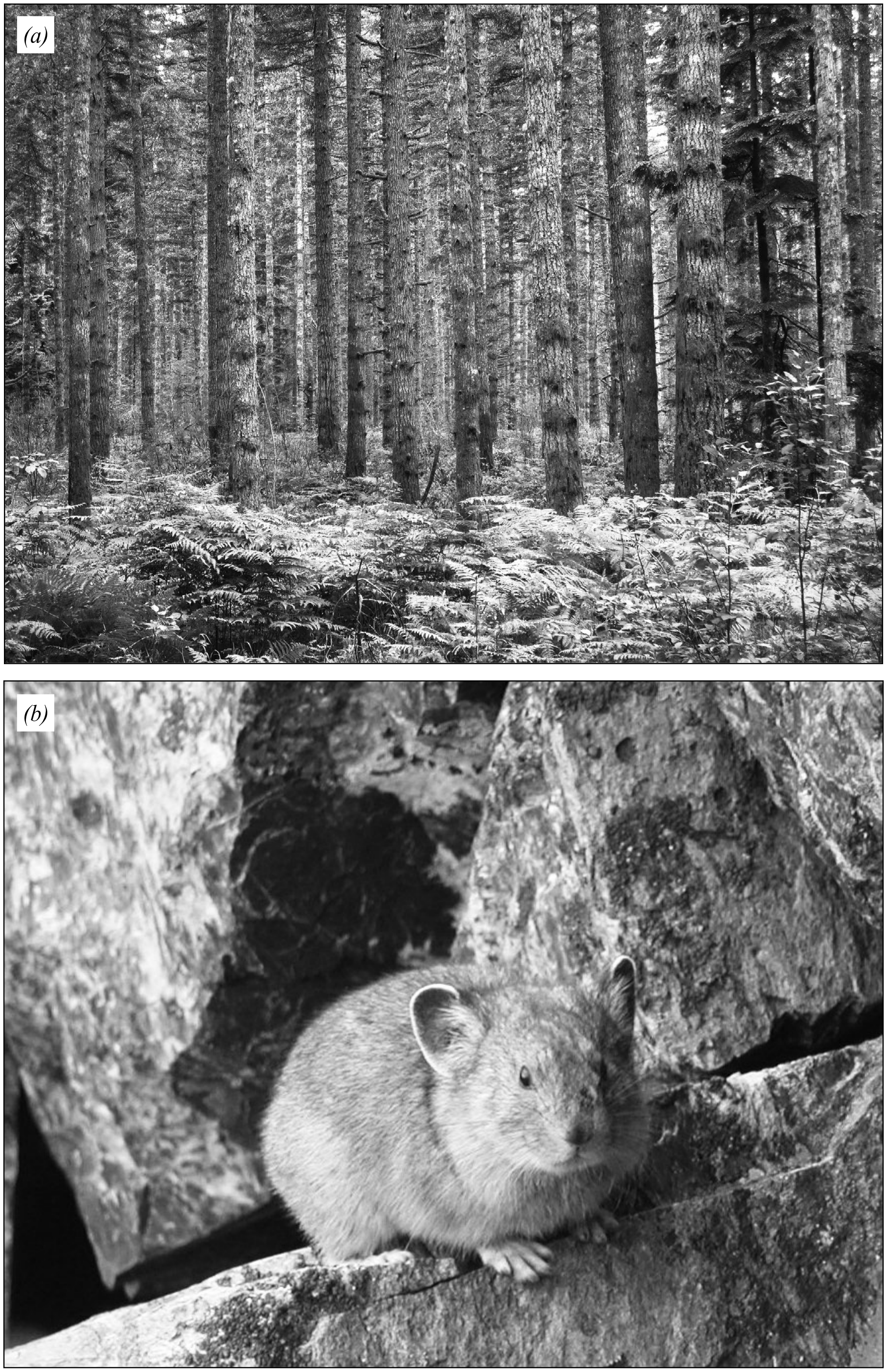
Two key concepts are embedded in this latter definition. First, the organism defines its habitat through its selection of resources to meet its unique needs (Morrison et al. 2006). Corollary to this concept is the notion that no single system of habitat classification can describe habitat for all species.[2] Daubenmire (1952, 1984) conceived the term ***habitat type*** to refer to the vegetation association in an area or to the potential of vegetation to reach a specific climax stage. We (the authors of this technical guide) concur with Hall et al. (1997) in discouraging use of the term "habitat type" when referring to wildlife-habitat relationships because of its original usage in referring to vegetation but not wildlife.

Second, habitat is not equivalent to vegetation or vegetation structure. Although vegetation is the foundation for wildlife habitat, habitat may also be composed of natural physical features (e.g., water bodies, caves, or crevices), anthropogenic structures (e.g., bridges and mines), other nonvegetative factors (Morrison et al. 2006), or other organisms, such as prey species (figure 1.1). The definition by Hall et al. (1997) presumes that if the required resources are present (i.e., habitat), then the organism will occur there. In some instances, however, the suite of requisite habitat components may be present, but other circumstances, such as competitive exclusion of northern spotted owls (*Strix occidentalis caurina*) by barred owls (*Strix varia*), may prevent occupancy.

The importance of specific attributes may vary with a species' life stage, season of use, or order of habitat selection (chapter 2, section 2.3.2). For example, large trees and closed canopies are important attributes of northern goshawk habitat for nesting, but they are not essential at other times of the year (Squires and Reynolds 1997). Similarly, marbled salamanders (*Ambystoma opacum)* require ponds for depositing eggs (Petranka 1990), but adults migrate to a variety of wooded upland habitats in the nonbreeding season.

[2] Systems of habitat classification are commonly used in wildlife management and conservation planning (e.g., Northwest Habitat Institute 2006); these systems are best described as classifications of terrestrial communities or ecosystems. We avoid the term *habitat classification* in this guide because its use implies that habitat may be defined without reference to the species.

Figure 1.1.—*Although vegetation structure provides key habitat attributes for many wildlife species (a), it is not equivalent to habitat. Habitat is species specific and may include manmade or physical features such as talus slopes occupied by American pika (Ochotona princeps) (b). Photo credit: Mark Penninger (pika).*



Although habitat can be defined conceptually, the process of monitoring habitat requires that habitat be defined in quantifiable, reportable terms (chapter 2, section 2.3.2; chapter 3). Further, habitat can be monitored by selecting individual habitat attributes (e.g., snag density) or by combining attributes in an integrated measure to describe habitat through use of a habitat model (chapter 5).

1.3.2 Definition and Types of Monitoring

This technical guide emphasizes monitoring, rather than inventory, following the definition from FSM (1940: 19)—"The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a resource or management objective. A monitoring activity may include an information needs assessment; planning and scheduling; data collection, classification, mapping, data entry, storage, and maintenance; product development; evaluation; and reporting phases." The repetition of measurement is a fundamental concept of a monitoring program (chapter 3). The detection of change over time may alert managers to positive or deleterious effects of an activity. Conversely, the detection of no change may demonstrate a lack of effect or the need to continue monitoring for a longer time period.

In contrast to monitoring, inventory is the survey of "an area or entity for determination of such data as contents, condition, or value, for specific purposes such as planning, evaluation, or management" (USDA Forest Service 2009: 19). Although measurements or evaluation conducted for inventory may underpin a future monitoring program, and often precede monitoring, the data are not always useful for monitoring (Elzinga et al. 1998) (chapter 3, section 3.2.3).

Holthausen et al. (2005) defined three types of monitoring for terrestrial animals and their habitats.

1. **Targeted monitoring** keeps track of the condition and response to management of species and habitats that are identified as being of concern or interest.
2. **Cause-and-effect monitoring** investigates the mechanisms that underlie habitat and species response to management and other forms of disturbance. This type of monitoring is conducted using a rigorous statistical sampling framework, testing a priori hypotheses.
3. **Context monitoring**, which is broader in scope, addresses a wide array of ecosystem components at multiple scales without specific reference to influences of ongoing management.

The focus of habitat monitoring described in this guide is targeted monitoring of specific management activities on habitat. Monitoring of selected habitat attributes for species or species groups at the initiation and completion of a planning period permits evaluation of whether desired conditions or management objectives were met and whether species exhibited associated responses. Context monitoring may be useful when it evaluates a broad suite of habitat attributes at multiple scales and across multiple management

units, such as national forests or grasslands. Cause-and-effect monitoring is generally outside the scope of this guide because it requires a fully developed research program (Elzinga et al. 1998, Holthausen et al. 2005).

Habitat Versus Population Monitoring

A clear distinction between habitat and population monitoring is necessary for developing a successful wildlife habitat monitoring program—habitat monitoring should not be confused with population monitoring. In habitat monitoring, key attributes of habitat, such as canopy cover of key tree species or the number of vernal pools, are monitored over time, whereas in population monitoring, the organisms themselves are monitored through appropriate protocols, such as point-counts or line transect surveys. Although habitat is essential for population persistence, the maintenance or restoration of habitat does not guarantee population persistence or recovery (Mulder et al. 1999), or even presence. Information about species' habitats is used to ensure that essential habitat attributes are maintained or restored to meet desired conditions. This information is especially important for the Forest Service because of its land management stewardship responsibilities. The Forest Service must not only identify the habitat needs of species of concern, but it must also evaluate the condition of wildlife habitat and compare it with desired conditions as part of the planning process described in planning documents.

The emphasis on habitat monitoring in this guide does not replace the need to assess population status and trend (chapter 2, section 2.2.2). Monitoring to detect changes in population status under different management scenarios provides valuable information about a species' response to management activities. Population monitoring is often recommended in recovery plans for T&E species. Also, situations in which habitat does not strongly influence population dynamics require population monitoring to adequately address species' responses to other forms of environmental change (O'Neil and Carey 1986). For example, many populations of *Sceloporus* lizards are believed to be declining because of effects of temperature warming during the breeding season (Sinervo et al. 2010).

Concurrently collecting habitat and population data strengthens wildlife-habitat-relationships models and provides more valid interpretation of observed changes in both populations and habitats (Cushman et al. 2008b, Manley et al. 2006, McComb et al. 2010, Mulder et al. 1999). The Multiple Species Inventory and Monitoring (MSIM) protocols provide explicit guidelines for this dual-purpose monitoring (Manley et al. 2006). Habitat monitoring may sometimes be more logistically feasible than population monitoring. For example, rare species (e.g., Allen's hummingbird [*Selasphorus sasin*]), or those with low detectability (e.g., wolverine [*Gulo gulo*], northern pygmy-owl [*Glaucidium gnoma*]), that are not at risk are often better candidates for habitat monitoring than population monitoring, owing to the extensive effort required in sampling their populations compared with sampling habitats (chapter 2, section 2.3.1). Even in these situations, habitat monitoring results need to be compared periodically with population data to verify the assumed relationship between habitat and populations.

Habitat monitoring may be critical when the ecological trajectory of habitat is unclear—for instance, if the outcome of management is uncertain or the ecological response of habitat to disturbance is not clearly understood. In addition, habitat monitoring could be a useful way to evaluate the effects of climate change on species or species groups (chapter 2, section 2.2.7).

1.3.3 Sources of Uncertainty in Habitat Monitoring

Several sources of uncertainty challenge the development of habitat monitoring protocols and their subsequent application (chapter 3). These challenges include the following—

- Determining all relevant attributes that define habitat for a given species.
- Using the correct spatial and temporal scales to monitor habitat for a given species.
- Accurately measuring selected habitat attributes.
- Identifying errors associated with modeling and mapping wildlife habitat.
- Understanding how management actions affect habitat and how species respond to habitat change.
- Evaluating the relative role of habitat versus other factors (e.g., plasticity of behavioral responses, competition, or life history traits) that also influence population response to environmental change.

By definition, habitat is multiscalar and multidimensional, encompassing a suite of attributes associated with a particular species (1.3.1; chapter 2, section 2.2.6). Moreover, our knowledge of precisely what environmental attributes constitute habitat for a species is scant for all but the most well-studied organisms. Because of this inherent complexity, monitoring habitat presents unique challenges that are not found with other forms of monitoring, including population and vegetation monitoring. Monitoring efforts may not correctly identify the key habitat attributes for common species, or even reveal them for rare species.

1.3.4 The Habitat Monitoring Team

The habitat monitoring team is the group of people assembled for developing a habitat inventory or monitoring program at a local planning unit (e.g., forest or grassland level or regional level). The members of the team should collectively have the following skills:

- Sufficient understanding of the monitoring objectives.
- Knowledge about the **habitat requirements** of the species selected for monitoring.
- Understanding and experience with statistical sampling issues.
- Knowledge of management plans or activities that might affect **habitat quality** or quantity.
- Knowledge of the potential response of selected species to changes in habitat quality or quantity resulting from management actions.

Recommended members of a team are one or more wildlife biologists or ecologists, a planning specialist, and a statistician. The team may also include expertise drawn from forest, range, grassland, and fire ecology disciplines. The team should use expertise from Research and Development (R&D), including members of the FIA program, and expertise within the National Forest System (NFS). Forest Service cooperators should also be encouraged to participate in habitat monitoring teams.

1.3.5 Partnerships

Effective habitat monitoring requires collaboration with multiple entities, because habitats for most species or species groups are not confined to lands managed by the Forest Service, and a variety of rules and regulations (e.g., Migratory Bird Treaty Act, Endangered Species Act), many of which are administered by other agencies, govern activities that affect wildlife habitats and populations. Habitat monitoring programs can be expensive and time consuming, owing to development, implementation costs, and application of results (chapter 3). Because of these constraints, the implementation of a monitoring project often lies beyond the means of a single organization. Thus, the Forest Service may benefit from sharing monitoring responsibilities and costs when appropriate (Holthausen et al. 2005, Schoonmaker and Luscombe 2005). Monitoring projects that successfully share information among multiple practitioners ensure that future monitoring incorporates previous lessons learned (Schoonmaker and Luscombe 2005). Using stringent data-quality standards also enhances sharing of monitoring data among multiple partners (chapter 9).

1.3.6 Role of Monitoring in Adaptive Management

Adaptive management is a systematic approach for improving environmental management and building knowledge by learning from management outcomes. It entails explicit hypothesis testing, monitoring, and evaluation in a process that accelerates learning based on results of policy implementation (Holthausen et al. 2005, Stankey et al. 2005, Walters and Holling 1990). Monitoring is thus a key component of adaptive management—only through monitoring can the results of management and the potential need for change in management be determined (Elzinga et al. 1998, Murray and Marmorek 2003). For monitoring to inform adaptive management, it must readily distinguish between effects of local management activities and effects of more broad-scale processes or activities, such as wildfires and climate change (Holthausen et al. 2005).

Any of four actions may be appropriate in an adaptive management context after comparing monitoring results with management direction and the original monitoring program objectives: (1) modify the monitoring approach to improve its ability to estimate changes or trends in habitat and to evaluate effects of management direction, (2) modify management direction in response to noncompliance or undesired effects, (3) modify both

monitoring and management direction, and (4) document that none of the previous actions are necessary because the monitoring process worked effectively to meet monitoring program objectives.

Changes in habitat monitoring protocols as a result of adaptive management practices must not be so frequent or drastic that consistency in data collection and analysis is lost (Schoonmaker and Luscombe 2005). Habitat monitoring programs must find a balance between consistency and flexibility; monitoring should provide comparable data over time, but it should provide flexibility so the data collected remain relevant over time as conditions change.

1.4 Recommended Roles and Responsibilities

1.4.1 National Responsibilities

- Develop the habitat monitoring technical guide using expertise from ecologists within the NFS and R&D (including FIA) and from external organizations.
- Ensure that habitat monitoring protocols developed for the technical guide comply with standards previously adopted by the Forest Service, such as those for classifying and mapping existing vegetation (Warbington 2011).
- Encourage the use of existing Forest Service data sources such as FIA, Common Stand Exam data, national geographic information system layers, and regional vegetation inventories for monitoring wildlife habitat (Powell 2000); other data relevant to habitat monitoring, such as species distributions and habitat databases, are available from nongovernmental organizations such as The Nature Conservancy and NatureServe.
- Periodically review the habitat monitoring technical guide for relevance to agency business requirements and update as needed (section 1.7).
- Work collaboratively with national applications, such as the Natural Resource Manager (NRM; http://fsweb.nris.fs.fed.us/), to integrate habitat monitoring information into existing applications (chapter 9). (This Web site and others beginning with “fsweb” are internal to the Forest Service and thus not available to outside users.)
- Provide training and technical expertise to regional and local management unit (e.g., forest, grassland, national recreation area, prairie) staff, as appropriate, for implementing habitat monitoring protocols.

1.4.2 Regional Responsibilities

- To ensure compatibility and scalable results, encourage habitat monitoring across multiple regions and local management units for species whose geographic ranges span more than one region or local management unit.
- Collaborate with other regions and the Washington Office to develop, coordinate, and conduct training in the use of existing data sources and the collection of field data.
- Coordinate with Federal, State, and local government agencies, tribes, scientists, partners, and members of the public to maximize collaboration in habitat data collection across administrative boundaries.
- Evaluate and apply habitat monitoring data, as needed, to inform broad-scale assessments.
- Collaborate with Forest Service R&D to develop additional habitat monitoring protocols, as needed.
- Synthesize and interpret local monitoring data for regional application.

1.4.3 National Forest Responsibilities

- Determine the need for monitoring specific habitats or habitat attributes used in evaluating progress toward achieving or maintaining land management plan objectives or desired conditions.
- Follow the protocols described in the habitat monitoring technical guide when monitoring habitats of specific species or species groups.
- Collaborate with adjacent private and State landowners in implementing habitat monitoring whenever feasible.
- Use data from existing and ongoing data-collection efforts to the extent possible.
- Seek opportunities to monitor habitats in collaboration with adjacent NFS lands and with other agencies, organizations, scientists, and members of the public.
- Ensure that local management units enter habitat monitoring data into the appropriate information system, such as NRM.
- Use the information obtained from habitat monitoring to inform local Forest Service management decisions.
- Alert region of unique, local habitat monitoring situations or a need for improved monitoring protocols.
- Integrate broad-scale habitat monitoring strategies beyond the boundaries of the local management unit, as appropriate.
- Synthesize and interpret local and regional monitoring data for national application.

1.5 Relationship to Other Federal Inventory and Monitoring Programs

The protocols developed and data collected under the auspices of habitat monitoring relate to several existing inventory and monitoring programs within the Forest Service, with other Federal agencies, and beyond. The programs to which the habitat monitoring protocols relate most directly are described in the following paragraphs.

- This technical guide for monitoring wildlife habitat builds on existing protocols contained in the Terrestrial Ecological Unit Inventory (TEUI) (Winthers et al. 2005) and Existing Vegetation Classification and Mapping (Warbington 2011) technical guides. Classification of vegetation is a key step in defining vegetation components of habitat for many species (Morrison et al. 2006; chapters 4, 5). The TEUI protocols include the classification and mapping of ecosystems, which also may be used in defining habitat for species or species groups. Moreover, the ecological units defined in the National Hierarchy Framework, such as the land type associations described in the TEUI technical guide, may form the geographic basis for mapping, ranking, and sampling habitat at appropriate scales (Cleland et al. 1997, DeMeo 2002, MacFaden and Capen 2002, Winthers et al. 2005).
- Protocols developed by Manley et al. (2006) for habitat monitoring include field measurement of several environmental characteristics at MSIM sampling points, such as tree density by size class, canopy cover, and snag and log density (see Manley et al. 2006: table 11.1). At the MSIM monitoring points, FIA data (phase 2 [P2] and some phase 3 [P3]; chapter 4, table 4.3) function as the primary environmental measures. Environmental data collected at MSIM points within the sampling area for a specific habitat monitoring program can be examined to determine what, if any, additional habitat data need to be collected to meet habitat monitoring objectives. Data collected under the MSIM protocols can also be used in wildlife-habitat relationship modeling and thus can inform the selection of habitat attributes to monitor (chapter 2, section 2.3.4; chapter 5).
- This technical guide prescribes use of data from ongoing inventory and monitoring programs (e.g., FIA data, LANDFIRE products; see chapter 4, sections 4.4 and 4.5 for details about use of existing data and protocols) to the degree possible. Core variables collected by FIA (chapter 4, table 4.3) can provide baseline information about habitat attributes on forested lands, but they may not be measured frequently enough at an individual point to satisfy some habitat monitoring objectives (e.g., sampling at many western FIA grid points occurs at 10-year intervals). Data collection under the auspices of FIA on nonforested lands is increasing and will be useful in describing habitat attributes, such as shrub cover, on these lands.
- This technical guide will be entered into the Natural Resources Monitoring Partnership protocol library, an online database of protocols maintained by The Nature Conservancy

and accessible to every natural resource agency and organization in the United States and Canada (http://www.conservationgateway.org/ExternalLinks/Pages/natural-resources-monitor.aspx).
- Habitat monitoring protocols as described in this guide can assist in activities undertaken under the auspices of the Healthy Lands Initiative of the Bureau of Land Management, which emphasizes science-based monitoring and habitat conservation and enhancement.

The approaches to habitat monitoring described in this technical guide may be useful in collaborating with States as they implement State Comprehensive Wildlife Action Plans. Among the eight elements mandated by Congress for these strategies are a monitoring plan and descriptions of the abundance, locations, and conditions of key wildlife habitats (Schoonmaker and Luscombe 2005; http://teaming.com/state-wildlife-action-plans-swaps).

1.6 Quality Control and Assurance

Habitat monitoring protocols described in this technical guide have been designed to be scientifically defensible. Processes that ensure the protocols are sound and uniformly applied include (1) incorporation of existing, standardized data-collection methods (e.g., FIA) built on a science-based sampling methodology; (2) reliance on qualified personnel to craft the protocols; (3) rigorous peer review of the document; and (4) training to encourage consistent application of the protocols. Subsequent chapters describe quality-control measures related to specific aspects of habitat monitoring.

The authors of this technical guide represent a diverse cross-section of expertise from professional and scientific ranks, including national and regional wildlife and vegetation ecologists, research ecologists and wildlife biologists, statisticians, and planners. Qualified professionals, both within and outside the Forest Service, reviewed the technical guide (see acknowledgments). In addition, a statistical review of the entire technical guide ensured that it provides robust methods of data collection, sampling design, and statistical analysis, which, in turn, will generate reliable results when properly applied.

1.7 Change Management

Monitoring programs and protocols must be adaptable to reflect the refinement of existing monitoring techniques and the evolution of new techniques as well as (1) changing conditions on NFS lands (e.g., impacts on habitat of climate change or increasing human population density near NFS lands); (2) emerging issues facing land management (e.g., energy development); and (3) new agency direction resulting from laws, regulations, policies, or case law that affect monitoring. After 5 years, a review of the habitat monitoring technical guide will determine whether the protocols for monitoring habitat attributes and

effects of human disturbance agents on wildlife habitats remain credible and current, or if they need updating with better and more recently developed methodologies. Given the rapidly evolving development of some techniques, especially remote sensing applications, the authors anticipate changes in the technical guide will be warranted at the 5-year review checkpoint. The basic direction of the guide, however, in terms of selecting habitat attributes for monitoring, planning and designing a monitoring program, and establishing monitoring objectives will likely remain intact.

1.8 Conclusions

Habitat monitoring is a critical component of a comprehensive inventory and monitoring program for wildlife on lands managed by the Forest Service and other agencies and organizations. Although several existing excellent resources describe population monitoring protocols, this guide provides standardized protocols for monitoring wildlife habitat, which is of special concern to the Forest Service, given its role as steward of nearly 200 million ac of lands across the United States. Strategic monitoring of a carefully selected suite of habitat attributes, using standardized protocols and existing data where suitable, will yield key information to guide management to meet or maintain desired conditions. Applying the results of habitat monitoring within an adaptive management framework ensures that management and the monitoring protocols evolve as needed to address emerging issues and changes in habitat conditions.

Chapter 2. Selecting Key Habitat Attributes for Monitoring

Gregory D. Hayward
Lowell H. Suring

2.1 Objective

The success of habitat monitoring programs depends, to a large extent, on carefully selecting key habitat attributes to monitor. The challenge of choosing a limited but sufficient set of attributes will differ depending on the objectives of the monitoring program. In some circumstances, such as managing National Forest System lands for threatened and endangered species, habitat monitoring may focus on tracking habitat for one or a few **emphasis species**. In other settings, such as monitoring the effects of broad-scale land management plans, habitat monitoring may need to address many species. Regardless of scope, similar processes are used to identify attributes for monitoring. The complexity of the organizational and analytical task, however, will differ significantly with scope. In this chapter, we describe steps for choosing habitat attributes for monitoring and for reducing the list of key habitat attributes to those that are affected by management and can be feasibly measured. In this chapter, and throughout this guide, a **habitat attribute** is defined as any living or nonliving feature of the environment that provides resources necessary for a species in a particular setting. Selecting habitat attributes depends on management priorities and whether monitoring habitat for a particular species or species group is useful or necessary. Selecting habitat attributes for monitoring is based on an understanding of threats and limiting factors that influence population growth and the status of each emphasis species, as well as the factors that may limit their distribution based on physiological ecology and thresholds. This understanding is summarized through the development of a **conceptual model** of habitat relationships for each emphasis species, which forms the foundation for the selection process.

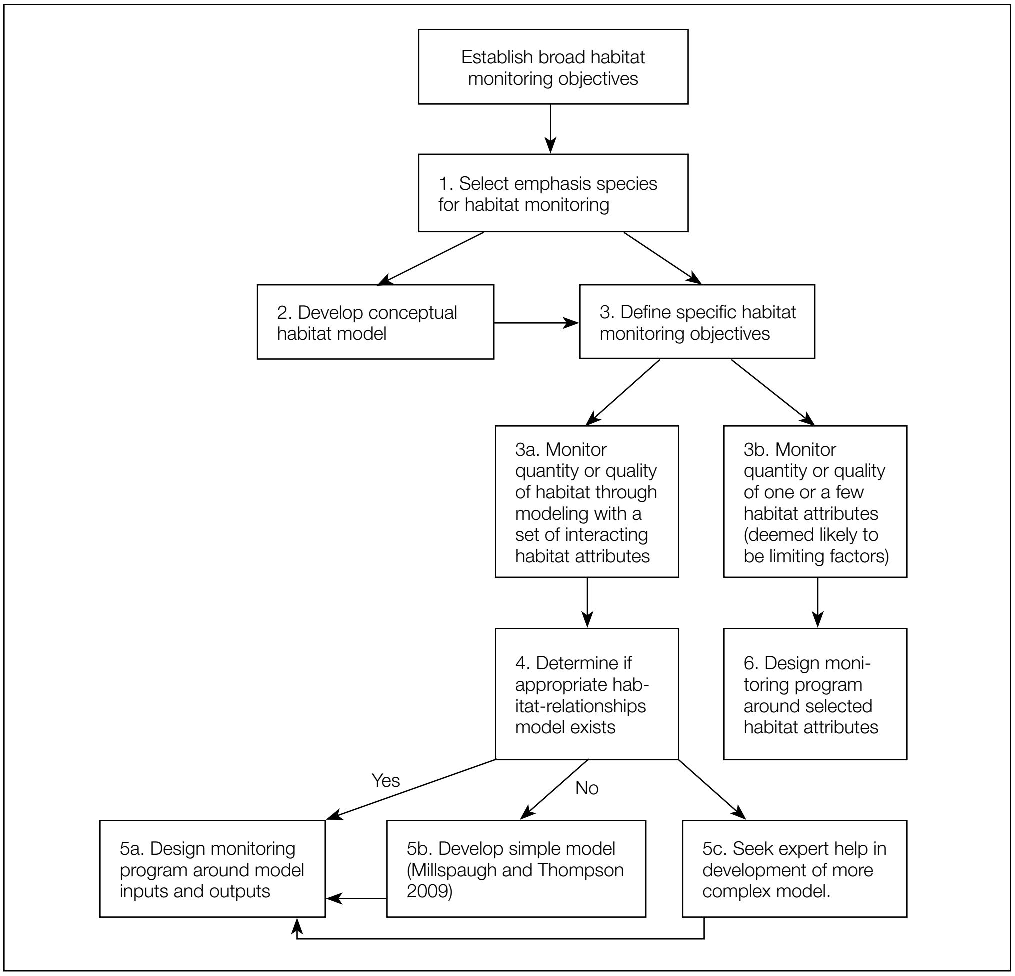
The objective of this chapter is to provide guidance for selecting habitat attributes to monitor that reflect the habitat requirements, limiting factors, and threats of emphasis species at relevant spatial and temporal scales. The chapter also provides guidance on reducing the list of key habitat attributes to those that are affected by management and that can be feasibly measured.

2.2 Key Concepts

2.2.1 Setting Habitat Monitoring Objectives

This chapter focuses on identifying key habitat attributes for monitoring. We assume that broad monitoring objectives have been established and the need to monitor habitat for a species or group of species has been carefully evaluated. The importance of establishing monitoring objectives that will provide knowledge to inform future management decisions cannot be overemphasized (Elzinga et al. 1998, Holthausen et al. 2005). The context for this chapter may be most clearly illustrated using a graphic (figure 2.1). As emphasized in this schematic, setting objectives may occur at two stages of the process. Chapter 3 addresses the establishment of monitoring objectives, including consideration of desired outcomes, **spatial extent**, and precision.

Figure 2.1.—*Considerations in monitoring key habitat attributes.*



2.2.2 Habitat Monitoring Versus Population Monitoring

Numerous published documents describe protocols for monitoring populations of plants and animals (e.g., Elzinga et al. 1998, Manley et al. 2006, McComb et al. 2010). This technical guide describes protocols for monitoring wildlife habitat, which is a need the Forest Service previously recognized (see chapter 1, section 1.2.1). Although the primary objective of habitat monitoring is to provide information on the status of habitats in relation to desired conditions, habitat monitoring is sometimes viewed as a proxy for population monitoring (see chapter 1, section 1.3.2). Using habitat monitoring as a proxy for population monitoring is based on the assumptions that population size is strongly correlated with quality and quantity of habitat and that habitat is the primary driver of population change. The relationship between population size and habitat conditions depends on the life history of the species, the spatial and temporal scale examined, historical legacies, and the specific geographic and ecological context. Evaluating whether a strong relationship exists between habitat and population abundance in any particular situation is difficult. A large body of research, however, demonstrates an association between occupancy by bird species and habitat attributes (reviewed in Wiens 1989a).

Most vegetation attributes measured as habitat are really proxies for the true attribute of interest. For example, prey for insectivorous birds is difficult to accurately quantify, so other attributes that serve as proxies for prey abundance, such as foliage volume, typically are measured (Morrison et al. 2006). In these situations, measurements of vegetation attributes are at least one step removed from the food or other resources used by the organism and are therefore at least two steps removed from evaluating population size. As a result, it is unlikely that vegetation measures can reliably serve as proxies for absolute measures of population abundance, unless the emphasis species is a plant. Consequently, although it is reasonable to monitor vegetation attributes associated with an organism's habitat and make inferences regarding the trends in habitat and, therefore, the capability of the site to support the species, it is inappropriate to assume a one-to-one relationship between habitat amount and population status. Population changes often are the result of factors unrelated to the physical structure of habitat, such as weather, disease, or inter- and intra-species interactions (e.g., predation and competition [Chase et al. 2002]), as well as the recent history of the population.

2.2.3 Considering Management Objectives

Effective monitoring programs reflect specific management objectives. Management objectives and context must influence the rigor and precision of the monitoring program, as well as the habitat attributes monitored. Examining trends in habitat is useful only if that knowledge informs management decisions (e.g., predicts changes that can be encouraged or averted, as appropriate, by management actions) or helps assess the effectiveness

of past management actions. In addition, policymakers and resource managers must be able to interpret the implications of monitoring results in the context of management actions for the effort to be effective.

Because of differences in management context, monitoring habitat for a particular species may differ across local management units. Management goals and expectations for environmental change will influence the choice of habitat attributes to examine, the necessary precision required, and the temporal and spatial scales of interest. Forest-to-forest variation in how monitoring is accomplished should represent major differences in context, however, rather than thoughtless inconsistencies.

2.2.4 Emphasis Species

In this guide, *emphasis species* is a generic term for any species that warrants specific attention in planning or analysis. We use this term to convey the breadth of species addressed by this guide and to transcend terminology that may imply special circumstances or definitions beyond our intended focus. Categories such as **focal species** or **umbrella species** have led to much confusion (Caro 2010) and also confer the concept of surrogacy, which is not inherent in our definition of emphasis species.

Emphasis species can be drawn from species with special conservation status, such as federally listed threatened or endangered species, sensitive species, species of high public interest, and **management indicator species**. For purposes of setting monitoring objectives, not all species with special conservation status are emphasis species. Only those species that a planning unit has targeted for additional management or analysis beyond what is prescribed to sustain ecosystem diversity are emphasis species. Emphasis species can also be species that are particularly vulnerable to climate change, species with special habitat requirements, or species that are vulnerable to human presence and activities (chapter 7). Moreover, even if specific management is not needed, sufficient interest in a species or group of species can justify focused evaluation of its habitat.

2.2.5 Grouping Species as an Efficient Way for Monitoring Species' Habitat

Inventory and monitoring of habitat in large areas, such as a single national forest or grassland or multiple management units, may require evaluating 50 or more species and conceivably can include hundreds or even thousands of species (e.g., Groves 2003, Groves et al. 2000, Marcot et al. 1998, Thomas et al. 1993). For land managers, individual attention to such large numbers of species is impractical from logistic and financial perspectives. To address these inefficiencies, various methods have been proposed to eliminate or reduce the number of individual species that are explicitly considered in monitoring or assessment and in subsequent management (Wiens et al. 2008, Wisdom et al. 2005). One shortcut is to select an individual species to represent an entire group of species (e.g., umbrella species, focal species, management indicator species [Noss

1999]). Another approach is to identify and then manage for an entire group of species (e.g., sagebrush [*Artemisia* spp.]-woodland inhabitants) rather than selecting individual species to represent the group, with groups based on criteria such as commonality in habitat associations, life-history traits, or threats to persistence (Andelman et al. 2001, Wiens et al. 2008, Wisdom et al. 2005).

In contrast to relying on individual species, the use of species groups explicitly attempts to address the needs of single and multiple species in a hierarchical fashion. For example, species can be grouped by their use of fine-scale attributes and then grouped at a broader level through vegetation types (Andelman et al. 2001, Wiens et al. 2008, Wisdom et al. 2000). Consequently, the use of species groups in habitat monitoring may be effective if assumptions are tested about how well the species groups represent the needs of individual species, as part of implementing land management plans. The advantages of using species groups compared with other multispecies approaches are that efficiency is increased by analyzing several species as one, yet the habitat requirements of each species is accounted for in the analysis. A disadvantage is that the cross-species relationships must be verified, as described previously, to ensure that the associated group meets the needs of individual emphasis species (Wisdom et al. 2005).

Last, when using species groups, it is important to clearly describe the rationale for using a group, the corresponding habitat attributes of the group, and the process for identifying the group, including critical assumptions and the uncertainty associated with conclusions derived from this approach (USDA Forest Service 2005b).

2.2.6 Spatial and Temporal Scales

Habitats generally must be monitored at several scales because species select and relate to habitat at multiple scales. Many aspects of describing the relationships of wildlife species with their habitat are contingent on the spatial and temporal scales of habitat selection and the spatial context of the management area. Spatial and temporal scales are defined by their **grain**, extent, and hierarchical structure. Each spatial scale identified for each emphasis species should be defined in terms of spatial grain (**resolution**) and extent (Peterson and Parker 1998, Wiens 1989b). Extent refers to the size and boundaries of the area under evaluation. Estimates of habitat attributes across broad spatial extents often reveal different patterns than those derived from smaller spatial extents. Neither estimate is incorrect; patterns revealed at different extents are complementary.

From a statistical perspective, extent is the area of inference and the area from which a sample is drawn (i.e., **sampling frame**; see chapter 3, section 3.3.1). The concept is simple, yet paramount, because it is impossible to make meaningful inferences about monitoring data unless the spatial extent has been clearly established and the sampling points are drawn using an objective process from throughout this extent (see chapter 3). Grain is the resolution at which spatial patterns are measured or the plot size used to measure characteristics (Wiens 1989b). The level of an organism's perception of the

landscape is defined according to spatial grain (i.e., the smallest scale at which an organism responds to environmental patterns) and extent (i.e., the largest scale of heterogeneity to which an organism responds) (Kotliar and Wiens 1990, With 1994). Using this approach provides a functional link between selecting the monitoring approach and the species ecology. Ultimately, the match between grain and extent influences what questions to ask and what patterns to observe.

Ecological relationships have hierarchical structures because different processes occur at different spatial and temporal scales. These relationships influence processes occurring at other scales. Within a hierarchy, processes operating across longer timeframes and greater spatial extents serve as constraints on processes occurring across shorter timeframes and smaller extents (O'Neill et al. 1986). This concept has direct bearing on habitat selection because habitat relationships often change across spatial scales, reflecting the hierarchical nature by which animals select resources (Johnson 1980, Mayor et al. 2007, Orians and Wittenberger 1991).

Applying hierarchical structure to habitat selection, Johnson (1980) defined first order (i.e., level) habitat selection as the physical or geographic range of a species. Second order selection determines the home range of individuals within the physical or geographic range of a species. Third order selection is the specific use of sites within a home range, usually for particular functions (e.g., roosting or breeding). Fourth order selection is the choice of individual food items within third order selection sites. Orders of habitat selection are hierarchical because an individual's selection of food items is constrained by what is available at feeding sites, which is constrained by what is available within the home range. The home range must fall within the species' geographic range, which for most species was determined through an evolutionary timeframe.

Hierarchical structure can also apply to limiting factors that may influence the distribution of individuals, populations, and species through the effects of limiting factors on survival, growth, and reproduction (Krebs 2002, Rettie and Messier 2000). Some limiting factors, such as large expanses of undisturbed, high-elevation, mountainous terrain for breeding by wolverines (*Gulo gulo*), operate primarily at broad spatial scales, whereas other factors, such as physical structure for a roost site, come into play only at finer scales. Selecting a particular resource across multiple scales may indicate greater importance of that resource (Bridges 2003, Rettie and Messier 2000). Because of the hierarchical nature of habitat selection, habitats generally must be described and monitored at more than one spatial scale. Work by Knick and Rotenberry (1995), like the previous study by Rotenberry and Wiens (1980), highlighted the multiscaled nature of habitat selection. They reported that nest-site selection by shrub-steppe birds depended on landscape features and local vegetation cover. The previous work (Rotenberry and Wiens 1980) showed that strong patterns of habitat association in grassland and shrub-steppe birds at broad spatial scales disintegrated and were replaced by new patterns at finer scales.

2.2.7 Climate Change and Habitat Monitoring

Habitat monitoring programs are primarily oriented toward evaluating the effects of management actions and providing information to guide changes in management. Managers, however, must also consider the role of climate as a change agent, alone and in concert with management actions. The Intergovernmental Panel on Climate Change (IPCC) has published a number of assessment reports (e.g., IPCC 2007) that provide scientific evidence of global climate change, with the primary indicators of change being increased temperatures, regional changes in precipitation, and an increase in extreme weather events. Numerous researchers have documented environmental consequences of climate change, including changes in hydrologic systems (Bureau of Reclamation 2011, Lettenmaier et al. 2008), vegetation and ecosystems (Harsch et al. 2009, Ryan et al. 2008), and wildlife populations (Morzillo and Alig 2011, NABCI 2010).

The intended consequences of management actions may be thwarted, promoted, or altered in unexpected ways by regional shifts in climate. Become familiar with regional climate change scenarios, especially regarding future water availability, vegetation changes, and wildlife responses, to create monitoring programs that can inform managers about the potential effects of climate in addition to the effects of management actions. For example, if habitat of an emphasis species is likely to shift upslope under a scenario of warmer temperatures, the sampling design could be expanded to include upslope areas that currently are not habitat.

Numerous publications and reports provide guidance for incorporating climate change adaptation into planning, and these resources can provide ideas for monitoring. We recommend Millar et al. (2007) for an overview of managing forested ecosystems under changing climates. We also recommend Glick et al. (2011) because a vulnerability assessment can help identify attributes that may be most susceptible to climate change. Hansen and Hoffman (2011) provide adaptation strategies that also could lead to identifying attributes to monitor. In addition, if you are a Forest Service employee, you should become familiar with the *Forest Service Strategic Framework for Responding to Climate Change* (USDA Forest Service 2008) and the *National Roadmap for Responding to Climate Change* (USDA Forest Service 2010a).

2.3 Process Steps for Selecting Key Habitat Attributes

Identifying habitat attributes to monitor for a species or species group is part of a larger process (figure 2.1). After establishing broad monitoring objectives, initiate a review of emphasis species to determine which species or species group will be the focus of habitat monitoring (figure 2.2). Identify habitat attributes suitable for monitoring by developing conceptual models for each species or species group that focus on habitat requirements, limiting factors, and threats at the spatial scales appropriate for each species or group. Select a subset of priority attributes from the list of habitat attributes identified

in conceptual models based on an understanding of monitoring objectives, potential for attributes to respond to management or climate change, feasibility of monitoring, budget, and efficiency. The remainder of this chapter addresses each step more completely, and the case examples in chapter 10 demonstrate the steps.

Figure 2.2.—*Summary of process steps in selecting key habitat attributes for monitoring.*

Step 1
Select emphasis species for which habitat monitoring is appropriate (2.3.1)
- Management considerations (e.g., review laws, regulations, policies, management objectives, and priorities)
- Biological considerations (e.g., document population-habitat links)
- Logistic considerations (e.g., assess monitoring feasibility)
- Assess risk of not monitoring

Step 2
Develop a conceptual model of the emphasis species' habitat (2.3.2)
- Levels of habitat selection
- Habitat requirements, limiting factors, and threats
- Measurable attributes

Step 3
Use/develop species habitat-relationships models (2.3.3)

Step 4
Identify habitat attributes suitable for monitoring (2.3.4)
- Assess the relationship of the attribute to habitat requirements, limiting factors, and threats
- Assess degree of change over time
- Consider geographic scale
- Evaluate ease of measuring and quantifying
- Determine potential response to management activities
- Evaluate environmental context

Step 5
Set monitoring priorities among attributes (2.3.5)
- Determine which attributes are common to many emphasis species
- Determine which attributes best address emphasis species conservation priority
- Evaluate response of attribute to environmental changes over time
- Evaluate the cost of measuring the habitat attributes

2.3.1 Select Emphasis Species for Which Habitat Monitoring Is Appropriate

In most management settings, emphasis species have been identified through a rigorous process reflecting the relevant social, economic, and ecological contexts. Numerous approaches exist for identifying emphasis species (e.g., Bani et al. 2006, Carignan and Villard 2002, Lambeck 1997), and established law and policy may dictate certain criteria for identifying emphasis species (e.g., National Forest Management Act planning regulations). Effective monitoring, however, requires further evaluation to identify a subset of emphasis species that is appropriate and would be effective for monitoring habitat. During the selection process, consider management direction, biological factors, logistical factors, and the risk of not monitoring. This evaluation forms the basis for selecting species and habitat attributes that are to be monitored and should be well documented.

Management Considerations

Management objectives will differ substantially among species and, thus, influence habitat monitoring objectives. Emphasis species for which habitat may be monitored may come from a wide spectrum of conservation categories from taxa listed under the Federal Endangered Species Act to ubiquitous species that may be hunted or trapped.

The process of identifying monitoring priorities begins with a review of pertinent laws, regulations, policies, regional and forest management objectives, and priorities set through partnerships and agreements to determine those emphasis species for which monitoring of populations is required. Recovery plans for threatened or endangered species often require that cooperating agencies monitor population parameters for the species (e.g., red-cockaded woodpecker [*Picoides borealis*] [USDI USFWS 2003]). Others commit the Forest Service to monitor habitat (e.g., Mexican spotted owl [*Strix occidentalis lucida*] [USDI USFWS 1995]). Memoranda of understanding with State wildlife agencies obligate the Forest Service to assist with monitoring populations of important game species (e.g., Sitka black-tailed deer [*Odocoileus hemionus sitkensis*] in the Alaska Region).

Regional and forest management objectives also influence whether habitat is monitored for an emphasis species. If a land and resource management plan specifies management activities in ecological systems that also provide habitat for an emphasis species, it may be advisable to monitor habitat for that species (e.g., woodland caribou [*Rangifer tarandus caribou*] [USDA Forest Service 1987]). Conversely, an emphasis species associated with habitat that is not likely to be influenced by planned management actions may be a poor candidate for habitat monitoring (e.g., gray-crowned rosy finch [*Leucosticte tephrocotis*] in alpine habitats relative to timber management activities).

Biological Considerations

Habitat monitoring should focus primarily on species that are most likely to respond to changes in habitat condition because of management actions, disturbances, or climate change. In particular, management actions may impact systems in ways that are detrimental or positive but remain uncertain and require monitoring. Thus, selecting emphasis species should include not only those that are associated with forest plan objectives or desired conditions, but also those that have the potential to be affected by management actions that modify habitat.

In addition, developing a successful habitat monitoring program requires making a clear distinction between habitat and population monitoring (i.e., habitat monitoring should not be confused with population monitoring) (see chapter 1). In some cases, the monitoring objective for a species at risk will specify the detection of relatively small changes in population size (especially decreases) or occupancy. Depending on the management concern, monitoring objective, detectability, demography, and ecological relationships of a species, it may be prudent to monitor only populations, rather than to also track habitat. Under some limited circumstances, behavioral and spatial relationships may exist that allow populations to be closely linked to specific habitat attributes (e.g., amount of recently burned conifer forest is directly related to populations of black-backed woodpeckers [*Picoides arcticus*] [Hutto 1995]). If strong evidence indicates that habitat features are directly associated with population size of an emphasis species, then habitat

monitoring, with the objective of indirectly monitoring populations may be an acceptable approach under a limited range of management circumstances (Haufler et al. 1999, Molina et al. 2006). Species that are difficult to detect and, therefore, difficult to monitor for population abundance are good candidates for habitat monitoring if strong habitat relationships have been documented and if information on annual population fluctuations are not needed. Under these circumstances, compare habitat monitoring results periodically with population data to ensure that the assumed relationship between habitat and population remains (see chapter 1). The indirect nature of the monitoring program relative to the link between habitat and populations must always be considered when the resulting monitoring data are used.

Logistic Considerations

The efficacy of monitoring habitat for some emphasis species depends critically on logistic feasibility. Problems associated with consistently detecting, measuring, and precisely quantifying habitat attributes can prevent adequate monitoring of habitat for even the highest priority species. Conduct a thorough evaluation of logistical constraints early in the development of a habitat monitoring program and again later in the process to ensure that a monitoring program can be initiated and maintained within budget during the identified time horizon.

Determining whether to sample a species or its habitat can also be influenced by species abundance and detectability. Abundant, easily detectable species will generally require less effort to monitor directly rather than to monitor their habitat because individuals of the species will be encountered more frequently during sampling than would individuals of rare species. Subsequent analysis of population data collected on abundant species will be much more robust for easily detectable species than for rare species because fewer sample sites will exist that do not have detections. Consequently, when understanding habitat condition is a priority, monitor the habitat of rare species that are not at risk because it may be less expensive and may provide more rigorous results than attempting to monitor populations directly.

Logistics

Assessing logistic feasibility includes evaluating whether habitat attributes can be monitored effectively with existing technology. For example, spotted salamanders (*Ambystoma maculatum*) are dependent on the presence of vernal pools dispersed through upland forests (Gates and Thompson 1981, Petranka 1998). These vernal pools, however, are difficult to detect with remote sensing techniques in coniferous forests, and they are less detectable in deciduous forests after leaves have appeared in the tree canopy. Field-based sampling of vernal pools would require much time and effort because the pools are relatively rare and are present for only a short time in the spring.

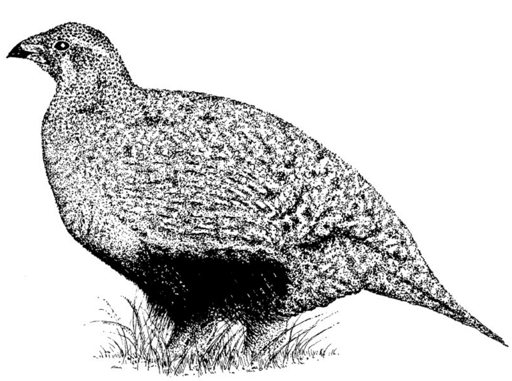
Risk of Not Monitoring

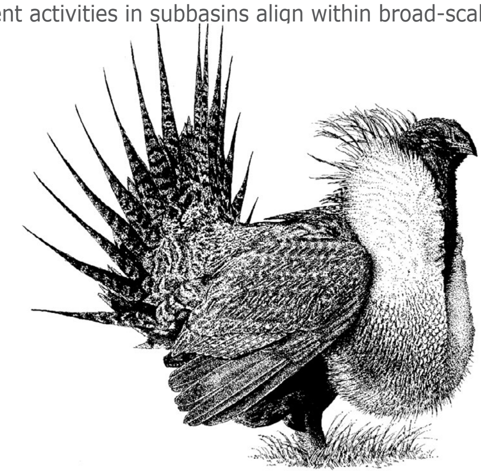
Formal or informal risk assessments will assist you in making decisions about the selection of species for habitat monitoring. These assessments are most helpful if accomplished for all emphasis species rather than for individual species in isolation so that priorities can be evaluated and the relative value of monitoring particular species compared. The risk assessment is undertaken to determine the relative cost (monetary, temporal, management risk) associated with **not** monitoring habitat for each emphasis species. The assessment, therefore, must consider the relative cost of obtaining information on population trend versus habitat and the relative value of habitat information for one species versus other species.

This analysis evaluates the potential for modifying habitat through climate change, management, natural disturbance, or succession. The analysis also evaluates whether an actual need for monitoring exists. Species associated with relatively stable habitats will have a low priority for habitat monitoring (all else being equal). In contrast, monitoring habitat for a species at risk will have a high priority for those species that are associated with disturbance-prone vegetation types, habitats likely to be intensively managed, or habitats that are particularly vulnerable to climate change.

Orders of Habitat Selection

The greater sage-grouse (*Centrocercus urophasianus*) habitat assessment framework provides an example of evaluating habitat at several hierarchical levels (Stiver et al. 2010). First order selection is the range of the species defined by the association of greater sage-grouse with sagebrush landscapes. Although habitat monitoring is seldom conducted across this extent, the range helps define the monitoring boundaries, and unoccupied sites within the range may be monitored for potential reintroductions of greater sage-grouse. Populations of greater sage-grouse define second order selection, with subpopulation or lek-group home ranges affected by configuration of sagebrush patches within the landscape. Within a home range, third order selection occurs in seasonal habitats (e.g., riparian areas, herblands, wet meadows, and grasslands) in proximity to sagebrush communities, and includes nesting, roosting, or feeding sites. Within seasonal habitats, greater sage-grouse select high-quality forbs during brood-rearing and nesting at the fourth order. Spatial and temporal scales are evident in this selection process, both becoming finer as selection order increases, and each higher order of selection is conditional on the prior order. Broad-scale greater sage-grouse population and habitat data include information generated at the national and regional levels, such as regional vegetation distribution maps (e.g., Gap Analysis Program [GAP] data; Jennings 2000). Midscale data reveal how management activities in subbasins align within broad-scale ecosystem and public land management emphasis.





2.3.2 Develop a Conceptual Model of the Emphasis Species' Habitat

A conceptual model is critical to developing a successful habitat monitoring program to ensure that monitoring is based on knowledge and founded in ecological theory (Vesely et al. 2006). Conceptual models describe the habitat requirements, threats, and limiting factors that influence population dynamics of a species and help identify gaps in our knowledge about a species (Manley et al. 2006, Mulder et al. 1999, Noon et al. 1999). Conceptual models document our understanding of the relationship of habitat attributes to the ecosystem components and processes that influence the species, they document our assumptions about how the habitat attributes and processes are related, and they identify gaps in what we know about the habitat attributes we wish to monitor (Manley et al. 2000). The overall purpose of the conceptual model is to provide a logical sequence to the selection and use of monitoring indicators (see examples of conceptual models in chapter 10).

Relevant Spatial Scales

When developing a conceptual model, first identify the spatial scales relevant to the emphasis species based on the orders of habitat selection (e.g., geographic range, home range [Johnson 1980]; see section 2.2.6). Target the most critical scale(s) by evaluating the ecological relationships of a species in the context of the spatial extent of management. Explicit consideration of scale ensures that wildlife-habitat relationships are integrated with land management activities at ecologically relevant scales (Apps et al. 2001). The species' natural history, limiting factors, and habitat relationships help define the orders of habitat selection and relevant spatial scales.

Issues of scale must be clearly considered and documented to be certain that monitored habitat attributes relate to the emphasis species and the specific threats experienced in that setting. Monitoring habitat attributes at an inappropriate spatial scale will result either in information that is too detailed and not helpful if the feature is measured with a resolution that is too fine or failure to identify relevant change if recorded with a resolution that is too broad (King 1997).

Habitat Requirements, Limiting Factors, and Threats

Our approach to selecting habitat attributes is based on the assumption that habitat monitoring is conducted to track environmental characteristics that are critical to emphasis species. Population growth is determined by a variety of factors influencing immigration, emigration, survival, and reproduction (Caughley 1977, 1994). Within the context of individual populations, however, in specific geographic and ecological settings, a small number of threats and limiting factors may strongly influence population growth. The threats and factors along with habitat requirements provide the foundation for identifying key habitat attributes to consider for monitoring. Therefore, habitat requirements, limiting factors, and threats are identified and assessed as a means to identify important habitat attributes to monitor.

Habitat Requirements, Limiting Factors, and Scale

Boreal owls (*Aegolius funereus*) provide a good illustration of how habitat requirements and limiting factors can be identified at different spatial scales (figure 2.3). Populations of this forest owl are likely to be limited by summer daytime high temperatures, nest site availability (large cavity), and prey availability (Hayward et al. 1993, Hayward 1997). The first factor (daytime high temperatures) limits these owls to boreal forests or high-mountain, subalpine forests and therefore defines the biome in which they occur. Monitoring the effects of climate change that are related to this factor may be useful to fully understand the response of boreal owl habitat to land management activities. Nest cavities represent a fine-grain habitat attribute that must be dispersed across broad areas. Prey availability, on the other hand, could relate to fine- or coarse-grain habitat attributes (Hayward et al. 1993). Vegetation structure within forest stands influences the vulnerability of prey to capture by owls, whereas broad forest vegetation types influence the abundance of principal prey (e.g., mature and older subalpine forest may have 10 times the abundance of small mammals of a midsuccession lodgepole pine (*Pinus contorta*) forest [Hayward and Hayward 1995]). This model of habitat associations suggests that habitat monitoring could focus on the extent of subalpine forest at broad spatial scales, large snag distribution and abundance at the scale of fifth level (Hydrologic Unit Code) watersheds, and forest structure (canopy closure and tree size) at a scale of watersheds or individual stands.

Figure 2.3.—*First recognized as a breeding resident of the central Rocky Mountains in the 1980s, the boreal owl is one of the important predators of small mammals in subalpine and boreal forests of North America. Habitat associations of the owl are determined by a range of factors at different spatial and temporal scales.*

The process begins by listing several of the most important habitat attributes associated with each potential limiting factor, threat, or habitat requirement. Often, these attributes are identified in existing species-specific wildlife habitat-relationships models (e.g., Mladenoff et al. 1995), species assessments (e.g., Johnson and Anderson 2004, Rahel and Thel 2004), species accounts (e.g., Weckstein et al. 2002), and other information sources (e.g., DecAID for snags and down and dead wood [Mellen-McLean et al. 2012]).

You may want to select habitat attributes that could indicate climate change effects. Conduct a **climate change vulnerability assessment** (Glick et al. 2011) for each emphasis species or species group to determine whether climate change might affect habitat requirements or limiting factors, and whether it should be added to the species' conceptual model as a potential threat. In this way, the effects of climate change are incorporated during the process of constructing the conceptual model.

The link between limiting factors or threats and habitat may be indirect. In some cases, habitat may not be directly associated with the limiting factor (e.g., ungulate populations limited by predation [Patterson et al. 2002]). If you can make a case for a functional link between limiting factors or threats and habitat, or if you can identify a habitat requirement, then develop a list of potential habitat attributes. Chapter 7 provides guidance for evaluating human disturbance agents as potential limiting factors and including them in a conceptual model.

Measurable Attributes

After you have identified requirements, limiting factors, and threats and linked them to habitat attributes, you may need to recast them so they are measurable. For example, a species' habitat requirement might be late-seral forest, but this must be translated into one or more measurable attributes such as basal area, quadratic mean diameter, or stand density index (see chapter 4, section 4.3.2).

2.3.3 Species Habitat-Relationships Models

Existing habitat-relationships models may represent a good foundation from which to build a conceptual model for identifying key habitat attributes to monitor. Useful habitat-relationships models have been created for a number of species (Morrison et al. 2006). In some cases, models have been evaluated (e.g., Cook and Irwin 1985, Rowland et al. 2003, Wisdom et al. 2002), while in other cases, they have been peer reviewed and corroborated through expert opinion (e.g., Holthausen et al. 1994), and others may be new models that are currently being tested. Nevertheless, habitat-relationships models represent a synthesis of knowledge regarding habitat associations and a potential resource for building a conceptual model for monitoring.

Because some models provide an index of habitat quality based on a suite of measurable attributes, those attributes may be the ones selected for monitoring if a suitable match in geographic scale and if the expected level of precision is sufficient (Morrison et al. 2006). Habitat-relationships models may also be used to screen large areas of potential habitat and focus monitoring on smaller areas where the probability of finding target habitat attributes is greatest (e.g., Welsh et al. 2006).

Furthermore, use of the outputs of habitat-relationships models (Beck and Suring 2009) to monitor habitat is attractive because the models generally avoid intensive, field-data collection (figure 2.1) (but see section 2.3.1). Well-designed habitat-relationships models may facilitate making habitat-based inferences to population trend. Making those inferences is dependent, however, on documented relationships between habitat condition and population status and on the absence of limiting factors independent of habitat. If a suitable habitat-relationships model exists that incorporates and combines selected attributes, the monitoring program may be designed around the model and its outputs. If such a model does not exist, then it may be developed with the assistance of species experts (see chapter 5). When developing a new model, consider incorporating aspects of human disturbance that could reduce habitat amount or **habitat effectiveness** (see chapter 7).

2.3.4 Identify Habitat Attributes Suitable for Monitoring

The conceptual model likely will result in identifying numerous habitat attributes at several spatial scales that could be monitored. The challenge and art of successful habitat monitoring is to select a subset of these attributes that not only represent key ecological

relationships for the emphasis species but also can be monitored at the appropriate scale with existing technology and within the anticipated monitoring budget. The process of attribute selection will likely be iterative. We discuss important criteria in the following section that influence the selection process.

Relationship of the Attribute to Habitat Requirements, Limiting Factors, and Threats

A review of relevant published literature and population surveys, to the extent possible, can help identify potential habitat attributes that are linked to habitat requirements, limiting factors, and threats identified within the conceptual model. For example, the red-cockaded woodpecker uses open, mature pine woodlands (e.g., longleaf pine [*Pinus palustris*]) and savannahs with large trees for nesting and foraging habitat (Conner et al. 2001). Likely habitat attributes associated with these habitat requirements are stand age, tree species composition, tree diameter, and understory composition and height. These relationships have been well established and documented in the published literature (e.g., Hovis and Labisky 1985). A primary limiting factor for this species is the availability of current or potential cavity trees; cavities are nearly always excavated in large, old trees, primarily those with decayed heartwood (Conner et al. 2004). Habitat attributes that represent this limiting factor are the number, size, and condition of trees (see chapter 4, section 4.3.2). Threats affecting this species include habitat loss and fragmentation and subsequent changes in the woodpecker population's genetic structure (Conner and Rudolph 1991). Habitat attributes that represent these threats include size and distribution of habitat patches (see chapter 6).

Degree of Change in the Habitat Attribute Through Time

Consider the potential magnitude of change in each habitat attribute across the timeframe of interest. Little information will be provided if the attribute is unlikely to change perceptibly during the life of the monitoring plan. For example, the American pika (*Ochotona princeps*) is a montane species restricted to talus slopes (broken rock below cliffs) that are fringed by suitable vegetation (Smith and Weston 1990). Although rock size is an important habitat attribute for pikas (Tyser 1980), it would not be a suitable attribute to monitor because average rock size of talus slopes is unlikely to change during the timeframe of most monitoring plans. Whether suitable talus slopes are actually used by American pikas, however, may be more strongly related to changes in predation risk (resulting in less time foraging) that may be stressing populations rather than direct habitat change. In this case, monitoring may more prudently focus on factors such as changes in numbers of human-subsidized predators (e.g., dogs [*Canis familiaris*] or ravens [*Corvus corax*]) rather than structural aspects of habitat. Chapter 7 discusses human-induced disturbance factors.

Also, consider the potential for changes in climate to produce changes in habitat through time. Ample evidence exists that shows distribution and traditional habitats for many species are already changing because of climate change (McKenzie et al. 2004). For

example, moths and butterflies have shown elevational changes in distribution, apparently in response to climate change. Ranges of populations of Edith's checkerspot (*Euphydryas editha*) and sachem skipper butterfly (*Atalopedes campestris*) have shifted upward along elevational gradients as compared with historical ranges (Crozier 2003, 2004; Parmesan 1996; also see the *Vegetation Phenology* subsection in chapter 4, section 4.3.2).

Geographic Scale

Consider the relationship between the geographic scale at which the attribute may be measured and the geographic scale of the ecological process of interest. For example, amount of suitable forage may limit elk (*Cervus canadensis*) population size in some locales in some years (Coughenour and Singer 1996). Although forage productivity can be monitored accurately at fine scales, it is more difficult to monitor at scales at which elk populations are generally managed (e.g., game management unit). Furthermore, it is often not apparent how much and which areas of a landscape should be managed for forage production to induce a measurable herd response (Cook 2002). It may, therefore, be infeasible to directly monitor forage productivity but, instead, more prudent to monitor habitat attributes related to forage availability for elk, such as percentage canopy cover within particular land cover types.

Ease of Measuring and Quantifying the Habitat Attribute

The ease of measuring attributes and the amount of inherent variation in attribute values influence the choice of habitat attributes to monitor. The advantages of choosing attributes that can be easily measured include a reduction in errors during data collection and an increase in repeatability among observers (Welsh et al. 1997). Also, using simple techniques will facilitate collection of larger samples resulting in more robust conclusions.

Many habitat attributes have considerable variation when measured, which can be attributed to true sample variation and observer variation (Roper et al. 2002). This variation has important implications for the design of monitoring programs and interpretation of the results (see chapter 3). Estimating required sample sizes will help in selecting habitat attributes by indicating the effort needed to be confident that changes in an attribute will be detected (Scheaffer et al. 1996). Calculating minimum sample sizes necessary to detect differences among sampling periods may provide guidance on which attributes would be best used in a monitoring program (i.e., power analyses [Zar 2010]). Chapter 3 provides a more complete discussion of these aspects, including power, effect size, and confidence levels.

Selecting habitat attributes will also depend on the level of sampling intensity needed for each attribute to meet the monitoring objectives and to provide information for management purposes (see chapter 3, section 3.3.1). Some attributes can be sufficiently measured with existing, remotely sensed data that would be relatively inexpensive to track over time; the same attributes could be measured through intensive field sampling at higher costs if greater precision is needed. Chapter 4 describes approaches for monitoring many common vegetation-based habitat attributes at different levels of intensity.

Similarly, the rigor of the sampling design (e.g., the number of sample sites) will influence cost. Therefore, decisions regarding which habitat attributes to measure and what sampling design to use should focus on what information is necessary to make management decisions. If a general understanding of habitat change is desired and can be obtained from existing remotely sensed data, gathering more accurate but expensive measurements of habitat attributes that are difficult to measure will not provide extra value. Also, if the effects of management can be effectively evaluated based on only an understanding of subtle, but important, changes in vegetation structure, then collecting information on land cover will be a waste of funds, even if it is relatively inexpensive. The most prudent habitat monitoring program will focus on measuring the least expensive habitat attributes that can indicate the status of habitat, for the species (or species group) in question, at a scale and level of precision that is relevant to management.

Potential Response of Habitat Attribute to Management Activities

To be useful for monitoring, a habitat attribute must exhibit some likelihood of change, either in response to management activities or in response to other factors of interest such as climate change. For example, black swifts (*Cypseloides niger*) nest on ledges or in shallow caves in steep rock faces and canyons, usually near or behind waterfalls (Lowther and Collins 2002). Although these nest sites are required habitat and limit black swift populations, few, if any, site-specific management practices exist that will increase the number of nest sites. Therefore, measuring changes in nest site availability would not reflect a potential response to management. In contrast, measuring changes in availability of nest sites for a cavity nester would reflect a potential response to management or to change in climate.

Environmental Context of the Habitat Attributes

Evaluating habitat attributes includes considering environmental context. Does the value of the attribute to be measured depend on the characteristics of the surrounding environment? For instance, mountain bluebirds (*Sialia currucoides*) are secondary cavity nesters (Power and Lombardo 1996); therefore, tree cavities are an important habitat attribute for them. Cavities occurring in interior forests would not be considered a habitat attribute beneficial to mountain bluebirds, however, because they select cavities at prairie-forest **ecotones** or in savannas, recently burned areas, or clear-cut forests.

2.3.5 Set Monitoring Priorities Among Attributes

The list of habitat attributes identified for monitoring will likely exceed budgetary capabilities (Marsh and Trenham 2008). Therefore, it is critical to evaluate the relative importance of all identified habitat attributes for all species and to prioritize among attributes. The following criteria provide guidance for setting these priorities. The criteria are not presented in rank order, rather, each should be weighed from the standpoint of its particular management context.

Attributes Common to Many Emphasis Species

Some habitat attributes will be shared by several emphasis species. Selecting these attributes for monitoring will result in meeting the monitoring needs of several species, especially if the scale of use is similar across species. Monitoring a specific attribute for one species might not be adequate for another species if the second species requires a different context for the same attribute. For example, mistletoe brooms in interior forests are a nest habitat attribute for numerous species, but great gray owls (*Strix nebulosa*) use brooms only in proximity to meadow-forest ecotones (Franklin 1988). Monitoring mistletoe brooms without that context would still indicate the amount of habitat for great gray owls, but only at a coarse level.

Conservation Priority

Prioritizing emphasis species and associated habitat attributes by their perceived threat or need for conservation action has become a standard practice in managing natural resources (Carter et al. 2000). Most conservation priority-setting approaches emphasize maintaining biological diversity and reducing threats when deciding where to focus investment (e.g., Groves et al. 2000). Socioeconomic and political attributes of emphasis species and associated habitat attributes may also influence the effectiveness of conservation actions, however. The need for a conservation priority-setting process is driven by limited resources that necessitate choices among subsets of all possible emphasis species in any given geographic area, given distinct differences among emphasis species and their need for conservation action.

Prioritization systems in conservation planning differ greatly in what factors are considered; how these factors are scored, weighted, and integrated; and how the resulting information is presented and used (Mehlman et al. 2004). Most systems are based on some estimation of risks to species, often using multiple **surrogates** that are thought to directly impact key population parameters, such as population size or trend. Other considerations include the importance of the emphasis species in the ecosystem (Rohlf 1991), its value as an umbrella or focal species (Lambeck 1997, Rohlf 1991), or its commercial value. By documenting the priority ranks by spatial scale, information can be provided on a variety of combinations of habitat attributes to monitor, depending on resources available.

Environmental Trends

Ideally, a selected habitat attribute should have a known short-term and consistent response to natural disturbances, anthropogenic stressors, or management activities through time. Otherwise, interpreting the implications of observed change in the attribute through time will be difficult. For example, creation of early seral habitats, including increases in herbaceous cover, typically follows wildfire. Thus, the attribute of percentage of the area in early seral successional stage is an appropriate one. By contrast, wildfire may lead to highly variable tree canopy cover, depending on the patchiness of the burned area (Swanson et al. 2011).

Cost of Measurement

Cost is often the limiting factor during implementation of a program to monitor habitat (Marsh and Trenham 2008). Priority setting must consider estimates of all implementation costs. Cost evaluation will be most effective when estimates include economy of scale because cost per attribute or cost per sample may be reduced when data are collected for multiple attributes at a given site.

2.3.6 Species Groups and Surrogate Species

When species groups or surrogates are used in land management planning (Wiens et al. 2008), habitat attributes should be selected for monitoring that are directly related to the whole group of species or to the surrogate. The conceptual model for habitat relationships will, therefore, be developed to relate to the group or surrogate. Likewise, the relationships between habitat attributes and limiting factors, threats, and habitat requirements should be defined for the entire species group rather than individual species within the group.

2.4 Conclusions

A habitat monitoring program for several emphasis species within a management area (e.g., national forest) is likely to include a broad spectrum of habitat attributes and associated monitoring approaches. Emphasis species are likely to include some with very narrowly defined niches and other species or groups associated with more generalized habitat attributes. Therefore, the monitoring program for the management area may require a wide range of sampling intensities and sampling designs. Some of the habitat attributes selected for monitoring may provide information on habitat status for several species, whereas others may help evaluate trend for a single species.

The challenge of selecting which habitat attributes to evaluate within an integrated habitat monitoring program is largely one of setting priorities and being honest about the scope of program the management area can afford. Difficult decisions must be made to determine which species will **not** be monitored. For the high-priority species, identifying habitat attributes that are associated with population status and are likely to respond to management practices is imperative; it is useless to track the status of habitat attributes unrelated to the life history of the emphasis species. Furthermore, if the habitat attributes cannot be monitored with sufficient precision to detect biologically meaningful change, it is unwise to collect the data.

We stress the value of using a conceptual model to highlight key habitat attributes to consider for monitoring. The bottom line is to choose habitat attributes based on the biology of the emphasis species and to monitor only if you can actually obtain a useful answer.

Chapter 3. Planning and Design for Habitat Monitoring

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3.1 Objective

This chapter provides guidance for designing a habitat monitoring program so that it will meet the monitoring objective, will be repeatable, and will adequately represent habitat within the spatial extent of interest. Although a number of excellent resources are available for planning and designing a monitoring program for wildlife populations (e.g., Busch and Trexler 2003, McComb et al. 2010, Thompson et al. 1998, Vesely et al. 2006), little guidance exists for creating a monitoring design for habitat. One could argue that the huge body of literature on vegetation sampling is useful for this purpose, and we acknowledge that the basic principles of planning and design for vegetation sampling are indeed relevant. Most texts on vegetation sampling do not address the multiscalar nature of habitat, however, or the nonvegetative aspects of habitat. Moreover, unique challenges arise related to using existing data and to using remotely sensed data for monitoring habitat. Our objective is to emphasize the basic principles of planning and design and to place them in the context of habitat monitoring.

In all aspects of planning and design, we recommend early consultation with a statistician. Too often, monitoring teams consult with a statistician only after data are collected. Seemingly innocent decisions in the design or placement of plots or points, however, can make statistical analyses exceptionally complex or impossible. Early consultation will ensure that statistical analyses are feasible and practical before implementing the monitoring design.

3.2 Key Concepts

3.2.1 Central Coordination and Long-Term Commitment

Long-term commitment and central coordination are paramount to a successful monitoring program, especially long-term programs. An agency or organization needs to have ownership in the program and an individual or team needs to ensure that the program

is carried out over time and that it will persist through funding obstacles. Successful programs often are driven by someone who has personal vision and commitment, but motivation can also come from an entity that is funded specifically for the monitoring purpose, such as the Breeding Bird Survey (BBS) that is coordinated annually by the U.S. Geological Survey (USGS) and the Canadian Wildlife Service (Sauer et al. 2008) or the Forest Inventory and Analysis (FIA) program funded by the Forest Service and numerous partners (chapter 4, section 4.4.1). Sometimes a combination of personal vision and consistent funding leads to success. For example, the 20-year success of the Northern Region Landbird Monitoring Program, a cooperative effort between the Forest Service and the University of Montana, was the result of a combination of individual leadership coupled with adequate funding for planning, training, data collection, and data analysis.

We begin this chapter on planning and design with this key concept, because it is during the planning and design phases that central coordination and long-term commitment must be identified. Long-term funding is rarely assured, but long-term commitment and ownership from individuals and organizations are essential.

3.2.2 Sources of Error and Uncertainty in Habitat Monitoring

A well-designed monitoring program will consider possible sources of error and uncertainty and reduce them where possible. The first source of uncertainty arises during the development of the species' conceptual model and the selection of habitat attributes to monitor (chapter 2). This form of uncertainty arises because population dynamics can never be modeled with absolute precision, and measured habitat attributes will always be a subset of the species' total habitat requirements. It is not possible to reduce this uncertainty through a sampling design. The best approach is to evaluate the underlying assumptions of what constitutes habitat by surveying for species' presence across a gradient of environmental conditions (chapter 1 and 5).

Another source of error occurs when habitat attributes are not directly measured but are derived through modeling. This topic is sufficiently complex to warrant treatment as a separate key concept (3.2.6).

In this section, we address two sources of error that can be somewhat managed through sampling design and data collection—environmental variability (also known as **process variation)** and **sampling variation (**White 2000). Biometricians originally coined the term *process variability* to explain the combined effects of demographic, temporal, spatial, and individual variation on wildlife populations (White 2000). In the scope of habitat monitoring, process variability is encountered when repeated estimates occur at different times. Temporal changes are expected to occur in the true values of the attributes regardless of the direction of long-term trends over a large area. For example, suppose we have three standing snags in a plot. Between time one and time two, the number of standing snags within this plot may change, regardless of whether the long-term trend is increasing, constant, or decreasing in the larger study area. Long-term trends may be

of interest, whereas annual fluctuations and other sources of process variation might be considered a nuisance. If the objective is a habitat inventory rather than monitoring, the estimates apply to a fixed study area and, ideally, to an instantaneous moment in time. Process variability still introduces uncertainty, however, in the sense that a single estimate at a point in time will fall below, on, or above the unobserved long-term trend line or curve.

Sampling variability occurs during data collection and analysis when one is estimating the true spatial distribution, abundance, or density of each habitat attribute from a sample at a specific point in time (in practice, a period during which the attributes are assumed to not change appreciably). This uncertainty stems from two sources: **variance** (i.e., precision; how close repeated measurements are to the same value) and **bias** (inversely related to accuracy, which is how close the average value of measurements is to the actual value of an attribute) (Thompson et al. 1998, Zar 2010). The variance of an estimate can also be attributed to two sources: environmental variance that stems from sampling the study area (because the true values of an attribute vary from one sampling unit to another) and measurement error (because any two independent measurements may yield different numerical values).

Bias stems from flaws in the sample design or measurement protocol that result in an estimate either consistently higher or lower than the true value. For example, the sample design can result in bias if sampling units are not randomly selected or represent only part of the area of interest (see Spatial Extent in the following section). The measurement protocol may also have inherent positive or negative bias relative to the true value (for instance, when an instrument is not calibrated correctly) (Elzinga et al. 1998).

Improving the measurement protocol can reduce bias and measurement errors. For example, bias in the measurement of forb abundance might be reduced by considering the phenology of the plants and by ensuring that all resampling occurs at the same phenological stage. Including more units from the study area can reduce sampling error. Sampling error, measurement error, and process variability are usually confounded, however, and cannot be separated without additional experimentation. Consequently, in most simple modeling of long-term trends, we crudely incorporate uncertainty by estimating the magnitude of variation arising from a combination of factors—process variability, sampling variance, and measurement error. Process variability can sometimes be separated from sampling variance and measurement error in relatively rich data situations using rather strict assumptions (e.g., Bolker 2008); however, those models and methods are beyond the scope of this text.

3.2.3 Competing Designs for Inventory and Monitoring

Although natural resource managers often view monitoring as a series of inventories across time, the optimal statistical design for assessing the status of a resource (inventory) can be very different from the design for detecting change (monitoring). Inventory design focuses on obtaining a representative sample of a **sampling frame** and controlling sampling

variance and bias through randomization and the selection of independent samples. In contrast, monitoring can be directed at specific areas with a different sampling frame for the purpose of trend detection without providing an overall estimate of the current status of a resource.

Consider, for example, the loss of meadows to conifer encroachment, which is a common problem for land managers. For an inventory, the question would be: What is the current area in meadows? For monitoring, the question might be: How rapidly is the meadow area changing? One could, of course, evaluate change in meadow area across time through multiple inventories, by randomly sampling from a sampling frame that contains all potential meadow area, but a much more efficient and sensitive approach to detect change would be to place plots at the meadow edges—the only place on the landscape where change is actually occurring, and revisit those plots. A different sampling frame of all units containing meadow edge would be constructed and sampling units selected by a probabilistic (e.g., simple random) sampling procedure. Note that this second approach will not provide an estimate of the total acreage of meadows in the area of interest.

3.2.4 Independent Samples Versus Repeated Measures

A fundamental choice in design of monitoring studies is between measurements on independent samples of units at each time point and repeated measurements on the same units (for two or more surveys over time). We will illustrate this choice using snag density as an example. If different independent samples of units are selected at each point in time, then the monitoring question of whether the number of snags per acre has changed between two points in time requires having two independent estimates, one for each point in time. Each of the estimates has an associated variance, as indicated with the subscripts 1 and 2 in the following equation for two independent samples. For moderate sample sizes, an approximate **confidence interval** on the difference is

$$(\overline{X}_1 - \overline{X}_2) \pm z_{0.25}\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}\ .$$

The variances are additive for the difference in means of independent samples and, if the variances associated with the two estimates are approximately the same (as expected to be if the same sampling design were used for both samples), the variance associated with a difference will be about double the variance of either point estimate for the number of snags per acre. This larger variance means that, with independent samples, it can be difficult to detect a meaningful change in the number of snags per acre (or any other habitat attribute) between two points in time.

A further difficulty with selecting independent samples at each time point is that, when attempting to detect changes in a habitat attribute across relatively short periods of time (e.g., 5 to 15 years for forest plan monitoring), the difference between two sample

means $(\overline{X}_1 - \overline{X}_2)$ will usually be relatively small. Thus, detecting change across short time intervals with independent samples may be difficult, because the difference often will be a number relatively close to 0.

In contrast, if repeated measurements are obtained on the same sampled units, then the data are essentially paired, and the analysis for detecting change between two points in time is conducted on the differences, $D_i = X_{i1} - X_{i2}$, for all units (plots) i = 1, …, n. The mean difference, $\overline{D} = \overline{X}_1 - \overline{X}_2$, and the variance s_D^2 of the differences are computed. A similar formula, but for a single sample of differences, unit by unit, is used to compute a confidence interval on the mean difference, i.e., $\overline{D} \pm z_{0.25}\sqrt{\frac{s_D^2}{n}}$.

With repeated measurements on the same sampled units, the variance, s_D^2, and, consequently, the **standard error** of the mean, $s_D/\sqrt{n}$, are usually much smaller for the differences, $D_i = X_{i1} - X_{i2}$, than the corresponding variance and standard error for either measures X_{i1} *or* X_{i2} at the two points in time. Consequently, as can be seen with the example of snag density, the width of the confidence interval on the mean difference is expected to be less than the widths of confidence intervals on the individual mean number of snags per acre at either time point. More importantly, the width of the confidence interval on the mean difference of any habitat attribute metric is usually much less with repeated measurements than for measurements on independent samples.

In conclusion, repeated measurements on the same units have the advantage over use of independent samples if it is important to detect change and trend more quickly in monitoring studies. The choice is not always easy, however, because measurements on independent samples have the advantage if it is more important to have better coverage of units throughout a study area over time. In the design of monitoring programs, usually the need to quickly detect change and trend is considered to be more important than ensuring independence of sampling units because of pressing management issues.

3.2.5 Monitoring for Thresholds Versus Trends

Although the customary objective of monitoring is to detect a trend, an alternative is to monitor for the relationship between a current condition and a preestablished **threshold** value in one or more habitat attributes to evaluate whether a change in management is needed. The first objective typically requires relatively long-term monitoring, whereas the second objective can be achieved with an inventory or at any point within a short- or long-term monitoring program.

To illustrate the difference, consider two different monitoring objectives regarding American marten (*Martes americana*) habitat. The question of whether the amount of habitat has changed requires the ability to detect change over time and may necessitate monitoring over several years or decades unless the change is abrupt (e.g., wildfire). In contrast, the question of whether 50 percent of forested land within an analysis area is

suitable for American martens requires the ability to make a reasonable point estimate, which can then be compared with the 50-percent threshold or desired condition value at the end of one survey or at any point in time during a monitoring program.

The ability to detect changes in habitat over time becomes more tractable over many years, when samples are collected across many time points, allowing trend lines or curvilinear models to be fitted. The question then becomes whether the slope of a trend line is statistically different from zero; the answer is obtained through regression analysis.

3.2.6 Measured Versus Modeled Attributes

Habitat attributes for each emphasis species may be either measured directly or estimated through modeling. This distinction is critical because the source of data can affect the precision associated with an observed change in habitat over time. Measured attributes include original data and simple summary statistics of these data (e.g., sums, means, proportions, and variances).

Modeled attributes are derived from measured data by using statistical modeling processes or by assuming relationships of measured to unmeasured data through professional judgment (e.g., **Bayesian belief networks** in which prior distributions of parameters are assigned through a combination of expert opinion and existing data). A statistical modeling process estimates the correlation between two or more measured attributes and then uses this correlation to model or predict the value of an unmeasured attribute. For example, the correlation between the number of trees tallied with a basal area factor prism and the actual, measured basal area of the stand provides a modeled relationship that enables surveyors to obtain stand basal area from the number of trees tallied with a basal area factor prism.

Examples of commonly measured attributes are tree diameters, shrub height, and miles of maintained roads. Examples of modeled attributes are growth and yield based on measured tree heights and diameters, the amount and spatial distribution of vegetation types based on classification of **multispectral data,** and the amount and distribution of rainfall within a monitoring area based on rainfall measured at weather stations (point locations). The line between modeled and measured attributes is often blurry: although elevation can be a measured attribute, it can also be derived from radar through modeling.

Maps of classified vegetation are probably the most common source of modeled attributes of wildlife habitat. When using satellite imagery, the measured data are light reflectance values, whereas habitat classifications based on these light reflectance values are modeled data. The modeled data incur error based on a variety of factors: time of day and year, haziness, aspect, cloud cover, and other environmental conditions (Warbington 2011). For both satellite imagery and high-resolution aerial photography, additional error occurs when a map specialist classifies pixels as vegetation types because this form of classification is usually based on professional judgment and is often undefined in an absolute sense. As a result, small changes in the definition of a given vegetation type can have

large effects on the amount of that vegetation type assigned to the map. This potential source of error explains why ground truthing is so important when developing maps of classified vegetation.

Because modeled attributes are derived rather than directly measured, the calculations and modeling assumptions add layers of imprecision to estimates of the attribute values. If the models are complex, it may be impossible to evaluate variance or standard errors of the modeled attributes. In addition, some sources of error can never be incorporated into measures of precision because the error is from professional judgment in selecting which form of model to use, the methods of estimating **coefficients**, and the process of setting criteria for selection among fitted models. The error generated from these decisions is less obvious than the estimated standard errors around the modeled attributes, but can have huge influence on the modeled attribute values and precision.

The problems associated with modeled attributes are compounded further when the attributes are used to monitor change over time. It is important to know whether the maps for each time period are derived from the same data sources, are based on the same statistical estimation methods, and use the same classification system for vegetation types or other attributes, because changes in any of these conditions can make it difficult to compare the values of modeled attributes over time. Modeled attributes are often preferred because they are less expensive to acquire than measured attributes. They should be used with caution, however, because of the many potential sources of error that we have described.

3.2.7 Cause-and-Effect Monitoring

As stated in chapter 1, cause-and-effect monitoring is outside the scope of this technical guide because it requires a fully developed experimental design (Elzinga et al. 1998, Holthausen et al. 2005). Noon (2003) described the concept of cause-and-effect monitoring and contrasted prospective and retrospective approaches to investigating cause and effect. Prospective approaches use experimental designs that assign treatment and reference sites to study units through a probabilistic method and are usually limited to laboratory studies and field studies with small plots. The design must incorporate sufficient replicates of each treatment as well as replicates of the reference or control areas to support any statistical conclusions and inferences on cause-and-effect relationships. Most individual national forests and grasslands will have insufficient replications of similar treatments or management actions to yield a high level of confidence in conclusions, but this type of monitoring can be accomplished over broad spatial scales with involvement from the research community. One example is the Birds and Burns project (http://www.rmrs.nau.edu/wildlife/birdsandburns/), which has established burn treatments and controls on several national forests and other lands in the Western United States (Saab et al. 2007a).

In contrast to cause-and-effect experimental designs, monitoring programs for detecting a trend or observing progress toward or away from a threshold are usually unreplicated observational studies. Sampling units are selected through a probabilistic or systematic

procedure, resulting in units that represent the entire area of interest—managed and unmanaged. If the managed and unmanaged areas are similar except for the management action, strong conjectures are possible concerning the effectiveness of management. Unfortunately, the effects of management actions are nearly always confounded with inherent differences between sites in observational studies. Only with replication of treatments or the existence of other collaborating information will managers have the evidence necessary to convince critical peers that the results and strong conjectures have actually led to knowledge of cause-and-effect relationships concerning the management actions.

3.3 Process Steps for Designing a Habitat Monitoring Program

Use the following key steps to design a habitat monitoring program.

- Develop the monitoring objective.
- Evaluate whether existing information can be used to meet the monitoring objective.
- Plan and design for new data collection, where needed.
- Run a pilot study (or evaluate the statistical properties of existing data).
- Document the design decisions in a monitoring plan.

This section provides guidance for completing each of these steps. Figure 3.1 illustrates the process steps and some of the major decisions associated with the key concepts listed previously.

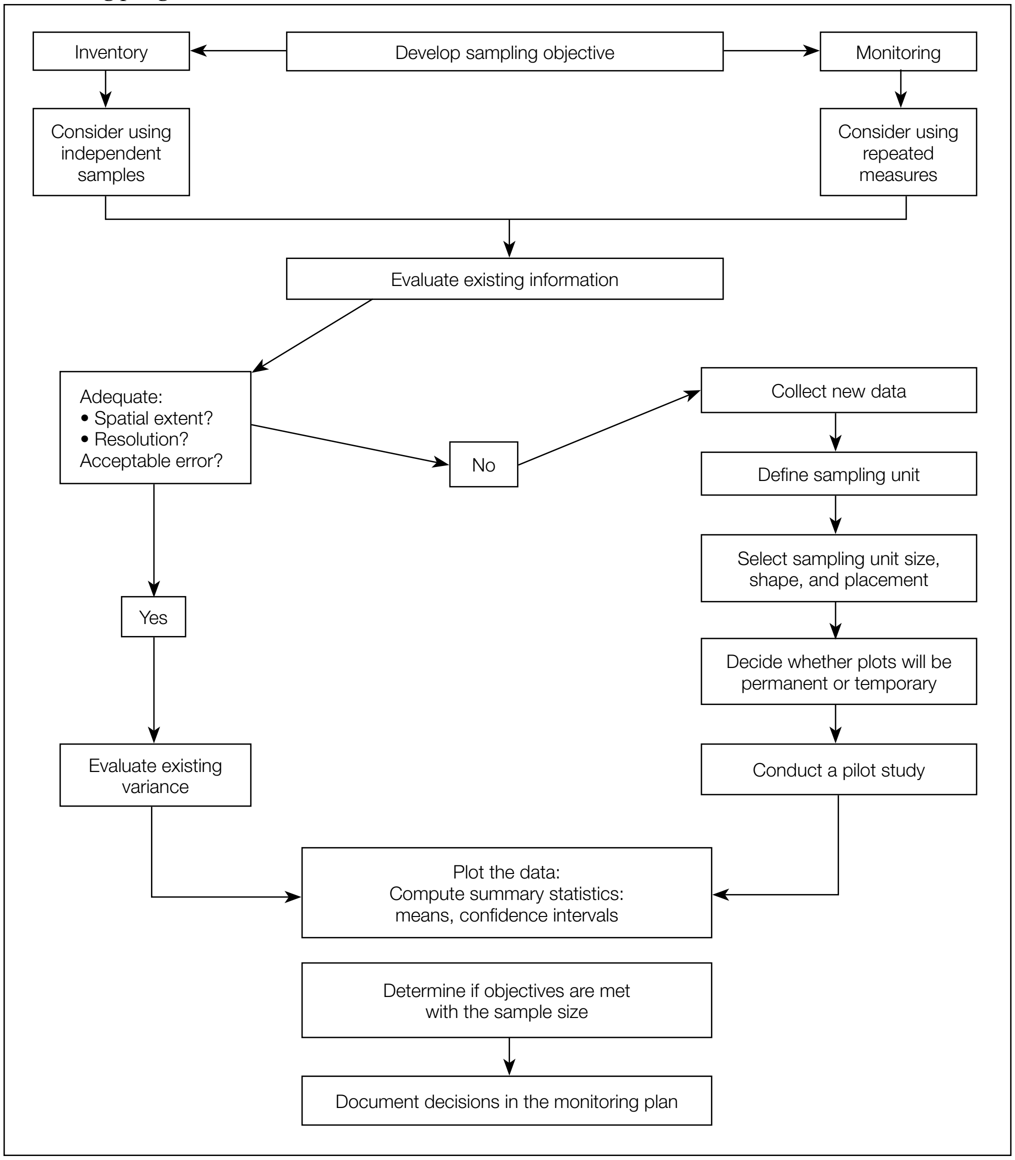
3.3.1 Develop the Monitoring Objective

After identifying the emphasis species and their key habitat attributes (chapter 2), the next task is to state the habitat monitoring objective with sufficient detail so that decisions can be made about how data will be collected and analyzed. A detailed objective is requisite for a well-designed habitat monitoring program and is critical to its success (Elzinga et al. 1998, Oakley et al. 2003). The monitoring objective provides a direct link between the management objective and the resource being monitored (e.g., a habitat attribute, such as large snag density). The following components comprise a monitoring objective (Elzinga et al. 1998, Vesely et al. 2006).

- The desired information outcome of the monitoring activity.
- The spatial extent over which the information is needed.
- The level of confidence or precision desired to fulfill management information needs.
- The desired **minimum detectable change** (or **effect size**); i.e., the size of change that is biologically meaningful.
- A quantitative standard against which the monitoring results would be compared in the short term; e.g., a desired condition, historical condition, or threshold that would trigger management actions in the near future.

Each of these objective components is described in the following sections.

Figure 3.1.—*Process steps and major decision points that occur during the development of a monitoring program.*



Desired Information Outcome

First, determine whether the monitoring program will be a one-time inventory or a multiyear effort. For a one-time inventory of a large study area, **stratification** can be a useful tool for reducing variance or for blocking on potential confounding factors, but this same tool can cause problems for multiyear monitoring programs, especially if strata boundaries are based on ephemeral conditions such as existing vegetation type. Differences between an inventory and a multiyear monitoring program can also influence the decision of marking plots. Multiyear monitoring may incur the added cost of marking permanent plots, with the benefit, however, that revisiting the same sample plots will usually detect important changes or trends more quickly than visiting new plots each sampling period.

Next, decide if individual habitat attributes should be tracked separately, or if it is more meaningful to aggregate all selected attributes in a model that defines habitat quality. This decision can influence whether the final product can simply be tabular data that summarizes the amount of each selected habitat attribute, or whether the data need to be mapped to evaluate spatial patterns.

If the monitoring objective is to observe a specific level of change, then sampling must be designed to determine whether the target has been met. If a plan states that a threshold must not be crossed (e.g., a maximum road density or minimum canopy cover), then monitoring must produce information that allows for this criterion to be tested.

In contrast to target or threshold-based monitoring objectives, long-term (context) monitoring programs must meet the needs of management issues that have yet to be discovered. For example, the BBS, with 50 years of data across the United States and Canada, provides trend information with variable power to detect change for a wide range of bird species, most of which have no stated desired trends or minimum thresholds.

When a monitoring team selects a set of habitat attributes to measure, they must also decide the level of intensity needed for measuring each attribute, because the cost of monitoring will vary, depending on how intensely the attributes are measured. Monitoring intensity is a combination of sample size (sampling intensity), the number of subplots within each sampling unit, the precision with which measurements are made (e.g., ocular estimate, measured to the nearest centimeter), and whether attributes are measured or modeled (section 3.2.6). Some attributes can be sufficiently estimated with existing, remotely sensed data that are relatively inexpensive to track over time. Although other attributes require fairly accurate field measurements, the cost for sampling can be reduced by taking measurements at low sampling intensities over broad spatial extents. For attributes that require estimates with smaller variance and standard errors, the sample size of field plots must be increased. Ultimately, the intensity of the monitoring effort must be sufficient for meeting monitoring objectives and for providing affordable information for management actions.

A monitoring program can reduce costs and obtain sufficiently detailed information by incorporating both low- and high-intensity approaches. Extensive sampling (low spatial intensity) over a broad geographic area can quickly identify the level of variation within the target population and locate areas meriting more intensive sampling. For example, FIA data can provide a comparison of conditions across broad areas to help select areas requiring greater precision of estimates and more spatially intensive sampling. The *Rangeland Ecosystem Analysis and Monitoring Handbook* for the Forest Service Pacific Northwest Region (USDA Forest Service 2006a) provides an example of how sampling methods vary with intensity and scale. Each scale of analysis includes recommended methods for extensive and intensive approaches.

Another example is the use of landtype associations (e.g., midscale; Winthers et al. 2005) to rank areas for more intensive sampling. On the Monongahela National Forest

(West Virginia), managers used low-intensity data at the midscale to rank areas as Indiana myotis (*Myotis sodalis*) habitat. Most of the forest was quickly removed from consideration as bat habitat (DeMeo 2002), which released intensive survey funds for other important survey efforts. Chapter 4 describes approaches for monitoring many common habitat attributes at different levels of intensity and at multiple scales.

Spatial Extent

As a component of the objective, state the geographic area where the monitoring will take place. Not only does this information identify the location, but it also defines the spatial extent so that the monitoring design team can select sampling methods, sampling intensity, and levels of precision that are appropriate for the spatial extent identified. Identifying the spatial extent is also the first step in delineating the sampling frame, the area from which sampling units will be drawn and to which statistical inferences can be made.

Ideally, the sampling frame covers the full spatial extent over which information is needed for the monitoring results to accurately represent the habitat conditions within the area of interest. In reality, however, the sampling frame is frequently a subset of all potential habitats across the defined spatial extent. The full range of potential habitats is the **target population**, and the selected range of habitats to be monitored is the **sampled population.**

For example, managers might select the entire sagebrush (*Artemisia* spp.) community on a national forest as the target population, yet limit the sampled population to units that are of a certain size or proximity (e.g., units in sagebrush stands within 0.5 mile of a road and more than 1.0 acre in size). Statistical inferences are thereby limited to relatively large sagebrush stands close to roads. Another example is the target population, which might be habitat on lands of multiple ownerships that are adjacent to or embedded within National Forest System (NFS) lands. If habitat data on non-NFS lands are available or can be readily obtained, these lands can be included in the sampling frame. If not, the team must recognize that the sampled population does not necessarily represent the target population, and that the study design justifies statistical inferences about habitat quantity or quality only to the sampled population on NFS lands.

Decisions concerning the extent of the sampling frame are particularly important because the sampling frame constrains both current and future sampling. If the monitoring team wanted to change the sampling frame extent at a later time, some of the detected differences in habitat would be the result of sampling a different population. It could be impossible to determine the degree to which the measured change represents a meaningful difference in habitat or is simply an artifact of sampling different populations. Thus, the sampling frame chosen at the beginning of a monitoring program will constrain all future monitoring. For this reason, the careful choice of an appropriate sampling frame is essential to the success of a long-term monitoring effort.

Desired Precision of the Monitoring Information

The desired precision for habitat monitoring (i.e., variance, size of standard errors, and confidence intervals) is established through an iterative process that includes deciding the level of sampling intensity, determining whether existing data will meet the information needs, choosing an appropriate sampling design and method of data analysis, and then using the data analysis method to evaluate the precision of existing or new data with confidence intervals or **power analysis**. Avoid using generic levels (e.g., an estimate that is within 10 percent of the actual value, 90 percent of the time), unless those values are appropriate for the attribute(s) of interest. Nichols and Williams (2006) suggest that monitoring programs be designed to address narrow and well-defined system responses, following the model of hypothesis testing. If this approach is followed, it is much easier to determine meaningful levels of precision of the data. The decision regarding how much precision is needed for each attribute places requirements on the monitoring sampling intensity, because low-intensity sampling methods will, by nature, yield less precision (e.g., larger coefficients of variation, wider confidence intervals, or less power in statistical tests) than more intensive methods.

Because each set of data has its own limits in precision, it is necessary to decide whether monitoring will be accomplished with a specific set of existing data, with new data, or through a combination of the two. When choosing a source of data, recognize that, over time, changes in technology or field methods could greatly affect the original estimate of attainable precision if data collected in the future will no longer be comparable to the original data. If data acquisition might undergo substantial changes between monitoring intervals, consider using another data source, even if the apparent precision at the onset appears to be less.

Sampling designs and analysis methods affect the type of power analysis used for evaluating expected precision and accuracy. For example, trend analyses, repeated measures, and analyses of proportions each use a different type of power analysis (Gibbs and Ene 2010).

Minimum Detectable Change

An effect size or minimum detectable change (Elzinga et al. 1998) should be determined primarily by ecological criteria early in the planning stages of a monitoring study. Knowledge of the expected variability associated with the selected attribute(s) is also helpful for estimating the attainable values of effect size or minimum detectable change, however. Either using pilot data or existing data, examine the width of confidence intervals relative to the desired minimum detectable change on the most important two or three attributes, and use formulas in standard statistics textbooks to evaluate the sample size necessary to produce confidence intervals with acceptable width. If new data are to be collected, estimate the required sample size using procedures described in section 3.3.3 under the subheading, Estimate the Number of Sampling Units Required. One can

evaluate the power to detect a given minimum detectable change by a standard statistical test that is appropriate to the analysis method. We recommend evaluating the width of the confidence intervals because that is usually easier to understand than **Type I** and **Type II errors** associated with a power analysis.

For trend detection, use preliminary data and a simple linear regression to see whether a trend is evident as a positive (or negative) slope. Are the sample size and the number of sampling periods sufficient to produce an estimated slope so that the confidence interval on the slope does not contain zero? Equivalently, is adequate power available to detect a certain positive (or negative) slope in the regression line?

If a power analysis or an evaluation of the confidence intervals indicates that the data are unlikely to provide the desired precision or to detect the desired level of change, consider increasing the sample size (section 3.3.3). This augmentation will require collecting new data using the same sampling design and data measurement protocols as the existing data.

Several Web sites provide information to assist with power analyses. To help plan for adequate power to detect a positive (or negative) slope, the Southwest Fisheries Science Center offers TRENDS (Gerrodette 1987), available at http://swfsc.noaa.gov, under the tab Publications/Research software. Another freeware package is MONITOR (Gibbs and Ene 2010), available at http://www.esf.edu/efb/gibbs/monitor/. Lenth (2009) provides software for several forms of power analysis at http://www.stat.uiowa.edu/~rlenth/Power/. Forest Service employees have access to information on power analyses, formulas, and SAS codes on the internal Forest Service statisticians' Web site at http://fsweb.rmrs.fs.fed.us/statistics/statmethods/IntroSASpower.html. (This Web site and other sites beginning with "fsweb" are only available to Forest Service employees or those with access to a Forest Service server.)

After performing sample size calculations, evaluate funding capabilities to determine whether it will be possible to achieve the estimated sample size with available resources. If not, adjust the desired precision to a level that is less optimal, yet capable of providing useful information, to help meet the stated objectives. If it is not possible to obtain precision that is sufficient for the information needs, it may be necessary to abandon plans for using the selected attribute(s) in the monitoring program and to seek alternative attribute(s) whose mean values can be more accurately estimated.

Quantitative Standard for Evaluating Monitoring Results

Ultimately, the purpose of monitoring is to support management objectives and to inform managers when current approaches need to be altered. Therefore, the monitoring objective statement needs to describe the condition or set of conditions expressed as one or more quantitative standards that could trigger a change in management.

For trend monitoring, the standard could be a specified percentage of increase or decrease in the amount or quality of habitat or specific habitat attributes. We recommend

selecting a value that is meaningful and observable for the attribute or habitat being monitored. For threshold monitoring, the quantitative standard could be a desired condition statement from the current land management plan or a threshold established in a species' recovery plan. The quantitative standard can also be a historical reference condition (see chapter 6).

3.3.2 Evaluate Whether Existing Information Can Be Used

Two types of existing information are available: field-sampled data and remotely sensed data, such as aerial photography and satellite imagery (see chapter 4 for a thorough review of existing information).

Field-Sampled Data

Field-sampled data are any form of data collected by surveyors on the ground, as opposed to data collected through airborne devices and satellites. The FIA program provides the most comprehensive source of field-sampled vegetation data in the form of a continuous inventory, with broad applicability for monitoring purposes. Other forms of field-sampled data are forest stand exams (including the nationally standardized Common Stand Exam), rangeland inventories (including current vegetation sampling methods), Terrestrial Ecological Unit Inventories, and wildlife habitat surveys.

Evaluate the potential for using field-sampled data using the following steps.

- Determine the spatial extent of existing data and compare it with the spatial extent of the proposed monitoring program.
- Evaluate whether the data were collected with a structured sample design (e.g., simple random, stratified random) or whether potential bias exists from **convenience sampling**.
- Determine whether the existing data include measurements of the desired habitat attributes and, if not, if it will be possible to derive these habitat attributes from other measured variables in the data set.
- Compute confidence intervals (or run a power analysis) on attributes of interest to determine sample size requirements (see subheading, Estimate the Number of Sampling Units Required, in section 3.3.3).
- If the existing data cover a smaller spatial extent than the proposed monitoring program, OR if the existing plot data have less precision than needed for the monitoring objective, design an unbiased probabilistic sampling procedure for increasing the sample size.
- Become familiar with the field protocol used for the existing data so that it can be repeated at existing and new sites. This process includes evaluating whether the field protocol documentation is sufficient to allow for repetition.

Remotely Sensed Data

The Forest Service and other land and resource management agencies use a wide variety of **remotely sensed data**, including traditional aerial photography, moderate- to very-high-resolution digital satellite imagery, regional downscaled climate models, and active systems such as radar and Light Detection and Ranging (**LIDAR)**. Some of these data (discussed in more detail in chapter 4, section 4.5) have been regularly acquired, have been archived for decades, and are available as data layers in a Geographic Information System (GIS).

The process of evaluating whether remotely sensed data can be used for a specific habitat monitoring program is similar to the process of evaluating field-sampled data.

- Determine the spatial extent of existing data and compare it with the spatial extent desired for the monitoring program.
- Determine whether the data source will likely be available over the desired time frame of the monitoring program because rigorous monitoring requires continuity in all aspects of data collection and analysis. If the remote sensing **platform**, **sensor**, or classification algorithms will change across the desired timeframe, using these products for monitoring may not be feasible.
- Determine whether the existing data include the habitat attributes of the emphasis species and, if not, whether it is possible to derive the habitat attributes from other analyzed or sampled variables in the data set.
- Become familiar with the methods and assumptions that went into the classification process.
- Determine whether the **spatial resolution** is appropriate for one or more scales of habitat used by the emphasis species.
- Evaluate map accuracy to ensure it is sufficient for the intended analysis objective (Foody 2002, 2009). If using a subarea of a larger remotely sensed product, try to determine the likely error rates within the subarea for those habitat attributes that are most critical.

3.3.3 Plan and Design for New Data Collection if Needed

Frequently, an inventory or monitoring objective will require acquisition of new field-sampled data when any of the following are true.

- The area of interest is fairly small.
- The habitat attributes cannot be derived from existing data.
- The existing data do not indicate use of an appropriate sample design.
- The sample size of existing data is inadequate to meet monitoring objectives.
- The existing data are useful but not current.

In the last two cases, and assuming those existing data meet minimum standards for bias and precision, the new monitoring program should use the same sampling design and

data-collection methods as the existing information to facilitate analyses of the attributes between sampling periods. If the need for new data is not tied to an existing data source, data acquisition will require development of a sampling design (i.e., making decisions about the sampling units and their placements) and development of new standard operating procedures for measuring variables in the field.

Numerous books and articles discuss sampling methods and designs. Introductory texts by authorship include Elzinga et al. (1998), McComb et al. (2010), Morrison et al. (2008), Scheaffer et al. (1990), and Thompson et al. (1998). In addition, Vesely et al. (2006) provide a good introductory presentation of sampling in the context of population monitoring. Sampling methods that account for imperfect detectability include distance sampling (Buckland et al. 2001) and occupancy modeling (Mackenzie et al. 2006). Figure 2.4 of Elzinga et al. (1998) illustrates the process steps for creating a sampling design for quantitative monitoring. The following section follows these authors' steps with special emphasis on details relevant to a habitat monitoring program.

Define the Sampling Unit

Select an appropriate type of **sampling unit** for the attribute(s) that will be measured. If more than one type of sampling unit seems appropriate, use the experience of others to guide in this decision. For example, a fixed-area plot is the typical sampling unit used for measuring plant density, frequency, and biomass (chapter 4, section 4.4.2), whereas a plotless method is the typical sampling unit frequently used to obtain tree basal area. Some attributes are best measured within subsamples of primary sampling units (secondary sampling units or elements). Measurements within secondary sampling units are usually not independent from one another, so the data are generally aggregated into mean values for each primary sampling unit, which serve as the basis for analyses.

Describe Sampling Unit Size and Shape

Before choosing the size, shape, and placement of the sampling units, it is important to become familiar with the spatial distribution of the selected attribute(s) within the area of interest. Most attributes demonstrate some degree of spatial clumping, whether from the topography of the site, species-specific growth patterns, site quality, or site history. The size of the sampling unit should reflect the scale at which the clumped patterns of distribution occur. Nested plot designs are a good approach when monitoring for both common and rare attributes. For example, larger plots might be used for rare elements such as snags, and smaller nested subplots used for more abundant saplings. The larger plots, used for rare elements, help avoid having many sampling units with zero values, which affects data analysis.

As the size of the sampling unit increases, the amount of time required to measure the attributes increases, so a monitoring team should select a sampling unit size that is reasonably small while still reflecting the spatial variability of the attribute. Larger plots

have fewer problems with edge effects, however. Ultimately, sampling unit size should be one that yields the highest statistical precision for a given area sampled or a given total amount of available time or money (Elzinga et al. 1998).

The shape and orientation of the sampling units should reflect the spatial distribution of the attribute. The goal is to include as much variability within plots and reduce variability between them to achieve higher precision in the estimated parameter of the habitat attribute.

Determine Method of Sampling Unit Placement

Sampling unit size and shape are influenced by the spatial distribution of measured attributes, but the placement of the sampling units must be made by a probabilistic procedure (e.g., simple random sampling, stratified random sampling, or systematic sampling) and must provide good interspersion throughout the area of interest (Elzinga et al. 1998). Regarding stratification, we reemphasize that "Strata should remain fixed on the landscape over time and data should not be restratified based on some other strata of interest that may arise in the future" (Vesely et al. 2006: 3-11). Stratified random sampling should only stratify on characteristics that will not change during the life of the monitoring program. In particular, one should not stratify on attributes such as current vegetation types and habitat quality that are almost certain to change.

Probabilistic location and good interspersion of units provide the basis for making valid statistical inferences for the study area that will stand the test of time. Problems with lack of independence in systematic sampling plans have been overemphasized in the literature, and methods exist for obtaining relatively unbiased estimates of the sampling errors for systematic sampling (Manly 2001, Stevens and Olsen 2003). Nevertheless, a certain amount of art and professional judgment are involved in designing and analyzing systematic sampling plans. Therefore, we reiterate the importance of involving a statistician in all aspects of monitoring program planning.

Much of this chapter has focused on single-attribute monitoring, but in reality, wildlife habitat is multidimensional and multiscalar, resulting in an interaction of many attributes at several scales. Because of these interactions, it is not possible to select a sampling design and sampling unit placement that are optimal for all attributes. We recommend designing the monitoring program around the two or three attributes judged to be most important to the emphasis species, with the understanding that other attributes will also be measured, although less optimally.

Decide Whether Sampling Units Will Be Permanent or Temporary

Monitoring can be done using either the same sampling units or new ones for each sampling period. The advantage of resampling the same units (repeated measures design) is that it reduces the variance and width of a confidence interval on the slope of a trend line (or other coefficients in more complex models). Similarly, the variance of the difference in means is less when evaluating abrupt changes between sampling periods (section 3.2.4).

Statistical tests for detecting trends or abrupt change between sampling periods are more powerful because the evaluated metric represents the change across time at each sample location rather than change between means of different sampled units.

A disadvantage of repeated measures, however, is the additional expense of marking permanent plots in the first year and the added amount of time required to relocate them during subsequent sampling periods, especially if field personnel change between sampling periods. Moreover, permanent markers are often less than permanent because they can be removed or displaced by humans or damaged by animals and weather. Fortunately, Global Positioning System units have added tremendously to the ease of georeferencing sampling units, but plot corners, centers, and microplots may still need to be physically marked. The use of buried iron, such as pieces of rebar, reduces loss of permanent markers.

An alternative to using permanent plots is to select new sampling units each sampling period, a strategy that may be necessary if visits to a unit tend to bias future measurements owing to trampling or collection of materials. Moreover, if the locations of measured attributes are expected to shift around from year to year (e.g., annual plants), the advantages of permanent plots diminish, and the added cost of marking plots may not be justified.

Selection of new units for each sampling period does not have the inherent bias of a fixed set of units (a fixed set is always greater or less than the true mean for a specific period) and will tend to provide a better estimate of true status of a parameter over time. When the monitoring objective is detection of change or trend in the least amount of time, however, we recommend the repeated measures design.

A blend of these two strategies is the rotating panel design (McDonald 2003). With this approach, the entire set of sampling units is permanent, but only a subsample, known as a panel, is visited every sampling period. All sampling units are eventually sampled over the course of several sampling periods. The rotating panels enable a larger portion of the area of interest to be sampled, whereas the advantages of the repeated measures design come into play after all the sites have been visited for two or more rotations. See McDonald (2003) for a detailed discussion of the issues involved in the analyses of both types of designs. The FIA program uses a rotating panel design with each panel revisited on a 10-year rotation.

Estimate the Number of Sampling Units Required

A statistician with a sense of humor, Doug Johnson, USGS, once said that the answer to the question of how large the sample size should be is that which results in the use of all available funds, an answer that has a lot of truth in it. Certainly, selecting a sample size requires more input than simply using the outcome of a power analysis. Difficulties begin when a sample size that is optimal for one attribute is not necessarily best for other attributes. Also, a sample size based on variation in the past will not necessarily be adequate under a scenario of future variation. For overall sample size estimations,

we recommend selecting two or three of the most important attributes and basing the recommended sample size on a compromise for the set. Using these attributes, the recommended approach is to conduct a pilot test and estimate the number of sampling units that will be needed, using the desired width of confidence intervals or the outcome of an appropriate power analysis, as described in Gerrodette (1987) and Morrison et al. (2008).

Next, statistically resample the pilot data with an assumed model for the true status and trend of, for example, the mean response of an attribute over time (Manly 2007). Vary the minimum detectable change according to the model. Resample the **residuals** about the mean in the pilot data, with replacement, to mimic different sample sizes from the population of residuals and observations about the assumed model with a given minimum detectable change. Repeat the process perhaps 1,000 times and determine the number of times the simulated change is detected by an appropriate confidence interval procedure or statistical test. This proportion (say 911/1,000 = 91.1 percent) is the power of a given sample size to detect a given change from an assumed model using the variation evident in the pilot data.

In other words, resample the pilot data as if they are the populations to be observed in the future and determine the likelihood that important minimum detectable change levels can be discerned with different sampling efforts. The advantages of this procedure are that few assumptions must be made, the natural variation observed in real data is mimicked, and computations can be completed on standard desktop computers using add-ons to spreadsheet software. Manly (2007) provides a discussion of resampling and randomization procedures that do not require many of the assumptions in classical parametric statistics.

If a pilot study is not yet available and a rough approximation of sample size is needed, evaluate existing data to estimate the expected variance of the attribute. For example, if the range of measurements on an attribute is expected to be approximately symmetric from 40 to 100 with a mean of about 70, then a good guess for the standard deviation is 10; i.e., an interval about the mean of plus or minus 3 times the standard deviation is expected to contain about 99 percent of the observations. Be aware, however, that this approach involves varying degrees of approximations and assumptions (e.g., a normal distribution) and may yield unsatisfactory estimates of sample size requirements.

Scheaffer et al. (1990) and other statistics texts contain standard formulas for estimating the sample size necessary to achieve a confidence interval with prespecified one-half-width on parameters when comparing data to a threshold value. One of the best recommendations for planning to obtain power to detect a significant trend over time with a simple linear regression line is given by Gerrodette (1987). Also, see the discussion of freeware computer packages TRENDS and MONITOR in section 3.3.1 previously, under the heading, Desired Precision of the Monitoring Information.

Determining the sample size for an inventory or monitoring program is a mixture of art and science. Plan for a compromise of precision on the two or three most important parameters and make adjustments in unit size, unit shape, and methods for each attribute

(not all attributes need be measured in association with every sample unit); estimate the variation that will be present in the future, using a pilot study, if possible; estimate the sample sizes to detect important effects; and monitor the monitoring program.

3.3.4 Conduct a Pilot Study

If the monitoring program will be partially or fully based on data collection in the field, we highly recommend conducting a pilot study or series of studies before implementing the full monitoring program. One primary reason for a pilot study is to evaluate variability in the values of each habitat attribute to estimate the sample size needed for achieving the desired precision to detect a given change (as described under Estimate the Number of Sampling Units Required in the previous section). A pilot study, however, can also provide experience and information that will result in a more effective monitoring program.

For example, a pilot study can be used to test out a new protocol or new field equipment, train field personnel, resolve logistical problems related to accessing plots or obtaining measurements, and estimate the amount of time and the cost per sampling unit. Moreover, the outcome of a pilot study can be used to convince funding authorities that the full-scale monitoring program is feasible and practical (van Teijlingen and Hundley 2001).

Depending on the degree to which a particular monitoring protocol is novel, pilot studies will generally involve multiple stages with increasing rigor and formality as the final protocol is approached. For example, at the early stages, limited field testing of protocols can identify a plethora of practical problems. When these problems are systematically eliminated, concerns shift to the statistical reliability of the design. In these latter stages, we recommend that pilot studies be large and formal—dry runs of the actual monitoring program with sufficient sampling intensity to produce initial estimates of variance. Obviously, these later stages are more expensive and time consuming than smaller scale protocol development and will require formal acknowledgment when estimating labor and costs.

3.3.5 Document the Decisions in a Monitoring Plan

The final step in planning and design is to document all decisions and the underlying rationale for these decisions in a monitoring plan. We recommend a modified version of the outline shown in Vesely et al. (2006) for specific inventory and monitoring strategies. Our outline here is essentially the same, with the addition of an Introduction, and with the monitoring objectives embedded in the section on Planning and Design. Topics under each main heading can serve as subheading titles in the plan.

1. **Introduction.** Include the overall goals and objectives for monitoring and explain how they are tied to management goals. Provide rationale for monitoring habitat of an emphasis species or group of species (chapter 2, section 2.3.1).
2. **Planning and Design.** Present a conceptual model for the species or species group, including the levels of habitat selection, habitat requirements, and habitat stressors

(chapter 2, section 2.3.2). Identify the habitat attributes derived from the conceptual model. State the monitoring objectives for these habitat attributes at the appropriate spatial scales. Describe the sampling design, including sources of existing data as well as the spatial and temporal design for collecting new data, either field sampled or remotely sensed.

3. **Data Collection.** State how existing data will be obtained and augmented as necessary. For field-sampled data, describe methods of obtaining measurements of each habitat attribute. For remotely sensed data, describe the process of deriving habitat attributes through image interpretation, classification, or sampling. Include a section on logistics that describes required permits, personnel training, equipment acquisition, contracts for completion of field or GIS work or statistical consulting, and any other relevant logistical information.
4. **Data Storage.** Identify stewards of the monitoring data and state where data will be archived and maintained. (See chapter 9 for a discussion of data storage.)
5. **Data Analysis.** Describe the intended types of data analysis, including map products. Identify the summary statistics that will be used after the initial year, and identify the statistical tests (if any) that could be used to compare monitoring results from two points in time and to evaluate multiyear data.
6. **Reporting.** Identify a reporting schedule (e.g., 1 year, 5 years, 10 years). Include a description of the monitoring reports that will be associated with each reporting interval. State how these reports may inform management decisions.

Chapter 10 of this technical guide provides three examples of habitat monitoring programs. The first two examples systematically demonstrate the process steps that we identify in chapters 2 through 9. The third example is a monitoring plan for mole salamander (Ambystomatidae) habitat, following the outline presented in the preceding paragraphs. The salamander habitat monitoring plan may appear more complex because each main heading is subdivided into three spatial scales of habitat. It is a realistic example, however, that illustrates both the main principles of a monitoring design and the multiscale nature of habitat monitoring.

3.4 Conclusions

A monitoring program is more likely to be successful if time is invested in the initial planning and design. The basic principles of sampling design have been incorporated into numerous references for population monitoring, but this chapter provides the unique role of incorporating these principles into habitat monitoring.

Decisions about habitat monitoring are distinctly different from population monitoring in several ways. For example, population monitoring typically relies on field collection of new population data, whereas habitat monitoring may be able to use data collected

from other sources. The ability to use existing data is an advantage, but it brings with it the need for careful consideration regarding whether existing data adequately cover the area of interest, are at an appropriate spatial resolution, and will continue to be collected over the life of the monitoring program. The ability to monitor habitat attributes with remotely sensed data offers advantages as well, but it comes with increased error rates because the attributes are most often modeled, not measured.

Another unique challenge with habitat monitoring is that the team needs to decide whether to monitor attributes individually or to combine them in a model of habitat and then monitor the abundance and quality of that habitat. The decision to combine attributes into a model creates new challenges about model selection and increases uncertainty regarding whether the models adequately represent habitat of the emphasis species. For this reason, we recommend population surveys to evaluate habitat model assumptions (see also chapter 5).

In many ways, however, the basic principles of designing a monitoring program apply equally to population monitoring and habitat monitoring. These principles include stating an objective, selecting indicators (i.e., habitat attributes), deciding on the desired level of precision, deciding on a minimum detectable change that is biologically meaningful, deciding on whether to use independent samples or repeated measures, selecting the appropriate methods of data analysis, and making plans for reporting results and incorporating them into management. Although these principles have been stated elsewhere, they are so essential to any monitoring program that we have reiterated and emphasized them again in this chapter.

Chapter 4. Monitoring Vegetation Composition and Structure as Habitat Attributes

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4.1 Objectives

Vegetation composition and structure are key components of wildlife habitat (McComb et al. 2010, Morrison et al. 2006) and are, therefore, essential components of all wildlife habitat monitoring. The objectives of this chapter are to describe common habitat attributes derived from vegetation composition and structure and to provide guidance for obtaining and using existing and new vegetation data to monitor wildlife habitat.

We begin this chapter by addressing key concepts relevant to monitoring vegetation. Next, we describe each of the common habitat attributes associated with vegetation composition and structure and how they are measured or derived using field-sampled and remotely sensed data. We also describe sources of existing data, as well as methods for obtaining new data using established protocols. We conclude the chapter with a call for standardization and consistency in habitat monitoring efforts.

In developing a habitat monitoring program, the choice of attributes requires careful consideration of species ecology, available data and resources, and other factors (chapter 2, section 2.3). Although many vegetation attributes are associated with wildlife habitats, we chose to address these attributes (table 4.1) based on national technical guides (Warbington 2011, Winthers et al. 2005), a survey of the literature (e.g., Elzinga et al. 1998, Herrick et al. 2005, Morrison et al. 2006), and the practical experience of wildlife and vegetation ecologists.

Monitoring teams should check for existing data before planning for new data collection. To assist with this prework, we provide a list of numerous data sources that could be used for monitoring at broad, mid, and local scales (table 4.2). For example, data collected through the Forest Service Forest Inventory and Analysis (FIA) program

Table 4.1.—*Key habitat attributes of vegetation structure and composition for wildlife habitat monitoring.*

Attribute	Definition
Vegetation composition	
Vegetation type	A named category of plant community or vegetation defined on the basis of shared floristic and/or physiognomic characteristics (e.g., structure, growth form, floristic composition, and cover) that distinguish it from other kinds of plant communities or vegetation (FGDC 2008, Tart et al. 2011).
Cover type	A designation based upon the plant species forming a plurality of composition and abundance; typically based on the dominant species in the uppermost stratum of vegetation (e.g., Oak-Hickory) (adapted from Brewer et al. 2011b, FGDC 2008).
Association	The finest level of vegetation classification, defined on the basis of a characteristic range of species composition, diagnostic species occurrence, habitat conditions, and physiognomy (Jennings et al. 2006, as cited in FGDC 2008). Associations reflect topoedaphic climate, substrates, hydrology, and disturbance regimes. Defined using diagnostic species, usually from multiple growth forms or layers, and more narrowly similar composition. As many as five species may be necessary to define an association in an unusually diverse region with even dominance (FGDC 2008).
Species abundance	The total number of individuals in a taxon or taxa in an area or community, often measured as cover (Lincoln et al. 1998).
Vegetation structure	
Trees	
Canopy cover	Percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of the tree layer. Small openings in the crown are included (Warbington 2011).
Canopy closure	The proportion of the hemispherical sky obscured by vegetation when viewed from a single point on the ground (Jennings et al. 1999).
Diameter-derived attributes:	
Tree diameter	The length of a line passing through the center of a tree bole at breast height (4.5 ft), measured outside of the bark and perpendicular to the tree bole (Helms 1998).
Basal area	The cross-sectional area of the stem or stems of a plant or of all plants in a stand, generally expressed as square units per unit area.
Quadratic mean diameter	The diameter of the tree having the arithmetic mean basal area of a stand (Graves 1908, cited in Curtis and Marshall 2000).
Height	Distance from base of tree at ground level to growing tip of tree (Oliver and Larson 1996).
Canopy complexity	Diversity in number of layers and species within layers of forest vegetation (Lowman and Rinker 2004).
Stand density	A quantitative measure of stocking expressed either absolutely in terms of the number of trees, basal area, or volume per unit area, or relative to some standard condition (Helms 1998).
Snags[a] and defective trees[b]	
Decay class	A categorical measure of the amount of wood deterioration that is typically used to stratify diameter, height, and density into classes (table 4.8).
Diameter	Same metrics and definitions as for live trees, applied to dead or defective trees.
Height	Same definition as for live tree height, applied to dead or defective trees.
Density	Same definition as for stand density, applied to dead or defective trees.
Cavity size	Holes in trees; size is usually expressed as the width of the hole (Carey and Sanderson 1981).
Down wood	
Decay class	A categorical measure of the amount of wood deterioration that is typically used to stratify diameter, height, and density into classes (table 4.9).
Diameter:	
Line-intercept diameter	The diameter of a down log at the point where it is intersected by a line transect (Bate et al. 2008a).
Large-end diameter	For a log with root structure attached, it is the length of a line passing through the center of the log at the point equivalent to breast height if the log were standing. If the log has no attached root structure, it is the length of a line passing through the center of the log at its largest end (Bate et al. 2008a).
Length	Length of each log piece that meets the minimum diameter for inclusion in the sample (Bate et al. 2008a).
Cover	Percentage of ground covered by logs, derived from length and diameter of all pieces encountered on a line transect or within strip plots (Bate at al. 2008a).

Table 4.1.—*Key habitat attributes of vegetation structure and composition for wildlife habitat monitoring (continued).*

Attribute	Definition
Volume	Cubic feet of log per acre or cubic meter per hectare, derived from length and diameter of all pieces encountered on a line transect or within strip plots (Bate at al. 2008a).
Density	Number of logs per unit area, usually stratified by decay class and/or diameter class (Bate et al. 2008a).
Shrubs	
Shrub cover	Percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of the shrub layer (Warbington 2011). Use the term canopy cover when small openings in the shrub canopy are included in the measurement; use the term foliar cover when small openings in the shrub canopy are excluded (SRM 1989).
Height	Height from ground to top of shrub (Johnson and O'Neill 2001).
Herbaceous vegetation	
Herbaceous cover	Percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of the herbaceous layer (Warbington 2011). Use the term canopy cover when small openings in the herbaceous canopy are included in the measurement; use the term foliar cover when small openings in the herbaceous canopy are excluded (SRM 1989).
Height	Height from ground to top of herbaceous plant, or base of flower if plant is flowering.
Structural stages/seral stages	
Structural stages	Stand classification based on the horizontal and vertical distribution of components of a forest stand, including the height, diameter, crown layers, and stems of trees, shrubs, herbaceous understory, snags, and down woody debris (Helms 1998).
Seral stages	Stand classification based on temporal and intermediate stages in the process of succession (Helms 1998).

ft = foot.

[a] A snag is "…a standing, generally unmerchantable dead tree from which the leaves and most of the branches have fallen—note for wildlife habitat purposes, a snag is sometimes regarded as being at least 10 inches (25.4 centimeters) in diameter at breast height and at least 6-ft (1.8-m) tall (Helms 1998: 168–169); see section 4.3.2 for further description.

[b] Defective trees are living trees with wounds, scars, decay, and/or cavities; see section 4.3.2 for further description.

contains field-sampled and derived variables that are equivalent to wildlife habitat attributes (USDA Forest Service 2011) (table 4.3 provides a crosswalk between the habitat attributes listed in table 4.1 and FIA variables). In addition, Natural Resource Manager (NRM) database modules, particularly Field Sampled Vegetation (FSVeg; tabular data) and FSVeg Spatial (a polygon spatial layer), provide vegetation data at the forest level if they have been populated by local datasets (chapter 9). Moreover, many national forests and grasslands have databases of habitat attributes associated with both vegetation composition and structure that were measured in the process of vegetation **classification** and mapping. The national *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011) provides guidance for measuring vegetation-based habitat attributes. Within FIA, the Vegetation Indicator provides standard protocols for data collection of vegetation composition and structure attributes (Schulz et al. 2009). Data for FIA indicators are collected on a subset of plots, but the grid can be intensified as needed (sections 4.4.1, 4.4.3). Using standard protocols for measuring habitat attributes across a region greatly facilitates data integration and comparison among local management units, and it enhances the utility of compiled datasets. More information on acquiring and using **legacy data** is available in section 4.4.

The habitat attributes addressed in this chapter are important indicators of vegetation diversity as well as wildlife habitat and are, therefore, also relevant to vegetation monitoring. For example, a local management unit may choose to monitor vegetation composition and structure to determine whether progress is being made toward desired vegetation

Table 4.2.—*Example methods and data sources for measuring habitat attributes of vegetation structure and composition at three scales (see text for more details).*

Habitat attribute	Broad scale		Midscale		Local (base) scale	
	Methods	**Existing data source**	**Methods**	**Existing data source**	**Methods**	**Existing data source**
Vegetation composition						
Vegetation type	NN, data summaries	FIA/CVSc/local data, satellite imagery, and aerial photos	NN, data summaries	FIA/CVS/local data, satellite imagery, aerial photos	Ocular macroplot and other fixed area plots, quadrats, line intercept, point intercept, frequency	FIA/CVS/local data
Species abundance	NN, FIA/CVS data summaries	FIA/CVS/local data	NN, data summaries, autocorrelation analysis	Landscape transects	Ocular macroplot and other fixed area plots, quadrats, line intercept, point intercept, frequency	FIA/CVS/local data
Vegetation structure						
Trees						
Canopy cover and closure	NN, dot grid/Digital Mylar	Satellite imagery, aerial photos	Dot grid/Digital Mylar, LIDAR	Aerial photos	Ocular macroplot or fixed-area plot; line intercept; point intercept; fisheye lens, moosehorn, ground-based LIDAR	CSE/CVS/FIA/local data
Diameter-derived attributes						
Diameter	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data	NN, FIA/CVS data summaries, aerial photos	Satellite imagery, aerial photos, landscape transects	Variable radius plots, fixed area circular plots, CSE	CSE/CVS/FIA/local data
Basal area	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data	NN, LIDAR	Satellite imagery with FIA/CVS/other plot data	Variable radius plots, fixed area circular plots; prism	CSE/CVS/FIA/local data
Quadratic mean diameter	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data	NN, FIA/CVS data summaries, aerial photos	Satellite imagery, aerial photos, landscape transects	Variable radius plots, fixed area circular plots, CSE	CSE/CVS/FIA/local data
Height			LIDAR		Ocular macroplot or fixed area plot; point intercept; laser scope, clinometer, Relaskops	CSE/CVS/FIA/local data
Canopy complexity	NN, FIA/CVS data summaries					FIA/local data
Stand density	NN, FIA/CVS data summaries	Satellite imagery with FIA/CVS/other plot data. Difficult at this scale.	NN, FIA/CVS data summaries, aerial photos	Satellite imagery, aerial photos, landscape transects	Variable radius plots, fixed area circular plots, CSE	CSE/CVS/FIA/local data

Table 4.2.—*Example methods and data sources for measuring habitat attributes of vegetation structure and composition at three scales (see text for more details) (continued).*

Habitat attribute	Broad scale		Midscale		Local (base) scale	
	Methods	Existing data source	Methods	Existing data source	Methods	Existing data source
Snags and defective trees						
Decay class	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects, fixed area plots	CSE/CVS/FIA/local data
Diameter	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects, fixed area plots	CSE/CVS/FIA/local data
Height			LIDAR		Ocular macroplot or fixed area plot; point intercept; laser scope, clinometer, Relaskops	CSE/CVS/FIA/local data
Density	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects	CSE/CVS/FIA/local data
Cavity size	Not applicable	Not available	Not applicable	Not applicable	Fixed area plots	Local data
Down wood						
Decay class	NN, FIA/CVS data summaries	Not applicable	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects	Local data
Diameter	NN, FIA/CVS data summaries	Satellite imagery, but FIA/CVS data also essential	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects, fixed area plots	CSE/CVS/FIA/local data
Length					Line transects, fixed area plots	CSE/CVS/FIA/local data
Cover					Fixed area plots	CSE/CVS/FIA/local data
Volume					Line transects, fixed area plots	CSE/CVS/FIA/local data
Density	NN, FIA/CVS data summaries	FIA/CVS data	NN, data summaries, autocorrelation analysis	Landscape transects	Line transects	Local data
Shrubs						
Canopy cover	NN, FIA/CVS data summaries	FIA/CVS data	NN, data summaries, autocorrelation analysis	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	Local data
Height	NN, FIA/CVS data summaries	FIA/CVS data	NN, data summaries, autocorrelation analysis	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	Local data

Table 4.2.—*Example methods and data sources for measuring habitat attributes of vegetation structure and composition at three scales (see text for more details) (continued).*

Habitat attribute	Broad scale		Midscale		Local (base) scale	
	Methods	**Existing data source**	**Methods**	**Existing data source**	**Methods**	**Existing data source**
Herbaceous vegetation						
Canopy cover	NN, FIA/CVS data summaries	FIA/CVS/local data	NN, data summaries, autocorrelation analysis	Landscape transects, FIA/CVS/local data	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data
Height	Not applicable	Not applicable	Data summaries, autocorrelation analysis	Landscape transects, FIA/CVS/local data	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data
Structural stages/seral stages						
Structural stages	Derive from CVS/FIA data summaries	CVS/FIA/local data summaries	NN, data summaries	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data
Seral stages	Map analysis	Aerial photos and satellite imagery	NN, data summaries	Landscape transects	Ocular macroplot and other fixed area plots, quadrats; line intercept, point intercept; frequency	FIA/CVS/local data

CSE = Common Stand Exam. CVS = Current Vegetation Survey (used only in the Pacific Northwest Region). FIA = Forest Inventory and Analysis (section 4.4.1). LIDAR = Light Detection and Ranging. NN = Nearest-neighbor methods (section 4.5.2).

Note: Table 4.10 provides descriptions of various types of satellite imagery used in habitat monitoring.

Table 4.3.—*Cross-walk of vegetation structure and composition habitat attributes with FIA program variables.*

Attribute	FIA variable(s)[a, b]	FIA table(s)	FIA sampling phase	Explanation
Vegetation composition				
Vegetation type				
Cover type	FORTYPCD = forest cover type	COND	P2	Forest cover type code[c]
Association	NA	NA	NA	Not directly available in FIA, but can use species-level data in plots to key sites to local plant association
Species abundance	VEG_SPCD = species code; SPECIES_ CANOPY_COVER_TOTAL = total canopy cover of species	VEG_SUBPLOT_SPECIES	P3 VEG	For each vascular species recorded on P3 plots, abundance is recorded as ocular estimate of percent cover of the subplot area
Vegetation structure				
Trees				
Canopy cover	VEG_SPCD = species code, SP_ CANOPY_COVER_TOTAL, and either SP_CANOPY_COVER_LAYER_3 and SP_ CANOPY_COVER_LAYER 4 or MAX_COVER_ LAYER_NBR_PRE2004	VEG_SUBPLOT_SPECIES	P3 VEG[d]	Ocular estimates of tree species canopy cover;
	TOTAL_CANOPY_COVER_LAYER_3 and TOTAL_CANOPY_COVER_LAYER_4	VEG_SUBPLOT	P3 VEG	Layer 1 = 0 to 2 ft Layer 2 = 2 to 6 ft Layer 3 = 6 to 16 ft Layer 4 = > 16 ft Ocular estimates of total cover (all species; can include trees, shrubs, and vines) in four layers over a standard subplot area
Canopy closure	Unavailable from FIA		NA	NA
Diameter-derived attributes:				
Tree diameter	DIA = tree DBH (in)	TREE	P2	Current diameter measured at breast height in the field, in inches
Basal area	BALIVE = live basal area (ft^2/ac), in FIA table name = COND; DIA = tree DBH (in)	TREE	P2	Computed from diameters of all live trees > 1-in DBH sampled in the condition; expressed as ft^2/ac
Quadratic mean diameter	DIA = tree DBH (in)	TREE	P2	Compute basal area of each tree on the plot: basal area = $(0.005454)(DBH^2)$ (when DBH is in inches and basal area in ft^2); next determine mean basal area of all the trees on the plot or stand, then convert this back to quadratic mean diameter using: $Dq = (\text{mean basal area}/0.005454)^{1/2}$

Table 4.3.—*Cross-walk of vegetation structure and composition habitat attributes with FIA variables (continued).*

Attribute	FIA variable(s)[a, b]	FIA table(s)	FIA sampling phase	Explanation
Height	HT = total tree height (ft)	TREE	P2	Develop height distributions and associated parameters (e.g., mean, standard deviation, maximum); summarize data by user-defined height classes
Canopy complexity	TOTAL_CANOPY_COVER_LAYER_1, TOTAL_CANOPY_COVER_LAYER_2, TOTAL_CANOPY_COVER_LAYER_3, and TOTAL_CANOPY_COVER_LAYER_4	VEG_SUBPLOT	P3 VEG	Ocular estimates of total cover (all species) in four layers over a standard subplot area.
Stand density	STATUSCD = tree status, DIA = tree DBH (in)	TREE	P2	STATUSCD indicates whether trees are alive, dead, removed, etc., compute density measures (e.g., trees/ac) based on user-defined tree size classes
Snags and defective trees				
Decay class[e]	STANDING_DEAD_CD = standing dead trees, DECAYCD = decay class	TREE	P2	FIA uses five decay classes (recorded only for dead trees)
Diameter	STANDING_DEAD_CD = standing dead trees, DIA = tree DBH (in)	TREE	P2	Can develop diameter distributions and associated parameters (e.g., mean, standard deviation, maximum); summarize data by user-defined diameter classes or FIA-defined classes using FIA data tools
Height	STANDING_DEAD_CD = standing dead trees, HT = total tree height (ft)	TREE	P2	Can develop height distributions and associated parameters (mean, standard deviation, maximum); summarize data by user-defined height classes
Density	STANDING_DEAD_CD = standing dead trees, DIA = tree DBH (in)	TREE	P2	Compute density measures (e.g., snags/ac), by size class if desired (using DIA)
Cavity size	Unavailable from FIA		NA	NA
Down wood				
Decay class[f]	DECAYCD = CWD decay class	DWM_COARSE_WOODY_DEBRIS	P3 DWM	FIA uses 5 decay classes for coarse woody debris[f] (CWD); see also Woodall and Monleon (2008)
Diameter				
Line-intercept diameter	TRANSDIA = CWD transect diameter (in)	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Diameter of a piece of coarse woody debris where it intercepts the line used to tally large wood pieces
Large-end diameter	LARGEDIA = CWD large-end diameter (in)	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Summarize data by user-defined diameter classes

Table 4.3.—*Cross-walk of vegetation structure and composition habitat attributes with FIA variables (continued).*

Attribute	FIA variable(s)[a, b]	FIA table(s)	FIA sampling phase	Explanation
Length	LENGTH = CWD length (ft)	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Summarize data by user-defined length classes
Cover	NA	NA	NA	NA[h]
Volume	NA	NA	NA	NA
Density	NA	DWM_COARSE_WOODY_DEBRIS	P3 DWM	Compute density measures (e.g., number of pieces/ac), by decay class if desired
Shrubs				
Canopy cover	VEG_SPCD = species code, SP_CANOPY_COVER_TOTAL	VEG_SUBPLOT_SPECIES	P3 VEG	Ocular estimates of percent cover for species of interest, collected only in forested condition classes; compute shrub cover by summarizing total cover of shrub species
Height	VEG_SPCD = species code; SP_CANOPY_COVER_LAYER_1_2, SP_CANOPY_COVER_LAYER_3	VEG_SUBPLOT_SPECIES	P3 VEG	Shrub height measurements are not collected specifically, but species canopy cover is collected by height layers in addition to total canopy cover
Herbaceous vegetation				
Canopy cover	VEG_SPCD = species code; SP_CANOPY_COVER_TOTAL	VEG_SUBPLOT_SPECIES	P3 VEG	Ocular estimates of percent cover for herbaceous species of interest; collected only in forested condition classes; compute herbaceous cover by summarizing total cover of herb species
Height	VEG_SPCD = species code; SP_CANOPY_COVER_LAYER_1, SP_CANOPY_COVER_LAYER_2	VEG_SUBPLOT_SPECIES	P3 VEG	Herbaceous height measurements are not collected specifically, but species canopy cover is collected by height layers in addition to total canopy cover
Structural stages/seral stages				
Structural stages	NA	NA	NA	NA
Seral stages	NA	NA	NA	NA

CWD = coarse woody debris. DBH = diameter at breast height. ft^2/ac = square feet per acre. FIA = Forest Inventory and Analysis. ft = foot. in = inch. NA = Not applicable. P2 = Phase 2. P3 = Phase 3.

[a] *Table 4.1 provides definitions of vegetation-based habitat attributes.*

[b] *Visit the Web site for more information (e.g., current field guides, FIA P2 and P3 sampling protocols, and FIADB documentation): (http://www.fia.fs.fed.us/library).*

[c] *Requires crosswalk of codes; available in FIA table REF_FOREST_TYPE.*

[d] *Tree canopy cover can also be derived from data collected in the more abundant P2 plots using modeled relationships (see Toney et al. 2009 for one example).*

[e] *Table 4.8 provides descriptions of decay classes used by FIA for snags and defective trees.*

[f] *Table 4.9 provides descriptions of decay classes used by FIA for down wood.*

[g] *Coarse woody debris is sampled on transects, thus requiring different summarization processes than area-based samples.*

[h] *Estimation procedures for cover and volume of CWD in FIA are available (Woodall and Monleon 2008), and DWM raw data can be downloaded.*

conditions described in the unit's plan. When vegetation monitoring relates to habitat monitoring for a selected set of emphasis species or species groups, it can also be considered a **coarse filter** strategy for conservation. In this approach, representation of natural communities in protected reserves is hypothesized to protect a large percentage of associated species (Noss 1987, Noss and Cooperrider 1994). Using this approach, key **vegetation types** that serve as habitat for several emphasis species can be identified and protected, leading to more effective conservation.

4.2 Key Concepts

4.2.1 Vegetation as Habitat

Components of vegetation composition and structure frequently are the primary descriptors of habitat for a wide variety of wildlife species. Plant species are often indicators of site conditions. Compared with ecosystem processes, such as nutrient cycling, water flows, or disturbance, vegetation attributes are relatively easy to measure. Wildlife species can be grouped and associated with specific vegetation types and **structural stages** to increase efficiency of both management and monitoring (e.g., Johnson and O'Neil 2001, Wisdom et al. 2000; chapter 2, section 2.2.5). Vegetation types describe the dominant species present, whereas structural stages describe the size, height, and vertical arrangement of those dominant species.

Often, habitat attributes are only proxies for the true environmental relationship of interest. For example, prey for insectivorous birds is difficult to accurately quantify, so biologists typically measure other attributes, such as foliage volume, that serve as proxies for prey abundance (Morrison et al. 2006). When deciding which attribute to measure in a particular habitat, the conceptual basis for selecting that attribute must be clearly stated (Morrison et al. 2006). Chapter 2 (section 2.2) further addresses attribute selection.

Although this chapter focuses on attributes of **existing vegetation** for monitoring wildlife habitat, the concept of **potential natural vegetation (PNV)** may aid in delineating habitat or in stratifying the area of interest. PNV is the plant community that would become established if all successional sequences were completed without human interference under the present environmental and floristic conditions, including those created by humans (Tüxen 1956, as cited in Winthers et al. 2005). Potential vegetation is a useful organizing concept to delineate habitat by elevation bands, microclimates, productivity, or soils, which may be related to wildlife occurrence. The *Terrestrial Ecological Unit Inventory (TEUI) Technical Guide* (Winthers et al. 2005) is the Forest Service standard for potential vegetation classification and mapping. The agency is also developing a national potential vegetation classification and mapping guide; definitions and concepts in that document concur with the *TEUI Technical Guide*.

4.2.2 Vegetation Composition and Wildlife Habitat

Vegetation composition includes the kinds, absolute amounts, or relative proportions of plant species present in a given area (Warbington 2011). At the most basic level, **physiognomic** types (e.g., forests, shrublands, and meadows) describe the vegetation present. Vegetation types are defined on the basis of floristic and physiognomic characteristics that distinguish them from other kinds of vegetation (Tart et al. 2011, table 4.1). Using vegetation types, researchers can rapidly evaluate the relative value of various vegetation communities to the emphasis wildlife species of a habitat monitoring program.

Information about vegetation composition is vital to understanding and managing wildlife habitat because plant species are closely tied to wildlife use, past or future disturbance, and site productivity. For example, susceptibility to fire, associated wildlife species, and forage production could differ vastly between a loblolly pine (*Pinus taeda*) and a longleaf pine (*Pinus palustris*) forest. Differences in vegetation composition lead to opportunities for niche differentiation for birds, mammals, reptiles, and amphibians as well as for insects and other invertebrates that are prey (Morrison et al. 2006, Odum 1969). Vegetation composition data can be used in wildlife habitat monitoring in many ways, such as (1) identifying how plant species are capturing site resources (e.g., evaluating nonnative cheatgrass [*Bromus tectorum*] **dominance** in a native shrub community), (2) determining how key plant species are distributed across an environmental gradient in relation to the wildlife emphasis species, and (3) assessing changes in vegetation composition following management actions that may affect habitat of an emphasis species.

4.2.3 Vegetation Structure and Wildlife Habitat

Structure is the spatial arrangement of the components of vegetation, such as live and dead stems, branches, and foliage (Lincoln et al. 1998). It is a function of plant size and height, vertical stratification into layers, and horizontal spacing of plants (Mueller-Dombois and Ellenberg 1974, Warbington 2011). Plant condition also creates structure; for example, whether plants are alive, diseased, dead, heavily browsed or grazed; and, for trees, whether they are standing or fallen. In general, more structural diversity means more wildlife species diversity (Huston et al. 1999, MacArthur and MacArthur 1961) because vegetation structure enables organisms to occupy different niches within the same ecosystem (Morrison et al. 2006, Willson 1974). Greater diversity of organisms results in food webs that are more complex. Structural diversity contributes to greater diversity of food resources for most species within the system while also providing refuges for potential prey. Structure also creates sites for resting, denning, conducting breeding displays, avoiding inclement weather, and overwintering. Marcot et al. (1997) identified compositional and structural habitat elements for wildlife, and Johnson and O'Neil (2001) further associated these elements with a number of species.

4.2.4 Monitoring Vegetation at Different Spatial and Temporal Scales

We use scale in this guide to mean areal extent (as ecologists do), rather than as a map ratio (as geographers do). Spatial scale is a critical consideration in habitat monitoring for many reasons. For one, the relative importance of vegetation composition compared with structure can depend on the extent of the area of interest (Morrison et al. 2006, Rotenberry 1985). The habitat needs of wildlife species can vary greatly in areal extent; consider the foraging area of grizzly bears (*Ursus arctos*) or wolves (*Canis lupus*) compared with that of field mice. In addition, data resolution influences the derived values and, hence, the understanding of habitat conditions. For example, when measured in a Geographic Information System (GIS), edge density (total length of edge per unit area) declines as pixel size increases because at the coarser resolution patch edges are smoother. As a result, the amount of habitat for edge-associated species appears to be less at coarser resolutions (Trani 2002). Likewise, habitat of interior forest specialists, such as the hooded warbler (*Wilsonia citrina*) and worm-eating warbler (*Helmitheros vermivorus*), tends to be underestimated at coarse resolution because the percentage of forest interior declines with loss of resolution (Trani 2002). In a more general sense, effects of spatial aggregation and spatial resolution could lead to underestimation when a certain vegetation type (e.g., hardwood forest) is uncommon, and to overestimation of the same type when it is abundant. This inaccuracy in estimation is true for thematic attributes but not for continuous attributes (Nelson et al. 2009b). The concept of spatial and temporal scale in relation to habitat monitoring is addressed in detail in chapter 2 (sections 2.2.6, 2.3.2; Tavernia and Reed 2010).

Monitoring methods vary by spatial scale because not all methods are appropriate at the same or at multiple scales; moreover, a trade-off generally exists between level of detail and cost. As spatial extent increases, it is usually necessary to place plots at increasing distances and to use remotely sensed data at coarser resolutions. Monitoring implies repeated measures through time to detect change; therefore, before selecting a monitoring approach, consider the costs of acquiring new data with each time step. Thus, the area of analysis for a monitoring program will greatly influence decisions regarding using existing data and collecting new data. Also, some questions, such as habitat quality or abundance for a large predator, can be addressed only at specific scales. For example, fine-scale vegetation data collected within a small portion of a watershed will be of little use in evaluating grizzly bear habitat but may be critical for evaluating the habitat of a small invertebrate.

Throughout this chapter, we refer to three general spatial scales: local, mid, and broad. This framework follows the national *TEUI Technical Guide* (Winthers et al. 2005) and *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011). We modified these approaches somewhat by omitting the national scale and by using the term local scale to refer to the base scale described in Warbington (2011) and the **land unit** scale of *TEUI Technical Guide* (Cleland et al. 1997, Winthers et al. 2005). The following

three scales (referred to as levels in table 1.1 of the *Existing Vegetation Classification and Mapping Technical Guide* [Warbington 2011]) provide an organizing concept for sampling strategies.

Local scale. Ranges from a few acres to a few thousand acres. At this scale, the integration of soil, vegetation, and local topography define ecological units.

Midscale. Equivalent in area to a watershed in the range of a sixth to a fourth field hydrologic unit of capability (HUC) (i.e., in the thousands to low hundreds of thousands of acres). At this scale, geomorphology and broad vegetation zones become the primary drivers of diversity. Midscale is equivalent to the landscape scale of *TEUI Technical Guide* (Cleland et al. 1997, Winthers et al. 2005).

Broad scale. Large regional and subregional areas defined by consistent climate and geology. Examples include the Central Appalachians and the Piedmont in the Eastern United States and the Coast Range and the Klamath Mountains in the Pacific Northwest. Areas range from thousands to millions of acres. At this scale, the primary drivers of ecosystem function are climate and geology (Cleland et al. 1997, Winthers et al. 2005). As used in this technical guide, broad scale is equivalent in area and ecological function to the ecoregion and subregion scales of *TEUI Technical Guide* (Cleland et al. 1997, Winthers et al. 2005) and is also consistent with its usage in the *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011).

Temporal Scale

Monitoring objectives will determine monitoring frequency. Often long-term monitoring is needed for demonstrating trends, but it can be difficult to implement effectively because of erratic funding, personnel changes, and shifting importance of issues. If the objective requires long-term monitoring, ensure a structure is in place that includes written support from leadership, commitment from partners, and a contingency plan in the case of unforeseen reduced funding and personnel changes. Long-term monitoring efforts are also more likely to succeed if the selected attributes are relatively simple and straightforward to measure.

Shorter term monitoring (1 or 2 years) may sometimes be appropriate, such as in testing the efficacy of a monitoring method or determining if a short-term answer will meet monitoring objectives. For example, if you implement a silvicultural treatment with an objective of providing only transitory deer forage, and monitoring reveals that the treatment area has lost its deer forage value after 2 years, you can end data collection and complete a monitoring report.

4.3 Habitat Attributes—Vegetation Composition and Structure

In this section, we address specific vegetation composition and structural attributes, including definitions, wildlife use of the attribute, and standard methods of measurement. Because of the length and complexity of this section, we have also included table 4.1, which presents the attributes in the same order and with the same hierarchical structure as we present them here, along with a standard, published definition for each attribute. The first subsection (subsection 4.3.1) focuses on two primary attributes of vegetation composition that are important to wildlife: vegetation type and species abundance. The second subsection (subsection 4.3.2) describes 25 structural attributes, organized under the general **life form** and functional categories of trees, snags, down wood, shrubs, and herbaceous vegetation. Within both subsections, we describe standard methods of obtaining attribute values, either through field measurement or through estimation from remote sensing. We present standard ways to summarize attribute data in table 4.4.

4.3.1 Vegetation Composition Attributes

Vegetation composition can be an important component of wildlife habitat (section 4.2.2). A common link between vegetation composition and wildlife habitat is food. The relative forage value of plant species to herbivores varies greatly. For example, differences in food value of an oak (*Quercus* spp.) compared with a Douglas-fir (*Pseudotsuga menziesii*) stand can be substantial, even if the two stands are identical in other attributes, such as structure or density. When evaluating the value of vegetation composition data for habitat monitoring, it is especially important to collect data that are biologically relevant to the emphasis wildlife species. If a plant species has forage value, for example, the absolute amount of the species will be most relevant, followed by its relative proportion. Simple presence/absence data will be much less informative.

Many plot types and methods are available to assess vegetation composition; the protocol you select will depend on monitoring objectives. Use fixed-area plots (section 4.4.2) of various sizes to quantify species abundance at local scales. You can also use large, circular **macroplots** with a technique developed by Braun-Blanquet known as the **relevé method** (Barbour et al. 1987, Warbington 2011; see table 2.2 in Warbington [2011] for a listing of commonly used macroplot sizes for vegetation classification). Elzinga et al. (1998) provide comprehensive guidelines for particular measurements of vegetation composition. Vegetation composition plot data are often compiled into a plot-species matrix for analysis (see Warbington [2011] for details). Collect plant abundance, height, and other measurements concurrently, providing more detail on how various species contribute to vegetation structure (section 4.3.2).

Begin collecting vegetation composition data with recording plant species of interest in the plot. The level of information needed for a particular monitoring program can vary

Table 4.4.—*Common data summaries for vegetation habitat attributes.*

Habitat attribute	Data summary methods
Vegetation composition	
Vegetation type	Report the percentage of area and number of acres of each vegetation type present in a given spatial extent. For example, a given landscape might be composed of 74 percent Douglas-fir/western hemlock (*Tsuga heterophylla;* 740 ac), 15 percent western redcedar (*Thuja plicata;* 150 ac), and 11 percent red alder (*Alnus rubra*) vegetation types (110 ac) in a subwatershed of 1,000 ac.
Species abundance	Report number of individuals of a species, the species' frequency of occurrence (density), biomass, or percent cover. Summarize and report abundance on either absolute or relative scales. Relative abundance most commonly is reported, e.g., calculating mean cover of each species across the sample units and comparing estimates among all species of interest. The range of values observed may also be reported. See Schulz et al. (2009) for equations for variance for plant abundance.
Vegetation structure	
Trees	
Canopy cover	Report percent cover within the area sampled, or the mean percent cover for the species or vegetation type/structural stage combination in the area of interest. Classify canopy cover if monitoring objectives have been defined for cover classes.
Canopy closure	Report percent closure within the area sampled, or the mean percent closure for the species or vegetation type/structural stage combination in the area of interest. Classify canopy closure if monitoring objectives are defined for closure classes.
Diameter-derived attributes:	
Tree diameter	Report diameters in classes, i.e., the number of individual trees tallied per diameter class. Classes will vary with the species of interest, so store raw, unclassified data and classify as dictated by monitoring objectives. Deciding on the classes should be an interdisciplinary effort that reflects multiple objectives within data constraints. For example, 2-in diameter classes can probably not be accurately determined using satellite imagery.
Basal area	Derive from diameter class data where basal area (in ft) = (*[pi]r*^{2})/144, where pi is the constant 3.1416, and where r is the radius (one-half the diameter [in]).
Quadratic mean diameter (QMD)	Calculate QMD from diameter class data using formula from Buckingham (1969): QMD = the square root of [n_s/the sum of (1/d^2)], where d represents the diameters and n_s is the number of trees viewed in the sample using an angle gauge or prism.
Height	Report mean height of predefined overstory class or for all tree diameter classes of interest.
Canopy complexity	Generally, report as the number of canopy layers when measured vertically. Various equations can be used (Herrick et al. 2005), but data often are summarized as the proportion of vegetation occurring in each canopy layer relative to total vegetation intercepted.
Stand density	Report number of trees per unit area (stems per acre). Data for multiple samples or stands can be used to report the mean and range; density can also be used to identify structural and seral stages. For example, knowing that an area has 10,000 trees/ac indicates a young, regenerating site with high productivity. Stand density becomes more useful when coupled with diameter information; i.e., reporting the number of trees per acre in each diameter class, rather than a simple total of trees per unit area.
Snags and defective trees	
Decay class	Report snags by decay class, using the five decay-class system recommended by Forest Inventory and Analysis. Summarize as the frequency distribution of snags and defective trees by decay class; can also report by diameter class within decay classes.
Diameter	Report snags by diameter classes as dictated by objectives (Bate et al. 2008b). For wildlife use, snag diameter often is reported in terms of a threshold (e.g., all snags at least 10-in DBH). Defective trees can be reported using the same diameter classes as other live trees, unless some compelling reason to use a different class system exists that is based on the emphasis species or monitoring objective. Data can also be summarized by diameter class within decay classes; can also be reported by frequency distribution of snags and defective trees by diameter classes.
Height	Report mean height of predefined overstory class or for each decay class of snags; can also report frequency distribution of snags and defective trees by height classes.
Density	Report number of snags per acre by species and/or decay classes; can also report for stand level.
Cavity size	Report cavities based on the method in McComb et al. (1986) using four diameter classes: 12.5 to 19.9 cm (5 to 8 in), 20.1 to 39.9 cm (8 to 16 in), 40 to 59.9 cm (16 to 24 in), and 60 cm (24 in) or greater (Pattanavibool and Edge 1996, McComb et al. 1986).

Table 4.4.—*Common data summaries for vegetation habitat attributes (continued).*

Habitat attribute	Data summary methods
Down wood	
Decay class	Report logs by decay and diameter classes using the three decay classes defined by Bate et al. (2008a).
Diameter:	
Line-intercept diameter	Report mean diameter of logs at the point that logs are intercepted along transect lines, using the intercept method described by Bate et al. (2008a). Report diameters by decay and length classes relevant to the habitats or species of interest.
Large-end diameter	Report mean diameter of logs as measured at their large end, when the large end is equivalent to the measurement of DBH of trees (see Bate et al. 2008a for details). Report diameters by decay and length classes relevant to the habitats or species of interest.
Length	Report mean length of all logs measured within strip plots or similar sample units, averaged among all sample units by vegetation types or areas of interest, following methods of Bate et al. (2008a).
Cover	Report percent cover of down wood using the methods of Bate et al. (2008a) or using the conversion methods of Mellen-McLean et al. (2012).
Volume	Summarize log volume using the method in Bate et al. (2008a). Calculating volume by diameter class of logs is probably the most useful approach, rather than simply reporting overall volume. Report density by number of pieces per unit area, by decay and diameter class.
Density	Report mean number of logs per unit area, summarized among all sample units by vegetation types or areas of interest. Mean log density is typically summarized by log decay and length classes (Bate et al. 2008a).
Shrubs	
Shrub cover	Report shrub canopy cover as average percent cover of the plots sampled or for the area assessed (such as on an image or photograph). Also report range of values. Depending on objectives, total shrub cover may be adequate; for some monitoring programs, cover by individual species or genera may be needed.
Height	Report mean and range of shrub heights for each species of shrub of interest, or for life forms of shrubs, such as shrubs below or above a specified height (short versus tall shrubs).
Herbaceous vegetation	
Herbaceous cover	Report mean canopy or foliar cover occupied by each species of interest, or the mean frequency and mean length that cover is intercepted along a sampling line (e.g., line-intercept sampling) within sample units for vegetation types or areas of interest.
Height	Report mean and range of herbaceous vegetation heights of each species of interest or for life forms of interest. Example life forms of herbaceous species for which summaries are reported include prostrate versus vertical growth forms of species.
Structural stages/seral stages	
Structural stages	Report percentage area and number of acres of each structural stage present in a given spatial extent. For example, a given landscape may be composed of 25 percent old forest (250 ac), 40 percent sapling-pole (400 ac), and 35 percent grass-forb (350 ac) structural stages.
Seral stages	Use the same summary procedures as for structural stages.

ac = acre. cm = centimeter. DBH = diameter at breast height. in = inch. m = meter.

from basic physiognomic types (forests, woodlands, shrublands, meadows) to specific plant **associations**. Existing remotely sensed data, local vegetation type maps, and plant association guides may provide the required information. If not, you may focus collection of additional data for inventory or monitoring on all or a portion of the plant species present. For example, data may include (1) only vascular plants, (2) only life form, (3) a subset of species associated with a particular habitat attribute (e.g., huckleberry [*Vaccinium* spp.]), or (4) all plant species present at more than a certain abundance threshold (e.g., 5 percent canopy cover).

Vegetation composition can be assessed at multiple scales but generally requires field measurements at a local scale that are then either grouped and summarized at a

broader scale or related to the landscape by associating plot data to remotely sensed data (see Nearest Neighbor Imputation, section 4.5.2). Conducting literature searches and conferring with experienced colleagues can help identify the best assessment strategy. Follow these actions with preliminary surveys using various combinations of numbers and sizes of sample units to determine the optimal sample size for quantifying vegetation composition (Elzinga et al. 1998). After researchers obtain an adequate sample, the resulting list of species and their abundance (measured as counts of individuals, cover, or size) will provide a coarse characterization of vegetation composition and enable the monitoring team to make spatial (across multiple areas) and temporal (across multiple years or sampling events) comparisons (Daubenmire 1968). When comparing estimates of vegetation composition through time in a habitat monitoring program, sample vegetation with the same effort each time (i.e., number and size of sample units should be equal) and preferably at the same time of year to capture or exclude ephemeral species (species that appear only seasonally). Chapter 3 further addresses sampling design practices.

Vegetation Type

Vegetation type, a plant community based on its unique characteristics (table 4.1) is often the first and sometimes the only vegetation attribute used to describe wildlife habitat. For example, Nelson et al. (2009a) estimated breeding **habitat abundance** for flammulated owls (*Otus flammeolus*) across western North America, primarily using the distribution of ponderosa pine (*P. ponderosa*) and Jeffrey pine (*P. jeffreyi*) vegetation types within specific size or diameter classes, as determined from FIA data. Biologists often use vegetation type or **cover type**, combined with structural stages (section 4.3.2), to describe wildlife habitat relationships. Examples include the California Wildlife Habitat Relationships System (Meyer and Laudenslayer 1988), which uses CalVeg (http://www.fs.fed.us/r5/rsl/projects/classification/system.shtml#hier), and the wildlife-habitat type relationships described for Oregon and Washington (Johnson and O'Neil 2001). Wisdom et al. (2000) used cover type and structural stage combinations to describe habitats for more than 90 wildlife species of concern in the interior Columbia River Basin. For example, habitat for white-headed woodpecker (*Picoides albolarvatus*) included old multistory and old single-story Pacific ponderosa pine (*Pinus ponderosa* var. *ponderosa*). The terms vegetation type and cover type are sometimes used interchangeably but, in accordance with the Federal Geographic Data Committee (FGDC) (2008), we distinguish between them, defining cover type as a floristic classification within vegetation type (table 4.1).

Vegetation types are defined in vegetation classification systems that are typically hierarchical, with the highest levels using broad combinations of dominant general growth forms to define classes, such as mesomorphic shrub (FGDC 2008). Classification systems use floristics (species composition) to classify vegetation at lower levels. For example, in the National Vegetation Classification (FGDC 2008), the two lowest levels of classification are **alliance** and association. An alliance contains one or more associations and is named for the dominant growth forms (e.g., northern pin oak [*Quercus ellipsoidalis*] or

mountain big sagebrush [*Artemisia tridentata vaseyana*]). An association is described by the dominant species in each of several vegetation layers (e.g., sugar maple-American basswood [*Acer saccharum-Tilia americana*]/stinging nettle [*Urtica dioica*]) (table 4.1).

To determine what level of vegetation type is appropriate for the monitoring program, first consider the level of habitat selection by the emphasis species (Johnson 1980; chapters 2 and 10 of this technical guide). This information will help guide the corresponding selection of vegetation types and the resolution of data that is appropriate. After selecting the level of vegetation type, such as broad cover types, determine whether field-sampled or remotely sensed data, or a combination of both, are needed to measure this habitat attribute.

For example, the Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) and closely related Virginia northern flying squirrel (*G.s. fuscus*) are associated with specific boreal conifer and mixed-conifer cover types, especially red spruce (*Picea rubens*), in the southern Appalachian Mountains (Loeb et al. 2000, Odum et al. 2001, Payne et al. 1989, Weigl 2007). The squirrels are seldom found in pure conifer stands (Weigl 2007), however, but are often associated with open understories supporting isolated, large-diameter conifers (Odum et al. 2001). Understory vegetation is an important habitat component for these subspecies, but understory vegetation composition and cover vary widely among sites used by the squirrels (Payne et al. 1989, Weigl 2007). Thus, habitat monitoring for these subspecies is best accomplished using field-sampled data, supplemented by remotely sensed data when available and of sufficient accuracy.

In contrast, remotely sensed data provide a method for measuring vegetation type when the amount or configuration of vegetation types is important. For example, in chapter 10, the hypothetical monitoring plan for the American marten (*Martes americana*) focuses on amounts of particular vegetation types and structural stages, which can be obtained from classified vegetation maps derived from remotely sensed data. For some species, the spatial distribution of key vegetation types may be important. The area in these types may need to be distributed in large polygons or patches, monitored through landscape metrics, such as patch size, shape, or isolation (chapter 6).

Even if vegetation type is not used as an attribute in a habitat monitoring program, it can be a filter to help define the monitoring area. For example, if an emphasis species is associated with only paper birch (*Betula papyrifera*), identifying the areas where this type occurs can quickly focus the monitoring effort. Vegetation type may also serve as the framework for sampling other vegetation composition attributes (e.g., species abundance). Potential vegetation can also fill this filtering role; it is often an efficient first step for identifying areas of wildlife habitat interest across a landscape. After this step, measure specific vegetation composition or structure attributes within the vegetation type of interest. Another key metric is the number of patch types or vegetation types within a particular area, expressed as habitat diversity or patch richness (for examples see Saab 1999 and Sawyer et al. 2007).

All available sources should be checked before initiating a new vegetation classification and mapping project for habitat monitoring because classification and mapping can be costly and time-consuming depending on the level of information required and the area involved. This guide provides examples of existing vegetation classification systems (table 4.5) and map products (table 4.6). Also, most national forests and grasslands have maps of existing vegetation, typically accessible through agency servers or file transfer protocol sites; many forests also have developed guides to local plant associations or communities. Contact the GIS staff for the land management unit of interest to access these products and to determine if existing vegetation maps are static (i.e., one-time products) or will be updated. If no existing vegetation maps exist for the monitoring area, or the maps do not meet the specifications of the monitoring objectives, follow the guidelines in the *Existing Vegetation Classification and Mapping Technical Guide* (Warbington 2011) to classify and map existing vegetation in the monitoring area.

Vegetation classification and mapping are not the same as habitat classification and mapping, although the two approaches are closely related. Vegetation classification and mapping focus on comprehensively describing the composition of existing vegetation to meet a specific information need, which may or may not include describing habitat for an emphasis species or species group. Because existing vegetation is often a key component of wildlife habitat, however, classifying and mapping vegetation can provide important inputs to habitat classification and mapping. In some cases (e.g., if vegetation type is the only habitat attribute monitored), vegetation classification and mapping units may directly match habitat classification and mapping units for a species or species group needed. Vegetation mapping, however, usually forms a core spatial layer from which wildlife habitat maps are derived, based on the species or group of species of interest.

Species Abundance

Measurements of plant species abundance typically reflect the total number of individuals per taxon and their size in an area or community. If the association between a species and certain site conditions is strong, then the abundance of that plant can be used as an indicator of site conditions and, by extension, it can function as a surrogate index of habitat. For example, if a mollusk species is closely associated with particular nutrient-rich soils and shield fern (*Dryopteris* spp.) grows only on those soils, the fern may serve as an indicator of the mollusk's habitat.

Plant abundance can be assessed in several ways, such as cover, counts, biomass, or volume, but it is commonly expressed as canopy cover of a genus, species, or species group. Canopy cover is the percentage of a given area covered by some part of the plant, typically the foliage (section 4.3.2); as such, canopy cover is also a measure of vegetation structure. Cover can be reported for individual species, groups of species, by life form, or as total vegetation cover for a plot or specific area regardless of whether referring to trees,

Table 4.5.—*Examples of existing vegetation classification systems and standards.*

Name	Extent	Author/steward	Current version	Reference	Web site
Ecological systems of the United States	United States	NatureServe	2003	Comer et al. 2003	http://www.natureserve.org/library/usEcologicalsystems.pdf
Rangeland cover types	United States	Society for Range Management	1994	Shiflet 1994	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044255.pdf
Forest cover types	United States and Canada	Society of American Foresters	1980	Eyre 1980	
Silvicultural systems	United States	USDA Forest Service	1983	Burns 1983	http://www.fs.fed.us/rm/pubs_other/wo_1973_agric_handbook445.pdf
Existing vegetation types	Pacific Northwest	Oregon State GNN team/IMAP	2009	Ohmann and Gregory 2002	http://www.fsl.orst.edu/lemma/main.php?project=imap&id=home
National Vegetation Classification Standard	United States	Federal Geographic Data Committee	2008	FGDC 2008	http://www.fgdc.gov/standards/projects/FGDC-standards-projects/vegetation/NVCS_V2_FINAL_2008-02.pdf

GNN = gradient nearest neighbor. IMAP = Interagency Mapping and Assessment Project. USDA = U.S. Department of Agriculture.

shrubs, herbaceous plants, or grasses. Techniques to estimate cover vary (section 4.3.2) depending on growth habit and life form, but the most common method is ocular or visual cover estimation. Potential weaknesses in ocular estimation, including observer bias and lack of precision, can be reduced somewhat by rigorous training, multiple quality control checks throughout the sampling period (e.g., randomizing observer sampling schedules), and use of multiple small quadrats rather than one large, fixed-area plot.

Dominance is the extent to which a given species influences a community because of its size, abundance, or coverage (Warbington 2011); it is estimated by calculating relative cover. Dominance can be assessed for all species in a sampling unit (e.g., plot), across all species within a life form, or only for a group of species of interest (e.g., nonnative or invasive species). Vegetation ecologists use dominance to characterize plant communities and to group them into dominance types, thereby defining vegetation communities at a broader scale (Barbour et al. 1987, Hall 1998).

Counts of individual plants as a measure of abundance or density (usually assessed in a plot or quadrat) may be appropriate in some cases but can be very time consuming and are usually limited to a few species, such as the number of berry producing shrubs in a fixed-area plot. Plot size should be sufficiently large to capture vegetation pattern but small enough to count the individual units, such as stems or seedlings, efficiently (Elzinga et al. 1998). Belt or strip transects, which are long, rectangular plots, are typically used for tree and shrub density estimates. Develop boundary rules (i.e., which individuals are counted as in or out) before sampling.

Abundance can also be estimated using biomass, usually as annual production. Biomass is often measured in herbaceous (primarily grassland) systems and is based on the current year's growth. Biomass also can be estimated in woody vegetation. Multiple small plots are clipped and weighed and vegetation is typically air or oven dried; green vegetation also can be corrected to air-dry weight. Double sampling (clipping small units

Table 4.6.—*Example existing vegetation map products currently available at State, regional, and national extents.*

Existing vegetation maps	Spatial extent	Classification system	Remote sensing source	Resolution	Date	Additional comments/references
LANDFIRE EVT	Nationwide	Ecological systems[a]	Landsat TM	30 m	2006	"Refresh" products are updates available for 2001 and 2008; http://www.landfire.gov/NationalProductDescriptions21.php
NLCD	Nationwide	NLCD	Landsat ETM+	30 m	2006	NLCD; broad land cover classes (e.g., evergreen forest); http://www.mrlc.gov/
NW ReGAP	OR, WA	Ecological systems	Landsat ETM+	30 m	2008	http://www.pdx.edu/pnwlamp/existing-vegetation
SW ReGAP	AZ, CO, NM, NV, UT	Ecological systems	Landsat ETM+	30 m	2004	http://fws-nmcfwru.nmsu.edu/swregap/default.htm
Other State-level GAP maps	Statewide	Various	Various	Various	Various	Jennings 2000.
Forest Service regions:						
R1 (Northern)	All NFs except Beaverhead-Deerlodge	R1 vegetation classification system (Barber et al. 2009)	Landsat 7 (west-side); Landsat 5 and NAIP color infrared (east-side)	15 m (west-side), 5 m (east-side)	2001 (west-side); 2005 (east-side)	Known as VMap; created different products for west-side versus east-side forests; downloads available at http://www.fs.usda.gov/detailfull/r1/landmanagement/gis/
R3 (Southwestern)	All NFs in R3	Dominance types (Triepke et al. 2005), size and cover classes (Warbington 2011)	Landsat 7	1:100,000	2004–2009	http://fsweb.r3.fs.fed.us/eng/MID-SCALE_VEG/index.html
	All lands in R3	ILAP	Landsat 7	1:100,000	2006	Pacific Northwest Research Station, Oregon State University Institute of Natural Resources (ftp://131.252.97.79/ILAP/)
R4 (Intermountain)	Humboldt-Toiyabe (H-T) NF	Midlevel existing vegetation maps	NAIP, DOQQ, Landsat 5, resource air photos	10 m	2004	H-T and B-T are being updated. Caribou-Targhee and Sawtooth National Forests will be completed in 2013. Remaining R4 forests are scheduled through 2016.
	Bridger-Teton (B-T) NF			5 m	2007	
	Boise NF			5 m	2012	
	Payette NF			10 m	2012	
R5 (Pacific Southwest)	All national forests in R5	Calveg	Primarily Landsat TM and SPOT	5 m	2012	http://www.fs.fed.us/r5/rsl/projects/mapping/ minimum mapping unit 2.5 ac; maps updated on 10-year schedule
R6 (Pacific Northwest)	OR, WA		Landsat	30 m	2006 (OR); various (WA)	Known as ILAP; uses a gradient nearest neighbor approach with ground data; http://www.fsl.orst.edu/lemma/
R8 (Southern)	All NFs in region	NA	NA	NA	In progress (1996 for SAA)	Under development for Southern Appalachian Assessment (SAA), see http://sunsite.utk.edu/samab/data/SAA_data.html
R9 (Eastern)	NA					

ac = acre. DOQQ = Digital Orthophoto Quarter Quads. ETM = Landsat 7 Enhanced Thematic Mapper Plus. ETV = existing vegetation type. GAP = Gap Analysis Program. ILAP = Integrated Landscape Assessment Project. m = meter. NA = data not available. NAIP = National Agriculture Imagery Program. NF = national forest, NLCD = National Land Cover Database. NW = Northwest. SPOT = Satellite Pour l'Observation de la Terre. SW = Southwest. TM = Thematic Mapper.

[a] *Comer et al. (2003) provide descriptions of ecological systems.*

of vegetation, weighing these units, calibrating the estimate using the weighed unit, and estimating biomass/annual production) increases efficiency in estimating biomass. The interagency technical reference titled *Utilization Studies and Residual Measurements* (Interagency Technical Team 1996) describes several methods to estimate or measure biomass. The Robel pole field guide (http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml) also provides protocols to estimate biomass in herbaceous vegetation communities. (This site and other Intranet sites beginning with "fsweb" are internal to the Forest Service and, thus, not available to external users.)

Volume is typically a measure associated with shrubs. Biologists estimate shrub volume from the combined measurements of shrub height and shrub canopy length and width (horizontal measurements of canopy taken at varying heights of each plant). The volume of each species or life form of interest may be reported by height class. Crimmins et al. (2009) estimated woody browse abundance in recent clearcuts in West Virginia using image texture analysis with 1-meter (m) (3-feet [ft]) National Agriculture Imagery Program (NAIP) photography.

Plant species abundance can sometimes be estimated effectively using remotely sensed data and applied in a wildlife context. For example, Larson et al. (2003) and Rittenhouse et al. (2007) used the relative proportion of white oak (*Quercus alba*) and red oak (*Q. rubra, Q. coccinea, Q. velutina,* and *Q. marilandica*) species as an indicator of hard mast production. They incorporated this index as a variable in landscape-level habitat suitability models for several eastern species that rely on mast crops. In the central hardwoods region of the United States, Rittenhouse et al. (2007) used the dominant overstory tree species as an input variable in habitat suitability models for 10 wildlife species.

4.3.2 Vegetation Structure Attributes

The importance of vegetation structure in wildlife habitat is addressed in section 4.2.3. In this section, we describe a suite of key structural attributes of wildlife habitat (table 4.1). First, we define each attribute and describe it in the context of wildlife habitat. Next, we present typical methods for measuring the attribute with field-sampled data and remotely sensed data, when appropriate. We also describe how some attributes can be obtained through FIA data (see table 4.3 for the attribute-to-FIA crosswalk). Finally, we also address structural and seral stages; wildlife may be associated with particular structural stages, such as early successional or young forest vegetation (for examples, see Wisdom et al. 2000).

Trees

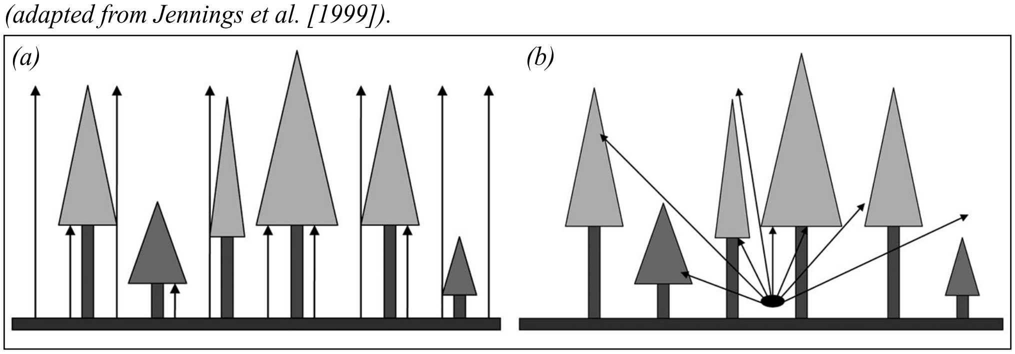
Canopy Cover and Canopy Closure. The terms canopy cover and canopy closure are often used interchangeably, but we recommend following Jennings et al. (1999) in distinguishing between them. In forested systems, canopy cover is the proportion of the forest floor covered by the vertical projection of tree crowns, whereas canopy closure is

the proportion of the sky hemisphere obscured by vegetation when viewed from a single point on the ground (Jennings et al. 1999; figure 4.1). Hemispherical instruments integrate across a larger area and include more canopy cover from tree trunks than do vertical methods. For this reason, hemispherical measures of canopy closure tend to produce higher canopy values than vertical estimates of canopy cover (Ganey et al. 1994). If habitat monitoring is based on an existing habitat relationship model that includes a measure of canopy, determine whether vertical or hemispherical projections were used and then select the equivalent measure for monitoring.

In a wildlife habitat context, the two measures reflect different aspects of the environment. Canopy cover, when combined with species composition, is often used to indicate plant abundance and dominance (section 4.3.1). Canopy closure is indicative of light conditions that affect tree growth, temperature, and humidity regimes. The habitat monitoring objective must clearly state whether the intent is to measure tree canopy cover or canopy closure by distinguishing between the need to obtain a true vertical projection of tree canopy as an indication of tree status (Nuttle 1997) or the need to measure light interception (and its influence on ecological processes). For example, if the habitat attribute of interest is the ability of the forest canopy to intercept snowfall, then canopy cover should be measured. By contrast, if the attribute of interest is the influence of the total tree canopy on a point, such as an animal's perception of cover or total understory production, then canopy closure is best (Nuttle 1997). We address each of these metrics separately in the text that follows.

Canopy cover. Field estimates of canopy cover are challenging to obtain, especially in forested systems where canopy cover is highly variable across space, thus requiring many measurements to make a useful estimate. Jennings et al. (1999) reported very low precision of field-sampled canopy cover when using fewer than 100 measurements/stand. Consider the level of confidence needed in the canopy cover estimates; often habitat requirements are described in broad ranges of canopy cover and precise estimates are not needed. If suitable resources exist and the level of precision in canopy cover is acceptable to meet monitoring objectives, estimate canopy cover from remotely sensed data.

Figure 4.1.—*Illustration of (a) vertical projection used to estimate canopy cover (adapted from Jennings et al. [1999] and Nuttle [1997]) and (b) angle of view to estimate canopy closure (adapted from Jennings et al. [1999]).*



See the field-sampling methods for the cases when remotely sensed data are not adequate or available. Record canopy cover for all trees combined, by species, or species group (e.g., hardwoods or conifers).

Estimates of canopy cover are available from FIA data and LANDFIRE (section 4.5). For FIA, canopy cover can be obtained from either Phase 2 (P2) or Phase 3 (P3) plots (table 4.3; see section 4.4.1 for more information about FIA plot types). In P3 plots, tree canopy cover is estimated for individual species and can be summarized by species or for all trees combined. Use data from the larger sample of P2 plots to derive tree canopy cover through models that incorporate species-specific crown-width equations and sapling contributions to total cover (Toney et al. 2009). In LANDFIRE, the Existing Vegetation Cover (EVC) layer is available for the conterminous United States at 30-m (98-ft) pixel resolution (http://www.landfire.gov/NationalProductDescriptions23.php). This layer represents vertically projected cover of the live canopy layer and merges data from herbaceous, shrub, and tree life forms into a composite EVC layer. The derived data layer is based on field-sampled data coupled with Landsat imagery, elevation, and other data. The Forest Service is developing a new national-scale tree canopy cover map as part of the 2011 National Land Cover Data release (NLCD; http://www.mrlc.gov/) (Coulston et al. in press); publication is expected in December 2013.

GIS analysts can estimate canopy cover using dot grid sampling from either aerial photographs or satellite imagery (section 4.5.2). Using this technique, the analyst superimposes a dot grid on a digital image and assigns each dot to the type class in which it falls. Determining where tree crowns end and shadows begin, however, is difficult and midcanopy trees may be hidden in shadows. The time of year the image or photo was taken, tree species, and canopy complexity can confound the method. With photos, oblique images can also be a problem. Estimate cover as a percent coverage of the area of interest using software (e.g., Digital Mylar; section 4.5.2) to analyze digital images, whether from aerial photographs or satellite imagery. You can also estimate cover on aerial photography visually or using a dot grid, but these methods are rapidly becoming obsolete with the development of digital dot grid methods.

Another method of estimating canopy cover remotely uses a vegetation or greenness index from the amount of light absorbed by chlorophyll, which relates to the amount of leaf area on a site. A common approach to creating a greenness index is to apply the tasseled cap transformation on satellite imagery, which transforms spectral data into estimates of brightness, greenness, and wetness (Huang et al. 2002, Lillesand and Kiefer 2000). As with dot grid sampling, greenness measures do not accurately separate overstory from understory.

Aerial Light Detection and Ranging (**LIDAR**) is a data-rich method of estimating tree canopy cover, even for individual canopy layers (Lefsky et al. 2002; section 4.5.1). LIDAR is accurate and repeatable and separates overstory from other layers well, but it may overemphasize the contributions of very small gaps. Aerial LIDAR is similar to

a very precise dot grid, with each laser reading representing a dot. Because the LIDAR beams are very thin, however, they can pass through minute canopy gaps. These small gaps are invisible to photo interpreters and generally ignored by ground measurements; thus, systematic differences in canopy cover measures can be expected when comparing LIDAR-derived estimates with those derived using other methods.

When measuring canopy cover in the field, the surveyor can use a sighting tube (James and Shugart 1970) to obtain the vertical projection; the observer takes numerous readings at random or systematic points, which are then averaged to obtain a percentage of canopy cover. Jennings et al. (1999) recommend a minimum of 100 points/canopy cover estimate. Surveyors must establish and document criteria for the size of small openings in tree crowns to include in the measure of canopy cover (Warbington 2011: 52). No established standard exists for the minimum size of openings to use in measuring canopy cover, and this lack of a standard is a major source of variability in canopy cover estimates between observers and between methods.

Ocular estimation of tree canopy cover on a large circular plot is generally used to generate data for ecosystem classification efforts (Bonham 1989, Braun-Blanquet 1965, Daubenmire 1959), because the large plot design is designed to capture the full array of species characteristic of an ecosystem. This approach is adequate for many wildlife habitat applications as well. In this method, users define a standard plot area on the ground and estimate the percentage of canopy covering the area by eye, using the outermost perimeter of the natural foliage of the plants. Small openings in the canopy are included as cover (SRM 1989, USDA NRCS 1997). The key weakness of this method is the unknown amount of observer bias (Elzinga et al. 1998), but careful training and comparison of results from different observers will improve the consistency of the results.

Canopy cover increases as the eye moves from treetops to the forest floor, and changes in canopy cover can be large and relatively sudden if tall brush is present. In some forests, a clear break exists between overstory and understory vegetation, but in many systems tree heights are relatively continuously distributed. Thus, biologists may need to define canopy cover for a particular height or stratum above the forest floor to avoid differences in cover estimates because of measurement methods.

Canopy closure. A visual estimate of canopy closure may provide sufficient accuracy when the monitoring objective is to meet or avoid a predetermined threshold (chapter 3, section 3.2.5). Before seeking greater precision, first consider whether the time, training, and expense are justified.

If greater precision is needed, such as for statistical analyses of 2 or more years of data, a number of tools are available for estimating canopy closure from ground plots. Hemispherical photography uses a fisheye lens at the measurement point, and a threshold in pixel darkness is used to distinguish canopy from sky (Chan et al. 2003, 2006; Fiala et al. 2006). The advent of digital photography has facilitated rapid, portable analysis of photographic data. Some software (e.g. Pocket PC; see http://www.idruna.com/products_pocketpc.html)

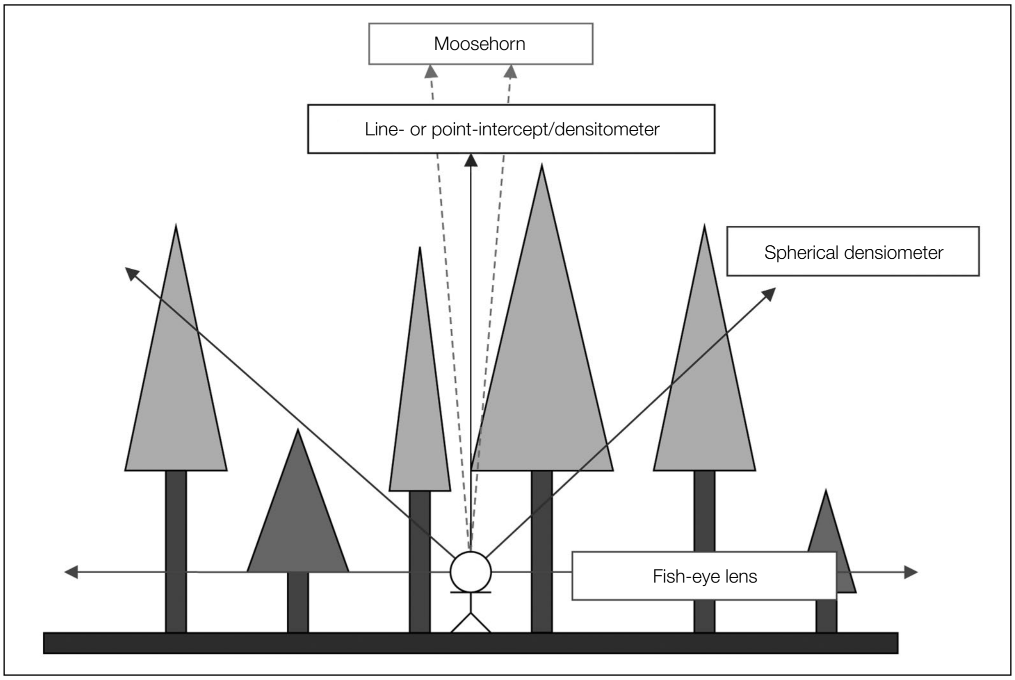
provides accurate, on-the-fly estimates of tree canopy cover from digital camera images. Bright or reflective vegetation, however, as well as slight changes in the threshold value, can result in substantial differences in canopy closure values (Jennings et al. 1999).

In recent years, ground-based hemispherical LIDAR has become an additional option for estimating canopy closure (Van der Zande et al. 2006). As with aerial LIDAR, the distance measures provide the advantage of differentiating canopy layers, so this method also can be used to estimate canopy complexity, which is addressed later in this section.

Other options include hemispherical photographs or ground-based LIDAR for monitoring canopy closure. Both options provide accurate, repeatable measurements and introduce less observer bias. Most published wildlife habitat models that include canopy measures were developed using previous sampling tools, often the **spherical densiometer** (Lemmon 1956) or the **moosehorn** (Robinson 1947; figure 4.2). Both instruments were designed as tools for improving visual estimates of canopy cover, although both use a hemispherical approach and thus measure canopy closure. Each instrument provides a wide-angle field of view of the canopy above the surveyor, and the surveyor tallies the proportion of points covered by vegetation. A densiometer can be insensitive to variations in cover (Cook et al. 1995) and can be prone to low accuracy and precision (Cook et al. 1995, Griffing 1985, Strickler1959). Observer variation, which can be significant and difficult to quantify (Block et al. 1987), makes the densiometer method ill-suited for monitoring, although it may be useful for rapid assessment. Little information exists about the accuracy of the moosehorn. Fiala et al. (2006) compared canopy estimates from hemispherical photography, the moosehorn, and the spherical densiometer and found that estimates from the moosehorn were consistently lower than those from the densiometer or hemispherical photography. The authors provide simple linear regression models to convert estimates of canopy closure from one technique to another, which can be of value in adapting prior estimates of canopy closure (e.g., from a habitat model) to other techniques.

For all methods of estimating canopy closure, measurements will change depending upon the **zenith angle** selected (figures 4.1 and 4.2). The zenith angle should reflect the intent of the canopy measurement; usually a strictly vertical (90-degree) zenith angle is appropriate. With digital images, however, photos can be analyzed repeatedly using different zenith angles (Rich et al. 1999), as can ground-based LIDAR data. Equally critical is the height above the forest floor at which canopy closure is assessed. Unlike canopy cover, which is tree-oriented, canopy closure measures the light environment at a point of biological interest. For a salamander, logically this would be at the forest floor. For a spotted owl (*Strix occidentalis sp.*), it could be above the brush layer if the interest were in the thermal environment of potential roost sites or at the forest floor if the interest were in the ability of the owls to perch-drop on prey. Canopy closure is a meaningful variable for habitat monitoring to the extent that it captures potential changes in the

Figure 4.2.—*Comparison of angles of view and associated effects on cover estimates for devices commonly used to measure canopy cover or closure (adapted from Fiala [2003]).*



operational environment of the organism of interest. Because of the many techniques available to measure canopy cover or closure, use caution if these attributes are used in long-term monitoring.

Diameter. Tree diameter is the cross-sectional width of each tree at breast height (DBH), which is 4.5 ft above ground level. For woodland tree species less than breast height, the measurement is diameter at root collar. FIA and Common Stand Exam (CSE) protocols call for using a diameter tape to measure the diameter of all trees in the sampling plot with a DBH of 5 inches (in) or more.

Tree diameter is an important habitat attribute, especially for species that require cavities in large-diameter trees or snags for nesting. The distribution of diameter size classes describes the diversity of tree sizes in an area and is the primary variable used to delineate structural stages (section 4.3.2; table 4.7). Habitat management for old-growth-associated species often is based on diameter thresholds, especially for species that require large-diameter trees or snags for nesting. Individual tree diameters are not always the habitat attribute of interest, however, but instead may be the building blocks for deriving several stand-level attributes, such as basal area, quadratic mean diameter, and basal area weighted average diameter (table 4.4), which we describe in the following section. Also use tree diameter in reporting other attributes, such as stand density by diameter class. Individual tree diameters are part of the tree list data used for nearest neighbor modeling of forest stands (section 4.5.2).

Each of the metrics derived from individual tree diameter data provides a different interpretation of stand structure. Therefore, biologists must be aware of these differences to ensure they effectively use the metric as a habitat attribute. Basal area, quadratic mean diameter, and basal area weighted average diameter are derived from all individual tree diameters in a plot, whereas overstory diameter uses only a subset of individual tree diameter data. All these metrics are summary statistics with a measure of variability (standard deviation) at the plot and stand levels. In contrast, diameter class distribution is not a summary statistic; report it as a frequency distribution or histogram.

All these diameter metrics are available in FSVeg from either FIA or CSE data (table 4.3), but see caveats in section 4.4.1 regarding sample size for local scale and midscale analyses. If one or more of the diameter metrics are key habitat attributes for the emphasis species, we recommend using field-sampled data rather than remotely sensed data for monitoring, because neither aerial photos nor satellite imagery can reliably estimate any of the diameter metrics using current technologies. Current advances in regression modeling approaches do allow for estimation of tree diameters by combining field-sampled data with satellite imagery (e.g., quadratic mean diameter; Ohmann and Gregory 2002; O'Neil et al. 2000). Modeled estimates of tree diameter are more appropriate for inventory than for monitoring, however, given the potential for inconsistent interpretation of imagery among years and changes in modeling algorithms.

The monitoring team must decide which diameter metric is most meaningful from the standpoint of the emphasis species. For example, the team should ask such questions as: Is habitat adequately characterized by the average diameter of trees in the stand, or is it more important to ensure the existence of a certain number of trees of a particular species that exceed some specified diameter? To what extent do small-diameter trees influence habitat quality and contribute to a metric of average tree diameter? These questions and ones like them should be carefully considered when monitoring the habitat of the species of interest. We recommend a thorough literature review of species-habitat interactions before proceeding. The following description of diameter metrics should assist in making decisions about which to use as habitat attributes.

Basal area. Basal area is the cross-sectional area of a tree at DBH. A minimum basal area value is frequently used in wildlife habitat relationship models to represent a rough threshold below which a forest stand no longer serves as habitat for the emphasis species (or conversely becomes desirable for an early successional species). Use basal area in concert with other stand structure variables, however, because similar basal area values can be obtained for high density, small-diameter stands and for low density, large-diameter stands.

FIA and CSE protocols calculate basal area from individual tree diameter data and summarize basal area as ft^2/ac (square feet per acre) at the plot and stand levels (table 4.3) (USDA Forest Service 2010b, 2011). There is a long tradition of deriving basal area from a basal area factor prism or Relaskop; however, we do not recommend using this method

Table 4.7.—*Examples of vegetation structural stage or class systems.*

Structural class system	Forest conditions		Shrubland/grassland conditions	
	Stage/class	Measure/unit	Stage/class	Measure/unit
Oliver and Larson (1996)	Stand initiation	Single and multiple cohorts	Not applicable	
	Stem exclusion	Single and multiple species		
	Understory reinitiation			
	Old growth			
Johnson and O'Neil (2001)	**Tree size**	**DBH**	**Shrub height**	**Feet**
	Shrub/seedling	<1 in	Low	< 1.6 ft
	Sapling/pole	1 to 9 in	Medium	1.6 to 6.5 ft
	Small tree	10 to 14 in	Tall	> 6.5 to 16.5 ft
	Medium tree	15 to 19 in		
	Large tree	20 to 29 in		
	Giant tree	At least 30 in		
	Canopy cover	**Percent**	**Shrub cover**	**Percent**
	Open	10 to 39 percent cover	Open	10 to 69 percent cover
	Moderate	40 to 69 percent cover	Closed	70 to 100 percent cover
	Closed	70 to 100 percent cover		
	Canopy layers	**Number**	**Shrub age class**	**Amount crown decadence**
	Single story	1 stratum	Seedling/young	Negligible
	Multistory	2 or more strata	Mature	< 25 percent
			Old	26 to 100 percent
Pacific Northwest Region	**Structural stage**	**DBH**		
Structural standards	NA			
	Grass/forb	NA		
	Shrub/seedlings	< 1 in	NA	
	Sapling/pole	1 < 5 in		
	Small tree	5 to < 15 in		
	Medium tree	15 to < 20 in		
	Large Tree	20 in plus		
	Canopy cover	**Percent**		
	(No class name)	< 10 percent cover		
	(No class name)	10 to 59 percent cover		
	(No class name)	60 to 100 percent cover		
	Tree canopy structure	**Number of layers**		
	Single	One		
	Multi	Two or more		

Table 4.7.—*Examples of vegetation structural stage or class systems (continued).*

Structural class system	Forest conditions		Shrubland/grassland conditions	
	Stage/class	**Measure/unit**	**Stage/class**	**Measure/unit**
Interior Columbia Basin Assessment (Hann et al. 1997)	**Structural stage**	**DBH**		
	Stand initiation	< 5 in	**Open low-medium shrub**	A canopy of low (< 20 in) or medium-sized (20 to 39 in) shrubs with < 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Stem exclusion	5 to < 20 in		
	Understory reinitiation	5 to < 20 in	**Closed low-medium shrub**	A canopy of low (< 20 in) or medium-sized (20 to 39 in) shrubs with < 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Old	20 in plus		
	Canopy cover	**Percent**		
	Open	10 to 59 percent cover	**Open tall shrub**	A canopy of tall (6.6 to 16.4 ft) shrubs with < 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Closed	60 to 100 percent cover		
	Tree canopy structure	**Number of layers**		
	Single story	One	**Closed tall shrub**	A canopy of tall (6.6 to 16.4 ft) shrubs with at least 66 percent projected canopy cover; shrubs dominate; tree cover < 10 percent; 2 strata, 2 cohorts possible
	Multistory	Two or more		
LANDFIRE	**Seral stage**	**Age class**	**Seral stage**	**Age class**
Succession Classes	Early seral	Varies with the ecosystem	Early seral	
	Midseral closed		Midseral closed	Varies with the ecosystem; also often mixed with descriptive structural attributes
	Midseral open		Midseral open	
	Late seral open		Late seral open	
	Late seral closed		Late seral closed	

DBH = diameter at breast height. in = inch. ft = feet. NA = not applicable.

if the data will eventually be combined with FIA plots for a single analysis because of problems stemming from combining data collected by using different field methods. In addition, basal area can be modeled by combining field-sampled data and remotely sensed data using gradient nearest neighbor methods (Ohmann and Gregory 2002; see section 4.5.2).

Quadratic mean diameter. Quadratic mean diameter (QMD) is a stand metric that corresponds to the diameter of a tree representing the stand's mean basal area (Graves 1908, cited in Curtis and Marshall 2000). It is calculated from the square root of the arithmetic mean of squared diameter values (table 4.4). QMD is widely used in forestry; it has a higher correlation to stand volume than does the arithmetic mean because it places greater weight on larger diameter trees. Depending on the variance, it will be equal to or greater than the arithmetic mean diameter. Moeur et al. (2005) used large QMD as an indicator of late-successional forest structure in the Pacific Northwest, but a single-storied large-diameter stand can also produce a relatively large QMD.

Another diameter metric that reflects the contribution of large trees is the basal area-weighted average diameter, which is calculated as the sum of each tree diameter multiplied by its basal area and then divided by total basal area. QMD and basal area-weighted average diameter are weighted toward large-diameter trees, but the latter metric reduces the influence of small trees, even for large numbers of small trees. If the emphasis species is a cavity nester, basal area-weighted average diameter could be a useful diameter metric because it approximates the average diameter of dominant and subdominant trees and indicates whether diameters are suitable for nesting cavities.

Height. Height is a basic attribute collected in most vegetation data sets. Tree height has implications for **seral stage** and canopy complexity (see following section), and, in mature forests, it is a rough measure of site productivity. Tree height is an important habitat attribute for many wildlife species. For example, northern goshawks (*Accipiter gentilis*) often select tall, sturdy trees for nesting, placing the nest at the base of the tree canopy (Speiser and Bosakowski 1987).

In the field, record tree height using a laser **clinometer** while standing a defined distance from the tree bole. Heights of individual trees can be tallied, but often the heights of only one or two representative trees are measured. FIA protocols prescribe measuring the height of each tree in the plot (table 4.3), however. Remote sensing methods to estimate tree height traditionally have involved using stereoscopes with paired aerial photographs, but recent advances in LIDAR and interpretation of high-resolution satellite imagery allow for accurate estimates of tree height with these methods as well (section 4.5.1; McCombs et al. 2003).

Canopy Complexity. Canopy complexity is a measure of diversity in the number of layers and associated species in forest canopies (Lowman and Rinker 2004). A closely related concept, **foliage height diversity** (FHD), indexes how evenly vegetation is distributed in vertical space, typically through measurements of foliage density at various heights within a vegetation community (Cooperrider et al. 1986, MacArthur 1964, MacArthur and MacArthur 1961). Both attributes have important implications for wildlife

niche diversity, particularly in avian communities, where they have been demonstrated to be reliable predictors of species diversity (MacArthur 1964, MacArthur and MacArthur 1961, Magurran 1988). Management activities, such as thinning, that result in potentially large changes in the vegetation component of a habitat often affect diversity of vegetation layers, and thus canopy complexity (Morrison et al. 2006).

At the broad scale, use remote sensing approaches to estimate canopy complexity, but not FHD, in forested ecosystems. A newer form of LIDAR, multiple-return LIDAR, can provide detailed and accurate measures of canopy complexity (section 4.5.1; Lefsky et al. 2002). In this method, major peaks (typically up to five) in the return signal are identified, which correspond to distinct vegetation layers.

Nearest neighbor methods offer a second approach in estimating canopy complexity and are appropriate at broad and mid scales (section 4.5.2). In this approach, field-sampled data (e.g., FIA or Current Vegetation Survey [CVS]) are related to environmental gradients of the monitoring area (e.g., biophysical attributes), some of which are estimated using satellite imagery. For example, data collected for the vegetation diversity and structure indicator (VEG) in P3 FIA plots include total canopy cover in each of four layers of vegetation (table 4.3); this information can be used to calculate canopy complexity. Use other data sets independently or to supplement FIA data to calculate canopy complexity using nearest neighbor methods.

Another approach is to use image texture and satellite imagery or digital photographs to indicate complex canopy structure through measures of roughness (Lillesand and Kiefer 2000). Regardless of which method is used, these broad-scale approaches, with the exception of LIDAR, are coarse, generally resulting in canopies described simply as single-storied (one stratum) or multistoried (two or more canopy strata) (O'Neil et al. 2001). (Section 4.5 addresses other methods for analyzing satellite images.) Moreover, because of potentially large differences in estimates of canopy complexity arising from different imagery sources and technicians, remote sensing methods for deriving this attribute may be most useful for one-time inventory or for threshold monitoring versus monitoring to detect change (chapter 3, section 3.2.5).

In contrast to canopy complexity, FHD is derived from a variety of field measurements (James and Shugart 1970, MacArthur and Horn 1969, MacArthur and MacArthur 1961). The methods use systematic sampling of the canopy at several heights above the ground (e.g., 2 ft, 10 ft, 30 ft, and 75 ft) recording the number of times that a vertical line from the ground through the canopy intercepts foliage. The resulting data provide a useful index of canopy complexity; individual layers can be compared, as well as the overall score.

In nonforested environments, such as shrublands, vertical diversity is much less complex. In these sites, measuring clump size of shrubs and their height distribution may provide a more meaningful measure of canopy complexity (Morrison et al. 2006, Roth 1976). In grassland or shrubland environments, calculate FHD using a marked pole to calculate the number of bands obstructed by vegetation (see Herrick et al. [2005] for equations to calculate FHD in nonforested vegetation types).

Stand Density. Stand density is the number of trees in a given unit area (Bonham 1989) and is an important attribute in describing structure because of its relation to canopy closure and understory development. In a wildlife context, stand density has implications for nesting success, hiding cover, and other aspects of species' life cycles. Tree stem density is an important habitat attribute for many species of forest-associated wildlife, including bird communities (Hagar et al. 1996), snowshoe hare (*Lepus americanus*) (Sullivan and Sullivan 1988), and other small mammals (Homyack et al. 2005).

Stand density can also be used to identify structural and seral stages. For example, an area with 10,000 trees/ac indicates a young, regenerating site capable of supporting high productivity. Stand density becomes more useful when coupled with diameter information (i.e., the number of trees in each diameter class provides a more meaningful indicator of structure than a simple count of trees per unit area). If density is recorded for individual tree species, this measure reflects an attribute of vegetation composition, namely species abundance (section 4.3.1). In addition to calculating density from field-sampled data, stand density can be estimated using LIDAR (section 4.5.1).

Snags and Defective Trees

Snags are standing dead trees or stumps that provide habitat for a broad range of wildlife (Johnson and O'Neil 2001). Defective trees are living trees with wounds, scars, disease (e.g., dwarf mistletoe or brooms), decay, and/or cavities; they also provide wildlife values by creating microhabitats (Johnson and O'Neil 2001). Snags not only provide nest or den cavities for specific vertebrate species, but they also are a vital part of functioning ecosystems. For example, they affect nutrient cycling, water retention, and regeneration seedbeds. They also support complex food webs and habitats for a variety of nonvertebrate life forms, such as fungi and insects (Johnson and O'Neil 2001, Maser and Trappe 1984, Maser et al. 1988).

The primary habitat attributes for snags are diameter, height, and density, which are usually stratified by tree species and decay class (table 4.8). The species of snag is important because tree species vary in hardness, which affects the ability of bird species to excavate nesting cavities. In addition, tree species decompose at different rates, which affect snag longevity. Decay class matters because some wildlife species use snags only at a specific stage of decay. Diameter is important because some species forage on snags of smaller diameters (less than 20 in DBH) but require larger snags for nesting or roosting (at least 20 in DBH) (Bate et al. 2008b).

Monitoring teams will generally find existing data for snags in FSVeg and on the FIA Web site because CSE and FIA collect similar data on snags and defective trees as they do for live trees (table 4.3). Use FIA or CSE protocols to augment these existing data. Decay classification systems vary across geographic locales, but all of the snag sampling protocols can accommodate whatever system is used locally. FIA recommends a 5-class system (table 4.8).

An alternative to CSE and FIA protocols for small monitoring projects is SnagPRO (Bate et al. 2008b), which includes software for sampling and analyzing snags and defective trees at the scale of stands and small landscapes. SnagPRO identifies optimal transect lengths that minimize sampling variance. If surveyors use a line intercept sampling method for sampling logs (section 4.4.2), a belt transect (strip plot) can be added along the line transect to streamline data collection for snags and logs simultaneously.

Cavity Size. A cavity is a hole in a tree, with estimated horizontal depth of at least 7.5 centimeters (cm) (3.0 in) (Gumtow-Farrior 1991) and an entrance width of at least 3.0 cm (1.2 in) (Pattanavibool and Edge 1996). McComb et al. (1986) specified a 2.5-cm (1.0 in) minimum width requirement for cavities in den trees (live, cavity-bearing trees). Cavities provide habitat critical in the life cycle of a number of wildlife species, including flying squirrels, a variety of woodpeckers, other birds, and bats (Hunter 1990). It is possible to estimate the availability of cavities of different sizes using a variety of protocols (Bechtold and Knight 1982, Knight and McClure 1979, Lehmkuhl et al. 2003, McComb et al. 1986, Pattanavibool and Edge 1996). We recommend the criteria in McComb et al. (1986), used on thousands of FIA plots in the Southern United States, in which all cavities at least 2.5 cm (1.0 in) wide on live trees at least 12.5 cm (4.9 in) in diameter were counted. This protocol records only cavities found in the two largest trees on the plot. Correction factors may be necessary to account for cavities that are too high up on tree boles to detect, or to estimate the depth of their excavation.

For upper bole cavities that are difficult to reach, surveyors climb and record data on a subsample of trees; these data can then be used to develop a correlation allowing for extrapolation to other trees (Pattanavibool and Edge 1996). We recommend categorizing cavities into diameter classes. Pattanavibool and Edge (1996) used three diameter classes: 20.0 to 39.9 cm (7.9 to 15.7 in) DBH (small), 40.0 to 59.9 cm (15.7 to 23.6 in) DBH (medium), and greater than 60.0 cm (at least 23.6 in) DBH (large). We also recommend an additional class from 12.5 to 19.9 cm (4.9 to 7.8 in), based on McComb et al. (1986).

Table 4.8.—*Snag/defect tree decay classes.*

Decay class stage[a]	Limbs and branches	Top	Percent bark remaining	Sapwood presence	Sapwood condition	Heartwood condition
1	All present	Present	100	Intact	Minimal decay	Sound and hard
2	Few limbs, no fine branches	May be broken	Variable	Sloughing	Advanced decay	Sound at base but beginning to decay in the outer part of the upper bole
3	Limb stubs only	Broken	Variable	Sloughing		Advanced decay in upper bole and is beginning at the base
4	Few or no stubs	Broken	Variable	Sloughing	Cubical, soft, reddish to dark brown	Advanced decay at the base and is sloughing in the upper bole
5	None	Broken	< 20	Gone	Gone	Sloughing throughout

[a] *From Forest Inventory and Analysis Phase 2 Field Guide: http://www.fia.fs.fed.us/library/field-guides-methods-proc/.*
*Characteristics are for Douglas-fir (*Pseudotsuga menziesii*). Snags for other species may vary somewhat; use this table as a guide.*

Down Wood

Down wood, also known as logs or coarse woody debris (CWD), is a category of dead and down pieces of wood generated from trees and large shrubs. The FIA program uses the term CWD, and defines it as pieces of wood with at least a 3-in diameter that are at least 3-ft long and detached from the bole of a standing live or dead tree; if still partially rooted, the lean angle of the piece must be greater than 45 degrees from vertical (Woodall and Monleon 2008). Down wood is an important habitat attribute for many forest-dwelling wildlife species because it provides denning, resting, and thermal cover sites and serves as a foraging substrate (Bate et al. 2008a, Maser and Trappe 1984). Down wood fulfills numerous other ecological roles in the process of decay, such as providing microclimatic conditions for fungi, plants, insects, and a variety of microorganisms, and serving as nutrient reservoirs (Harmon et al. 1986).

The primary habitat attributes for down wood are percent cover, volume, and density. Because all these attributes are derived rather than measured, we first describe the data measured in the field and then describe the habitat attributes. The measured data, collected under the FIA and SnagPRO protocols (addressed in the following section), are tree species of the log, decay class, diameter at point of intersection with the line, and log length. Tree species and decay class are descriptors used to stratify down wood attributes into categories meaningful to a wildlife emphasis species; whereas diameter and length are the building blocks for deriving percent cover, volume, and density.

It is not always possible to determine the tree species from which a log originated, especially if it is substantially decayed. Tree species can be important if the wildlife emphasis species uses log cavities for dens, however, because some species form cavities more readily than others. The cavities form when the tree is still standing rather than after the tree becomes down wood (Bate et al. 2008a). Decay class is a key descriptor because certain species (e.g., American marten) require logs in early stages of decay, whereas other species, such as ruffed grouse (*Bonasa umbellus*) require more advanced decay. SnagPRO (Bate et al. 2008a) uses two decay classes (sound and rotten) as the default, but the software can accept more detailed decay classes. Improved precision of these estimates is obtained by post-stratifying the sample using geospatial datasets (Hatfield 2010). FIA uses five decay classes of down wood (table 4.9).

Existing data for down wood, in general, are less available than are data for live trees and snags, but monitoring teams should check NRM FSVeg to see what information exists locally. The FIA program collects information on all classes of down woody material on P3 plots (a subset of P2 plots; see section 4.4.1 and table 4.3) at a spacing of approximately 1 plot/96,000 ac (and these data are stored in NRM FSVeg). Most wildlife monitoring programs will need to augment P3 plot data to obtain a sufficient sample of log information for monitoring purposes. FIA provides core data summaries of CWD biomass (tons per acre, volume (cubic feet per acre), the number of pieces per acre, and

percent cover (Woodall and Monleon 2008), which can be reported for subgroups of the data as defined by diameter class, species, or decay class. Improved precision of these estimates is obtained by post-stratifying the sample using geospatial datasets (Hatfield 2010).

Current remote-sensing technologies provide low accuracy for estimating any of the down wood metrics. Researchers are exploring options for using nearest neighbor methods to derive useful estimates of down wood for midscale and broad-scale analyses.

We recommend two protocols for measuring down wood, the *FIA Field Guide for Phase 3 Measurements*, available at http://fia.fs.fed.us/library/field-guides-methods-proc, and the log sampling methods in SnagPRO (Bate et al. 2008a). Both protocols use the line intercept method (Brown 1974), but SnagPRO also uses the strip-plot method (Bate et al. 2004), a recommended design for sites with low density of logs (Bate et al. 2008a). The FIA field guide focuses primarily on how to use the line intercept method for measuring down wood and how to resolve a variety of data-collection issues that arise in the field. SnagPRO has similar field protocols, but also provides software for conducting a pilot test so that users can identify the optimal length of the transect to minimize the variance of the metrics of interest for future sampling. Down wood information from FIA is most useful for midscale and broad-scale monitoring, whereas SnagPRO provides software for sampling and analyzing down wood at the scale of stands and small landscapes.

Percent Cover of Down Wood. Mellen-McLean et al. (2012) found that percent cover of CWD was the most common metric used in studies of wildlife habitat use (20 of 50 studies). In the past, biologists made visual estimates of percent cover, but this attribute is more accurately derived from algorithms using the number of pieces, length, and diameter. Mellen-McLean et al. (2012) provide tables that convert volume and number of pieces to percent cover, with these conversions specific to many of the common

Table 4.9.—*Down wood decay classes (known as coarse woody debris [CWD] in Forest Inventory and Analysis).*

Decay class[a]	Structural integrity	Texture of rotten portions	Color of wood	Invading roots	Branches and twigs
1	Sound, freshly fallen, intact logs	Intact, no rot; conks of stem decay absent	Original color	Absent	If branches are present, fine twigs are still attached and have tight bark
2	Sound	Mostly intact; sapwood partly soft (starting to decay) but can not be pulled apart by hand	Original color	Absent	If branches are present, many fine twigs are gone and remaining fine twigs have peeling bark
3	Heartwood sound; piece supports its own weight	Hard, large pieces; sapwood can be pulled apart by hand or sapwood absent	Reddish-brown or original color	Sapwood only	Branch stubs will not pull out
4	Heartwood rotten; piece does not support its own weight, but maintains its shape	Soft, small blocky pieces; a metal pin can be pushed into heartwood	Reddish or light brown	Throughout	Branch stubs pull out
5	None, piece no longer maintains its shape, it spreads out on ground	Soft; powdery when dry	Red-brown to dark brown	Throughout	Branch stubs and pitch pockets have usually rotted down

[a] *From the Down Woody Material Coarse Woody Debris Table, Forest Inventory and Analysis Database Version 4.0 (Woodall et al. 2010).*

vegetation types of the Western United States. These tables are available on the DecAID Web site (http://www.fs.fed.us/r6/nr/wildlife/decaid). FIA also provides percent cover estimates for P3 plot data.

Down Wood Volume. Volume is the second most common attribute of down wood used in studies of wildlife habitat use (14 of 50 studies, Mellen-McLean et al. [2012]). If down wood volume is reported not in size classes but as raw data, changes in down wood volume through time may be small and not easily detected. Although this attribute has value as a habitat descriptor and therefore could be an important attribute for inventory or assessment, total down wood volume across all diameter classes may show little change through time and may not be the best down wood attribute for monitoring purposes. The ability to detect change might improve if down wood volume is reported using diameter classes.

Formulas for estimating volume use log diameter, log length, and a taper coefficient specific to the tree species. Bate et al. (2009) found that diameter at the large end of the log is a more accurate measure for deriving volume than diameter at the line intercept. Line intercept diameter underestimates the proportion of total volume from large-diameter logs and overestimates the contribution of smaller diameter pieces (Bate et al. 2009). Because of the added costs of leaving the intersect line to measure large-end diameter (LED), Bate et al. (2009) recommend making a visual estimate of the LED size class while standing at the intersect line. Down wood density is the number of pieces per unit area, usually reported by diameter class and/or decay class.

Shrubs

Cover. Shrub cover is defined as the proportion of ground, usually expressed as a percentage, occupied by the aerial parts of the vegetation of one or more shrub species (table 4.1; Warbington 2011). Canopy cover estimates include small openings or gaps in the canopy, whereas foliar cover estimates exclude small openings (SRM 1989). Foliar cover is an important concept in quadrat and line intercept methods because it is more useful for detecting subtle changes in cover than the canopy cover method. Bonham (1989) recommended measuring canopy cover, however, with an appropriate gap rule, rather than foliar cover because foliar cover measurements may have less user repeatability. Shrub cover can be recorded by individual species or all shrubs combined, depending on the monitoring objectives.

Shrub canopy cover can sometimes be estimated at broad and mid scales using aerial photography. Forest canopies often obscure detection of the shrub layer, which is a disadvantage of this method in forested landscapes. When the method is appropriate, cover is estimated as the percentage of the area of interest, using software to analyze digital imagery, whether from satellites or aerial photographs. Cover of shrubs on aerial photography can also be estimated visually or manually using a dot grid, but these methods are rapidly becoming obsolete because photographs can be converted to digital format and electronic dot grids can be superimposed on images (e.g., with Digital Mylar; section 4.5.2).

Collect shrub canopy cover data at local scales using one of the following methods: (1) ocular estimation within plots or quadrats; (2) line intercept along a line or multiple lines; or (3) point intercept along multiple lines, corners of quadrats, **point frames**, or by step point transects (section 4.4.2; see also Bonham 1989 and Herrick et al. [2005]). Selecting an appropriate method and its variants depends on the size, canopy pattern, and spacing of the shrubs. Large fixed-area plots (either circular, rectangular, or square) can be used for visual estimates of shrub canopy cover, but these estimates are less repeatable owing to the angle of observation (oblique) and size of plot. Line intercept is best for large, widely spaced shrubs. Quadrats are appropriate for sampling cover of closely spaced small shrubs or **subshrubs**. The point intercept method can be used to measure cover on any type of shrub, but the number and spacing of points should be adjusted based on these characteristics. In shrublands, such as sagebrush, line intercept is used most often to measure shrub foliar or canopy cover. The *Existing Vegetation Classification and Mapping Technical Guide* (section 2.4.5 in Warbington [2011]) provides detailed guidance on canopy cover estimation. The NRM field guides for these methods are located at: http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml. (See section 4.4.2 for more details on field methods described previously.)

For some wildlife species, such as snowshoe hare, the degree to which shrubs, saplings, and woody debris provide hiding cover is important and may be critical to survival (Sullivan and Sullivan 1988). Sometimes referred to as horizontal cover, this attribute is generally measured using a vertically held quadrat. A board (or cloth) divided into small squares is held vertically at a specified distance from a plot center and height off the ground, and the number of obscured squares is used to index horizontal cover.

Horizontal cover has the same relationship to shrub cover as canopy closure has to canopy cover. Whereas shrub cover is measured as a vertical projection of cover on the ground and includes only shrubs, horizontal cover incorporates all objects that create visual obstruction. As with canopy cover and closure, the biological roles of horizontal cover and shrub cover are different. Measurements of horizontal cover are not standardized and are mostly absent from existing data sources. If a habitat-relationship model indicates that horizontal cover is an important habitat component for the emphasis species, the best approach is to determine how horizontal cover was measured in the model, and then collect data using the same method.

Height. Shrub height, defined as the distance from the growing tip of the shrub to the ground, is an important habitat attribute for many terrestrial vertebrates. For example, optimal sagebrush height for brood-rearing habitat of greater sage-grouse (*Centrocercus urophasianus*) is 40 to 80 cm (16 to 31 in), whereas sagebrush heights of 25 to 35 cm (10 to 14 in) are best for winter habitat (Connelly et al. 2000). Shrub height is an indicator of plant vigor (Elzinga et al. 1998) as well as plant physiological response to browsing, and thus can be used to measure changes in habitat in response to herbivory. A method for assessing plant architecture as a function of browsing pressure, based on height and other

factors, is available and can be used to determine whether shrubs and deciduous trees (especially aspen [*Populus tremuloides*]) can either escape browsing pressure or recover after the pressure is removed (Keigley and Frisina 1998).

For field sampling, use a tape measure to record height of low (less than 0.5 yard [yd]) or medium (0.5 to 2 yd) shrubs, or a clinometer for tall (greater than 2 yd) shrubs. If only coarse estimates of height are required, shrub height can be measured rapidly using a lightweight pole, such as 0.5-in PVC pipe, with marked gradations. Samplers can collect shrub height data concurrently with canopy cover when using line intercept methods (Herrick et al. 2005; section 4.4.2) or in fixed-area plots and quadrats. Remote sensing methods can also be used to measure shrub height; sagebrush height and canopy cover were characterized using classified Landsat imagery to describe greater sage-grouse winter habitat in Utah (Homer et al. 1993). More recently, researchers used LIDAR to estimate shrub heights in sagebrush steppe, although LIDAR-derived estimates are uniformly lower than field-measured data (Streutker and Glenn 2006).

Herbaceous Vegetation

Cover. Herbaceous cover functions in a variety of roles as wildlife habitat. In addition to its obvious value as forage for herbivores, herbaceous vegetation provides hiding cover and nesting habitat for many species, such as grassland birds, and supports insect populations important as prey. For example, eastern meadowlarks (*Sturnella magna*) prefer moderately tall grasslands with a high proportion of grass and moderate to high forb density (Hull 2003). Herbaceous cover is also an important indicator of level of herbivory by domestic and wild ungulates, which may affect ecosystem processes such as nutrient cycling and primary productivity (Hobbs 1996).

Use quadrats of varying sizes and shapes to visually estimate cover of herbaceous vegetation, small shrubs, and subshrubs (plots and quadrats are further addressed in section 4.4.2 for more details). Cover can be recorded for all herbaceous plants by life form (e.g., grasses versus forbs) or by species. If small openings are included, record canopy cover of herbaceous vegetation; however, if small openings are excluded from measurements, record cover as foliar cover (SRM 1989). Foliar cover is an important concept in quadrat and line intercept methods because it is more useful for detecting subtle changes in cover than the canopy cover method. Line intercept (section 4.4.2) can also be used on tufted herbaceous vegetation with discrete canopies to measure intercept, but it is more difficult to use on rhizomatous vegetation. The point intercept method can be used, either along lines (line-point intercept), on corners of multiple quadrats, or less commonly by using the step point method or point frames (Elzinga et al. 1998). Point intercept is superior to line intercept or plot/quadrat methods when assessing cover of fine-leaved (grasses) and/or open, lacy vegetation, such as ferns. See section 4.4.2 for more details on these methods.

Height. As described previously, herbaceous vegetation can be an important habitat attribute, and height is simply another metric to describe their quantity. A tape measure

or ruler is used to measure height of graminoids, forbs, and other herbaceous vegetation, often along a transect (Herrick et al. 2005). A modification of height estimation is the Robel pole method, or visual obstruction reading, developed to estimate herbaceous vegetation biomass and vegetation height density in grasslands (Robel et al. 1970, Toledo et al. 2010). Height density is highly correlated with vegetation height, but these are not equivalent (Higgins et al. 2005). The pole can also be used to record maximum vegetation height, however. Depending on the vegetation height at the sampling site, the pole is marked with bands that are typically in alternating light and dark colors varying in width (Robel et al. 1970, Uresk and Juntti 2008). The number of the lowest visible band is recorded, typically from a distance of 13 ft from the pole and from a height of 3 ft (e.g., Benkobi et al. 2000, Robel et al. 1970). In general, five transects with 20 stations each, typically 30 ft apart, are adequate to characterize one section (640 ac). For larger areas, however, a stratified random design is advised.

Vegetation height and visual obstruction readings are often highly correlated, but height measurements obtained from a pole, such as at specified intervals along a line transect, are more repeatable and interpretable than are estimates of visual obstruction (Toledo et al. 2010). A field guide for using the Robel pole method to measure vegetation structure is available through the Rangeland Inventory and Monitoring Web site (http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml).

Herbaceous height also can be measured in quadrats by using a calibrated ruler or tape (Higgins et al. 2005), and reported as described previously for shrubs. Effective plant height is measured as the maximum height of the leafy portion of herbaceous vegetation (Higgins et al. 2005). For example, measure graminoid height at the maximum height of the vegetative part of the plant, not the flowering culms. Stubble height is a measure of herbaceous vegetation remaining after grazing (Clary and Leininger 2000), often in relation to grazing by livestock. Compared with other grazing intensity monitoring indicators, recording stubble height has the advantage of simplicity, rapidity, high repeatability, and accurately reflecting grazing severity (Holechek and Galt 2004). Rodgers (2002) found stubble height correlated with pheasant (*Phasianus* spp.) abundance on the Great Plains. Stubble height also is used as a habitat measure for great gray owls (*Strix nebulosa*) in California (Lile et al. 2003). The value of stubble height as a wildlife habitat attribute needs further research on a species-by-species basis.

Structural Stages

Vegetation structural stage and seral stage are closely related, but are not synonymous concepts. Structural stages are based on vegetation community processes of initiation, growth, competition, and mortality (Johnson and O'Neil 2001, Oliver and Larson 1996). By contrast, seral stages are intermediate communities in an ecological succession (Johnson and O'Neil 2001). It is possible to have multiple structural stages within a seral stage. For example, open and closed structural stages are commonly used divisions of

seral stages in the Pacific Northwest (Johnson and O'Neil 2001, Moeur et al. 2005; table 4.7). In many wildlife habitat applications, structural, rather than seral, stages are used.

After vegetation type (section 4.3.1), structural stage is probably the most important wildlife habitat concept in a management context. Johnson and O'Neil (2001) define wildlife habitat as cover type plus structural conditions, in conjunction with specific habitat elements. Wildlife managers often think of structural stages in defining older forests, but an increasingly important focus for wildlife and land managers is early successional habitats, in which seral and structural stage concepts are used (Fritcher et al. 2004, Jenkins and Starkey 1993, Thompson and DeGraaf 2001).

Johnson and O'Neil (2001; chapter 3) provide an excellent organization and practical illustration of using structural stages in describing wildlife habitat. Although written for the Pacific Northwest, the structural stages presented apply to a wide variety of ecosystems. For forested ecosystems, structural stages are combinations of tree size groups (based on diameter classes), percent canopy cover (in classes), and the number of canopy layers. For example, one structural stage is referred to as "sapling/pole-closed," indicating small-diameter trees (1 to 9 in) with relatively high canopy cover (more than 70 percent) and a single canopy layer (Johnson and O'Neil 2001). Table 4.7 presents the criteria used for all forest and shrub/grassland structural stages.

We recommend this table as a starting point for use of structural stages in habitat monitoring. The table can be refined based on specific needs, but regions should carefully coordinate and define the structural stage definitions they will use. Because wildlife habitat needs are often defined based on specific thresholds (e.g., trees with diameter greater than 21 in and trees older than 80 years), structural stage definitions should incorporate these thresholds when possible.

For habitat monitoring, structural stage is a derived attribute associated with attribute measures, such as tree size distribution and canopy cover. Structural stages assigned through visual estimation are difficult to replicate and change statistics will be of unknown value.

Vegetation Phenology

Vegetation phenology relates to the timing, interannual and within 1 year, of recurring life history events, such as bud burst, leaf emergence, first flowering, and senescence (Morisette et al. 2009, Willis et al. 2008). Weather and climate are strongly tied to changes in plant phenology, especially in temperate climates, which in turn can affect plant growth, herbivory effects, forage availability, or even community composition and structure (Cleland et al. 2007, Morisette et al. 2009, Parmesan 2006). Changes in plant and animal phenology have been key indicators of climate change (Parmesan 2006). Thus, monitoring vegetation phenology may be useful in predicting future modifications of wildlife habitat, including geographic shifts or changes in quality, as a result of climate change (chapter 2, section 2.2.7; chapter 7, section 7.2.1).

Altering vegetation phenology can affect wildlife habitats in multiple ways. For example, timing of flowering is variable among taxa; those taxa that do not respond to changes in temperature may experience sharp declines in abundance, thus altering vegetation composition and potentially affecting habitat quality (Willis et al. 2008). Links between wildlife species and vegetation components of their habitats can become uncoupled with climate-induced shifts in phenology. These broken links can lead to mismatches in life cycle events between predators and prey or insect pollinators and plants, often with negative consequences for fitness (Miller-Rushing et al. 2010, Parmesan 2006). For example, in Colorado, yellow-bellied marmots (M*armota flaviventris*) emerged from hibernation 23 days earlier during a span of 25 years, but the timing of plant flowering and snowmelt did not change leading to asynchrony between the marmots and their food sources (Inouye et al. 2000). For these reasons, assessing plant phenology as part of a habitat monitoring program may be essential for understanding changes in habitat quality or amount through time, and how those changes may ultimately affect wildlife populations (Miller-Rushing et al. 2010).

Metrics to assess vegetation phenology can be derived from field-sampled and remotely sensed data. In the field, characteristics, such as dates of first flowering or timing of leaf emergence of key plant species are often measured. Although such records can be valuable, they are typically limited in geographic scope and context, and local measurements of phenology are highly variable and strongly influenced by microclimate (Fisher et al. 2006, Morisette et al. 2009). Newer technologies have emerged using digital cameras and wireless imagers to monitor plant phenology. For example, researchers can accurately estimate the number of flowers on images from a pan-tilt-zoom camera (Morisette et al. 2009). Although local in extent, historical records of vegetation phenology have been invaluable in documenting changes in plant phenology for hundreds of years (Bradley et al. 1999, Cleland et al. 2007).

Remote sensing methods are increasingly used to measure aspects of vegetation phenology (Cleland et al. 2007, Morisette et al. 2009). Two especially useful metrics that can be captured from moderate resolution satellite imagery (e.g., 250 meters) are the Normalized Difference Vegetation Index (NDVI) and the Wide Dynamic Range Vegetation Index (WDRVI) (Morisette et al. 2009). These indices reflect land surface greenness and are thus good indicators of seasonality, such as season start and end dates and length of season (Morisette et al. 2009, Viña et al. 2008). Recent studies have demonstrated the value of field-sampled data in interpreting remote sensing derived measures of plant phenology (Fisher et al. 2006).

Resources for addressing phenology, including protocols and data sets, are available from a variety of sites. The National Phenology Network (http://www.usanpn.org) has developed a suite of protocols for monitoring phenology for plants and animals, and is an excellent source for emerging technologies and uses of phenology in resource management, as well as phenology data sets. We encourage use of these standardized protocols

for measuring phonological events for habitat monitoring when appropriate, and sharing data collected for habitat monitoring with the network to augment the data available for others interested in phenology. A National Phenology Data Set, based on NDVI values, is available; maps of these data can be viewed in Google Earth through a KML file (Hargrove et al. 2009; http://data.forestthreats.org/phenology/). Products available include a variety of parameters including spring arrival (date when 20 or 80 percent of maximum NDVI for the year attained) and cumulative phenology (summed NDVI values) and derived products, such as duration of fall or spring, and the variability of these seasonal lengths.

Two additional potential sources of information for habitat monitoring related to phenology and climate change are the Climate Change Tree Atlas (Prasad et al. 2007–ongoing) and the Climate Change Bird Atlas (Matthews et al. 2007–ongoing). These Forest Service products present current distributions of 134 tree species and 150 bird species of the Eastern United States, along with their predicted distributions under a suite of emission scenarios and climate models (http://www.nrs.fs.fed.us/atlas/index.html). The atlases are easy to use in a Web-based environment, and individual species can be selected and results summarized. The site also produces information about which factors limit the current distribution of species, which factors are the best predictors of current distributions, and which range of precipitation conditions a species will experience in the future.

4.4 Existing Protocols and Sources of Field-Sampled Data

To improve efficiency and transferability, we recommend using existing data collected using standard protocols rather than collecting new data, if this approach will meet the objectives of the monitoring plan. Carefully evaluating available datasets before initiating a habitat monitoring program is a good investment of time, especially when budgets and personnel are limited. Establishing a new monitoring program in the context of other monitoring at subregional and regional scales will offer gains in efficiency. Often a carefully designed monitoring plan can yield useful data at multiple scales, with only minor changes in sampling design required. If specialized data collection is required, consult Elzinga et al. (1998) for a comprehensive review of all aspects of vegetation monitoring. (See also chapter 8 for guidance on data analysis and chapter 9 for information about data management and reporting.)

The following sections describe sources of existing field-sampled data, protocols for data collection, and guidelines for use of field-sampled data. Some of these data are currently being collected under well-established protocols (e.g., FIA data), and vary in quality and age. To be useful for monitoring purposes, data must be associated with a specific sampling protocol, and the data need to have a sampling design that can be intensified or extended to the area of interest for the monitoring program. FIA provides several tools, such as EVALIDator, to help determine the number of plots required to achieve population estimates with desired confidence. Occasionally older data sets (i.e., legacy data) can

provide baseline information. Use legacy data carefully, however, because they may have been collected in the absence of a sampling design or protocol, or collected using a protocol that is not consistent with more recent data collection. As detailed in the following section, methods of data collection can result in differences in the derived attribute values. Monitoring is the business of change detection, and managers need to ensure that the observed changes from baseline conditions are biological rather than sampling artifacts.

4.4.1 Existing Protocols and Data in NRM

The NRM is the standard system of the Forest Service for data-collection protocols, standards, and formats. (See http://fsweb.nris.fs.fed.us/products/index.shtml.) The most relevant NRM modules for habitat monitoring are FSVeg, which includes FIA, its GIS environment, FSVeg Spatial, and Rangeland Inventory and Monitoring. The Inventory and Mapping module is also relevant for its potential vegetation context.

For monitoring habitat in riparian areas, the National Riparian Monitoring Protocol is under development for the Western United States (USDA Forest Service, in press). In addition, the *Riparian Methods Technical Guide* provides summaries of a variety of methods for mapping, monitoring, and inventorying riparian vegetation. The guide is intended to introduce resource managers to remote sensing methods that can be used to fulfill a variety of riparian business needs. The guide also will include links to other information about riparian assessment and will be located with the *Rangelands Methods Technical Guide* as part of the Landscape Toolbox (http://www.landscapetoolbox.org/).

FSVeg

The best source for plot- and stand-level information at the local scale, especially in forested ecosystems, is FSVeg. This application stores plot data collected under the CSE protocol, as well as strategic grid data, insect and disease study data, FIA data, and remeasured permanent growth plot data.

CSE protocols for stand and compartment examinations include standards for collecting stand, plot, tree, surface cover, understory vegetation, and down wood data (USDA Forest Service 2010b, available within the Forest Service Web intranet environment at http://fsweb.nris.fs.fed.us/products/FSVeg/documentation.shtml). CSE also contains data codes, portable data recorder software, forms, reports, and export programs. See chapter 9 for additional information about the corporate data structure of NRM.

Data and associated reports in FSVeg can be extremely valuable for monitoring wildlife habitat because most forest-related habitat attributes are either measured directly using the CSE protocol or are available as derived attributes in FSVeg. Therefore, the primary questions are whether CSE data were collected across the local area of interest for the emphasis species and whether the data are sufficiently current to use as the basis of a monitoring program. If existing CSE data are inadequate to meet monitoring objectives, use the CSE protocol to collect new data or augment whatever CSE data are available.

FIA

A second source of plot data is FIA, which is the continuous forest inventory on all land ownerships in the United States. The current quasisystematic sampling design is based on a hexagonal grid across the United States, with each hexagon containing approximately 6,000 ac, with a measurement cycle of 5 years in the Eastern United States and 10 years in the Western United States, implemented under a rotating panel design (chapter 3, section 3.3.3).

The inventory involves the following three phases. Phase 1 (P1) entails stratification of estimation units (e.g., counties) to increase the precision of sample estimates. P2 is comprised of ground plots that occur at an intensity of roughly 1 plot/6,000 ac. P3 plots are a 1/16 subset of P2 plots. Technicians collect additional data in P3 plots on forest health indicators, such as down wood, understory vegetation, soils, lichens, ozone, and tree crowns. In some FIA regions, however, all vegetation types, including shrublands and grasslands, are sampled using the FIA P2 plot grid. This All Condition Inventory (ACI) creates P2 plot grid coverage of forested and nonforested sites. While the ACI is not yet a national approach, there is potential to implement this inventory on a national basis.

FIA data offer great utility for estimating or deriving wildlife habitat attributes. Table 4.3 describes habitat attributes addressed in this chapter that are available, or can be calculated, from FIA data. When constructing wildlife-habitat-relationships models from FIA data, these models can be applied across large landscapes (e.g., Zielinski et al. 2006, 2010). FIA data are stored in FSVeg and are also available on the FIA Web site (http://fia.fs.fed.us), two sites where data are organized by State with each file containing all levels of data (tree-level data, condition-level data, etc.) and a set of derived variables (e.g., tree volume).

The FIA program also includes valuable tools that generate tabular and spatial summaries based on user-defined inputs (accessible at http://fia.fs.fed.us/tools-data/default.asp). These tools include the following applications.

- EVALIDator—available either as a Web-based tool or as a downloadable Microsoft Access database. Analyses can be conducted for any State, and reports can be created for nearly 100 different attributes. In addition, spatial and attribute filters can be applied to customize the output to meet the user’s needs (Miles 2009).
- FIDO—a Web-based reporting tool that creates tables and maps from user-defined areas of interest and survey years. Nearly 50 standard reports are available, or the user can develop customized queries. The results can be displayed in several output formats (Wilson and Ibes 2005).

There are four important caveats for using FIA data. First, Federal law mandates that FIA plot locations remain undisclosed to the public. Thus, plot locations (e.g., latitude and longitude) of publicly available data sets are approximated and do not represent the true locations of the plots. Although the rules vary by FIA unit, all plot locations are “fuzzed”

(up to 1 mile), and a proportion of locations on private lands are swapped with other locations. Any fuzzed and swapped locations always remain within the original county, however. Approximate plot locations or even simple tabular data may be sufficient for monitoring habitats of emphasis species or for monitoring specific habitat attributes, such as snag density. The effect on analyses depends on the spatial resolution and the use of the data (McRoberts et al. 2005). For analyses requiring exact plot locations, FIA has established a spatial data services center (SDS). This facilitates linking FIA plot data with spatial information while keeping plot locations confidential. To learn more about SDS, visit http://www.fs.fed.us/ne/fia/spatial/index_ss.html.

Second, with 1 plot/6,000 ac for P2 plots and 1 plot/96,000 ac for P3 plots, a local-scale analysis might contain only one to two plots, which is insufficient for an analysis of habitat data for monitoring. Therefore, FIA data are best used for analyses at broad scales (regional or subregional), although they can also be useful for forest-scale applications, such as prioritizing habitat by broad vegetation type. Some regions increase the regional sample of FIA plots through grid intensification, in which additional plots are sampled between the normal FIA grid spacing. The regions collect data under the FIA protocol or a modified CSE protocol to combine the original FIA sample with the local sample for a seamless analysis. Exploring existing FIA data will demonstrate the variability of the attributes of interest and will help determine how many additional plots are needed. Consult your regional Forest Service office to determine whether grid intensification has occurred in your area. If not, use data from the FIA plots that fall in your analysis area, but acquire new data using either the FIA protocol or a modified CSE to obtain a sufficient sample to meet monitoring needs.

Third, FIA is primarily a forest inventory. Although some programs sample nonforested vegetation (ACI was addressed previously), the plots are selected based on stratification at a national scale of forest/nonforest vegetation types. FIA sampling therefore does not generally extend into nonforested vegetation.

Fourth, the Forest Service does not sample FIA plots annually. As such, FIA data are best suited for long-term monitoring. If a habitat monitoring program requires information on rapid vegetation response at fine spatial scales, extant FIA data will likely not be useful. Advantages still exist to collecting new data using FIA protocols, however. Local results can be directly compared with and potentially applied to the larger spatiotemporal domain in which FIA excels, if this strategy is followed (e.g., Zielinski et al. 2006).

FSVeg Spatial

FSVeg Spatial provides an environment for displaying and analyzing vegetation attributes in a GIS environment. This application uses a polygon approach and is strongly recommended as a standardized, Agency-supported vegetation mapping environment at the local scale. Polygons can be populated with a variety of data sources. For example, in the Forest Service Pacific Northwest Region, raster data from satellite imagery for mid-scale mapping are summarized and used to populate FSVeg Spatial polygons for some

local planning units. Polygons are also often developed from legacy stand examination polygon data layers. Forests nationwide are gradually implementing this application. A limitation of the application is that only National Forest System lands are mapped.

Rangeland Inventory and Monitoring

While this application provides methods for sampling all life forms, the primary emphasis focuses on sampling nonforested vegetation, including shrublands and grasslands because there are more methods available for these vegetation types. In addition, the methods, analysis, and geospatial tools in this application meet a different set of sampling objectives than those in CSE (FSVeg). Rangeland Inventory and Monitoring includes protocols, such as visual macroplot, line intercept, and cover/frequency for sampling vegetation; these applications will be useful when the CSE protocol does not meet inventory and monitoring information needs. Line intercept is currently supported by a protocol in the NRM (see http://fsweb.nris.fs.fed.us). Go to http://fsweb.nris.fs.fed.us/products/Rangeland_Inventory_Monitoring/index.shtml for a full list of methods and associated field guides available in this application. In the past, acquiring existing data for nonforested vegetation types was challenging because the Forest Service has collected data less consistently in these ecosystems. All Forest Service regions are now collecting data within some of the nonforested areas, however.

4.4.2 Data-Collection Methods for Field-Sampled Data

The section that follows describes commonly used methods of field data collection to sample the vegetation attributes described in this chapter. We assume decisions about organization, placement, and intensity of field plots or transects have already been carefully made before the collection of new data begins (chapter 3). The methods described in the following section are located in NRM (section 4.4.1). Details about using these methods for particular vegetation attributes are presented in sections 4.3.1 and 4.3.2. Consult Elzinga et al. (1998) and Herrick et al. (2005) for more specific information on a wide range of field-sampling methods for the plot, quadrat, line intercept, and point methods that follow.

Plots and Quadrats

Plots and quadrats are area-sampling methods because they have two-dimensional area (length and width or radius and diameter). Fixed-area plots are typically large enough to walk within the boundaries. In general, plot size is a function of vegetation size, spacing, and pattern, regardless of life form, but may vary by vegetation type (i.e., the dominant vegetation). For forested vegetation, 1/5-ac plots are common, whereas in shrublands, 1/10-ac plots are often used. In herbaceous vegetation (e.g., grasslands and wet meadows), 1/24-ac (or smaller) plots are commonly used. Plot shapes vary, but shape is typically circular in most upland vegetation and rectangular in riparian vegetation.

When estimating cover in fixed-area plots, the sampler usually walks the plot to avoid viewing the vegetation at an oblique angle from the plot center, which results in an

overestimation of cover. Estimating plant abundance in large, fixed-area plots lacks adequate precision and repeatability through time and among different observers, but may be sufficiently repeatable for monitoring broad changes in vegetation cover (e.g., by life form).

Quadrats are smaller than fixed-area plots and can be viewed from one point, usually standing and looking directly down on the vegetation. Because of their smaller size and the position of the sampler, measurements from quadrats are more precise and more accurate than those from fixed-area plots; they are also more repeatable through time and among different samplers. Using small quadrats reduces the number of items encountered, as well as the search time. The appropriate number of quadrats to be sampled, the number of lines (if quadrats are placed along lines), and the size, spacing, and shape of quadrats are functions of the size, pattern, and spacing of the vegetation.

Multiple quadrats also can be nested within a fixed-area plot, such that tree or large shrub cover and density are assessed in the large plot, and herbaceous and small shrub/subshrub cover and density are assessed in the quadrats. Currently, protocols in NRM support visual macroplot and cover/frequency methods (http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml).

Line Intercept

In line intercept, the sampling plane is one-dimensional. When sampling, a line or transect is drawn between two points; all objects of interest that intercept the line are counted and/or measured. Transects can be positioned at any height (determined by the dimensions of the sampling plane), depending on the item being sampled (e.g., shrub cover and ground cover). In general, the line is approximated using a tape that is suspended above the vegetation or laid flat on the ground. For many attributes, transects provide very repeatable measurements and are therefore good choices for monitoring. This method is most often used to measure **cover (canopy or foliar)** of shrubs, grasses, and herbs (Canfield 1941; see Shrubs and Herbaceous Vegetation, section 4.3.2) or to count items that intersect the line, such as down wood by size class (section 4.3.2). Line intercept is commonly used to estimate cover in nonforested ecosystems, but it is also used in forested systems to measure understory shrub cover.

Multiple lines can be oriented perpendicular to a baseline, forming a large square or rectangular macroplot, which is the sampling unit. Another approach is to arrange the lines as spokes within a large circular macroplot and start the intercept measurements an appropriate distance (e.g., 1 to 5 ft) from the center of the plot to avoid oversampling of vegetation at the plot center. Intercept of either canopy, foliar, or **basal cover** of vegetation is measured and summed along each line, and average cover is then calculated across all transects for the entire macroplot. This method is most appropriate for shrubs (typically less than 5-ft tall) or vegetation with well-defined canopies, such as matted forbs or subshrubs (Elzinga 1998).

A hybrid of the plot and line intercept methods is the belt or strip transect, which is essentially a long linear rectangle. Strip transects have the advantage of sampling a much larger area than a line transect and are therefore best used if the object of interest is scarce yet easy to detect. Strip and belt transects are poor choices for common objects, however, because the strip functions as a long, narrow plot. As such, this approach has a very large edge-to-area ratio, requiring multiple boundary decisions (i.e., in or out) along the plot edge.

We also recommend the variable strip transect, which is most useful in measuring tree boles. Using this approach, an observer walks a transect looking for trees of interest. When spotted, the observer walks forward until the tree is perpendicular to the transect and then uses a prism or Relaskop to determine whether the tree is tallied. Advantages of this approach are that for large-diameter trees, plot size is huge (transect length by limiting distance) and prisms and Relaskops, combined with limiting distance tables, allow for highly repeatable counts with minimum time spent measuring distances. Because of the large plot area, variable transects are well suited for counting rare trees, such as large-diameter snags.

Point Methods

The point intercept method is commonly used to measure cover, including foliar and basal vegetation cover and ground cover (e.g., bare ground, moss, rock, and litter). Because points are essentially dimensionless, this method is considered the least biased and most repeatable for determining cover (Bonham 1989, Elzinga et al. 1998). If the point intercepts the item being measured, such as basal vegetation, it is tallied. Determine the percentage composition by cover for each category (e.g., species, life form) by dividing the number of points within a category by the total number of points and multiplying by 100.

In typical low-statured herbaceous vegetation, points are usually identified using a sharp rigid object, such as a range pin or a ballpoint pen. Equal-sized points are used for consecutive measurements and documented in the project metadata. Points can be organized along lines (line intercept; Herrick et al. 2005), in point frames, or in quadrats (intercept recorded on quadrat corners). A point frame typically yields more repeatable results because the angle of intercept is fixed. Typically, the pin is placed perpendicular to the ground surface. In grasslands dominated by fine-leaved rhizomatous species, however, an oblique angle can be used (Elzinga et al. 1998). Because the point-intercept method samples the least amount of area within a sampling unit, it may be necessary to sample many points to obtain an adequate sample for estimating cover.

Herrick et al. (2005) present a variety of options to supplement the basic line-point intercept method, such as recording height on a subset of the points. The resulting dataset can be used to assess structural complexity (see canopy complexity, section 4.3.2). Point intercept is appropriate for trend monitoring because it is repeatable through time and among users. Detailed metadata documentation (e.g., sampling rules about maximum gap for foliar cover, side of tape read, and overlap) is critical for consistency in measurements, however.

4.4.3 Guidelines for Using Field-Sampled Data

For any given monitoring program, using existing field-sampled data depends on the spatial extent of the monitoring program and the desired level of precision in monitoring results. For broad-scale monitoring, we recommend P2 and P3 FIA data because (1) the sampling design provides a statistically valid, spatially balanced sample; (2) the data are collected through a stringent, documented protocol; and (3) the data are free and readily available through NRM. Although a national forest of approximately 1 million ac has 100 to 200 P2 plots, field-data collection normally occurs on only forested P2 plots. On many western national forests, this practice can substantially reduce the amount of information available for forested areas. Further reductions occur when only a subsample of forested P2 plots meets habitat requirements for the emphasis species, such as all P2 plots in mixed conifer, late seral forests. As a result, there will likely be insufficient data to obtain the desired standard errors for monitoring and the grid must be intensified within the vegetation types of interest while maintaining a spatially balanced sample.

If there are too few P2 plots within an analysis area, collect data on existing and new plots using the FIA protocol or a modified CSE to combine new data with existing data for a seamless analysis. The choice of whether to use FIA or CSE data depends on what protocol is locally available and the approach used by the applicable Forest Service region. Three Forest Service regions (Pacific Northwest, Pacific Southwest, and Northern) have intensified the FIA grid through specific regional protocols. Contact the regional FIA coordinator to learn more about the regional grid and to obtain assistance with accessing and using the data.

Midscale monitoring programs can also take advantage of FIA data but will need to intensify the grid to increase sample size, reduce variance, and achieve the desired precision for the monitoring objectives. Midscale monitoring programs can also use CSE data; they can be augmented using the existing data stored in the Ecosystem Inventory and Monitoring application to further describe additional vegetation characteristics. Again, the choice of whether to use CSE or FIA protocols depends on which protocol is being implemented on a local or regional basis.

Because of the small spatial extent of local monitoring programs, it is rare that existing data are available for the area of interest. Therefore, the standard approach will be to collect new data for all or most of the identified habitat attributes. To the extent possible, use CSE or FIA protocols to collect new data; augment these protocols using methods from the Vegetation Inventory and Monitoring application of NRM (e.g., line intercept, cover/frequency) if the sampling objective requires additional data.

When using existing local data, carefully evaluate the sampling design under which the data were collected. If collected for a specific project or specific area, the data may not be representative of the area of interest to be monitored and might not meet statistical standards for randomized or unbiased sampling. These data are purposive or convenience sampled, and although they may have served a purpose for a past objective, they can

cause statistical problems if they become the basis of a new monitoring program (Anderson 2001). It is also important to ensure that the sampling unit is clearly defined and that subsamples are not confused with samples (see chapter 3, section 3.3.3).

4.5 Existing Protocols and Sources of Remotely Sensed Data

The Forest Service and other land and resource management agencies use a wide variety of remotely sensed data sources that may be useful in wildlife habitat monitoring programs. These sources include traditional aerial photography, moderate to very high-resolution digital satellite imagery, and active systems, such as radar and LIDAR (tables 4.2 and 4.10). The data can be acquired from either airborne or spaceborne platforms and can be either in photographic or digital form. The Forest Service and other Federal agencies have acquired and archived these data types regularly for decades.

As with field-sampled data (section 4.4), we recommend using existing remotely sensed data when possible, rather than collecting new data. The Forest Service Geodata Clearinghouse provides access to numerous raster and vector data sources as well as existing maps and other tools (http://svinetfc4.fs.fed.us). A variety of spatial data sets, primarily but not solely derived from remote-sensing methods, are maintained by the Forest Service and described in the National GIS Data Dictionary (table 4.11). Availability of layers varies by land management unit and many data sets are available on public-facing Web sites in addition to internal Forest Service intranet sites. Other sites that offer free downloads of spatial data layers for a variety of land ownerships include the following:

- The U.S. Geological Survey (USGS) National Map site (http://nationalmap.gov/), which provides public access to high quality geospatial data for a wide variety of thematic areas, such as geology, climate, ecoregion boundaries, transportation networks, ownership, Breeding Bird Survey routes, and locations of nonnative species.
- The National Atlas (http://nationalatlas.gov/), a U.S. Government Web site that offers on-demand mapmaking, enables users to create maps from a large number of data layers. The Web site includes data layers from the ranges of bat species in the United States to water features, such as streams, lakes, and dams.
- LANDFIRE (Landscape Fire and Resource Management Planning Tools Project), an interagency project to map vegetation, fire, and fuel characteristics across the United States (http://www.landfire.gov/index.php; Rollins and Frame 2006). The Forest Service wildland fire management programs and the U.S. Department of the Interior share this project. The goal of LANDFIRE is to produce a comprehensive, consistent, and scientifically credible suite of spatial data layers for the entire United States. Data products are 30-m (98-ft) spatial resolution raster data sets, which vary in accuracy by geography, product, and scale of use. The LANDFIRE National component includes more than 20 mapping products, many of which are pertinent to habitat mapping and

monitoring. The existing vegetation type map uses ecological systems, a midscale vegetation classification system between fine-grained ecological communities and coarse-grained ecoregions, to map vegetation across the United States (Comer et al. 2003; tables 4.5 and 4.6). Other map layers include environmental site potential, a potential vegetation layer, existing vegetation cover and height by life form and class, and historical fire regimes. An additional resource for habitat monitoring is the LANDFIRE reference database, which includes thousands of records of plot data used to generate the mapping products. For those interested in better understanding LANDFIRE products and their potential use in habitat monitoring, an online training course is available (https://www.conservationgateway.org/ExternalLinks/Pages/landfire-training.aspx).

- The National Elevation Dataset (NED) (http://ned.usgs.gov/), which merges the highest resolution, best-quality elevation data available across the United States into a seamless raster format. The NED provides coverage of the entire United States, including Hawaii, Alaska, and the island territories. These layers can be used to

Table 4.10.—*Characteristics of commonly available satellite imagery applicable in wildlife habitat monitoring (adapted from Brewer et al. 2005). Brewer et al. (2011a) provided a more complete and current list of Earth resource satellite sensors.*

Sensors (by recommended scale)	Swath/footprint	Spatial resolution	Revisit time	Image availability
Broad scale				
AVHRR	2,600 km	1 km/4 km	Daily[a]	1978 to present
MODIS	2,300 km	250 m, 500 m, 1 km	Daily	2000 to present
Mid scale				
Landsat MSS	185 km	80 m	16 days	1972 to 1992
Landsat TM	185 km	15-m B/W and 30-m multispectral	16 days	1982 to 2012
Landsat ETM+	185 km	30 m	16 days	1999 to present
ASTER	60 km	15 to 90 m	16 days	1999 to present
Local scale				
WorldView-2	16.4 km	0.5-m B/W and 1.8-m multispectral (8 bands)	1 to 7 days	2009 to present
QuickBird	16.5 km	0.6-m B/W and 2.5-m multispectral	1 to 3 days	2001 to present
IKONOS	11 km	1-m B/W and 4-m multispectral	1 to 3 days	1999 to present
SPOT	60 km	10-m B/W and 20-m multispectral	1 to 3 days	1986 to present
	80 km	5-m B/W		2002 to present

ASTER = Advanced Spaceborne Thermal Emission and Reflection Radiometer. AVHRR = Advanced Very High Resolution Radiometer. B/W = Black and white (also referred to as panchromatic). IKONOS = From the Greek word eikon, or "image." km = kilometer. Landsat ETM+ = Landsat 7 Enhanced Thematic Mapper Plus; note that, beginning in 2003, a permanent scan line corrector failure occurred, resulting in a loss of about 22 percent of the data (along edges) in scenes from this satellite. Landsat MSS = Multispectral Scanner. Landsat TM = Landsat 5 Thematic Mapper. m = meter. MODIS = Moderate-resolution Imaging Spectroradiometer. SPOT = Satellite Pour l'Observation de la Terre (System for the Observation of the Earth), developed by the French.

[a] *Weekly or biweekly composited data are most often downloaded for use.*

Table 4.11.—*Example themes and feature classes with potential application in wildlife habitat monitoring, as described in the Forest Service National GIS Data Dictionary (http://fsweb.datamgt.fs.fed.us/current_data_dictionary/index.shtml).*

Theme	Example feature classes or layers	Description	Example habitat attribute or disturbance agent/process	Associated national application or references
Activities	ActivityLine, ActivityPoint, ActivityPolygon, ProjectArea	Four feature classes describe the spatial location of completed ground-disturbing activities (e.g., fire line construction, fuel removal, fence construction, weed treatments, recreation improvements) within or near an administrative unit.	Noxious weed distribution, timber harvest, trail locations	Forest Service Activity Tracking System (FACTS v.1.2; http://fsweb.ftcol.wo.fs.fed.us/frs/facts/index.shtml)
Ecomap Sections_2007	Climate, Ecomap provinces, Ecomap sections, soil sections	Includes polygons for ecological provinces and sections within the conterminous United States. This data set contains regional geographic delineations for analysis of ecological relationships across ecological units.	Ecological province, soils	http://fsgeodata.fs.fed.us/other_resources/ecosubregions.php
Fire management	Fire history, WUI	Points represent start locations for fires and polygons represent final mapped wildfire perimeter. Data are maintained at the forest/district level to track area affected by fire. WUI: the line, area, or zone when structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels; includes size of area and fire management zone identification.	Burned habitat, exurban development in the WUI	FIRESTAT, Reporting for National Fire Plan
Geology	geologic map unit (GeologyMapUnitsOrder2)	Polygon-based layer of geologic map units; polygons are delineated based on geologic characteristics and classifications. Includes NRM published feature classes for geology; includes all map unit orders for geologic map unit in NRM, point feature classes for site bedrock, and site surficial materials. Feature class polygons are attributed with stratigraphy, lithology, geomorphology, and descriptive text.	Local geologic unit (e.g., relevant for burrowing mammals)	NRM Terra
RMU	Key area, unit, subunit	Land units that support the management of rangeland needs and mapping. Includes a variety of land unit polygons (e.g., allotment, exclosure, and general resource area).	Grazing allotment boundaries, pastures, implementation monitoring boundaries	FSM 2200, http://fsweb.nrm.fs.fed.us/products/infra/
Recreation	RecreationSitePoint. RecreationSitePolygon, WildernessRecManagement Polygon	Spatial location of recreation sites (e.g., campgrounds, trailheads, boat launches) and recreational opportunity spectrum areas within or in close proximity to an administrative unit and wilderness recreation management areas within a federally designated wilderness.	Developed recreation sites (e.g., for calculating recreation site density)	FSH 2330, FSH 2340, FSM 2320; http://fsweb.nrm.fs.fed.us/products/infra/
Invasive species and TESP	InvasivePlantAll, InvasivePlantCurrent, TESP OccurenceAll	Published data provide occurrence and infestation information at a national extent.	Extent of invasive plants within a monitoring area (e.g., sage-grouse habitat), locations of sensitive plants	http://fsweb.nris.fs.fed.us/products/TESP_Invasive_Species/index.shtml
Transportation	Road, trail, travel management area	Spatial location of roads and trails within or in close proximity to an administrative unit.	Road and trail density	http://basenet.fs.fed.us/, http://fsweb.r6.fs.fed.us/eng/travel_routes/user_board/

Table 4.11.—*Example themes and feature classes with potential application in wildlife habitat monitoring, as described in the Forest Service National GIS Data Dictionary (http://fsweb.datamgt.fs.fed.us/current_data_dictionary/index.shtml) (continued).*

Theme	Example feature classes or layers	Description	Example habitat attribute or disturbance agent/process	Associated national application or references
Vegetation	EV, PNV	EV is the plant community, or floristic composition and vegetation structure, occurring at a given location at the current time; PNV refers to the plant community that would be established if all successional sequences were completed without human interference under the present environmental conditions, including those created by humans. PNV is a useful tool to stratify the landscape into basic units of land capability.	EV, PNV	NRM; Warbington 2011
Water	NHD, hydrologic units	Feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the Nation's surface water drainage system. Provides a national framework for assigning reach addresses to water-related entities, such as industrial discharges, fish habitat areas, wild and scenic rivers. NHD data is available to each forest or to a Forest Service region by navigating to the EDW Production database.	Streams, rivers, aquatic features; watershed boundaries (e.g., to establish ecologically based monitoring boundaries)	http://datagateway.nrcs.usda.gov/
Fish and wildlife	Wildlife sites, fish and wildlife observation	Terrestrial wildlife sites and the most recent visits to those sites; combines attributes of the point and polygon site layers from the NRM Wildlife application into a single polygon geodatabase feature class; locations of observations of aquatic and terrestrial wildlife.	Wildlife occurrence (to establish monitoring boundaries, habitat sampling sites, validate habitat models)	http://fsweb.nris.fs.fed.us/products/Wildlife/index.shtml

EDW = Enterprise Data Warehouse. EV = Existing vegetation. FACTS = Forest Service Activity Tracking System. FSH = Forest Service Handbook. FSM = Forest Service Manual. GIS = Geographic Information System. NHD = National Hydrography Dataset. NRM = Natural Resource Manager. PNV = potential natural vegetation. RMU = rangeland management unit. TESP = Threatened, Endangered, and Sensitive Plants. WUI = wildland urban interface.

derive topographic variables, such as slope, aspect, or topographic complexity, which is an important habitat attribute for species, such as bighorn sheep (*Ovis canadensis*) or pronghorn (*Antilocapra americana*).

- The Geospatial Data Gateway maintained by USDA Natural Resources Conservation Service (http://datagateway.nrcs.usda.gov/) provides a variety of natural resources and environmental data for downloading, such as soils, orthoimagery, and census data. Users can select a geographic location to see what data are available for that area or search by theme.
- USGS has satellite imagery available at http://earthexplorer.usgs.gov/.
- Some individual States have collated spatial data within State boundaries. For small-scale monitoring these sites provide easy data access to multiple data layers already edge-joined across the State and having a common projection. See http://nris.mt.gov/gis/ for an excellent example relevant to monitoring in Montana.

Check with your local remote sensing specialist for new applications because remote sensing is a dynamic field, and new data sources frequently become available. Remember, any map is simply a model of actual conditions and will contain error. The Image Classification (section 4.5.2) section addresses why a **classification accuracy** assessment is important and why you need to always look for the accuracy assessment associated with any map product considered for a habitat monitoring effort.

4.5.1 Types of Remotely Sensed Data

Aerial Photography

Aerial photography offers opportunities to monitor a variety of habitat attributes, particularly at a local scale. Most national forests and grasslands have collected aerial photographs at 1:24,000, 1:15,840, or 1:12,000 scales since the 1950s and sometimes back to the 1930s. The Forest Service continues to acquire aerial photography over most local management units every 10 years. This rich archive of information can be useful for retrospective analysis and is likely one of the best current information sources about vegetation and land cover. Archived aerial photographs can be digitized and analyzed using methods commonly used in analysis of satellite imagery, offering new information for use in habitat and other monitoring (Morgan et al. 2010).

The Farm Service Agency Aerial Photography Field Office, colocated with the Forest Service Remote Sensing Applications Center (RSAC) in Salt Lake City, UT, is the archival storage location for all aerial photography negatives acquired by any Federal or cooperating State agency since 1954. Users can purchase the archived imagery as hard-copy prints or digital scans. Photography and negatives acquired before 1954 are stored in the National Archives.

Several national programs provide aerial photography covering the lower 48 States. One example is the National Agriculture Imagery Program, which acquires imagery

during the agricultural growing seasons in the continental United States and provides digital orthographic photography within 1 year of acquisition. NAIP imagery is typically 1- or 2-m (3- or 6-ft) spatial resolution and is useful for identifying a variety of forest and range vegetation attributes, in addition to houses, roads, and other anthropogenic features (chapter 7). NAIP is a digital product and is available as county mosaics or 7.5-min quarter quads at http://www.apfo.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai-or. (See sidebar for other national aerial photography programs.) Available since 2001 and 2002, NAIP imagery is recorded annually, and is fast becoming a commonly used data source for a wide range of natural resource applications.

Light Detection and Ranging (LIDAR)

Laser altimetry, or light detection and ranging (LIDAR), is a more recent geospatial data source providing information about the three-dimensional structure of terrestrial and aquatic ecosystems (Lefsky et al. 2002, Vierling et al. 2008). LIDAR follows the same principle as sonar or radar in that a signal, in this case, a laser beam (in the visible, ultraviolet, or near infrared range), projects from a source either downward from an aircraft or upward from a source located at a set distance above the ground. As with a laser range finder, the beam bounces off solid objects that it encounters (e.g., vegetation, rocks, soil) and the elapsed time indicates the distance between the source and the object. After being collected, the LIDAR data can be separated into bare earth and canopy layers creating a three-dimensional portrayal of the site (Lefsky et al. 2002).

LIDAR can be superior to aerial photos for obtaining estimates of many habitat attributes in forests with highly variable canopy structure. Using LIDAR processing software, measurements can be made of canopy cover, tree height, crown diameter, understory canopy cover layers height, and stand density. From these measurements, users can estimate basal area, biomass, and other canopy measurements. Vierling et al. (2008) provide numerous examples of how LIDAR data are useful for wildlife habitat studies, especially when investigating species that use vertical forest structure.

Farm Service Agency Programs

In addition to the Forest Service programs, several U.S. Department of Agriculture, Farm Service Agency programs provide useful aerial photo data spanning more than 30 years (implemented with the Forest Service as a cooperating agency). These programs include the following:

- National High Altitude Photography (NHAP) program, which started in 1978 when several Federal agencies combined their funds and knowledge to provide consistent and systematic aerial photography (1:80,000 to 1:60,000) coverage for the United States.
- National Aerial Photography Program (NAPP), which began in 1987 as a replacement for NHAP with the objective of acquiring complete and uniform photo coverage (1:40,000) of the conterminous 48 States over a 5- to 7-year cycle.
- National Digital Orthophoto Program (NDOP), which has the objective of providing complete coverage of the United States and its territories and possessions, maintained and updated every 3 to 10 years. (Note: This program uses NAPP photography when available.)

Two obstacles currently hinder widespread application of LIDAR; the high volume of data obtained and the cost of data acquisition, processing, and analysis (Laes et al. 2006). The large volume of data points requires adequate storage capacity and data summarization involves skills that are not widely available. Recent studies, however, have demonstrated that costs and accuracy of LIDAR compared with traditional stand exams can be similar for measuring vegetation structure, and LIDAR can provide information across a much larger area (Hummel et al. 2011). LIDAR data sets are becoming increasingly available, and a consortium of Federal and State agencies provide reduced costs to member agencies. Regional remote sensing specialists typically have information about acquisition and cost of LIDAR products, which can help in decisions about using these data for habitat monitoring. Mitchell et al. (2012) provide guidance on LIDAR project considerations, data acquisition and processing, required software, products (e.g., canopy height and percentage canopy cover), and application of LIDAR products. Also visit the RSAC Web site dedicated to LIDAR, which describes training, sources of available LIDAR data, and LIDAR software tools (http://fsweb.rsac.fs.fed.us/lidar/).

Satellite Imagery

Table 4.10 summarizes available sources of digital satellite imagery. Although many sources of satellite imagery are available, with new satellites and sensors added regularly, data from the Landsat program represent the most extensive continuous and consistent archive of Earth imagery. Multispectral satellite imagery records the visible and near infrared portions of the electromagnetic spectrum. Photosynthetic vegetation is dark in visible wavelengths and very bright in NIR wavelengths, making multispectral remote sensing a particularly effective tool for distinguishing photosynthetic vegetation relative to all other Earth surface materials (Lillesand and Kiefer 2000).

Landsat data archived by the USGS represent a valuable source of historical Earth observation data. The USGS EROS data center has now made the entire Landsat data record available at no cost (http://glovis.usgs.gov/).

4.5.2 Guidelines for Using Remotely Sensed Data

This section provides a brief overview of approaches for using remotely sensed data, including how these data are typically extracted and how they relate to attributes of interest for wildlife habitat monitoring. For a more detailed description and discussion of these systems and principles, refer to Brewer et al. (2011b), Campbell (1987), Jensen (1996), and Lillesand and Kiefer (2000).

Whether using aerial photographs or satellite imagery, always document the image source, image-processing techniques, scale, and map accuracy (Glenn and Ripple 2004). Valid comparisons of habitat attributes among years using data obtained from remotely sensed sources require thorough documentation of these source characteristics. It is also important to match the monitoring information needs with the scale and type of remotely sensed data.

Whether in photographic or digital form, remotely sensed data can be used similarly. After the monitoring information needs and the image data source have been matched appropriately, information from remotely sensed data is derived by using three general analytical approaches—image interpretation, image classification, and image sampling. Image interpretation involves systematically examining image data and identifying attributes, such as canopy cover or tree height through interpretation of elements, such as image tone and texture (see Brewer et al. 2011b and Lillesand and Kiefer 2000 for further description). Image classification involves categorizing pixels into prescribed classes, such as vegetation types. Image sampling involves selecting, measuring, or recording a sample using aerial photographs or satellite imagery. In the following section, we present more detail on approaches that are especially pertinent to habitat monitoring, specifically image classification and image sampling.

Image Classification

Image classification is the process of categorizing pixels or polygons into land-cover classes or themes (Lillesand and Kiefer 2000). The resulting classification can be binary (e.g., habitat or not habitat) or complex (e.g., existing vegetation composition and structure). Five general analytical processes describe most image classification schemes. All have some applicability to wildlife habitat classification. Classification methods include unsupervised, supervised, an unsupervised-supervised hybrid, ancillary data hybrid classification, and change-detection methods (Brewer et al. 2011b). We do not include specific examples of these analytical processes; however, all of these approaches have been used to produce wildlife habitat-related map products.

Change-detection classifications are increasingly used for monitoring, especially at broad scales. Change detection compares the spectral values of two or more images obtained at different time points at the same geographic location. This method can evaluate changes in the size or shapes of vegetation patches, changes in the width or character of linear features, changes in vegetation type or species composition, changes in condition of a single vegetation type, or changes in timing or extent of seasonal processes (Kennedy et al. 2009). Lu et al. (2004) and Coppin et al. (2004) provide detailed reviews and address change detection methods. Kennedy et al. (2009) describe the four main steps of a change detection analysis and address practical considerations that arise at each step.

A classified image is simply a model and will contain errors because of a variety of factors. Similarities in color or texture at coarse resolutions, for example, may lead to difficulties in differentiating between deciduous tree species. Also, national classification systems have a finite number of classes that can be used efficiently, so some species may not be represented in a given region or landscape. Estimates of more broadly defined vegetation types will often have high accuracy relative to individual species classifications. Bradley and Fleishman (2008) describe the utility of vegetation-based remotely sensed

products beyond land cover maps, such as greenness indices and leaf area index. Not only are these measures useful for species distribution and habitat modeling, but they also are useful for offering wide spatial and temporal coverage (table 4.10).

It is important to assess the quality of thematic maps and quantify the error in a meaningful way, a process known as classification accuracy assessment (Foody 2002, Lillesand and Kiefer 2000). The assessment can be done for one or more purposes; for instance, to estimate either overall accuracy, the accuracy in mapping a specific class, or accuracy in area measurements (Foody 2002). Accuracy assessments generally require a comparison with field-sampled data, but the purpose of the accuracy assessment must be clear to ensure that the field samples include the desired properties (Lark 1995). Foody (2002) provides an overview of classification accuracy assessment approaches. Foody (2009) provides a deeper understanding of the sample size of field plots needed to make classification accuracy assessments.

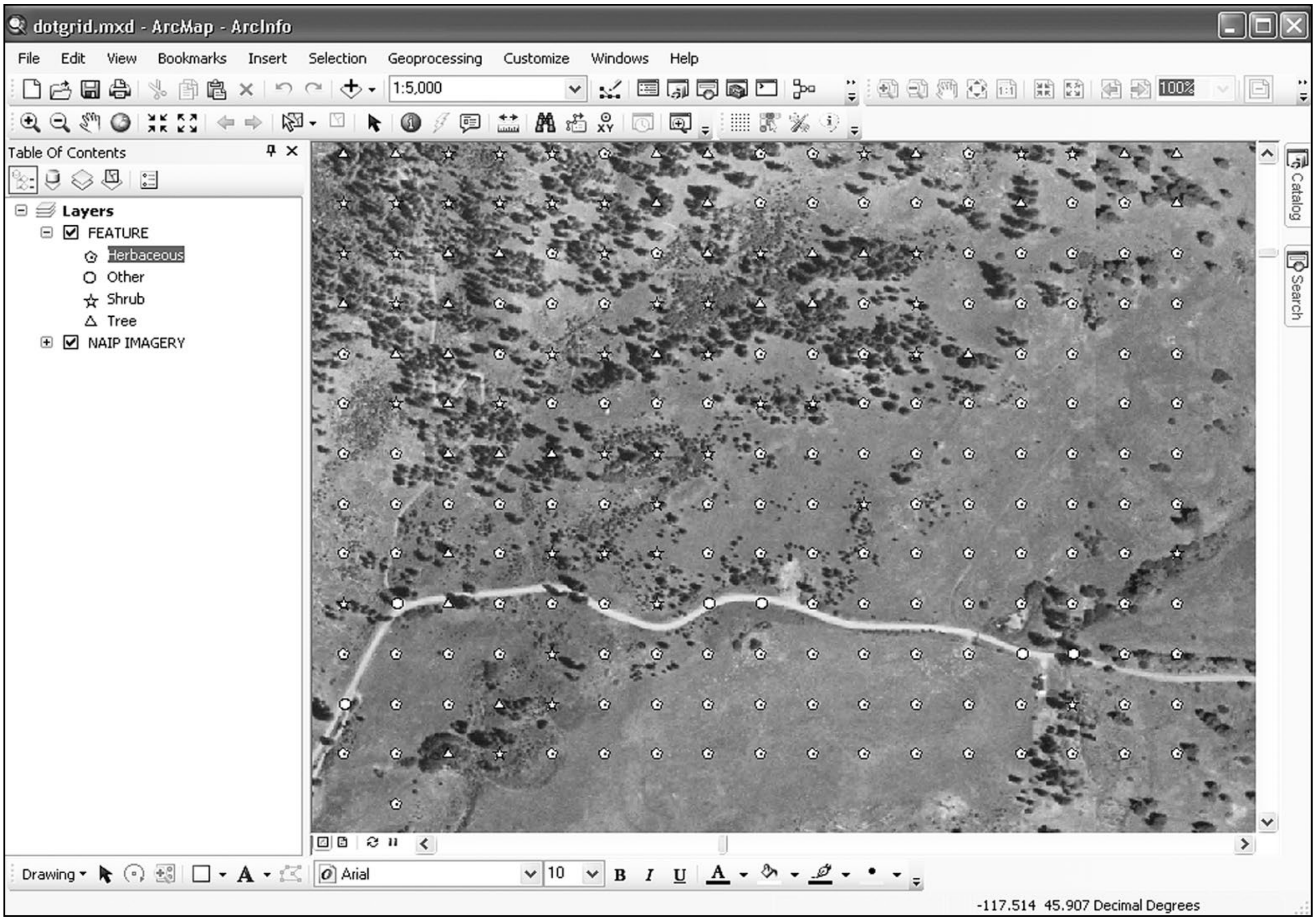
Image Sampling

Direct Image Sampling. Direct image sampling is the process of randomly selecting a discrete set of points or areas from an image to characterize the entire image or an attribute of interest. An example is dot grid sampling, which can be used to estimate canopy cover or to estimate the proportion of the image occupied by different vegetation types. Use the Digital Mylar Image Sampler tool (http://fsweb.geotraining.fs.fed.us/tutorials/digmylar/) or other standard GIS tools in ArcGIS software (figure 4.3) to conduct dot grid sampling in a GIS framework. In addition to dot grids, the Digital Mylar Image Sampler tool offers a variety of templates for estimating vegetation cover attributes from high resolution, digital imagery sources. Use of digital dot grids has become commonplace because of the availability of high-resolution digital imagery (e.g., NAIP).

Dot grid sampling can be part of a multistage sample design that includes field data collection, or it can be a surrogate for field data collection. Maiersperger et al. (2004) successfully tested techniques for monitoring shrub cover in sagebrush communities. Hamilton et al. (2004) used dot grid overlays on digital photos in conjunction with SPOT satellite imagery in a multistage inventory of pine (*Pinus* spp.) mortality.

Nearest Neighbor Imputation. Nearest neighbor **imputation** is a type of image sampling that uses a set of tools to create a spatial data layer of vegetation and other attributes by using sample data to estimate values for unsampled locations. It typically combines field-sampled data, remotely sensed images, and other environmental attributes, such as elevation and precipitation. Imputation is a process of assigning attribute values to each individual pixel or polygon within an area of interest based on attribute values at one to several field-sampled units. Each unsurveyed unit (target unit) is compared with the field-sampled units (reference units), and is then assigned the attribute values of the reference unit(s) most similar to it.

Figure 4.3.—*Example of dot grid sampling with the Digital Mylar Image Sampler tool.*



NAIP = National Agriculture Imagery Program.

To create new data layers using nearest neighbor methods, an individual who is knowledgeable about such methods can extract a set of vegetation habitat attributes from field-sampled data and create a spatial depiction of wildlife habitat across the entire area of interest. Most wildlife habitat monitoring teams will need substantial assistance with these techniques for a variety of reasons. Nearest neighbor methods are a current focus of research and are changing rapidly; therefore, consult with specialists to ensure use of the latest and most appropriate approaches. For example, researchers are currently exploring ways to incorporate LIDAR data when developing imputed map layers. Nearest neighbor algorithms are complex and require intense computing time. Software systems for automating the data management, modeling, and analysis required for developing nearest neighbor maps are increasingly available, but still evolving. Finally, if FIA plots are used as reference units, the user must meet certain standards and criteria to obtain exact plot locations because of the issue of plot confidentiality (section 4.4.1).

Researchers have developed several different nearest neighbor methods, using various distance measures (e.g., Euclidean, Mahalanobis) and algorithms. For Forest Service applications, these methods include *k*-nearest neighbor (*k*-NN; McRoberts et al. 2002),

gradient nearest neighbor (GNN; Ohmann and Gregory 2002), most similar neighbor (MSN; Crookston et al. 2002, Moeur and Stage 1995), and random forest (Breiman 2001). The term *k*-NN is sometimes used generically for all nearest neighbor methods, with the letter *k* representing using more than one reference unit for imputation. Random forest is actually a classification algorithm that was later adapted for imputation by Crookston and Finley (2008). Hudak et al. (2008) provide an overview and comparison of nearest neighbor methods.

Theoretically, nearest neighbor imputation can be used to model nearly any set of vegetation and abiotic attributes (Legendre and Legendre 1998, McCune and Grace 2002, Pielou 1984), although most imputation to date is of forest vegetation attributes because most reference units are forested. Among many examples, researchers have used GNN to map old-growth forest structure (Ohmann et al. 2007) and to model stand density, canopy cover, basal area, tree quadratic mean diameter, stand age, and tree species richness (Ohmann and Gregory 2002). Other researchers have used MSN to model canopy cover, basal area, stand density index, stand height, tree quadratic mean diameter, and total cubic foot volume (Crookston et al. 2002, Moeur and Stage 1995).

Fortunately, the availability of existing imputed map layers is increasing, so it may not be necessary to create new maps. For example, the Pacific Northwest Research Station, in collaboration with Oregon State University (Landscape Ecology Modeling, Mapping, and Analysis team [LEMMA]), has developed imputed maps for several projects, available at http://www.fsl.orst.edu/lemma. The Northern Research Station has developed an atlas of forest resources using GNN, FIA, and MODIS vegetation index data that will soon be available. A national pilot study for nearest neighbor imputation has produced several map products, available at http://blue.for.msu.edu/NAFIS.

INFORMS, a Forest Service decision-support framework (http://fsweb.nris.fs.fed.us/products/INFORMS/index.shtml), imputes forest stand attributes using CSE data as reference units to impute tree lists for unsurveyed stands. The original imputation method for INFORMS was MSN, but users now have options for using other nearest neighbor methods through the software package yaImpute (Crookston and Finley 2008). Imputation is only part of the decision support framework; INFORMS is a stand growth simulator with localized growth simulation formulas written for different geographic areas.

The reliability of imputed vegetation maps is contingent on the quality of the data used to develop them. Reference plots must be randomly selected and of sufficient number to represent the full range of ecological conditions within the area of inference. At midscales and broad scales, the Forest Service primarily uses FIA data as reference units because the data are collected under a systematic random sampling design and thereby avoid sampling bias. Other sources of reference units are regionally intensified FIA grids, such as the CVS in the Pacific Northwest. Adding LIDAR-derived metrics as an additional source of predictor variables improves imputation accuracy (Hudak et al. 2006, 2008; Maltamo et al. 2006), and this technology can be expected to be more widely used as LIDAR becomes more affordable.

Although nearest neighbor imputation provides a powerful tool for producing spatial depictions of wildlife habitat, these mapped products are modeled, not measured, which results in several sources of potential error at different stages in the modeling process (chapter 3). Current research focuses on improving the ability to map and measure changes in vegetation attributes through time. Although accuracy may continue to remain an issue at fine scales and for short time periods, imputed images can generally be used at midscales to broad scales and for time periods that exceed 10 years. Moreover, one can use imputed maps to characterize current conditions, monitor progress toward a desired condition, or ensure that habitat amount remains above a predefined threshold. In these contexts, nearest neighbor imputation can serve as a valuable set of tools for wildlife habitat monitoring.

Image-Based Stratification. Image-based stratification uses imagery and other geospatial data to reduce the variance of the attributes of interest by partitioning the population into homogenous strata. This process is often used to improve the statistical or operational efficiency of a sample (i.e., to improve the sample error of the estimate with a given number of field plots or to achieve a given level of sampling error with fewer field plots). Aldrich (1979) documents using image-based stratification to improve estimates of commercial forest land. McRoberts et al. (2006) provide a summary of FIA post-stratification procedures.

One example of image-based stratification is the Nevada Photo Inventory Project, a pilot effort conducted by Interior West FIA to explore potential gains in efficiency by combining photo-based samples with FIA field-sampled data (Frescino et al. 2009). This general analytical approach has been applied to remote-sensing-based sampling of resources other than forests, such as riparian area estimation (Blackard et al. 2008, Ruefenacht et al. 2005).

Image Counts and Observations. The simplest form of image sampling is to count items of interest. Within the Forest Service, counts include buildings and other structures (see chapter 7 for an example of housing density), water developments, transportation systems, recreation sites (authorized and unauthorized), wildlife use areas, and potential wildlife use areas, such as caves and mines for bats. If the count cannot be automated, owing to the need for human interpretation, generate a random sample of search areas to make inferences regarding the total number within the area of interest. The ability to count features within the image data requires consistent interpretation of the features of interest.

4.6 Conclusions

In this chapter, we present a discrete set of vegetation attributes that, based on experience and literature review, provide useful measures for monitoring habitat for a variety of wildlife species. Although the user will inevitably want to modify these attributes and add new ones, we encourage readers to use standard data-collection methods for all selected attributes. Monitoring by its nature requires remeasurement, and nonstandard methods

will be much more difficult to duplicate in the future. Even more important, interpretation of detected trends requires comparison with trends in other areas. Nonstandard methodologies greatly hamper data comparisons across time and space. In addition, standardized approaches from multiple sources in general are more defensible (they are usually tested and published) and efficient (they have been used repeatedly and tailored to maximize efficiency). Consequently, these methods are more likely to persist through time. Consistent monitoring approaches and data sets that persist for many years are relatively scarce, but they greatly contribute to species conservation.

When applying existing models to monitor habitat, it is important to determine how the vegetation data used for model construction were collected, and to carefully match those methods in subsequent data collection for monitoring. For this reason, we have sought to separate and define closely related terms throughout this chapter, as well as indicate where these differences are important in a monitoring context. For example, canopy cover is not equivalent to canopy closure (section 4.3.2), and which attribute is most appropriate must be distinguished in data collection for monitoring.

In an age of reduced fiscal and personnel resources, along with an emphasis on landscape-level assessments, standardization and consistency in methods and measurements are paramount. Developing cost-effective, standardized wildlife monitoring, whether based on highly individualized habitat models or a suite of selected vegetation attributes, is a daunting challenge. We hope that the methods and resources highlighted in this chapter will help build standardized approaches for monitoring vegetation attributes as part of a wildlife habitat monitoring program. The need for timely, consistent, accurate, and meaningful collection of vegetation data, and its application to monitor wildlife habitat across large areas, is greater than ever.

Chapter 5. Using Habitat Models for Habitat Mapping and Monitoring

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5.1 Objective

This chapter provides guidance for applying existing habitat models to map and monitor wildlife habitat. Chapter 2 addresses the use of conceptual models to create a solid foundation for selecting habitat attributes to monitor and to translate these attributes into quantifiable and reportable monitoring measures. Most wildlife species, however, require a complex suite of multiple resources and environmental conditions. Therefore, monitoring single habitat attributes is often not sufficient to assess the true condition of habitat quality for a species. To quantify and map habitat as an integrated entity, more formal models of wildlife habitat are required. It is beyond the scope of this chapter to provide guidance to managers in building habitat models (e.g., Hegel et al. 2010, Manly et al. 2002, Morrison et al. 2008). Rather, this chapter is designed to help those who have decided to use existing habitat models or published habitat relationships for mapping and monitoring changes in habitat over time. We present five steps in the process of modeling and mapping habitat: (1) select an appropriate habitat model; (2) assemble relevant extant data; (3) apply the selected habitat model to estimate the amount, quality, and spatial distribution of habitat; (4) evaluate the model; and (5) monitor habitat through time.

5.2 Key Concepts

5.2.1 Habitat Models and Population Status

We do not advocate habitat monitoring as a surrogate for estimating the population status of a species. In general, most habitat models account for less than one-half the variation in species density or abundance (Morrison et al. 2008). For example, Cushman et al. (2008b) empirically evaluated a suite of habitat models for multiple species and found that even dozens of habitat attributes from multiple spatial scales were unable to explain most of the variance in species abundances. Even when a model indicates strong associations between the probability of species occurrence and habitat gradients, it will usually fail to explain most variability. Models can be effective in evaluating the

suitability of habitat for the species, however, and for monitoring changes in this suitability over time. It is important to understand this distinction before proceeding with the content of this chapter.

5.2.2 The Relationship Between Habitat Modeling and Habitat Classification

A model is a simplified version of a real object or situation and can take many forms, including verbal descriptions, three-dimensional abstractions, schematic diagrams, and mathematical formulas. Wildlife habitat models represent the presumed or known relationships between a species and the various environmental components that are needed for survival and reproduction. Because habitat selection is based on the perception and behavioral responses of each species (Johnson 1980, Wiens 1976 in Girvetz and Greco 2007), it follows that habitat quality is specific to a species and highly scale dependent (chapter 2, section 2.2.6; Cushman et al. 2010b, Grand et al. 2004). No one set of environmental variables or spatial scales define habitat for all species. Given the individualistic nature of species-habitat relationships, independent habitat models should be produced for each emphasis species. In practice, habitat quality is often defined for species groups, but such practice should consider habitat selection characteristics of each species when forming species groups to ensure acceptable similarity in these factors (chapter 2, section 2.2.5).

Classification is the process of grouping objects into named types or classes based on shared characteristics or their relation to a set of criteria. Habitat classification involves grouping units of area (e.g., pixels, plots, **patches**, and landscapes) into classes based on if the area meets one or more criteria (e.g., minimum or mean values of the habitat attributes). The simplest form of classification is binary (habitat, nonhabitat), but classification can also result in several categories of habitat quality (high, medium, and low), or can be represented as a continuous function.

Habitat classification can be based on a single criterion or attribute (e.g., longleaf pine [*Pinus palustris*]-dominated overstory), but doing so may overestimate habitat because use of a single attribute does not consider other factors that need to be present for the single attribute to serve as habitat. Habitat quality is often a conditional function of the simultaneous conditions of several attributes, such that measuring one or a few attributes does not sufficiently assess their joint contribution toward habitat quality. When more than one attribute is used to classify habitat, a model is needed to describe the range of values for all selected attributes used to define habitat for a species. The output from the model becomes the criterion for classifying habitat.

5.2.3 Habitat Mapping

A habitat map is the spatial representation of a habitat model for an emphasis species or species group. It is not always necessary to create a map to classify or monitor habitat;

the outputs of a habitat model can sometimes be displayed in a table, and subsequent monitoring would focus on changes in the tabular values of the attributes. Habitat models often contain explicit spatial attributes, however, such as patch size or edge ratios, so a map becomes an important representation of the habitat model. In addition, for habitat monitoring to provide guidance for management actions at particular locations, the spatial pattern of habitat conditions must be evaluated. Habitat mapping is usually necessary to accomplish this evaluation.

When we spatially model habitat, our objective is to predict the quality of each location in the landscape as habitat for the emphasis species. This prediction may be either in the form of delineation of patches that are similar in their quality as habitat for the emphasis species or mapping habitat quality as a continuous variable that varies through space, rather than assuming that categories or discrete boundaries exist. Habitat patches are defined by discontinuities in the combined set of conditions identified in the model as affecting habitat use by the species. In many cases, it may be more appropriate to model habitat as a continuous variable, rather than as a mosaic of habitat and nonhabitat patches, given that often habitat quality continuously varies along environmental gradients rather than categorically differing between habitat classes across discrete boundaries (Cushman et al. 2010a, Evans and Cushman 2009, McGarigal and Cushman 2005, McGarigal et al. 2009).

Spatially explicit habitat models present unique challenges because of different data sources and associated map error. Glenn and Ripple (2004) reported significantly different habitat assessments for the same species in the same study area using digital aerial photos compared with satellite imagery. In particular, maps developed from satellite imagery had greater heterogeneity in vegetation than maps developed from aerial photos, resulting in different model outcomes for landscape composition and pattern. In a literature review, Glenn and Ripple (2004) noted that researchers and modelers do not consistently report the source of spatial data, the resolution, and the image processing techniques that are used in habitat models or assessments, so it is difficult to make biologically meaningful comparisons between studies.

When combining spatial data layers to define habitat patches, concerns about data accuracy and precision are compounded, because integrating individual data layers makes error estimation difficult (McGarigal and Cushman 2005; chapter 4, section 4.5.2). In addition, if using spatial layers in which polygons of component attributes have already been defined (i.e., vector data), map unit design, such as a **minimum map unit**, of these component data can limit the precision with which habitat patches can be identified. For example, if a forest management stand layer identifies only forest stands 10 acres (ac) or larger, it will not be possible to identify all habitat patches for a species that is regularly found in patches as small as 2 ac. Alternatively, patch delineation using raster data is limited by pixel resolution. Raster data allow for aggregating pixels into habitat patches based on rules that reflect our understanding of factors affecting a species' habitat selection (e.g., Girvetz and Greco 2007).

5.3 Process Steps for Habitat Mapping and Monitoring

5.3.1 Select an Appropriate Habitat Model

Depending on the intended use, practitioners have used many approaches for developing wildlife habitat models, such as statistically associating species occurrence records with multiple environmental variables, linking habitat to demographic models, and developing broad-scale landscape assessments. The models developed for these various objectives differ in their structure, or modeling framework. Before selecting an existing model for monitoring a species' habitat, learn about the modeling framework and its intended use. Beck and Suring (2009) identified 40 modeling frameworks used for creating wildlife habitat models beginning in the mid-1970s and extending to contemporary times. In addition, Elith and Leathwick (2009) and Hegel et al. (2010) provide thorough reviews of a broad range of modern statistical modeling approaches to predict habitat quality and species distributions. These publications will assist in determining the modeling framework of each model under consideration, and in deciding if it will meet the purpose of monitoring habitat.

A previously developed, locally defined habitat model for an emphasis species is uncommon, but if one exists, and it has a modeling framework conducive for mapping and monitoring habitat, it may be suitable for use. It is typically necessary to evaluate the usefulness of a model developed from another geographical area or time period. In general, it is not scientifically defensible to extrapolate findings beyond the scope of inference of a study, and the same principle applies to models. When a model developed for one area is applied to a different geographical area, the model's applicability is unknown until tested. The accuracy and error rates relevant to the original landscape do not necessarily apply to a new landscape, particularly when the new landscape differs in appreciable ecological ways, in terms of climate, topography, vegetation, prevalent disturbance regimes, and human influence.

To evaluate if a model from another geographic area can be applied locally in the context of habitat monitoring, first determine if it is based on empirical data or expert opinion, and if error rates and model accuracy were assessed using independent data. Second, determine if the model variables match the environmental conditions present in the area to which you will apply the model. Third, determine if sufficient data on the value and distribution of each model variable exist for the local study area. To apply a model to predict habitat quality, all of the independent variables that define the model should be measured using appropriate methods, at appropriate scales, and using sample sizes that ensure sufficient precision of statistical inference (chapter 3).

Finally, consider the distance between the local monitoring area and the location in which the model was developed and determine if the ecological dissimilarity between the two areas is too great to reliably use the model. Occasionally, it is necessary to use

professional judgment and all available local information to modify the range of values for certain model attributes to reflect local conditions. For example, it might be necessary to reduce the range of canopy cover or tree diameter values to reflect conditions in a locale that are more xeric than where the original model was created. Such modifications will require validation by comparing model predictions with actual presence or abundance of the emphasis species in the area where managers will apply the model (section 5.3.4).

If several models are available from different geographic areas, a more rigorous approach is to conduct a meta-analysis, which is an analytical process that combines the habitat attribute values for all of the models and creates a generalized model. The task of conducting such a meta-analysis is not trivial, but will result in a scientifically defensible model (Gates 2002, Gurevitch and Hedges 1993, Hedges and Olkin 1985). Major challenges in meta-analysis include reconciling results of models that use different predictor variables, or are conducted at different spatial scales. Conducting formal meta-analysis of published models and habitat relationships will generally provide the most reliable inferences about the habitat factors of importance to the species of interest and the values of their parameters in a predictive model.

5.3.2 Compile Extant Data Required by the Selected Habitat Model

The data that need to be assembled will be governed by the nature of the habitat model. Often a habitat model will incorporate habitat attributes from a range of scales (e.g., Cushman and McGarigal 2002, Grand et al. 2004, Thompson and McGarigal 2002). For example, it may include plot-level attributes such as canopy cover and coarse woody debris, as well as patch-level attributes, such as vegetation cover type or patch size. It also may include landscape-level variables, such as the percentage of the local landscape in each cover type, the **contrast-weighted edge density**, **contagion**, or other measures of fragmentation (chapter 6 further addresses landscape pattern attributes and metrics). A well-conceived model will specify a list of the plot-, patch-, and landscape-level variables of interest and the spatial scale at which the landscape-level variables should be calculated (e.g., Grand et al. 2004, Thompson and McGarigal 2002).

If the habitat model includes only patch and landscape attributes, and if suitable land cover maps exist that depict the cover types included in the model with sufficient accuracy and at the correct spatial scale, then simply compile existing Geographic Information System (GIS) data (chapter 4, table 4.6 describes sources of existing vegetation maps) and apply the model directly.

Several recent examples of habitat suitability models are based entirely on attributes that can be measured from GIS data. For example, Larson et al. (2003) created GIS-based habitat suitability models for 12 species in southern Missouri, and Rittenhouse et al. (2007) created GIS-based habitat suitability models for 10 species in the Central Hardwoods region of the Midwestern United States. In both examples, the authors translated ecological requirements of the emphasis species into attributes that were easily obtained from a

combination of inventory data from a local national forest, Forest Inventory and Analysis (FIA) data, land cover data, and state Gap Analysis Program data (http://gapanalysis.usgs.gov/gap-analysis/). The added advantage of a GIS-based habitat suitability model is that it allows for the incorporation of landscape-level attributes that are typically not part of a traditional, field-based model.

If the habitat model includes fine-grain attributes that need to be field-sampled, we recommend using a grid of vegetation plots over the entire study area to obtain these data. The FIA program is the most extensive source of existing plot-level data for habitat monitoring on forested lands (chapter 4, section 4.4.1), and these data have proven useful for deriving habitat attributes for a number of wildlife species. Several recent papers have shown the utility of the FIA system to provide large representative samples of quality environmental data for wildlife habitat modeling (Carroll et al. 2010, Dunk and Hawley 2009, Zielinski et al. 2010). Users need to evaluate if existing FIA data are sufficient at the scale of the habitat monitoring program, however, and at a scale appropriate for the emphasis species. In some instances, a higher spatial density of sampling points will be required to produce reliable habitat models over spatial extents the size of a national forest or smaller. Some Forest Service regions have intensified the FIA grid for analyses over smaller areas or at finer resolution. These intensified FIA grids are particularly valuable in obtaining higher resolution environmental data at the plot level for habitat modeling. Bear in mind, however, that FIA data eventually have their limitations even using grid intensification. The data may not be applicable for monitoring certain species whose habitat consists primarily of fine-grain attributes that are not measured at a sufficient scale using FIA protocols.

Whether using plot-, patch-, or landscape-level attributes, strive to use data sources and spatial scales for habitat monitoring comparable to those used in developing the model. If an important attribute for the emphasis species is not included in a model because of lack of data, or is derived from poor quality sources such that errors are high or from sources of very different spatial scales, then model results will be of unknown value, difficult to interpret, and harder to defend.

Specialized modeling approaches were developed to integrate habitat data derived from different spatial scales into composite analysis. For example, hierarchical variance partitioning (Cushman and McGarigal 2002) allows for quantifying the independent contributions of plot, patch, and landscape level variables to habitat quality. Similarly, hierarchical and multilevel models (e.g., Wilson et al. 2010) allow for robust multiscale analysis. As habitat quality is very often a product of multiple environmental variables at several scales, such hierarchical and multilevel modeling approaches are particularly valuable.

5.3.3 Apply the Selected Habitat Model

Although there are numerous ways for mapping habitat model outputs, two general approaches involve applying the model to either GIS coverages or plot data, followed by

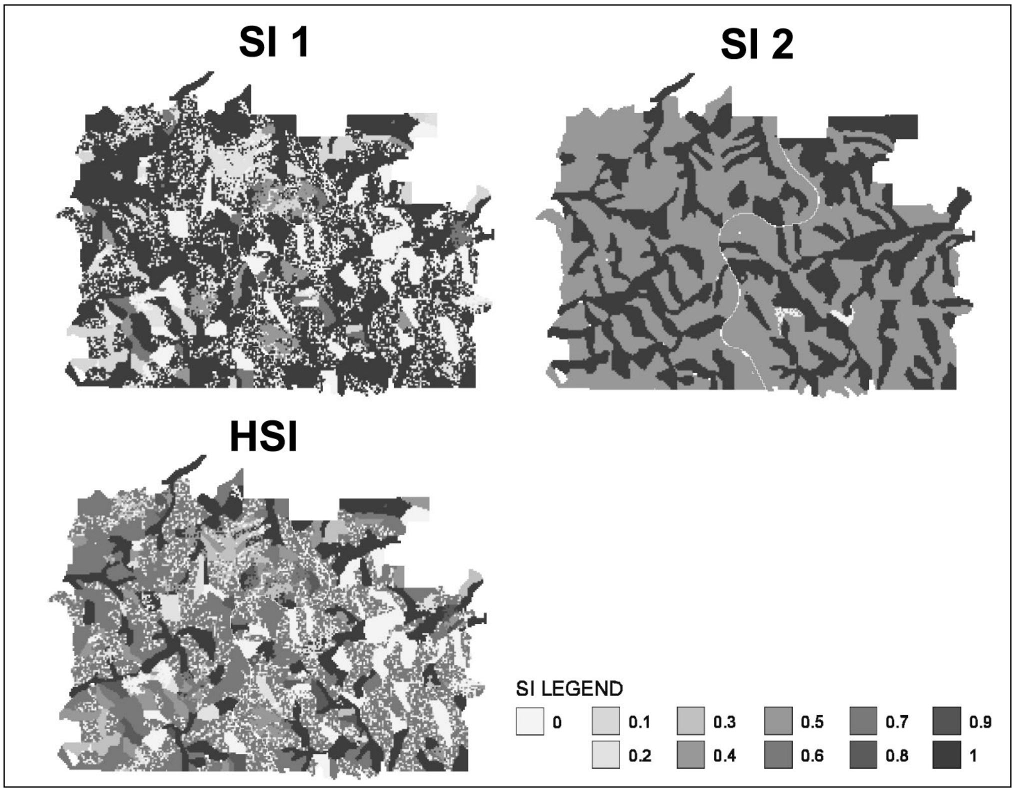
creating a habitat map through statistical modeling. The selected approach depends on the habitat model chosen and the extant data available for the monitoring program. When variables in the habitat model are available in extant or easily derived GIS coverages, the first approach applies. This approach involves simply applying the habitat model to the pixels (or polygons) in the GIS coverages to predict the occurrence of habitat (present/absent) or habitat quality (e.g., low, medium, or high, depending on the model output) at each pixel (or polygon). If some or all of the variables in the habitat model are not available as existing spatial layers throughout the area of interest but are available on a sample of ground plots, then the second approach applies. This approach involves applying the habitat model with data for each plot to calculate predicted habitat quality for the plot, then modeling these predictions as mathematical functions of extant GIS coverages across the monitoring area to produce a continuous habitat map. Hierarchical and multilevel statistical modeling approaches will likely be necessary to reliably combine plot and GIS data in this latter approach (Wilson et al. 2010).

In either case, applying the model will classify plots or pixels as habitat/not habitat in a binary classification, or as some measure of habitat quality in a continuous index or ordinal classification. To simplify the discussion, we describe an example using a binary habitat/not habitat classification. Depending on the nature of the model, several ways are available to implement this functional relationship. Typically, it will involve applying the mathematical function underpinning the model to the habitat attributes measured at each plot or pixel. Some common tools used to develop habitat models include linear regression, **logistic regression**, and classification and regression trees (Hegel et al. 2010). For more complex models, we advise using the same software tools to produce model predictions as were used in constructing the original habitat model. By applying the function to the observations (plots/pixels), the model will output predicted habitat for each plot.

Approach 1: Apply the Habitat Model to GIS Coverages and Map Through a Heuristic or Statistical Model

This first approach is an option in which all variables (or suitable surrogates) within the selected wildlife habitat model are available in complete spatial coverages and at the appropriate scale for the area defined in the habitat monitoring program. It is the simplest and least expensive method of mapping habitat, and relies on existing or easily derived map products that correspond closely with variables in the chosen wildlife habitat model. Examples of such map products include existing vegetation maps produced following the direction included in the Existing Vegetation Classification and Mapping Technical Guide (Warbington 2011). An easily derived habitat map might include data elements such as elevation and aspect from digital elevation models. These two types of map products can be combined using rule-based models in a GIS if known relationships exist between wildlife habitat and multiple landscape characteristics (figure 5.1).

Figure 5.1.—*Simple rule-based habitat models can be created and displayed in a Geographic Information System, such as this habitat suitability index (HSI) model for the southern red-backed salamander (*Plethodon serratus*) in the Mark Twain National Forest in southern Missouri. Suitability index (SI) 1 assigns greater suitability to pixels located in older stands, and SI 2 assigns greater suitability to pixels in more mesic land types as defined by slope and aspect. The HSI score is the geometric mean of the two SI values (adapted from Larson et al. 2003).*



Approach 2: Apply the Habitat Model to Plot Data and Map Through a Statistical Model

This approach is appropriate when some or all of the variables in a habitat model are not available as continuous coverages (i.e., wall-to-wall) but can be measured or derived only on a sample of locations throughout the monitoring area. In this case, use plot data (e.g., FIA data or data collected specifically for the monitoring program) to derive estimates of the plot-level attributes in the model and then predict habitat quality for each plot within the monitoring area by applying the model. Such cases will often use hierarchical or multilevel models (Wilson et al. 2010) because they combine habitat variables from different sources and different scales (such as FIA plots, digital elevation models, and other GIS coverages). Care must be taken to ensure that the sample of plot data is sufficient to reflect the distribution and condition of habitat across the analysis area. Generally speaking, for reliable application of habitat models, the analyst will require dozens to hundreds of plots to produce sufficiently precise estimates of habitat condition across the analysis area. The number of plots will depend on the size of the analysis area,

the heterogeneity of habitat, and the complexity of the species-habitat relationship. Much larger samples of plots will be required for large, heterogeneous areas for species with complex habitat relationships.

After the habitat model has been applied to all plots (i.e., each plot has been labeled as habitat or nonhabitat) predictions can be made about the spatial distribution of habitat throughout the monitoring area. Therefore, the next step is to build a statistical mapping model to relate predictions of habitat presence or quality on the plots to coarser scale variables, such as topographically derived variables, remotely sensed imagery of vegetation, and derived products, which are available across the monitoring area. This mapping model can then be used to predict habitat quality across the area of interest.

Numerous statistical models can be used to accomplish the task. These models will vary in the level of effort required to generate them as well as their ability to successfully predict habitat quality. We describe two methods in the following section to illustrate a range of options for using plot data to build a habitat map for monitoring.

Simple Post-Stratification Model

This very simple mapping model involves stratifying the landscape based on existing GIS coverages related to variables in the habitat model. For example, strata might include high versus low elevation based on digital elevation models, or conifer versus hardwood versus nonforest based on an existing vegetation map. Similarly, strata might be defined by a combination of GIS coverages such as aspen (*Populus tremuloides*) stands at high elevation on southerly slopes, pinyon-juniper (*Pinus-Juniperus* spp.) stands adjacent to ponderosa pine (*P. ponderosa*) in certain geographic regions, or other combinations. The plots that fall in each of the strata can then be used to generate estimates of the proportion of habitat contained in each stratum, which is then mapped along with the standard error of these estimates. From a modeling perspective this approach is equivalent to modeling habitat/not habitat (observed or assigned to the plots) as a simple linear function of a suite of categorical predictor variables (strata). Ultimately, the prediction for any given pixel is simply the mean of the plot values (proportion of presences) for the stratum in which the pixel is found. For example, if 60 of 100 plots in the stratum were classed as habitat, every pixel in that stratum receives a score of 0.6. This process does not usually produce the most visually appealing maps, because a broad brush is applied to paint categories of proportion of expected habitat within each stratum, rather than providing a continuous prediction. These simple maps are directly tied to estimates produced by a forest inventory, however, which can be very helpful when looking for significant changes in habitat quantity or quality through time, or defending estimates in court.

Flexible Statistical Model

While the post-stratification approach described previously can capture much of the relationship between extant GIS data and observations of habitat quality on plots, more detailed information could be obtained by using more flexible statistical models

to describe that relationship. When using flexible statistical models, the assignment of habitat/not habitat to inventory plots serves as the response variable, while plot characteristics, defined by ancillary spatial data sets (such as vegetation, topography, or other remote sensing products), are the explanatory variables. A variety of statistical modeling techniques can be used, including extensions to linear models (e.g., multiple linear regression: logistic regression, generalized linear models), generalized additive models, tree-based approaches such as classification and regression trees (Guisan and Thuiller 2005), Random Forests, Maxent (Phillips et al. 2006), or nearest neighbor imputation methods (chapter 4, section 4.5.2). Selected models can then be applied to all the ancillary data sets to produce a map of probability of habitat occurrence. The analyst then chooses a threshold in that probability surface based on application-specific criteria, above which a pixel is labeled as habitat.

Multiple logistic regression has emerged as the dominant statistical modeling tool in use today for developing single-species habitat relationships models (Hosmer and Lemeshow 2000). The logistic regression approach has a number of advantages. For example, logistic regression is relatively robust to departures from normality, produces easily interpretable models in which the relative effect and sign of each variable are readily apparent, and can be used in well-established multimodel and information theoretic approaches to identify the best alternative model within a large collection of candidate models (Burnham and Anderson 2002). Logistic regression is less effective, however, when species-environmental relationships are nonmonotonic (i.e., they do not consistently follow a mathematically functional relationship) or multimodal (i.e., the mathematical relationship has more than one peak). In particular, like all expressions of the generalized linear model, logistic regression is not appropriate when species express a multimodal response to multiple environmental gradients. In cases in which species-environment relationships are strongly nonlinear or multimodal, Random Forests has emerged as one of the more powerful prediction tools (Evans and Cushman 2009, Hegel et al. 2010). The major limitation of Random Forests is the difficulty in interpreting the species-environment relationship expressed in the model in terms of functional relationships using environmental variables. Maxent is an alternative modeling approach, which performs well when species-habitat relationships are complex and nonlinear (Phillips et al. 2006).

When compatible models must be built to predict habitat quality for multiple species, nearest neighbor imputation methods are a good choice (chapter 4, section 4.5.2; Ohmann and Gregory 2002). While maps in this latter case may not be as accurate for individual species, covariance between habitat quality for multiple species can be preserved.

For further understanding of these topics, we recommend the following papers.

- Cutler et al. (2007) provide an overview of Random Forests for classification problems.
- LeMay and Temesgen (2005) provide a brief summary of common imputation methods.
- Freeman and Moisen (2008) provide criteria for converting a probability surface into a presence/absence map.

5.3.4 Evaluate the Model and Provide Measures of Uncertainty

It is unwise to apply a habitat model developed elsewhere and assume that it will accurately reflect the habitat relationships and predict the habitat quality of a species of interest. Applying models developed in different regions may produce biased estimates of habitat quality and lead to poor management choices. Multiple court cases have indicated that for models to be defensible when challenged in court, they must be empirically validated. In actuality, a model can never be validated, in much the same way that a hypothesis can never be falsified. Johnson (2001) recommends that we evaluate models rather than validate them, because validation is an absolute term (something is either valid or not), whereas evaluation is a relative term.

The purpose of evaluation is to determine if the model is useful and if the model accuracy is sufficient for our needs. In addition, scientific defensibility requires demonstration that the model applies to the emphasis species in the analysis area. Therefore, evaluating the predictions of a habitat model by collecting independent data on the abundance or occurrence of the emphasis species in the monitoring area is important. Only by formally comparing predictions with observations of animals will it be possible to evaluate habitat model performance and produce rigorous estimates of error rates, which in turn are critical to legal and scientific defensibility of model predictions. In some instances, an existing model will be found to perform poorly when applied to a new geographical area. In such cases, we urge managers to seek partnerships with researchers to develop a new habitat model for the emphasis species based on local conditions and habitat relationships. Without evaluation, the performance of a model developed elsewhere to novel conditions will be unknown.

It is beyond the scope of this chapter to provide a complete description of the procedures for model evaluation. Generally speaking, however, such approaches involve collecting a large (in a statistical sense) and representative sample of abundance or occurrence data for the emphasis species in locations for which the model has produced predictions of habitat quality or quantity. When the model is applied to a collection of plots, then a new set of plots in the same area becomes the population of locations to be sampled for the emphasis species. If the model produces landscape maps, then each pixel is a potential sample location, and a sample is selected by stratifying across predicted habitat quality and collecting species occurrence data on as many widely distributed points as possible. The analysis then proceeds to compare predictions of habitat with observed occurrences in the validation sample. An error matrix is produced, describing omission and commission errors, accompanied by other statistical measures of model accuracy.

Although species occurrence data are essential for evaluating a habitat model, the opposite is not the case: the presence of habitat and/or habitat quality is not always a predictor of species' abundance (section 5.2.1,). Moreover, abundance is often a poor proxy for population performance (Van Horne 1983). The notion that habitat monitoring can serve as a proxy for population monitoring is based on two assumptions. First, that a

threshold percentage of each type of habitat will ensure viability, and second, that the methodology used for monitoring habitat is sound. As referenced in section 5.2.1, Cushman et al. (2008b) empirically evaluated several of the key assumptions of the habitat proxy on proxy, including if habitat is a proxy for populations and if easily mapped and monitored habitat elements are proxies for habitat requirements for forest birds. Their results indicate that habitat relationships models, even those based on dozens of variables from multiple spatial scales, are unlikely to explain most of the variance in species abundances. Thus, the suggestion that habitat models can be used as surrogates for population monitoring to satisfy the viability requirement is dubitable. Secondly, they found that commonly used habitat elements derived from classified vegetation maps are equivocal proxies for habitat requirements, such that only a small fraction of species abundance patterns can be predicted based on the amount of mapped vegetation types in a landscape. Therefore, we caution managers that obtaining a desired condition of certain habitat attributes does not guarantee a desired population level for a species that depends on that habitat.

Population monitoring is essential for evaluating the assumed relationships between habitat and population status. Population and habitat monitoring should be considered together in forest planning (Cushman et al. 2008b, Cushman and McKelvey 2010, Noon et al. 2003, Schultz 2010). We strongly advocate for rigorous population monitoring for emphasis species to evaluate the link between coarse (vegetation monitoring) and fine (population status of focal species) elements.

5.3.5 Monitor Habitat Through Time

Select the monitoring intervals early in the monitoring design phase, i.e., how frequently to recalculate habitat quantity and quality. This decision is usually made on the basis of planning requirements. For example, a planning rule may require reevaluating ecological conditions within a plan area with respect to desired conditions statements every 5 years. Several considerations must take precedence, however. First, model predictions, strictly speaking, are valid only for the time that the data were collected. Given the financial and logistical limitations of the agency, plot data and GIS coverages are typically updated only occasionally and at long intervals. Therefore, ensure that all variables used in a model are of the same vintage and that, before recalculating habitat quality, all variables were updated using new measurements. If a model is rerun on data that include measurements from previous time periods, then the output will be less interpretable or defensible. Managers need to advocate for required resources to ensure a regular update of the environmental data for habitat models that are used for monitoring.

Another step in the monitoring design phase is to choose a metric to assess changes, spatially and statistically. If the model is applied to a collection of plots, then the product is predictions of habitat quality for those plots. Over multiple dates one obvious index to monitor change is the proportion of plots meeting criteria for habitat classes (such as habitat versus nonhabitat, or high, medium, or low quality habitat). As shown by the FIA

program, when using large samples, proportion statistics can produce powerful estimates of the amount of habitat present in the monitoring area. When the model is applied to produce a map, then landscape pattern analysis is the appropriate approach to monitor change in habitat area and pattern (chapter 6). If habitat can be mapped accurately, landscape pattern analysis provides a large number of informative metrics to quantify habitat in the monitoring area, such as **connectivity**, fragmentation, and other spatial attributes of habitat pattern (chapter 6).

The goal of habitat monitoring is to track changes in the amount or quality of habitat in a plan area over time. Comparable and consistent models and environmental data as model inputs are essential. A conundrum exists, however, because adaptive management requires the continual improvement of management by incorporating improved knowledge of ecological relationships and the structure of the environment (Cushman and McKelvey 2010). Therefore, both models and data sources are expected to change over time, as additional research is conducted and incorporated into the localized meta-analysis, and as improved and updated inventory is conducted and new technologies for sensing, measuring, and mapping environmental variables are developed. Using habitat models as monitoring tools, therefore, will always be somewhat equivocal because of the impossibility of perfectly separating the effects of changing environmental conditions from changing models and data over time.

One simplistic way to avoid this dilemma is to fix a current model, data sources, scales, and methodologies and hold these items constant into the future to produce strictly comparable model predictions. Given the insufficiency of most current models, lack of extensive and accurate environmental data at multiple spatial scales, and lack of empirical data relating species to their environments, however, this approach of fixing model inputs cannot be accomplished for most species in most landscapes. Therefore, it is essential to adopt methods that flexibly incorporate improved knowledge.

The best approach for effective use of models in habitat monitoring is to keep detailed, formal documentation of the source of the model used, as well as details about the variables, the sources and vintage, spatial scale, and accuracy of data (chapter 9). This record is essential so that when the habitat model is reapplied in the future, often by new personnel, it will be possible to develop a model that will be as comparable as possible in its predictions to that used in the previous time period.

5.4 Conclusions

Most wildlife species require a complex suite of multiple resources and environmental conditions. To quantify and map habitat as an integrated entity more formal models of wildlife habitat are required. If a previously developed, locally defined habitat model for an emphasis species exists, and it has a modeling framework conducive for mapping and monitoring habitat, then feel fortunate and use it. More typically, it will be necessary

to evaluate the usefulness of a model developed from another geographical area or time period. It is essential to evaluate if a model from another geographic area can be applied locally in the context of habitat monitoring. If several models are available from different geographic areas, conducting formal meta-analysis of published models and habitat relationships generally will provide the most reliable inferences about the habitat factors of importance to the species of interest and the values of their parameters in a predictive model.

After a model is selected the next step is to compile data required by the selected model for the extent of the analysis area. If an important variable for the emphasis species is not included in a model because of lack of data, or is derived from poor quality sources such that errors are high or from sources of very different spatial scales, then model results will be of unknown value, difficult to interpret, and harder to defend when used in a monitoring program. The next step is to apply the selected habitat model. Application of the model will classify plots or pixels as either habitat or not habitat in a binary classification, or as some measure of habitat quality in a continuous index or ordinal classification. After predictions are obtained it is essential to evaluate model performance and uncertainty. Scientific defensibility requires demonstration that the model applies to the emphasis species in the analysis area. Evaluating the degree to which the model predicts species occurrence in the analysis area is critical for legal and scientific defensibility. Evaluating the predictions of a habitat model by collecting independent data on the abundance or occurrence of the emphasis species in the monitoring area is important. The final step is to use the model to monitor habitat through time.

The presence of habitat and habitat quality are not always good predictors of species abundance (Cushman et al. 2008b), and abundance is often a poor proxy for population performance (Van Horne 1983). We caution managers that observing a desired condition of certain habitat elements does not guarantee a desired population level for a species that depends on that habitat. We also strongly advocate for rigorous monitoring of the populations of emphasis species to confirm the link between predicted habitat and actual population status.

Chapter 6. Landscape Analysis for Habitat Monitoring

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6.1 Objective

The primary objective of this chapter is to describe standardized methods for measuring and monitoring attributes of landscape pattern in support of habitat monitoring. This chapter describes the process of monitoring categorical landscape maps in which either selected habitat attributes or different classes of habitat quality are represented as different **patch** types, using maps produced by the modeling approaches described in chapter 5. Although many alternative models of landscape structure exist, such as landscape gradients (McGarigal and Cushman 2005) and graph models (Urban et al. 2009), we focus on categorical landscape maps because of their familiarity to managers, long history of use in landscape ecology, and the fact that land management agencies largely base planning and analysis on this kind of representation of landscape structure (McGarigal et al. 2009). The salamander habitat monitoring plan in chapter 10, however, provides an example of a graph model (i.e., a model of habitat connectivity for **metapopulation** structure).

This chapter focuses on landscape pattern analysis as part of monitoring habitat for emphasis species. To use landscape metrics for model development, see Cushman and McGarigal (2002), Grand et al. (2004), and Thompson and McGarigal (2002). This chapter presents key issues that should be addressed to ensure meaningful landscape analysis, and it reviews the steps to be followed in conducting and interpreting landscape analysis in the context of habitat monitoring. We emphasize the use of FRAGSTATS (McGarigal et al. 2012) as a primary tool to quantify the composition and structure of habitat in categorical maps, given that FRAGSTATS is freely available, widely used, user friendly, and well documented, and it provides comprehensive analysis ability for categorical landscape maps (http://www.umass.edu/landeco).

6.2 Key Concepts

6.2.1 Landscape Analysis and Adaptive Management

Adaptive management works by specifying resource goals, conducting management for the purpose of creating or maintaining these desired conditions, and monitoring results

to confirm that the system is behaving as expected and that resources are moving toward the desired conditions (Holling 1978, Walters 1986). This approach presupposes that the state of the system is well known across time. For tracking the trajectories of ecological systems, monitoring provides the key data on condition and direction of the system necessary to guide incremental adjustments to management. As a result, monitoring resource condition and trend has greatly elevated importance under the adaptive management paradigm. Cost-effective, timely, representative, and broad-scale monitoring of multiple resources is the foundation on which adaptive management depends. Adaptive management literally cannot be adaptive without these data.

The adaptive management paradigm sets high priority on developing ongoing analyses, based on monitoring, to continually adjust or change land management planning decisions and thereby efficiently move toward desired conditions (Cushman and McKelvey 2010). Multiple resource monitoring is critical for establishing ecologically meaningful and appropriate desired conditions, evaluating current conditions relative to these objectives, and evaluating effects of management over time to guide adaptive changes to the management regime.

In the Forest Service, adaptive management is addressed through the land management planning process. The Land and Resource Management Plan (LRMP) provides a formal declaration of desired conditions that are implemented through goals, objectives, standards, and guidelines. LRMP objectives are measurable and can provide quantifiable threshold values for triggering a reevaluation of management. The LRMP monitoring plan enables managers to determine whether threshold values have been met. In the context of habitat for specific species, the LRMP might include objectives with specific habitat conditions, such as structural components, patch geometry (e.g., patch size and amount of edge versus core), and spatial context (adjacency to other habitat and connectivity). The LRMP monitoring plan would then use habitat attributes to quantify condition and trend relative to objectives and threshold values.

6.2.2 What Is a Landscape?

A landscape is a heterogeneous model of a region of the physical world in which certain attributes of the environment are represented spatially as linear features, patches, points, or continuously varying surfaces. Depending on the question of interest, a landscape may be of any size. For example, planning landscapes are usually watersheds and management zones measured at the scale of tens to thousands of acres. In contrast, ecological research focused on mycology or microorganisms might define landscapes of interest at the scale of a few square feet. The size and scale of a landscape are therefore direct functions of its purpose and, in the context of habitat monitoring, the landscape must also reflect a meaningful spatial extent and grain for the emphasis species.

Regardless of the size, landscapes are composed of elements—the spatial components that make up the landscape. A convenient and popular model for conceptualizing

and representing the elements in a categorical map pattern is known as the **patch mosaic model** (Forman 1995). Patch boundaries represent discontinuities in environmental states that are large enough to be perceived by the organism of interest or that are relevant to the ecological phenomenon under consideration (Wiens 1976). Therefore, patches must be defined relative to the emphasis species being monitored.

The patch mosaic model is most powerful when heterogeneous environmental conditions can be clearly defined and accurately mapped as discrete patches and when the variation within a patch is deemed relatively insignificant and can be ignored. For example, breeding habitat for many pond-breeding amphibians can be clearly defined and delineated with relatively little uncertainty, and the variation in habitat quality within ponds is insignificant compared with differences among ponds or between uplands and ponds. Other applications of the patch mosaic model include forested woodlots embedded within a contrasting agricultural or urban landscape, fields in a forested landscape, and stands of deciduous trees within a coniferous forest. In general, whenever disturbances (natural or anthropogenic) either create discrete patches or leave behind discrete remnant patches, the patch mosaic model is likely to be useful.

An alternative to the patch mosaic model is the gradient landscape model, in which landscapes are viewed as spatially complex assemblages of elements that cannot be simply categorized into discrete patches, so that heterogeneity is represented instead as a continuous function (Cushman et al. 2009, Evans and Cushman 2009, McGarigal et al. 2009). For example, habitat for elk (*Cervus canadensis*) may be a function of the juxtaposition of different land cover types that provide forage and cover, influenced by the proximity of roads and human disturbance. These conditions likely vary across the landscape as continuous gradients rather than discrete patches, so a gradient mosaic model would be the more appropriate depiction of elk habitat. Unfortunately, quantitative methods for assessing gradient landscape structure are still under development (e.g., McGarigal et al. 2009) and are therefore not included in this technical guide. The gradient model of landscape structure offers exciting new opportunities to explore landscape pattern-process relationships, however, in potentially more meaningful methods than the traditional patch mosaic approach (McGarigal et al. 2009).

A third representation of landscape structure is connectivity across landscape elements, using network analysis (Urban et al. 2009). Network analysis portrays the functional relationships of nodes and links in a graph. In the context of habitat, graph nodes represent habitat patches or local populations, and links represent functional connections among habitat patches. A central task in network analysis is to find the shortest path between any pair of nodes in a graph (Urban et al. 2009), which can be used to characterize dispersal or migration pathways or connectivity among metapopulations.

In this chapter, we address landscape structure only in reference to the categorical patch mosaic model because of its familiarity to land managers, its ease of analysis with commonly available tools, and its appropriateness for representing patterns of

habitat patches across landscapes. Simply put, habitat at the landscape level is typically represented as patches that are classified as habitat or nonhabitat, or as differing levels of habitat suitability. As mentioned previously, however, the salamander example in chapter 10 incorporates graph theory as part of the design for monitoring habitat connectivity.

6.2.3 What Is Habitat at the Landscape Level?

The habitats in which organisms live are spatially structured at multiple scales, and these patterns interact with organism perception and behavior to drive the processes of population dynamics and community structure (Johnson et al. 1992). For all species, habitat must have the following:

- Sufficient size and juxtaposition of resource patches to support reproduction.
- Sufficient size and proximity of habitat patches to facilitate dispersal.
- Sufficient size and proximity of patches to maintain metapopulation structure, if that is a characteristic of the species.

Each of these landscape functions operates at a different scale, but together, they define an organism's habitat at the landscape level.

At any scale, anthropogenic activities (e.g., urban development and timber harvest) can disrupt the structural integrity of landscapes through habitat loss and fragmentation. This disruption may reduce habitat area below critical occupancy thresholds and increase habitat fragmentation such that movements are impeded (Gardner et al. 1993) or unwanted movements of organisms are facilitated (e.g., predators or invasive species) (see chapter 7). The altered landscape structure can compromise the ability of a landscape to function as habitat at one or more scales. A full review of the implications of landscape pattern and habitat fragmentation on species' habitats and populations is beyond the scope of this chapter. Briefly, however, habitat fragmentation has been shown to decrease dispersal (deMaynadier and Hunter 2000, Gibbs 1998,), increase mortality (Carr and Fahrig 2001, Fahrig et al. 1995), and reduce genetic diversity of wildlife populations (Cushman 2006), thereby increasing extinction risk (Lande 1988, Tallmon et al. 2004).

Nonspatial habitat models are unable to reflect the major effects of landscape pattern in influencing the distribution and abundance of organisms. By contrast, landscape analyses allow for assessment of spatial pattern, isolation, and fragmentation of habitat patches relative to the ecological and demographic characteristics of the species.

6.2.3 The Importance of Scale

Scale is critical in defining a landscape, because pattern and its effect on process vary with scale. Thus, the scale of a landscape is inseparable from its definition. One cannot define a landscape without explicit consideration of its scale. At least two critical components of scale as it pertains to landscape definition exist: spatial scale and **thematic resolution**.

Spatial Scale

Several important considerations relating to spatial scale strongly influence results of landscape pattern analysis. The most important attributes are grain and extent (chapter 2, section 2.2.6). Both grain and extent affect landscape pattern analyses in fundamentally important ways. Many papers have investigated how changing spatial grain (Turner et al. 1989, Wickham and Riitters1995, Wu 2004, Wu et al. 2002) and landscape extent (Saura and Martinez-Millan 2001, Shen et al. 2003) affect landscape metrics. As a result of this rich body of work, extensive information is available about the scale dependency of landscape metrics in relation to grain, extent, and classification scheme of categorical landscape maps.

Grain sets a lower boundary on the range of detectable patterns. Extent sets an upper boundary on the extent of detectable pattern and defines the scope of inference of the analysis (see chapter 3, section 3.3.1). From the standpoint of habitat monitoring, the most important consideration of spatial scale relates to comparing analyses from different time periods. To be comparable, habitat maps from two or more analyses must share several characteristics, including (1) comparable thematic resolution (i.e., classification definitions are the same), (2) use of the same or highly similar data sources to provide comparable information (e.g., radiometric and spectral resolution in a remotely sensed imagery), and (3) comparable spatial scale in terms of both grain and extent. If any of these are inconsistent between analyses, then it is impossible to determine whether observed differences between habitat maps are because of differences in map characteristics or ecological differences. The issue of comparable data cannot be overstressed. Seemingly small differences in grain or classification definition can lead to widely divergent estimates of even simple attributes such as amount of forested area.

In general, studies conducted over large spatial extents tend to have coarse grain and low thematic resolution because of the difficulty of conducting fine grain analysis over large regions. Care must be taken to ensure that thematic resolution and spatial scale are appropriate for the emphasis species, however. These attributes are critical to the underlying habitat model (chapter 5) and must be specified correctly relative to the ecology of the particular organism or predictions will fail to reflect the true habitat conditions for the species (e.g., Thompson and McGarigal 2002). In addition, whenever comparing landscapes of different size, use area-normalized versions of landscape metrics.

Thematic Resolution

One of the biggest challenges in representing a categorical landscape mosaic is determining the appropriate thematic resolution**.** A number of papers have investigated how classification scheme and classification accuracy affect landscape metrics calculated from categorical patch mosaics (e.g., Shao et al. 2001, Wickham et al. 1997). Several well-known papers have evaluated the sensitivity and consistency of landscape metrics to variation in landscape pattern using controlled empirical sampling and neutral models (e.g., Cushman

et al. 2008a, Hargis et al. 1998, Hess and Bay 1997, Neel et al. 2004, Riitters et al. 1995). The thematic resolution refers to what attributes of the underlying environment are represented in the habitat map and how finely they are resolved into categories.

Typically, the landscape has been classified into habitat patches based on properties of vegetation cover. This classification approach may be very meaningful for some organisms but not for others. For example, fossorial mammals are likely to be more sensitive to soil characteristics (e.g., depth, texture, wetness, organic matter, pH) than to aboveground vegetation. For these species, we might classify the landscape based on soil properties. Many other legitimate frameworks for classifying the landscape exist; the best thematic classification of the landscape ultimately depends on the habitat attributes identified for the emphasis species and the availability of data. In practice, data availability is often the limiting factor in determining the thematic resolution, because our desire to resolve thematic differences often exceeds our ability to do so with existing data. Thus, the selected thematic resolution is usually a compromise between the ideal number and types of classes from the perspective of the emphasis species and the number and types of classes that can be resolved accurately with existing data.

6.2.4 Effects of Map Error on Landscape Pattern Analysis

Landscape analysts must pay close attention to map error, because landscape metrics vary in their sensitivity to this unavoidable property of all classified maps. Some metrics, such as mean patch size and number of patches, can exhibit extreme sensitivity to even minor map error rates (Langford et al. 2006); therefore, they should be avoided in most cases. Other metrics, however, are relatively insensitive to misclassification errors involving small patches. For example, area-weighted metrics weight each patch proportionately to its area, and small patches have very little weight when computing the landscape metric. Thus, most of the problems associated with at least minor map errors can be avoided by choosing the most appropriate metrics. Of course, major map errors create insurmountable problems. Unfortunately, no general rule of thumb exists regarding how large the error rate can be before even the best metrics produce erroneous results.

6.3 Process Steps for Conducting a Landscape Analysis

6.3.1 Establish Objectives for the Landscape Analysis

The general objective of landscape pattern analysis is to quantify current area and configuration of habitat in a landscape of interest to compare it with desired conditions and previously measured conditions. For each emphasis species, create a specific objective that addresses the primary monitoring focus of the landscape pattern analysis. For example, a specific objective could be to measure changes in habitat patch proximity at the home range scale and compare this spatial distribution with historical conditions or

desired future conditions. Another possible objective is to measure the extent to which habitat is well distributed across the plan area. A third objective might be to provide sufficient quantity and quality of habitat across an ecoregion to sustain metapopulation structure over long time frames.

Whatever the objective, it is critical to formally link it with the LRMP objectives and desired conditions that underlie the adaptive management cycle for the analysis area (section 6.2.1). Specifically, without detailed, specific guidance regarding what landscape elements to measure, what metrics to use, what the objectives are for monitoring, and what thresholds trigger a change in management, landscape analysis, at best, will be vaguely descriptive.

6.3.2 Define the Landscape

Choose a landscape extent that is meaningful from both an ecological perspective and a management perspective, given the scale at which the emphasis species operates and the specific objective of the landscape analysis. This choice might be the local range of an emphasis species or the extent of a local population, a metapopulation, or a group of species across an ecoregion. The extent may need to correspond to a specific project planning area (e.g., timber sale area), a timber or wildlife management unit, a watershed, or an administrative unit (e.g., ranger district or national forest), although these boundaries usually lack ecological context. If the landscape extent is small relative to the scale at which population processes for the species of interest act (e.g., emigration or dispersal), then it is likely that patterns in the broader surrounding landscape (i.e., the landscape context) will have as much (or more) effect on processes as patterns within the specified landscape. At a minimum, the scope and limitations of the analysis, given these scaling considerations, should be made explicit.

Next, define a relevant grain. Practically speaking, the grain of the data represents a balance between the desire for accurate calculations of landscape pattern, computational efficiency, and the desire to scale patterns appropriately for the organisms of interest and the chosen landscape extent (figure 6.1). The grain should be kept as fine as possible to ensure that small yet meaningful features of the landscape are preserved (figure 6.1). On the other hand, the grain should be large enough in relation to the extent so that unnecessary detail is not confused with the important coarse-scale patterns over large spatial extents. This clarity may be achieved by increasing the minimum mapping unit above the resolution set by the grain. In practice, these decisions are often guided by technical considerations owing to limited data sources and the availability of data-processing software. Again, the effects of scale on the scope and limitations of the analysis should be clearly addressed.

Ideally, the thematic resolution has been appropriately selected to match monitoring objectives. For example, suppose we chose to monitor the extent and pattern of cover type and seral stage classes as habitat attributes for a species. We might represent each cover type and seral stage combination as a separate class and consider each class as providing

habitat of varying degrees of quality that differentially affect the connectivity of late-seral spruce-fir (*Picea* spp.-*Abies* spp.) habitat patches. In this context, the same high elevation landscape can be represented at different thematic resolutions. Although some organisms may perceive and respond to changes in the amount and distribution of late-seral spruce-fir forest, other organisms may exhibit more general associations with late-seral conifer forest of any species composition. If this situation is the case, we might represent the landscape at a broader thematic resolution (e.g., late-seral conifer forest) (figure 6.2).

Figure 6.1.—*Spatial grain should be appropriate for the organism of interest. For the American marten (*Martes americana*), a grain of 50 feet (ft) is finer than is needed, whereas a grain of 500 ft may ignore important aspects of landscape pattern.*

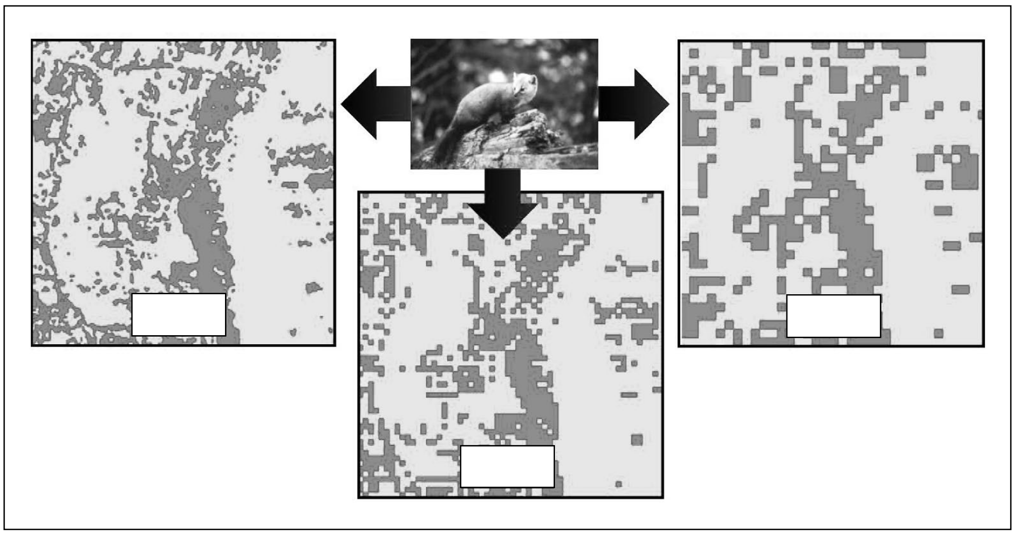
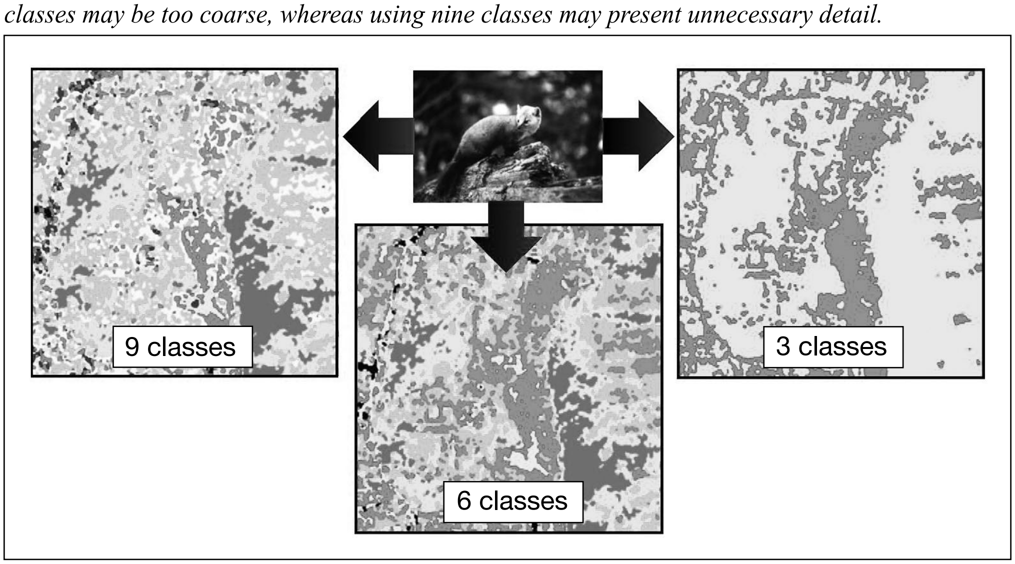


Figure 6.2.—*Ideally, the thematic resolution reflects the resolution at which organisms perceive the landscape. For the American marten (*Martes americana*), differentiating between only three cover classes may be too coarse, whereas using nine classes may present unnecessary detail.*



For yet other organisms, it might be more meaningful to classify with an even broader thematic resolution, treating all late-seral forest, including both deciduous and coniferous, or perhaps even all forested cover types as a single comprehensive class. Fundamentally, the same land area is viewed by different species at a different grain, which suggests an appropriate thematic resolution for each species.

If the objective of the landscape analysis is to quantify and monitor fragmentation, then decide which landscape elements will be viewed as fragmenting features. For example, does a small forest road bisecting contiguous forest constitute a fragmenting feature and split the forest into two distinct habitat patches? What if the road is an expressway? Is a small first order stream or a larger river a fragmenting feature? Linear landscape elements are often important features of the landscape; whether they function to disrupt the physical continuity of the landscape enough to warrant treatment as patch boundaries depends on the phenomenon under consideration and the specific capabilities of the species.

6.3.3 Identify the Larger Landscape Context

Ensure that the landscape defined for analysis is sufficiently bounded within a larger spatial extent to incorporate patterns and processes that operate at larger spatial scales. Landscapes, in general, are open systems; energy, materials, and organisms move into and out of the landscape. If the landscape of interest is too small, continuous landscape features important to animal movements will be truncated or not observable.

The larger landscape context is also essential to an analysis of habitat fragmentation because it is important to understand whether or not the habitat is both locally and regionally rare and fragmented. A larger extent of unfragmented habitat may offset any local fragmentation impacts. In addition, the larger landscape provides the context for discriminating between natural disturbance and succession processes operating to fragment habitat and anthropogenic activities that may be causing the system to move outside desired conditions (chapter 7 addresses human disturbance agents and processes). To address the influences of the surrounding landscape context, it is important to establish a **reference framework** that provides a description of regional landscape structure, range of variability, and other attributes of landscape context. This strategy is addressed in section 6.3.7.

6.3.4 Determine the Scope of Analysis

The scope of analysis pertains to the scale and/or focus of the monitoring program. In this chapter, we assume that the primary analysis tool is FRAGSTATS, because it is the most commonly used software for analyzing patch mosaics. Three levels of analysis in FRAGSTATS represent fundamentally different conceptualizations of landscape patterns and have important implications for the choice and interpretation of individual landscape metrics and the form of the results.

1. ***Focal patch analysis***. Under the patch mosaic model of landscape structure, the focus of monitoring is on the spatial character and/or context of individual **focal patches**. Results of a focal patch analysis are typically presented in table form, in which each row represents a separate patch and each column represents a separate patch metric, such as patch size.
2. ***Local landscape structure***. In many applications it is appropriate to assume that species experience landscape structure as local pattern gradients that vary through space according to their own perceptions and their ability to travel through or use different vegetation types. Thus, instead of analyzing global landscape patterns by conventional landscape metrics across the entire spatial extent, we use a moving window analysis to quantify the local landscape pattern because this approach more closely resembles the way that a species may perceive the landscape. A moving window analysis asks: From any given point, what is the composition and configuration of the landscape mosaic in the immediate vicinity? The window size should be selected to reflect the scale and manner in which the emphasis species perceives or responds to pattern. If this size is unknown, the user can vary the size of the window over several runs and empirically determine at which scale the organism is most responsive. The window moves over the landscape one cell at a time, thereby calculating this point-centered view for all locations on the landscape. The result is a continuous surface that is then combined with other such surfaces in multivariate models to predict, for example, the distribution and abundance of habitat continuously across the landscape. This approach is useful for evaluating changes in dispersal ability over time, given that the emphasis species may not be able to cross through certain vegetation types or land use types (see the salamander monitoring plan in chapter 10 as an example).
3. ***Global landscape structure***. The traditional application of landscape metrics involves characterizing the structure of the entire landscape with one or more landscape metrics. For example, traditional landscape pattern analysis would measure the total edge per unit area for the entire landscape. This global measure offers a landscape-centric perspective on landscape patterns using the entire patch mosaic in aggregate. The results of a global landscape structure analysis are typically presented in the form of a vector of measurements, in which each element represents a separate landscape metric.

6.3.5 Select Key Habitat Attributes of Landscape Pattern for Emphasis Species

Patches form the building blocks of landscape pattern. A patch is a delineated area that differs from adjacent areas in one or more attributes. Typically, after patches have been delineated on the basis of attributes and attribute values, the within-patch heterogeneity is ignored. Patches that share the same attributes or attribute values are grouped into a class.

Although the literature is replete with descriptors of landscape pattern, only two major components exist—composition and configuration. Landscape composition refers

to features associated with the variety and abundance of patch types within the landscape, whereas spatial configuration is the spatial character, placement, or location of patches within the mosaic.

Principal Attributes of Landscape Composition

- Proportional abundance of each class—proportion of each habitat class relative to the entire map; one of the simplest and perhaps most useful pieces of information. All landscape analyses should calculate this metric because proportional abundance of each class is necessary for understanding future analyses.
- Richness—number of different habitat patch types.
- Evenness—the relative abundance of different patch types. Usually reported as a function of the maximum diversity possible for a given richness; i.e., evenness is 1 when the patch mosaic is perfectly diverse, given the observed patch richness, and approaches 0 as evenness decreases.
- Diversity—a composite measure of richness and evenness; can be computed in a variety of forms (e.g., Shannon and Weaver 1949, Simpson 1949), depending on the relative emphasis placed on these two components. Richness, evenness, and diversity are highly correlated, and none of them provide information on which patch types are contributing to the change in metric over time.

Principal Attributes of Spatial Configuration

- Patch size distribution and density—the simplest measure of configuration; represents a fundamental attribute of the spatial character of a patch. Most landscape metrics either directly incorporate patch size information or are affected by patch size. Patch size distribution can be summarized for a class or landscape(e.g., mean, median, max, and variance), or represented as patch density, which is simply the number of patches per unit area. Users should generally employ area-weighted patch size metrics to avoid large influence of small patches. Also, users should use patch density (and not number of patches) any time landscapes of different extents are compared.
- Patch shape complexity—relates to the geometry of patches; i.e., whether they tend to be simple and compact, or irregular and convoluted. Most common measures of shape complexity are based on the relative amount of perimeter per unit area, usually indexed in terms of a perimeter-to-area ratio and often standardized to a simple Euclidean shape (e.g., circle or square).
- **Core area**—the area unaffected by the edges of the patch; represents the interior area of patches after a user-specified edge buffer is eliminated. The edge-effect distance will vary depending on the phenomenon under consideration and can be treated as fixed or adjusted for each unique edge type. This metric integrates patch size, shape, and edge-effect distance into a single measure. All else being equal, smaller patches with greater shape complexity have less core area. Most metrics associated with size distribution (e.g., mean patch size and variability) can be formulated in terms of core area.

- Isolation/proximity—refers to the tendency for patches to be distant from other patches of the same or similar class. The original **proximity index** in landscape analysis was formulated to consider only patches of the same class within a specified neighborhood of patches. This binary representation of the landscape reflects an island biogeographic perspective on landscape pattern. Alternatively, this metric can be formulated to consider the contributions of all patch types to the isolation of the focal patch, reflecting a landscape mosaic perspective on landscape patterns.
- Contrast—relative difference among patch types. For example, mature forest next to younger forest might have a lower contrast edge than mature forest adjacent to open field, depending on how contrast is user defined. Can be computed as a **contrast-weighted edge density** in which each edge type (i.e., between each pair of patch types) is assigned a contrast weight.
- Dispersion—tendency for patch distribution to be either regular or clumped (i.e., contagious); a common approach is based on nearest neighbor distances between patches of the same type.
- Contagion and interspersion—contagion refers to the tendency of patch types to be spatially aggregated; that is, to occur in large, aggregated, or contagious distributions; ignores patches *per se* and measures the extent to which cells of a similar class are aggregated. By contrast, interspersion refers to the intermixing of patches of different types and is based entirely on patch (as opposed to cell) adjacencies. Several different approaches are available for measuring contagion and interspersion. One popular index that subsumes both dispersion and interspersion is the contagion index based on the probability of finding a cell of type i next to a cell of type j (Li and Reynolds 1995). This index summarizes the aggregation of all classes and thereby provides a measure of overall clumpiness of the landscape. McGarigal et al. (2012) suggest a complementary interspersion/juxtaposition index that increases in value as patches become more evenly interspersed in a salt and pepper mixture.
- Subdivision—degree to which a patch type is subdivided into separate patches (i.e., fragments), and not the size, shape, relative location, or spatial arrangement of those patches. Because these latter attributes are usually affected by subdivision, it is difficult to isolate subdivision as an independent component in landscape analysis. Subdivision can be evaluated using a variety of metrics already addressed; for example, the number, density, and average size of patches and the degree of contagion all indirectly evaluate subdivision. A suite of metrics, however, derived from the cumulative distribution of patch sizes, provides alternative and more explicit measures of subdivision (Jaeger 2000). When applied at the class level, these metrics can be used to measure the degree of fragmentation of the focal patch type. Applied at the landscape level, these metrics connote the graininess of the landscape.
- Connectivity—functional connections among patches, which clearly depend on the application or process of interest; patches that are connected for bird dispersal might

not be connected for salamanders, seed dispersal, fire spread, or hydrologic flow. Connections might be based on strict adjacency (touching) of habitat patches, some threshold distance, a decreasing function of distance that reflects the probability of connection at a given distance, or a resistance-weighted distance function. Various indices of overall connectedness can be derived based on the pairwise connections between patches; i.e., **connectance** can be defined by the number of functional joinings, in which each pair of patches is either connected or not. Connectivity can also be defined in terms of **correlation length** for a raster map comprised of patches (defined as clusters of connected cells). A map's correlation length is the average distance an organism can traverse a map from a random starting point and moving in a random direction, while remaining in the same patch type (Keitt et al. 1997).

6.3.6 Selecting Landscape Metrics for Analysis

Landscape metrics are algorithms that quantify the specific spatial characteristics of patches, classes of patches, or entire landscape mosaics. *The proper indices to calculate are the ones that make ecological sense for the application at hand.* To select the appropriate suite of metrics, practitioners need detailed knowledge of the metrics, what they measure, and how they change. No substitute exists for this knowledge, and we strongly suggest that practitioners spend ample time studying the extensive documentation available on FRAGSTATS metrics (McGarigal et al. 2012). In general, however, all landscape analysis should include a measure of proportional abundance of the habitat classes of interest (PLAND in FRAGSTATS), and nearly always should include additional metrics on aggregation, edge, and other landscape structure attributes.

FRAGSTATS calculates all metrics for one or more of four major levels of the landscape mosaic.

1. ***Cell-level metrics*** are defined for individual cells, and characterize the spatial context or ecological neighborhood of each cell without explicit regard to any patch or class affiliation.
2. ***Patch-level metrics*** are defined for individual patches, and characterize the spatial character and context of patches. Individual patches possess relatively few fundamental spatial characteristics: size, perimeter, and shape.
3. ***Class-level metrics*** are integrated over all the patches of a given type (class). These metrics may be integrated by simple averaging, or through some sort of weighted-averaging scheme to bias the estimate to reflect the greater contribution of large patches to the overall index. Additional aggregate properties exist at the class level that result from the unique configuration of patches across the landscape. Class indices separately quantify the amount and spatial configuration of each patch type and thus provide a means to quantify the extent and fragmentation of each patch type in the landscape.
4. ***Landscape-level metrics*** are integrated over all patch types or classes over the full extent of the data (i.e., the entire landscape). Like class metrics, these metrics may

be integrated by a simple or weighted averaging or may reflect aggregate properties of the patch mosaic. In many applications, the primary interest is in the pattern (i.e., composition and configuration) of the entire landscape mosaic.

The two key concepts that will further help selecting landscape metrics for analysis include (1) gaining a theoretical and empirical understanding of metric behavior to guide interpretation, and (2) understanding redundancy among metrics to guide selection of a parsimonious suite of landscape metrics. In this chapter, we provide an overview and references to help move through the process of selecting landscape metrics for habitat monitoring.

The task of understanding the behavior and expected range of values of the landscape metrics has been a focus of research for more than 20 years (Cardille et al. 2005, Cushman et al. 2008a, Gustafson 1998, Hargis et al. 1998, Neel et al. 2004, Tischendorf 2001). Here, we distill the main points of metric selection. To select a proper set of landscape metrics for analysis it is essential that the monitoring team have a clear idea of (1) what attributes of landscape pattern are most important to meet the habitat monitoring objectives, and (2) which metrics are sensitive indicators of variability in these attributes within the context of the monitoring area. The first question (i.e., what attributes of landscape structure to measure) should be determined before analysis, through review of current scientific literature regarding the effects of landscape pattern on ecosystem and population processes and which aspects of landscape pattern are strongly related to which processes (see McGarigal et al. 2012). The second question of which metrics sensitively reflect these landscape patterns can be addressed partly by reviewing technical literature on landscape pattern analysis (Gustafson 1998, Hargis et al. 1998, McGarigal et al. 2012, Neel et al. 2004). The task of selecting a parsimonious suite from the pool of relevant metrics identified in the process steps described in chapters 2 and 5 can be facilitated by reviewing pertinent technical papers (Cushman et al. 2008a, McGarigal and McComb 1995, Riitters et al. 1995).

The best approach is to select relatively few metrics of both landscape composition and configuration at each of the class and landscape levels that measure the spatial attributes of interest and are not redundant with each other. Generally speaking, analysts will always want to choose one or more measures of landscape composition at the class and landscape levels (see section 6.3.5). In addition, analysts will generally select one or more class- and landscape-level metrics measuring contagion and interspersion, core area, contrast, patch size distribution, and isolation. We suggest analysts carefully study the FRAGSTATS user's guide and other documentation (available at http://www.umass.edu/landeco.) This review will provide information on how to obtain and use FRAGSTATS software, as well as detailed description of the different landscape metrics available to quantify different aspects of landscape composition and configuration.

6.3.7 Use an Existing or Establish a New Reference Framework of Landscape Processes and Patterns

The absolute value of any given landscape metric is often not directly interpretable without knowing the likely range of values represented by a relevant reference range of conditions, which we will refer to as the reference framework. Meaningful evaluation of contemporary conditions requires comparison with a reference to determine status and change, and to design management to provide sustainable yield of resources while also maintaining ecosystem heath (Hessburg et al. 1999, Swetnam et al. 1999). It is critical that the reference framework represent the dynamics of ecosystems as they vary over time and across landscapes (Swanson et al. 1994). One important reference framework is the historic range of variability (HRV; Cissel et al. 1994, Wiens et al. 2012, Swanson et al. 1994). HRV provides a spatial and temporal foundation for adaptive management (Keane et al. 2009, Landres et al. 1999). Some of the key attributes of a reference framework are the type, frequency, and severity of disturbance under a natural disturbance regime and mean and variation of patch size, extent, and pattern among the cover types represented in the map being analyzed (either selected habitat attributes or patches representing categories of predicted habitat quality).

When possible, use a quantitative approach to construct the reference framework. This approach may involve the use of retrospective studies of past landscape conditions (e.g., historical reconstructions of landscape patterns and dynamics) or the use of computer simulation models to simulate landscape changes based on the best understanding of the processes that drive landscape change (Keane et al. 2009). When habitat monitoring begins, the sequential reanalysis over time will augment the temporal reference framework.

A reference framework should include a much broader spatial extent than the landscape under consideration for habitat monitoring to provide a context to evaluate the broader regional significance of landscape pattern. For example, if the analysis objective is to monitor changes in habitat fragmentation, it is necessary to understand whether the habitat of interest was either locally or regionally rare and whether it was fragmented in the past (see chapter 10, greater sage-grouse [*Centrocercus urophasianus*] case example, for use of a reference framework). The broader landscape extent defined in section 6.3.3 might serve as a suitable spatial extent for a reference framework. It is beyond the scope of this technical guide to fully describe a process for creating a reference framework, and the task is challenging. Yet ultimately, it may be essential for interpreting landscape metrics and for evaluating changes in landscape pattern for an emphasis species.

6.3.8 Analyze and Interpret Landscape Pattern Through Comparison With the Reference Framework and Desired Conditions

A land management plan may contain desired condition statements that include specific reference to landscape pattern for one or more emphasis species. If the desired condition for landscape pattern is worded broadly, for example, “maintain large patches

of habitat that are well distributed across the plan area," rephrase these statements in terms of specific landscape metrics and the range of acceptable values for each metric based on the reference framework and on the conceptual model of the species' habitat. As addressed in section 6.1, it is essential to integrate landscape analysis of wildlife habitat into an adaptive management framework that includes detailed and specific objectives and quantitative **triggers** expressed in terms of the landscape metrics analyzed. This approach will provide clearly interpretable information that directly guides management decisions.

If an adequate reference framework exists, it will be straightforward to evaluate current conditions. The value of each landscape metric measured for the current landscape can be directly compared with the range of values in the reference framework and with the values described as acceptable in the desired conditions statements. This comparison is made in terms of departure in the value of each metric from either a threshold or the range of desired conditions and expressed as graphs and tables of percentage differences between existing, reference, and desired conditions. In this form, the analysis provides a directly interpretable evaluation of conditions in comparison with management goals and indicates which attributes are at variance with desired conditions and to what degree.

For example, an effort to monitor habitat for greater sage-grouse might include monitoring the number of habitat patches larger than some minimal size. The monitoring program may specify a minimum number of patches of a certain size that would serve as a trigger point for reassessing management (chapter 10, sage-grouse case example).

6.3.9 Monitoring Landscape Attributes Over Time

A monitoring team can retrospectively monitor changes in landscape attributes by using a series of two or more maps that represent vegetation types or land use categories at different points in time. To be comparable, the maps must represent the same thematic resolution at the same scale, be derived from a comparable data source, and use comparable methodology, such as using the same neighbor rule (e.g., 4- or 8-neighbor rule) to define patches. Changes in the maps will still occur because of improvements in data quality and methodology, but these changes will not have the adverse impact on comparability that would result from changes in grain, extent, or number of cover classes.

Betts et al. (2003) used a set of comparable maps for monitoring changes in habitat of seven forest-associated species in the Fundy Model Forest (1,700 square miles) in New Brunswick, Canada, from 1993 to 1999. The authors obtained Landsat-5 and Landsat-7 images from 1992, 1995, 1997, 1998, and 1999 and then used a local classified image of vegetation types from 1993 as the basis for classifying habitat. Using habitat capability models for each of the seven species, the authors collapsed the original vegetation map into cover type classes and focused on five cover types that constituted habitat of the indicator species. The authors also used the habitat models to identify a minimum patch size and maximum interpatch distance for each species so that patches that did not meet

the minimum or that were too isolated from other habitat would not be included in the total amount of habitat. The authors calculated changes in three landscape metrics—total habitat area, mean patch size, and nearest neighbor distance—and found that the rate of habitat fragmentation (reduction in mean patch size and increase in interpatch distance) exceeded the rate of habitat loss (total patch area).

The most important consideration for ensuring that results of a landscape pattern analysis for habitat monitoring are consistent and comparable over time is consistency in map definition (e.g., habitat classification method, grain, and extent). An inherent challenge exists in attaining this consistency, as, over time, our ability to map habitat features and the quality of habitat models will improve (chapter 5). These changes in spatial data will necessarily change map definitions, making it difficult to distinguish between changes because of methodology and changes in the true area and configuration of habitat. This dilemma is unavoidable, and we recommend using the best available models and maps of habitat and habitat attributes. Moreover, it is essential that the details of the data sources, their accuracy and definition, and the models used in previous analyses are well documented, to at least qualitatively consider the differences in methodology between measurement dates.

Finally, to be useful in monitoring changes in amount and pattern of habitat over time, a landscape analysis must be tied explicitly to a formal decisionmaking framework, such as a land management plan. In the context of adaptive management, the management plan will include desired conditions that are formally and quantitatively expressed in terms of landscape metric values and will include threshold values that specify the amount of departure from desired conditions that would trigger a change in management. Such formal and quantitative targets and thresholds, when coupled with a consistent and comparable landscape analysis, provide a direct means to evaluate change in spatial patterns in habitat over time and information to guide the adaptive management cycle. We recommend comparing the monitoring results to a threshold over statistically comparing two time periods. Compounded map error makes a statistical comparison difficult (Remmel and Csillag 2003), whereas comparing each time period with a predefined threshold is more tractable and more biologically meaningful.

6.4 Conclusion

Landscape analyses are an important part of habitat monitoring because the habitats in which organisms live are spatially structured at multiple levels and generally include a landscape level. In this chapter, we describe habitat as patches in a landscape mosaic, although we acknowledge and describe other approaches to characterize landscapes. Scale is critical in defining a landscape because the size and scale of a landscape is directly related to how it is used by a species. Moreover, pattern and its effect on process vary with spatial scale and thematic resolution.

To be effective, a landscape analysis must be directly tied to the objectives and desired conditions of a planning document such as an LRMP. Ideally, the LRMP provides a formal declaration of desired conditions, provides a quantitative description of current departure from desired conditions, and specifies a quantifiable threshold value or set of values that can be used to trigger a change in management toward desired conditions. We offer numerous approaches to quantify landscape pattern in terms of composition and spatial configuration, for use in quantifying desired conditions, and in establishing thresholds.

The nine process steps for conducting a landscape analysis outlined in this chapter are (1) establish objectives for the landscape analysis, (2) define the landscape, (3) identify the larger landscape context, (4) determine the scope of analysis, (5) select key habitat attributes of landscape pattern for emphasis species, (6) select landscape metrics for analysis, (7) use an existing or establish a new reference framework of landscape processes and patterns, (8) analyze and interpret landscape pattern regarding the reference framework and desired conditions, and (9) monitor landscape attributes over time.

Chapter 7. Monitoring Human Disturbances for Management of Wildlife Species and Their Habitats

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7.1 Objectives

Human disturbances dominate national forests and grasslands and affect habitats and species in multifaceted ways. In the past, planning and management efforts focused mainly on the management activities of silviculture, prescribed fire, and livestock grazing. Those disturbances remain as common agents to monitor and evaluate. A variety of additional human disturbances, however, are now prevalent and deserve attention, including roads and traffic, recreation, energy extraction, urban expansion, and nonnative or invasive species. Monitoring and evaluating the most prevalent human disturbances that occur in a given local management unit or ecoregion is needed to meet planning requirements and to assess the diverse effects of such disturbances on wildlife habitats and species.

The goal of this chapter is to provide guidance and methods to select and monitor the primary **human disturbance agents** operating in a given area as part of habitat monitoring for terrestrial habitats of emphasis species. We assigned the following objectives for this chapter.

- Describe the most common human disturbance agents that may affect habitats or species on national forests or other large spatial extents used for Forest Service planning and management.
- Summarize some of the general effects of example disturbance agents on habitats and species with supporting literature.
- Provide criteria and rationale for selecting human disturbance agents to monitor and evaluate.
- Describe methods for monitoring the selected human disturbance agents and for estimating or modeling the assumed effects on habitats and habitat use.
- Provide examples of the monitoring process for human disturbances common to most national forests and grasslands, but that have received less emphasis in traditional monitoring programs.

7.2 Key Concepts

7.2.1 Human Disturbance Agents and Regimes

We define a human disturbance, or human disturbance agent, as any human-associated factor that affects emphasis species or their habitats. This definition builds on the classical definition from disturbance ecology provided by Pickett and White (1985:11), which states, "A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." Our definition of a human disturbance, which is a subset of this broader definition, focuses on resulting changes in conditions for habitats and populations of emphasis species.

Importantly, our definition includes all human-caused changes in conditions, positive and negative. Moreover, whether human-caused changes are deemed positive or negative entirely depends on management objectives and societal values. An effect from a particular disturbance event that meets management objectives or societal values is predictably viewed as positive, and those that do not are typically considered negative. This point is particularly important, considering that any human disturbance typically increases habitat abundance or habitat use for some species, while simultaneously reducing abundance or use for other species. Which effects are important to management depend on objectives for the emphasis species (the species of interest) and their habitats, and this point is emphasized throughout this chapter. Without explicit management objectives, it will be difficult to select which types of human disturbances to monitor and what types of effects from the disturbances are considered acceptable or are of interest.

That as context, we refer to all human activities and land uses as disturbance agents because they affect species and habitats through the same pathways as other disturbances that operate in the absence of human influence, in the same manner defined by Pickett and White (1985) for all disturbances (table 7.1). Disturbance agents take many forms, with effects that manifest in myriad ways (table 7.1). Roads, for example, affect wildlife and habitats directly through habitat loss and fragmentation (figure 7.1), the spread of invasive plants, and increased mortality (section 7.5.1). Road effects typify the many pathways through which most human disturbances affect vertebrate species and change the probability of population persistence (figure 7.1). Human disturbances have thus received increasing attention as part of Forest Service planning and management in response to the increasing presence and influence of such disturbances, as required by the National Environmental Policy Act.

A concept closely related to disturbance agents is that of human disturbance regime, which is the extent, frequency, duration, and magnitude of how a human disturbance agent functions; that is, how a disturbance agent operates in time and space. Human disturbance regimes have these same characteristics as natural disturbance regimes (Van

Table 7.1.—*Human disturbance agents and potential negative effects on habitats and populations of emphasis species, with example references. See text for additional discussion about positive effects of human disturbance.*

Human disturbance agents	Associated effects	Examples	Example references[a]
Agricultural conversions	Habitat—habitat loss	Habitat loss from conversion of native plant communities to agricultural uses.	Dobler 1994, Fischer et al. 1997, Warner 1994
	Habitat—habitat fragmentation	Conversion of grassland and shrubland habitats to agriculture may lead to fragmentation of remaining native habitats, resulting in interference with animal movements, dispersal, or population fragmentation.	Connelly et al. 2004; Knick and Rotenberry 1995, 1997, 2002; Knick et al. 2003
	Population—direct mortality	Nest and egg destruction, or directly mortality of animals, from mechanical or other methods used to remove habitat or to cultivate lands adjacent to sagebrush.	Best 1986, Bryan and Best 1994, Patterson 1952
Climate change	Habitat—habitat loss and degradation	Gradually increasing temperatures have contributed to drought and more severe and frequent wildfires, escalating the spread of nonnative invasive plants; forest insect pests are able to survive in more northern climates and eliminate forest habitats.	Bachelet et al. 2001, Neilson et al. 2005, Root et al. 2002, Smith et al. 2000
	Population—major geographic shifts in animal communities	Major geographic shifts in habitats and associated animal distributions may lead to population fragmentation and isolation and increased species extinctions.	Parmesan 2006, Root et al. 2002, Root and Schneider 2006
Communication towers	Population—mortality	Collisions of birds and bats with cell and radio towers can lead to mortality or injury.	Mabey and Paul 2007, Manville 2005
Disease transmission	Population—direct mortality	Disturbance from oil and gas development may lead to concentrations of native ungulates on winter ranges, exacerbating disease transmission during the stressful winter season. Man-made water sources may increase transmission of mosquito-borne diseases, such as West Nile virus, in birds.	Naugle et al. 2004, 2005; Rowland 2004; USDI USFWS 2005; Walker et al. 2004, 2007
Nonnative and invasive plants	Habitat—habitat loss, degradation	Establishment of nonnative and/or invasive plants can displace native species and alter ecological processes.	Bergquist et al. 2007, D'Antonio and Vitousek 1992, Knick 1999, Menakis et al. 2003, Moser et al. 2009, West 1999
Fences	Habitat—habitat fragmentation	Construction of fences (e.g., along roadways or for allotment pastures) can fragment habitats and interfere with animal movement.	Boone and Hobbs 2004, O'Gara and Yoakum 2004
	Population—direct mortality	Animals can collide with fences or become entangled, leading to injury or death.	Boone and Hobbs 2004, Call and Maser 1985, Todd 2001
Herbicides	Habitat—habitat loss and fragmentation	Herbicides used extensively before the 1980s for conversion and removal of sagebrush and other shrubland communities, especially if native understory vegetation was in relatively good condition.	Best 1972; Braun 1998; Braun and Beck 1977; Connelly et al. 2000, 2004; Miller and Eddleman 2000
Livestock grazing	Habitat—habitat degradation	High grazing pressure by livestock can reduce native perennial grasses and forbs in the understory (changes in composition and structure) as well as increase presence of invasive species in some situations, with resulting declines in forage and other habitat conditions for emphasis species.	Bock et al. 1993, Fleischner 1994, Guthrey 1996, Thines et al. 2004
	Population—direct mortality	Livestock may trample eggs in nests or burrows of some species.	Beck and Mitchell 2000, Fleischner 1994, Holmes et al. 2003
Military training	Habitat—habitat fragmentation	Training exercises degrade and fragment habitat and facilitate invasion by nonnative plants.	Holmes and Humple 2000, Knick and Rotenberry 1997

Table 7.1.—*Human disturbance agents and potential negative effects on habitats and populations of emphasis species, with example references. See text for additional discussion about positive effects of human disturbance (continued).*

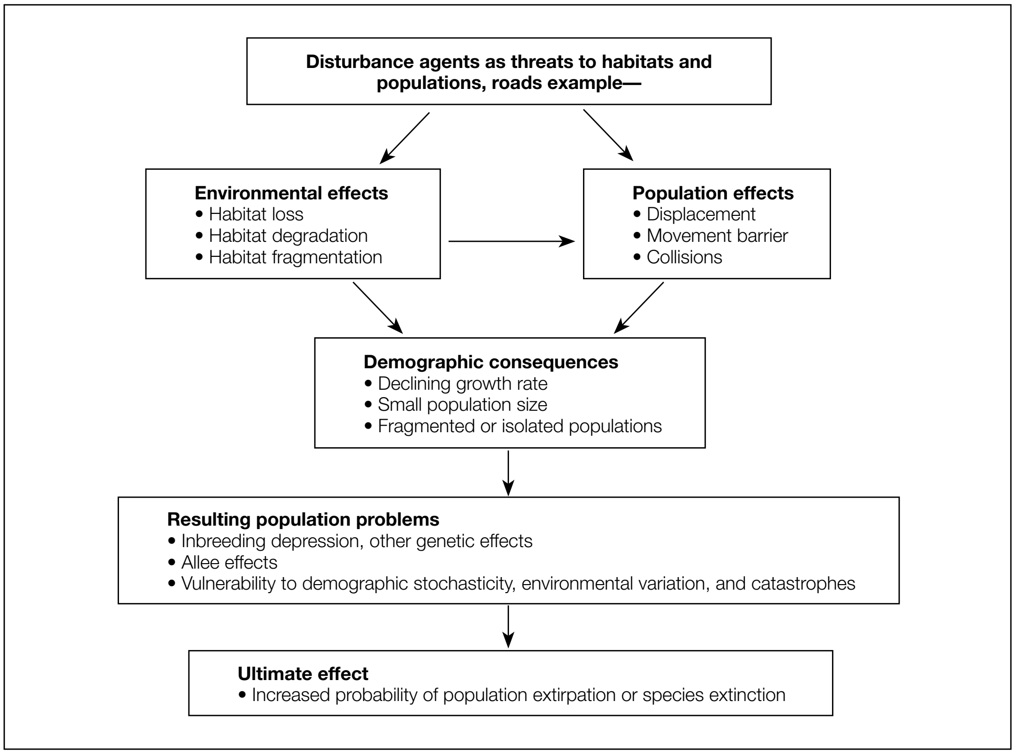
Human disturbance agents	Associated effects	Examples	Example references[a]
Mining	Habitat—habitat loss and fragmentation	Fragmentation and outright loss of habitat to surface mines and associated mine tailings and roads, especially coal mines.	Braun 1998, Neely et al. 2001, Ricketts et al. 1999,
	Habitat—habitat degradation	Native species diversity may decline when invasive species may become established in sites disturbed by mining activities.	Gonella and Neel 1996, Ripley et al. 1996
	Population—disturbance	Disturbance and potential abandonment of habitat because of traffic, noise, and related human activity at mine site; example affected species—bats and greater sage-grouse.	Bednarz 1984, Kuck et al. 1985
Oil and natural gas field development	Habitat—habitat loss, fragmentation	Pipelines, roads, well pads, and associated collection facilities fragment habitats; outright loss of habitat also occurs from roads and well pads and other facilities constructed for field development.	Thomson et al. 2005, Weller et al. 2002
	Habitat—habitat degradation	Disturbed sites (e.g., roadsides and well pads) may become infested with invasive species; disposal of water produced during coal bed methane extraction can lead to salinization of surrounding soils.	Doherty et al. 2008, Gelbard and Belnap 2003, McBeth et al. 2003, Parendes and Jones 2000, Sawyer et al. 2005, Thomson et al. 2005, Walker et al. 2007, Zink et al. 1995
Pesticides	Habitat—habitat degradation	Decrease in forage base by killing insects used as prey.	Holmes et al. 2003, Johnson 1987
	Population—mortality	Direct mortality of birds and other vertebrates, and nontarget invertebrates, exposed to pesticides, and indirect mortality through consumption of contaminated insects.	Blus 1996, Blus et al. 1989, Patterson 1952
Power lines	Habitat—habitat degradation	Disturbance of vegetation and soils in corridors can lead to increased invasion of nonnative species in these areas.	Braun 1998, Zink et al. 1995
	Population—increased rates of predation	Poles and towers for transmission lines may serve as additional perches or nest sites for corvids and raptors, increasing the potential for predation on emphasis species.	Knight and Kawashima 1993, Steenhof et al. 1993
	Population—direct mortality	Birds may collide with power lines, resulting in injury or death; electrocution of perching raptors and other birds also occurs.	Harmata et al. 2001, O'Neil 1988
Railroads	Habitat—habitat loss, degradation	Same effects as highways.	Jaeger et al. 2007, Van der Grift 1999
	Population—displacement, mortality	Same effects as highways.	Andersen et al. 1991, Seiler and Helldin 2006
Recreation (also table 7.2)	Habitat—habitat degradation	Off-road vehicle use can degrade habitats (e.g., by increasing presence of nonnative annual grasses).	Berry 1980, Havlick 2002, Munger et al. 2003
	Population—human disturbance	Recreational activities such as off-road vehicle use affect species in many ways (e.g., through increased physiological stress, displacement, or direct mortality).	Havlick 2002, Goldstein et al. 2010, Knight and Gutzwiller 1995, Munger et al. 2003
Reservoirs, dams, and other water developments	Habitat—habitat loss and degradation	Habitat loss from establishment of reservoirs; degradation of habitat near livestock water structures from overgrazing and man-made changes in hydrologic regimes.	Braun 1998, Nachlinger et al. 2001, Nilsson and Berggren 2008, Schroeder et al. 1999
	Habitat—habitat degradation	Altered stream flows and hydrological regimes may degrade or change habitat for aquatic and riparian species.	Pierson et al. 2001, 2002, 2003

Table 7.1.—*Human disturbance agents and potential negative effects on habitats and populations of emphasis species, with example references. See text for additional discussion about positive effects of human disturbance (continued).*

Human disturbance agents	Associated effects	Examples	Example references[a]
Roads, highways, and motorized trails	Habitat—habitat loss	Creation of roads and highways and their associated rights-of-way result in direct loss of habitat.	Forman 2000; Forman et al. 1997, 2003; Trombulak and Frissell 2000
	Habitat—habitat fragmentation, degradation	Creation of roads and highways fragments habitat; road construction and use facilitate the spread of invasive plants; dust from vehicle traffic can affect respiration in amphibians and alter rates of photosynthesis.	Forman 2000; Forman et al. 1997, 2003; Trombulak and Frissell 2000
	Population—barrier to migration or road avoidance	Roads may act as movement or migration barriers to less mobile species; animals may avoid areas affected by traffic or other activities associated with roads.	Coffin 2007, Goldstein et al. 2010, Reynolds-Hogland and Mitchell 2007, Spellerberg 2002
	Population—direct and indirect mortality	Death or injury from collisions with vehicles, and increased mortality from poaching because of improved access.	Blumton 1989, Dodd et al. 2004, Todd 2001, Woods et al. 2004
Silviculture	Habitat—loss or gain; change in habitat fragmentation	Timber harvest increases early seral habitat and reduces late-seral habitat; harvest, forest thinning, prescribed burns, and salvage logging often reduce large snag and large log habitat; small-area versus large-areas silvicultural prescriptions increase versus decrease habitat fragmentation.	Hanley et al. 2005, Hutto 2002, McIver and Starr 2001, Saab et al. 2007b, Wisdom et al. 2000, Wisdom and Bate 2008
Urbanization, human population growth	Habitat—habitat loss, degradation, fragmentation	Urban development results in habitat loss, degradation, and fragmentation of adjacent or nearby wildlands because of altered fire regimes, introduction of invasive plants, increased recreation activities, and other stressors.	Gavier-Pizarro et al. 2010a, 2010b; Gimmi et al. 2001; Gude et al. 2008; Hammer et al. 2007; Hansen et al. 2005; Hawbaker et al. 2005; Pilliod et al. 2006; Radeloff et al. 2005, 2010; Syphard et al. 2009; Theobald et al. 1997
	Population—human disturbance	Abandonment of habitats by native wildlife in response to increased human activities in urban and exurban areas. Predation by dogs and cats on native vertebrates in urban areas, and by corvids in which food associated with garbage is available. Human population density is highly correlated with threats to biodiversity.	Arrowood et al. 2001, Glennon and Porter 2005, Lenth et al. 2008, Maestas et al. 2003, Knick et al. 2003, Millsap and Bear 2000, Sawyer et al. 2005, Theobald et al. 1997
Wind energy development	Habitat—habitat degradation	Increase of noxious weeds in areas around turbines or along roads needed to access turbines; loss of habitat from road construction and turbine installation.	Arnett et al. 2008; Forman et al. 1997, 2003; Gelbard and Belnap 2003; Johnson et al. 2004; Leddy et al. 1999; USDI Bureau of Land Management 2005
	Population—displacement, mortality	Noise and other disturbances associated with wind farms may displace animals—deaths and injuries of birds and bats from collisions with wind turbines. Species avoidance of areas near turbines because of the association of such structures with nests or perches of avian predators such as corvids.	Erickson et al. 2001, Larsen and Madsen 2000, Leddy et al. 1999

[a] *Modified from Wisdom et al. (2005) and Rowland and Leu (2011).*

Figure 7.1.—*Example pathways of human disturbance effects on habitats and populations of emphasis species, using roads as the example disturbance agent (modified from Wisdom et al. 2005).*



der Maarel 1993). Some disturbance regimes are episodic, occurring infrequently at specific periods of short duration but at high magnitude, often playing out over large spatial extents (outbreak period), with longer periods of inactivity or dormancy. Examples include stand-replacement wildfires or hunting seasons of short duration but a high density of hunters. Other disturbance regimes are chronic, which manifest more evenly over time, often with magnitudes less obvious and frequently underestimated. Examples include networks of electric transmission lines and consistent but low-frequency vehicle traffic (Wisdom et al. 2000). Some chronic disturbance regimes can be deceptive, with substantial effects camouflaged as part of background conditions. An example is long-term herbivory by wild or domestic ungulates (Wisdom et al. 2006).

Not all human disturbance regimes are distinctly episodic or distinctly chronic, but may reflect characteristics of both. What is important, however, is that the regime associated with a disturbance agent is understood well enough to design and implement a meaningful monitoring approach compatible with the period over which the regime's characteristics can be measured (addressed in the following section and in chapters 1 and 3). Often, episodic disturbances are not measured over periods sufficiently long to fully capture outbreak and dormant periods. By contrast, chronic regimes may not be measured in sufficient isolation from other background conditions to detect their presence and accurately estimate their effects.

An example of these challenges is the potential effects on habitats and species from climate change. One potential effect of climate change is an increased frequency of a catastrophic event (e.g., increased frequency of tornados or hurricanes), which changes the episodic disturbance regime. Other effects of climate change may result in longer periods of drought each year, sustained over many years, which change the chronic regime.

Complicating the situation further is the interaction of multiple human disturbances, simultaneously and synergistically operating on a given landscape. For example, if climate change is projected to reduce the area dominated by wet forest vegetation types and increase areas dominated by dry forest and dry grassland types, this shift may increase the frequency and intensity of human-caused wildfires and associated habitat loss in areas of high human uses, such as in areas of high recreation use or near large **exurban** developments. Thus, a change in the chronic disturbance regime subsequently causes a change in the episodic disturbance regime. In such cases, monitoring the changes in all types of disturbance regimes associated with all the interacting human disturbances is essential for effective monitoring of the affected emphasis species and habitats of interest.

7.2.2 Human Disturbance Monitoring

Human disturbance monitoring is the detection of change in a disturbance agent's regime over time and space. In this chapter, we focus on human disturbance monitoring in relation to management of habitats and populations of emphasis species. Many other types of human disturbance monitoring are possible in relation to ecosystem and community properties and processes, but these topics are outside the scope and objectives of this chapter. Instead, our focus is on practical approaches for design and implementation of monitoring of the more common human disturbance agents and associated disturbance regimes, specifically in relation to the needs of terrestrial vertebrates selected for special management emphasis. Human disturbance monitoring requires appropriate and consistent methods, data sources, and data collection over multiple time points, as conducted at spatial and temporal scales compatible with the disturbance regime and associated management objectives.

The Forest Service (Holthausen et al. 2005) identifies three types of monitoring: (1) targeted, (2) context, and (3) cause-and-effect (chapter 1, section 1.3.2). The monitoring approaches described in this chapter are useful for targeted or context monitoring. Cause-and-effect monitoring typically requires manipulative, controlled experiments conducted as formal research, or carefully designed observational research, neither of which is addressed here. These types of formal research are not addressed here because we focus on management-based monitoring of human disturbances, rather than gaining new knowledge about effects from results of monitoring. The latter is a topic for research, in contrast to management-based monitoring.

Monitoring human disturbances can be conducted at different intensities. Low-intensity monitoring typically uses existing, coarse-grained data that require less effort for

acquisition and analysis. An example is corporate databases for road systems and recreation trails (chapter 4, table 4.11). High-intensity monitoring typically requires collecting new data at higher resolution, frequently addressing fine-grained temporal dynamics of human activities that may occur daily, weekly, or seasonally. An example is monitoring the daily frequency of motorized and nonmotorized trail uses. Chapter 3 (3.3.1) addresses the different levels of sampling intensity and scale.

7.2.3 Why Monitor Human Disturbances as Part of Habitat Monitoring?

Monitoring human disturbances as part of habitat monitoring for emphasis species is important for three reasons: (1) human disturbances can alter the distribution and abundance of habitats, and thus the suitability of habitats for species use; (2) human disturbances can change species use of habitats even when habitats themselves are not affected; and (3) compliance with, and effectiveness of, land management objectives can be addressed with this information. Consequently, human disturbance monitoring enables Forest Service managers to further evaluate changes in habitats or species use of habitats.

All human disturbances, however, have multifaceted effects on habitats and species (e.g., figure 7.1). Consequently, in sections in which we address evaluation of effects from human disturbance monitoring, as well as in tables 7.1 and 7.2, we do not restrict our treatment to habitats, but also address effects on populations, such as changes in habitat use, shifts in distribution, and identification of source versus sink environments (Wisdom et al. 2000). Source environments result in stable or increasing populations, whereas sink environments do not have sufficient resources or conditions to maintain a population (Pulliam and Danielson 1991). Human disturbances can have strong influences on the amount and distribution of source versus sink areas (see summary by Wisdom et al. 2000).

Monitoring human disturbances is by definition focused on the disturbance agent and regime (e.g., change in density of motorized routes or rate of motorized use on the routes). Estimating effects of a particular disturbance agent and event on habitats and species is a process that follows that of human disturbance monitoring. Effects on species will dramatically vary by species and spatial and temporal scales. Consequently, resultant effects on habitats and species are not part of the formal process of human disturbance monitoring included in this technical guide. We assume that specific effects on habitats and species will be evaluated or estimated based on existing, empirical knowledge or models developed from existing research rather than directly measuring these effects as part of monitoring human disturbances. We provide examples of different types of effects of human disturbances on habitats and species as part of each example, however, and summarize many types of effects in table 7.1. These example effects and summary effects are provided for context and rationale for why certain human disturbances might be selected for monitoring in relation to their potential effects on habitats and species of interest.

Low-intensity human disturbance monitoring often relies on existing spatial data or updates to these data from a variety of public sources. Additional data may be required for monitoring some disturbance agents at a high intensity, such as monitoring the frequency of all-terrain vehicle (ATV) use on motorized trails on a daily or weekly basis. The types of disturbances to be monitored and the intensity of that monitoring depend on management objectives and the types of potential effects of interest on emphasis species, as detailed in the next section.

Importantly, we focus on human disturbances common to most national forests and grasslands, but that commonly have received less emphasis in more traditional monitoring programs. Examples of human disturbances common to local management units, but not emphasized in traditional monitoring programs, include roads and associated human uses, recreation, and housing developments near NFS lands. By contrast, many other human disturbances common to national forests and grasslands have been emphasized in monitoring programs, such as silviculture, livestock grazing, mining, prescribed fire, and wildfire. Monitoring approaches for these latter disturbances are summarized in the following section but are not repeated in detail in this chapter because of past development and emphasis in traditional programs of Forest Service monitoring.

7.2.4 Additional Human Disturbances To Consider

We describe the following additional human disturbances that should be considered for monitoring because of their potential effects on habitats and species. Specific monitoring approaches for each of these disturbances are beyond the scope of this chapter. Many of these disturbances, however, such as livestock grazing, silvicultural activities, fire, and energy development and mining, have well-established monitoring programs. Data from these established monitoring programs often can be used to address monitoring objectives for emphasis species.

Invasive plants and animals**—**Nonnative invasive species (NNIS) of plants and animals pose major threats to habitats and species across many national forests and grasslands (Moser et al. 2009). Monitoring changes in habitat related to NNIS is an obvious, major issue for all national forests and grasslands. Displacement of native plant and animal species by NNIS is a common effect and one that is difficult or often impossible to anticipate. Challenges in managing these species are many and include (1) identifying which newly arrived NNIS have highest potential to spread and cause substantial problems; (2) accurately predicting the extent and degree of potential effects for those species identified as problems; (3) intervening at early stages to prevent or substantially reduce the spread of such species; (4) reacting effectively, following a major outbreak of such species, to mitigate or reduce the undesired effects; and (5) finding ways to adapt to the presence of, and changes brought about by, NNIS that have established themselves as major components of ecosystems. These five challenges are associated with five potential

phases of invasion and spread of NNIS: (1) local arrival, (2) local establishment, (3) extensive spread, (4) extensive establishment, and (5) extensive dominance and associated effects.

Because of the complexity of management challenges associated with NNIS and the different phases of invasion that require different management responses, no single method or set of methods for monitoring invasion and evaluating potential effects is relevant to all times and locations. Instead, the monitoring approach must be adapted to the particular phase of invasion, must address relevant aspects of the species' life history and competitive relations with native species, and must consider the environmental context and dynamics of the particular ecosystem. In addition, the dynamics of establishing invasive species can be facilitated substantially through many other types of human disturbance. Thus, holistic management of all human disturbances often is needed to effectively manage these species. Consequently, the methods required for effective monitoring of NNIS are beyond the scope of this chapter. See Mooney and Hobbs (2000), Zavaleta et al. (2001), and D'Antonio and Meyerson (2002) for recommended approaches to monitoring and managing NNIS. Data on existing locations of invasive species on National Forest System (NFS) lands are stored in a Natural Resource Manager (NRM) application and can aid in developing monitoring programs in which invasive species are an important consideration for the emphasis species (chapter 9, section 9.3.1). The Forest Service is currently developing protocols for inventory and monitoring of invasive species (FSH 2909.11).

Livestock grazing and supporting infrastructure—Grazing by domestic ungulates has a variety of effects on species and habitats (table 7.1). Most negative effects are geographically and context specific and thus do not apply to all times and environments. In general, effects of livestock grazing are increasingly negative in more arid environments or in areas that lack an evolutionary history of grazing by wild ungulates, especially by bulk grazers. In areas in which plants have coevolved with bulk grazing by wild ungulates, grazing by livestock may have positive effects, depending on the timing, extent, and utilization (Holechek et al. 2001).

Monitoring livestock grazing and estimating effects typically has focused on monitoring the grazing utilization of dominant grass species that often compose much of the livestock diet. Appropriate levels of utilization have been defined for all major biomes in North America (Holechek et al. 2001). Appropriate utilization levels have been established only in terms of sustaining major grass species for livestock forage, however, and do not necessarily relate to effects on habitats and species. Moreover, such monitoring often is generalized over large range allotments, and habitat-specific effects on riparian areas, meadows, flat terrain, and near developed water sources can be substantially different. Consequently, monitoring of livestock grazing and estimating effects require more fine-scale spatial analysis within grazing allotments beyond the conventional monitoring of forage utilization at a coarse scale of each allotment. Holechek et al. (2001) provided

examples of how distributions of livestock vary with common landscape conditions, such as variation in terrain and distance from water. We address this type of monitoring in the section on motorized routes regarding use of **distance bands**.

Fences are predictably associated with livestock grazing, and the type and degree of effects often are unrecognized or ignored. Fences act as barriers to movement of some large mammals, and they may disrupt movements and increase mortality of many large mammals (table 7.1). Fences also provide perches and hunting posts for raptors, which may impact some sensitive species that are prey for corvids, jays, hawks, eagles, and falcons. Evaluation of fence effects generally involves (1) mapping fence locations in relation to seasonal migration routes and daily movement patterns of large mammals and (2) monitoring changes in potential effects over time with mitigation activities or with planned additional fencing. Evaluation of predation effects can use distance bands away from fence lines and the change in those distance categories with changes in fence lines over time, similar to our examples for monitoring linear routes.

In addition, water developments are a common infrastructure in support of livestock grazing. Developed water sources for livestock have a variety of effects on habitats and species (table 7.1). A common misconception is that water sources developed for livestock also are needed by wildlife. In most areas, however, adequate water sources for wildlife exist, and the effects on wildlife from increased water development for livestock often are negative (table 7.1). Livestock use is highly concentrated near water, often resulting in habitat degradation and loss. Consequently, evaluating spatial effects using the distance from water developments and monitoring how those effects change with a reduction or increase in water developments are important components of habitat monitoring in relation to livestock grazing. Evaluation can be done by using concentric distance bands away from water sources and by monitoring changes in these spatial effects with changes in the location and number of water sources over time.

Monitoring livestock grazing and associated infrastructure and estimating potential effects typically involve the use of spatial data that accurately predict the distribution of livestock. For example, grazing use is highest on flat terrain and close to water, and it is reduced with increasing slope and distance from water (Holechek et al. 2001). Spatial layers of topography and water sources, therefore, can easily be used as part of the monitoring process and combined with maps of fence lines to estimate potential effects on species and habitats with use of distance estimates. Distance bands closest to water, to fence lines, and on flatter terrain will have the most negative effects on species and habitats, with least impact to areas farthest from water and fences and those on steep terrain. Monitoring involves mapping changes in water sources and fence lines over time or proposed by management, because water improvement projects for livestock are common and fence lines often are increased over time.

Distribution of livestock can be monitored in combination with knowledge of the grazing system and stocking rate (density). Stocking rate, in particular, affects the

structure and composition of vegetation more than any other variable (Wisdom and Thomas 1996). Changes in stocking rate thus are useful to monitor, along with the grazing system and season of use (Holechek et al. 2001), to estimate effects on habitats and species. Many of the effects of different types of livestock grazing on wildlife habitats and species are summarized in Krausman (1996).

Silviculture—Vegetation management for producing and harvesting wood for commercial products remains a major disturbance agent in most national forests. Consequently, silvicultural treatments have some of the most extensive effects of any management activity on vegetation structure and composition, patch size and configuration, and landscape composition. Accordingly, chapters 3, 4, and 6 provide guidance for monitoring vegetation change, including effects from silvicultural activities. In addition, a plethora of research syntheses have addressed this topic (e.g., see Hunter 1990, Oliver and Larson 1990, Lindenmayer et al. 2008, Swanson et al. 2011). Monitoring in relation to silviculture thus is not addressed in this chapter, with the exception of the road infrastructure that accompanies and supports most silvicultural treatments. Monitoring effects of such roads and their management is addressed as part of monitoring linear routes, as described in example 1.

Energy development and mining—Energy development and mining are common activities on many NFS and other public lands, and these land uses are growing rapidly. Examples include development of oil and gas fields and supporting infrastructure (e.g., pipelines, power lines, and roads that serve the field), wind farms, and strip or shaft mines for mineral extraction. Effects include habitat loss associated with the extraction area (i.e., the oil or gas well pad or the strip mine or shaft) and habitat loss and degradation associated with the supporting infrastructure (table 7.1). Often, the most deleterious and pervasive effects are associated with the multitude of roads, pipelines, and power lines that serve the extraction area. Monitoring energy development and estimating the resulting changes in habitats require spatial analysis in relation to varying distances from the energy development or mining site and from the supporting infrastructure and how those distances change over time with changes in development or mining, such as with use of the methods illustrated by Wisdom et al. (2005). Monitoring all associated infrastructure that supports energy development and mining sites, including roads, pipelines, transmission lines, and dump sites, is an essential part of this process (Wisdom et al. 2005).

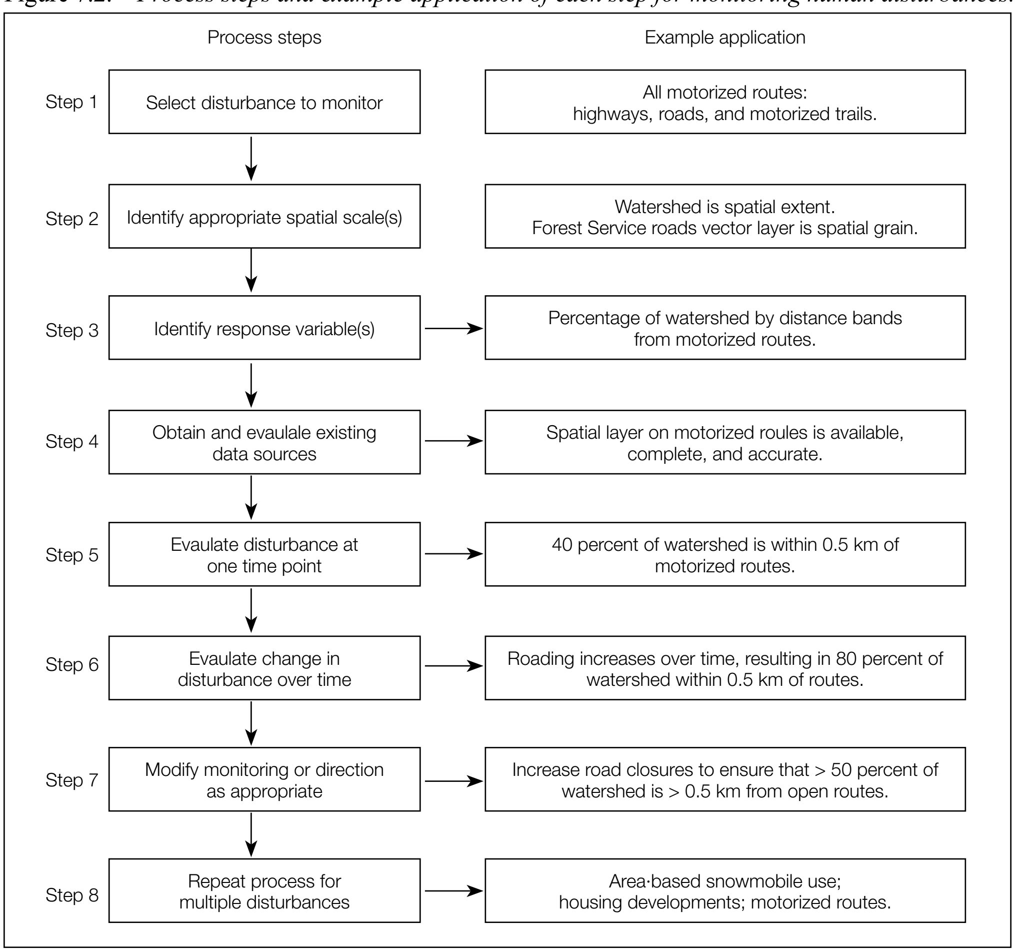
Power lines—Electric transmission lines often are overlooked as a major disturbance agent, despite their many negative effects on habitats and species and despite their widespread presence within and near national forests and grasslands. Transmission lines convert habitat to nonhabitat, increase fragmentation of remaining habitats, enhance predation of sensitive species, facilitate invasions of NNIS, establish movement barriers or avoidance zones for wildlife, and contribute to many other undesired effects related to motorized access and use along the transmission right-of-way (Wisdom et al. 2005) (table 7.1). Many of these negative effects diminish with increasing distance from the

transmission lines. Accordingly, the same type of distance band analysis used for other linear features such as highways, roads, and motorized trails can be used for monitoring the presence and change in line locations and estimating effects, as illustrated in Wisdom et al. (2005). Electric transmission lines are easily monitored with spatial data layers available from power companies and Federal agencies that regulate power use. Some information is restricted, however, and formal permission must be granted from power companies before spatial data on all lines can be obtained.

7.3 Process Steps for Monitoring Human Disturbances

The generalized steps for monitoring human disturbances (figure 7.2) are similar to those outlined for habitat monitoring in previous chapters, but are customized here for specific use in human disturbance monitoring. Decisions at each step are largely dictated by the management direction and policy on which the monitoring process is based (chapter 1) or by the associated conditions of management interest. Without clear management and policy direction, particularly quantifiable direction, the monitoring process will

Figure 7.2.—*Process steps and example application of each step for monitoring human disturbances.*



km = kilometer.

become more challenging and less effective, given the additional assumptions that must be made about how the monitoring process can be related back to the direction, policy, or associated conditions. Although these steps are logical and straightforward, actual design and implementation of an effective approach for monitoring human disturbances on emphasis species is a complex analytical endeavor, and it can be improved substantially from collaboration with a statistician or biometrician.

Step 1. Select Disturbance Agents To Monitor

The topics, controversies, effects, decisions, and management direction associated with land use planning provide essential context for selecting the disturbance agents that warrant monitoring. It is logistically impossible to monitor all human disturbances and estimate effects on all habitats and species. Consequently, a key starting point is to establish clear rationale and criteria for identifying and prioritizing which disturbance agents will be the focus of monitoring. The criteria in the following section were customized for consideration in human disturbance monitoring but support the more general criteria for habitat monitoring outlined in chapter 2. To identify which human disturbance agents to monitor, use the following criteria.

- ***Spatial extent or pervasiveness of the agent—***Disturbance agents that affect large areas of the planning unit are likely to affect many habitats and species and, thus, are likely targets for monitoring.
- ***Prior evidence of the agent having the potential for significant effects on habitats and species—***Some disturbance agents have obvious and significant effects that have been documented from the scientific literature and from their obvious presence on NFS lands (e.g., motorized routes), whereas other agents may have little history of operating on, or affecting, habitats on NFS lands (e.g., pesticides).
- ***Agreement among resource specialists and managers about the relative importance of the agent in the area and the rationale for the agent's importance, including consideration of expert views on the issue—***The expertise of resource specialists and managers, who have direct knowledge and experience with resource issues in the analysis area, provides a strong basis for selecting disturbance agents that warrant monitoring.
- ***Public opinion about the agent—***Views expressed by the public and vested land users provide context in helping select disturbance agents for monitoring. These views indicate the degree to which potential disturbance effects are of interest to society.
- ***Available resources to address the agent—***Funding or staffing shortages often limit the degree to which particular disturbances can be monitored. Nonetheless, resource shortages for monitoring important disturbance agents need to be clearly identified so that the shortages can be acknowledged and considered.
- ***Timeframe required to monitor a disturbance or resultant treatments designed to mitigate undesirable effects—***The time intervals appropriate to monitor a given

human disturbance can influence the feasibility of such monitoring, such as episodic disturbances that may be unpredictable in timing of occurrence versus chronic and often more cryptic disturbances that operate more evenly over time.

- ***Costs versus benefits of addressing the agent*—**Some disturbance agents may have already caused obvious negative effects on wildlife habitats or populations, or research may have documented the overwhelming nature of a given human disturbance, with negative effects that may be difficult or impossible to mitigate or reverse, thus reducing the benefits of monitoring the agent or the feasibility of mitigating effects in management. An example is an invasive plant species that is so well established that it defies obliteration and instead has become naturalized in many environments. A variety of NNIS fit this description (Richardson et al. 2000). These situations must be well documented from past research to justify the reduced focus on human disturbance monitoring.
- ***Management opportunities provided by contiguous land ownership, such as expansive areas of Federal lands*—**It might be challenging or impossible to effectively monitor disturbance agents on fragmented land ownerships if the goal is to monitor the agents as they relate solely to national forest and grassland management. Alternatively, monitoring human disturbances and estimating their effects on NFS lands adjacent to or near other land ownerships, particularly urban developments, may be of highest management priority, given the many negative effects on habitats and species in such areas.
- ***Technologies capable of monitoring the targeted resources and effects*—**Most disturbance agents require remote sensing technologies for effective and efficient monitoring; however, some fine-grained, dispersed disturbances, such as livestock grazing, may be difficult to monitor in contrast with remote monitoring of more easily quantified activities, such as oil and gas development. The correct match of methods and technologies with the disturbance agents is key to successful monitoring.
- ***Potential effects of the agent on nontarget habitats or species and other resource goals not directly related to the resources of interest*—**The monitoring approaches outlined here are designed to support management objectives for habitats and species. Potential effects on other resources, however, also justify the need for monitoring.

Documenting the rationale for selection of disturbance agents provides the foundation for an effective monitoring plan. Such documentation provides an essential framework for monitoring and for helping secure needed funds and staffing to conduct the work.

Step 2. Choose Targeted or Context Monitoring

A targeted monitoring approach is designed to address specific management direction or influences of management or conditions of interest. For example, management restrictions placed on the location and frequency of helicopter skiing, owing to concerns about disturbance effects on an emphasis species like wolverine, would justify targeted monitoring of this recreation activity.

In other situations, monitoring may not be explicitly designed to address existing management direction or specific habitats for particular species. Instead, monitoring might be designed to gain insight about a disturbance regime's characteristics (extent, frequency, duration, and magnitude), such that potential effects of emerging or previously unrecognized issues might be better understood, which is context monitoring. For example, a set of caves may not have specific management direction that protects these sites from spelunking, but understanding the context of human use and potential effects may be warranted to understand whether management protection may be beneficial for associated species such as bats (e.g., roosting in the caves). In these cases, context monitoring is appropriate, with results available for potential consideration in future management processes, but not explicitly tied to existing direction.

Step 3. Identify Appropriate Spatial Scales

After selecting a particular disturbance agent and type of monitoring, choose appropriate spatial scales for evaluating the associated objectives and actions. Chapter 2 (section 2.2.6) addresses spatial scale, which is composed of spatial extent and spatial grain, each of which requires consideration in matching the goals of human disturbance monitoring with the appropriate type of spatial data needed to meet goals (Gutzwiller and Cole 2005, Peterson and Parker 1998, Turner et al. 2001). Ultimately, the spatial accuracy of data used for human disturbance monitoring must be sufficient to meet goals. Spatial accuracy is the combination of bias and precision of spatial estimates. Low bias and high precision result in high accuracy of spatial estimates.

Deciding on the appropriate spatial scales is not trivial—monitoring results will vary with scale, and some results may be extremely scale sensitive (chapter 4, section 4.2.4). Consequently, all three characteristics of spatial scale (extent, grain, and accuracy) warrant careful consideration as part of monitoring. In addition, management planning and activities are scale specific, and monitoring needs to be compatible in scale.

Step 4. Identify Metrics for the Selected Disturbance Agents

Metrics are characteristics of the disturbance agent and associated regime that are measurable and relevant to monitor. For example, issues of road management might require monitoring the density of roads, the percentage of area by distance categories from roads, or the frequency of traffic on each road system (section 7.4). Similarly, energy extraction activities could be monitored by estimating the change in density of gas and oil wells; the associated number, type, and length of roads, pipelines, and transmission lines that serve the extraction sites; and the area impacted, summarized by distance categories from the extraction sites (section 7.2.4).

Three main types of metrics are commonly used for monitoring and evaluating human disturbances: (1) distance, (2) density, and (3) rate. Use of these metrics for human disturbance monitoring is illustrated in our examples in subsequent sections.

Select appropriate metrics based on prior management direction or specified conditions of interest. For example, if direction for managing motorized access is established in terms of density of roads open to motorized use, then density estimates are obviously of monitoring interest. Similarly, if management direction limits the rate of trail use (e.g., restrictions on the number of persons hiking or horseback riding per day on a trail system during particular seasons), then rate estimates are of interest. Unfortunately, in some cases, it may not be possible to make a straightforward connection to management direction. In such cases, the use of context monitoring, without explicit connection to management direction, may be appropriate.

Step 5. Obtain and Evaluate Existing Data Sources for Selected Metrics

Most data used to monitor human disturbances are spatially explicit. Moreover, many spatial layers currently exist for monitoring the more common human disturbances of interest, such as motorized routes or housing developments near NFS lands (chapter 4, table 4.11). Unfortunately, such data sources often are not centralized, and several disparate data sources may need to be assimilated for monitoring. In other cases, centralized data sources are available but have unknown accuracy. In still other cases, documented accuracy of the data is provided through metadata, but such data may still contain errors of omission, such as road systems that are not mapped. These problems require that data layers be evaluated before their use—for completeness, accuracy, and relevance to management objectives.

Step 6. Identify the Appropriate Period for Monitoring

Specify the desired, appropriate temporal scale for monitoring the disturbance agents. That is, select the proper temporal extent in relation to the disturbance regime associated with the particular human disturbance, and ensure that potential biases associated with different methods of estimating change over different periods (differences in **temporal grain** and resulting temporal accuracy) are reconciled (Noon and Dale 2002).

Notably, use of different methods or data sources to monitor disturbances for each period will affect the spatial grain and accuracy, in turn affecting estimates of change over time. As with spatial scale, the objectives of an analysis determine requirements for temporal extent and accuracy. Evaluations conducted over short periods may reveal little change in habitat conditions, incorrectly suggesting that change has been minimal. Or, evaluations over short periods may capture effects of an infrequent but large episodic event, falsely suggesting that change has been substantial. By contrast, changes measured over multiple time points, spanning longer periods, are more likely to reveal past dynamics of habitat change that are easier to interpret. Consequently, matching the appropriate period with the dynamics of the disturbance to be monitored, within the desired management timeframe, is essential for effective monitoring.

An additional complicating factor is that different methods often are used to estimate conditions at different times. In general, estimates become increasingly coarse in resolution as one goes farther back in time, when less powerful or sophisticated software or analysis tools were available. By contrast, estimates made closer to the present often rely on the same or similar methods of estimating conditions. Differences in methods used at different times must be accounted for in the analyses and subsequent inferences.

Step 7. Monitor the Metrics Over the Designated Period

After identifying an appropriate period for monitoring, estimate changes in metric values in relation to habitat of the emphasis species and management direction. Monitoring methods will differ substantially with the specific metrics and the designated spatial and temporal scales. For example, monitoring compliance with management direction that closes a set of roads to motorized traffic during hunting seasons may require use of automated vehicle counters or motion sensors installed at the start of a closed road system to detect motorized use on the closed roads during the hunting period. By contrast, monitoring compliance with management direction to obliterate specific roads and trails to eliminate motorized uses may simply involve field visits to the targeted road systems to monitor whether obliterations or other impediments to traffic have been implemented and continue to be maintained according to management direction.

The key to successful monitoring of these metrics is to follow a well-designed plan that is developed before actual monitoring begins. Such plans need to explicitly follow directions provided in previous steps (steps 1 through 6), detail all objectives and methods in written form, undergo formal peer review from experts on the specific topics, and receive management approval to ensure their utility for management and increase the probability of needed funding and staffing.

Step 8. Ensure That Monitoring Outcomes Are Reported in the Context of Management

Results from monitoring must be formally documented and reported so they can be used in planning and management (chapter 3, section 3.3.5). If results are part of targeted monitoring, several factors must be considered and interpreted correctly, including (1) whether the monitoring design was adequate to evaluate management direction or associated conditions, (2) whether the management direction or conditions were quantified clearly beforehand to allow for monitoring results to be used for effective evaluation of the direction or conditions, and (3) whether prior assumptions were clearly established to address problems arising from the previously listed factors. Many challenges associated with interpreting monitoring results for management can be reduced or mitigated by clearly documenting how changes in the habitat attributes will be interpreted and used in planning and management. This documentation needs to occur as part of the monitoring plan.

If results are part of context monitoring, findings may suggest the need to modify management direction or to allay any potential concerns about the issue or its potential effects on habitats and species. If the approach is targeted monitoring, any of four actions may be appropriate after estimating effects and comparing monitoring results with management direction: (1) the monitoring approach may need to be modified to improve its use in estimating effects and evaluating management direction or associated conditions, (2) management direction may need modification in response to noncompliance or undesired effects, (3) both monitoring and management direction may need modification to improve the relationship, and (4) none of these actions may be necessary because the monitoring process worked effectively and results indicated no need for changes in management.

Step 9. Repeat Process Steps for Multiple Disturbances

A combination of human disturbances typically operates simultaneously on a given landscape, with combined effects that can affect emphasis species and their habitats in ways that may exceed or differ from effects of the individual disturbance agents (Paine et al. 1998). As a consequence, an additional and often highly effective step in the monitoring process is to evaluate the combined effects of the individual disturbances that are monitored. Evaluating the combined effects from results of monitoring a set of human disturbances is important because the results can be used to further inform management direction or prompt changes in direction, owing to unexpected outcomes that are not apparent from estimating effects from individual disturbances. Three generalized types of potential effects are likely when considering multiple human disturbances operating together: (1) cumulative effects; (2) interactive effects; and (3) special types of interactions, such as threshold effects or limiting factor effects. The following paragraphs present a brief overview of these concepts.

Cumulative effects are those in which the combined effects of human disturbances are additive. That is, the effect of one disturbance combines with one or more other disturbances such that the total or cumulative effect equals the sum of effects from all individual disturbances (Gutzwiller and Cole 2005). An example is human footprint analysis in which the spatial effects of two or more conditions or disturbances are overlaid on one another (Leu et al. 2008, Sanderson et al. 2002). The resulting maps depict areas in which potential effects of multiple disturbances may be quite negative, versus areas in which multiple disturbance effects are relatively benign in nature. When classical statistical analyses are employed, additive effects are typically modeled and analyzed with multiple linear regressions. Kutner et al. (2005) provide helpful guidance on regression approaches.

Interactive effects are those in which one or more human disturbances affect other disturbances, such that overall effects are not additive but instead manifest in less predictable ways. Typically, a synergy of effects is brought about by the combination of individual disturbances, resulting in more severe or more benign effects than expected by simply adding individual disturbances. Multiplicative effects and geometric effects, for example, can

increase by orders of magnitude that can far exceed additive processes. One example is the coupling of roadside invasion by nonnative annual grasses with increased susceptibility of adjacent habitats to human-caused wildfires (Wisdom et al. 2005). In this case, disturbances from road maintenance activities and motorized uses facilitate the invasion and establishment of nonnative annual grasses along roadsides, resulting in habitat degradation. In turn, the nonnative grasses serve as an ideal flash fuel, sufficient to initiate wildfires, which often start from human activities along roads (e.g., burning cigarettes thrown from a car window). These fires then spread into nearby native vegetation, thereby eliminating important habitat for wildlife near roads. The resulting soil disturbance from the wildfire then provides an ideal medium for further spread and establishment of non-native annual grasses, in turn increasing the probability of subjecting adjacent native vegetation to additional fires. This cycle can continue at increasing distances from the road, with effects that are substantially greater than either the single or the additive effects of the combination of disturbances.

When classical statistical methods are used, interactive effects often are modeled using multivariate linear regression; values of the predictor variables often are multiplied together, or used in quadratic or cubic form, to create new predictor values. The number of possibilities becomes quite large, but the combinations provide flexibility in fitting the shape of a response to the interactive effects of human disturbances (predictor) variables.

Other types of interactions include threshold effects and limiting factor effects. Threshold effects can be interactive when two or more disturbances combine to cause habitat or population declines that are precipitous, after a particular condition is reached. Identifying such thresholds requires a detailed understanding of the synergy of two or more interacting disturbances across the spectrum of conditions above and below such thresholds. Similarly, limiting factor effects result when a particular effect from one disturbance overwhelms the effects of others (chapter 2, section 2.3.2). In these cases, equal attention to each disturbance agent is neither efficient nor effective. Gaining knowledge about which disturbance agents, if any, may be operating as limiting factors, however, may not be possible without monitoring all disturbances and estimating effects in relation to associated habitats and species of interest. Fitting of threshold and limiting factors may require complex, interactive multiple regression models, nonlinear regression models, or even neural networks and other data mining or curve fitting procedures (Kutner et al. 2005). In detecting and modeling these more complex relationships, include a statistician or biometrician as part of the habitat monitoring team.

Integrated monitoring of multiple disturbance agents may not be possible because of time, funding, or logistical constraints, thus limiting detection of some of the effects described previously. As the complexity of a model increases, the number of terms in the regression analysis increases and the old rule of thumb applies, namely the sample size (e.g., number of field plots) needs to be about 10 times the number of predictor terms in a model. Nonetheless, evaluating effects from multiple disturbances can take advantage of whatever results are available from monitoring individual disturbances, so that patterns

about potential types of effects like those described previously might be documented. Documenting and accounting for such patterns can complement the focus on individual disturbance agents in the monitoring process.

7.4 Key Metrics for Quantitative Monitoring of Human Disturbances

Three general metrics or types of estimates often are used to monitor human disturbances: (1) distance, (2) density, and (3) rate. We define and describe these disturbances here because they are most relevant among many possible metrics for monitoring the types of human disturbances most common to NFS lands (section 7.5).

Distance Estimates

Distance is a measure of the proximity of one object on a landscape to another. For human disturbance analyses, distance estimates often are used to partition the landscape into distance zones or categories in relation to a source of disturbance, such as a road, campground, or housing development. These distance zones or categories often are referred to as **distance bands** (Rowland et al. 2000, 2005; Theobald and Hobbs 2002). For example, a watershed might be partitioned into distance bands away from roads, each 0.1-mile (mi) wide, or away from transmission lines or campgrounds. Use of distance bands or zones provides a flexible and accurate means of identifying portions of the landscape close to, versus far from, linear routes. The percentage of a landscape within each distance band can then be mapped and monitored over time, and results can be compared with management goals and direction.

Density Estimates

Density is the number per unit area of a measurable feature of interest. Density is a common measure of many landscape features, such as roads, trails, campgrounds, livestock water sources, oil and gas wells, and any other human use areas that are readily mapped. Density is often used as a landscape metric because it is easy to estimate, presumably easy to interpret, and has a long history of use in establishing management direction. Perhaps the most notable density estimate is road density, which has been used as a generic indicator of human activities and their effects on a variety of large mammals such as elk (*Cervus elaphus*; Lyon 1983), brown bear (*Usrus arctos*) (Mattson et al. 1996), gray wolf (*Canis lupus*; Mech et al. 1988), and wolverine (*Gulo gulo*; Rowland et al. 2003).

Although density may be easy to calculate, exactly how the calculations are made and used to estimate effects on habitats and populations of emphasis species can strongly influence results. In most cases, density is actually a surrogate for distance because habitats and species are typically affected based on the distance from a human disturbance, often measured with distance bands (Rowland et al. 2000, Theobald and Hobbs 2002).

By contrast, density does not measure distance, instead measuring how concentrated a disturbance is at a given spatial extent. Such estimates can be misleading if a large analysis area has a high density of some feature in one area but a low density in the remaining sections and if the results are averaged across the entire area. In such cases, the mean road density calculated over the entire analysis area provides a result intermediate to these extremes and does not depict the full range of conditions. Use of distance bands in this same analysis area provides the area in each distance category in relation to a disturbance, which more accurately reflects spatial variation in the disturbance across the landscape (Rowland et al. 2000, 2005).

Rate Estimates

Rate is the frequency of an event per unit time, such as the number of vehicles passing along a road every 24 hours, or the number of hikers using a trail system per month. Many types of rates may be relevant when monitoring human disturbances because rates are a direct measure of a given disturbance regime in time and often are spatially explicit. For example, the daily rate of a certain recreation use can largely determine the types and magnitude of effects on a species' use of the affected habitat, such as the rate of motorized traffic on forest roads (e.g., Wisdom et al. 2004b) or motorized trails (Wisdom et al. 2004a), rate of snowmobile use on winter trails (Davenport et al. 2003), or rate of hiker use of a forest trail system (Gaines et al. 2003). Rates are an important complement to distance and density estimates because distance and density are estimated at fixed times, whereas rates measure temporal dynamics of a given disturbance on a more continuous or finer time scale. Often, the rate at which a human disturbance occurs more accurately depicts potential effects on habitats and species than a simple depiction of a human use area (e.g., road, campground, housing development) that reports distance or density estimates but does not estimate actual use (Wisdom et al. 2004b).

7.5 Common Disturbance Agents on National Forests and Grasslands

We focus on methods for monitoring and estimating effects of three of the most common human disturbances on national forests and grasslands: (1) motorized routes, defined as linear routes used for motorized travel, typically composed of highways, roads, and motorized trails (railroads can also be included); (2) recreation activities common to local management units; and (3) housing developments near national forests and grasslands, such as rural housing, suburban, or urban (exurban) developments with easy access to NFS lands. Many other human disturbances warrant monitoring on NFS lands, such as silvicultural activities, livestock grazing, fire, invasive species, energy extraction, electric transmission lines, mining, and climate change (table 7.1).

Some of these additional disturbances, however, typically are monitored as part of existing management programs (e.g., livestock grazing, silviculture, fire) and thus have prior monitoring protocols in use. Others are addressed indirectly in other chapters of this guide, as measured through protocols for monitoring vegetation-based habitat attributes (chapter 4). In other cases, these disturbances affect a substantial area of particular local management units but are less common or more localized on many national forests and grasslands (e.g., energy extraction, mining, transmission lines). Finally, in at least one case—climate change—the disturbance is not only appropriate to monitor at smaller spatial extents such as watersheds within an individual management unit, but also warrants monitoring at spatial extents vastly larger than that of individual or multiple management units, requiring approaches that span all land ownerships and administrative units at regional and continental scales (chapter 2, section 2.2.7). For the three examples highlighted in this chapter, we address how potential effects of climate change might interact with effects of the human disturbance that is featured in the example.

Regardless of the type of human disturbance, most types can be addressed by using methods highlighted in this chapter. Consequently, we briefly describe the general effects of each of the additional disturbances on habitats and species in section 7.2.4 and suggest how monitoring approaches described in this chapter could be adapted, if appropriate, for these disturbances. For other disturbance agents, we describe why these agents require monitoring approaches beyond the scope of this chapter.

Our three examples use the same spatial extent and landscape, which is a hypothetical, 20,000-acre watershed of mixed landownership (figure 7.3). Other spatial extents of larger size and type also are appropriate for monitoring the types of human disturbances in our examples. Our use of a watershed as an analysis unit is of no special significance; it simply is the spatial extent at which management objectives were established for the examples and, thus, the extent at which monitoring would be conducted. In addition, the mix of NFS and private lands within and adjacent to the watershed is typical of many landscapes. Consequently, this approach is helpful in illustrating the need to monitor human disturbances holistically among ownerships to fully understand and document changes over time and to estimate the effects accurately in relation to monitoring and management goals on NFS lands. Moreover, the watershed scale also is appropriate for a variety of landscape analyses for species of conservation concern on public lands (Wisdom et al. 2000).

Each example is composed of three sections: (1) introductory text that provides a brief overview, justification, and context for monitoring the disturbance; (2) the process steps and metrics as used for monitoring and a summary of the monitoring results; and (3) the potential effects on example habitats or species based on the monitoring results. It is important to note that monitoring a given human disturbance focuses on measuring change in the disturbance over time. Estimating effects from results of the monitoring approach is an important but additional process beyond the formal monitoring process.

Figure 7.3.—*The watershed spatial extent used for three examples of human disturbance monitoring and the pattern of public and private lands within it. This landownership pattern of a watershed dominated by National Forest System lands (areas of white), interspersed with small, disjunct blocks of private inholdings, is typical of many watersheds in national forests and grasslands, especially in the Eastern United States.*

Effects analysis can differ widely in approach and methods, as dictated by the specific emphasis species and habitats targeted for management or of conservation concern. Although we describe some general ways to estimate effects from our monitoring examples, comprehensive treatment of this topic is beyond the scope of this chapter.

For each example, we also address how projected effects of climate change might be considered as an additional, interactive disturbance factor with that of the human disturbance being monitored. We introduce and highlight climate change in this manner because it potentially interacts with all other human disturbances and effects, or it can override other disturbances and effects. Thus, consideration of potential effects of climate change provides important context for all other types of human disturbance monitoring in relation to emphasis species and habitats and associated management objectives.

7.5.1 Example 1—Motorized Routes: Highways, Roads, and Motorized Trails

Linear routes used for motorized travel are associated with a myriad of negative effects on habitats and species (table 7.1, figure 7.1). Effects include habitat loss, habitat fragmentation, and spread of invasive plants (Formann 2000, Spellerberg 2002, Trombulak and Frissell 2000). The composite effects of road-associated habitat loss and fragmentation favor vertebrate species adapted to patchy, disturbed habitats (Frid and Dill 2002). Motorized travel also directly impacts animals, through collisions, poaching, overharvest, displacement, movement barriers, and increased energy costs from exposure to human activities (Wisdom et al. 2000; table 7.1, figure 7.1). The scope and magnitude of these effects differ dramatically with the type of route, its infrastructure, and the frequency and types of motorized uses (Frid and Dill 2002, Havlick 2002).

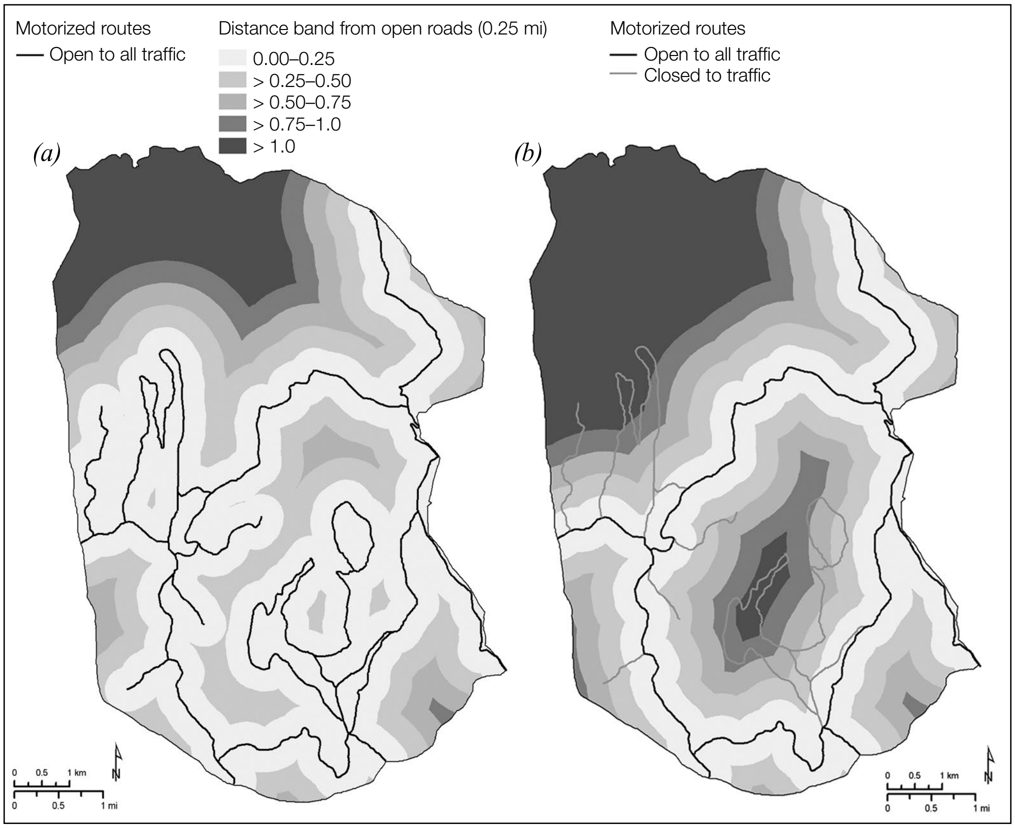
Highways, for example, eliminate the most habitats because of their extensive infrastructure and wide rights-of-way. Narrow trails used by ATVs and dirt bikes, by contrast, have a smaller area of direct habitat loss adjacent to these linear routes. High-speed, high-frequency traffic on highways and highly used railroads also are substantial causes of animal mortality via collisions (Clevenger et al. 2001, Dodd et al. 2004, Van der Grift 1999), whereas secondary or primitive Forest Service roads may cause less direct mortality. Despite these generalizations, the large network of motorized roads and trails on NFS lands may have cumulative effects on species and habitats—such as strong avoidance of habitats near such routes or the pervasive spread of invasive plants—that can exceed those from highways or railroads because of the extensive network of these roads and trails on most national forests and grasslands (Forman 2000). The specific effects depend on the type and spatial extent of the road and motorized trail systems. Another example effect is motorized trails and primitive roads facilitating overharvest of game animals and poaching (Cole et al. 1997); these sources of animal mortality may be substantially less along highways and substantially higher on NFS roads and trails.

Consequently, many effects from motorized routes are not obvious, and generalizations about more deleterious effects being associated with well-developed and higher frequency traffic routes may be unwarranted. Accordingly, the type of linear route used for motorized travel needs to be monitored in relation to, and characterized by, the potential effects associated with that route, considering the plethora of potential effects (table 7.1).

Monitoring

In this first example, the human disturbance selected for monitoring (step 1) is the linear routes open to motorized travel (motorized routes, figure 7.4). Rationale for selecting this disturbance follows that described previously for process step 1 (section 7.3). Importantly, all linear routes open to motorized use are included as part of monitoring, including highways, forest roads, and trails open to ATVs and dirt bikes. A targeted monitoring approach is taken (step 2), owing to the need to explicitly relate the results

Figure 7.4.—*Example watershed characterized by distance bands buffered from linear routes open to motorized travel, mapped for two time points 5 years apart. The specific road management direction for this watershed is that more than 40 percent of the area needs to be more than 0.5 mi from motorized routes. At time point 1 (a), 25 percent of the watershed is more than 0.5 mi from motorized routes. At time point 2 (b), 46 percent of the watershed is more than 0.5 mi from motorized routes.*



mi = mile.

to management direction. In this case, management direction specifies the percentage of watershed area to be maintained by distance from linear routes open to motorized use. Specifically, the watershed is to be managed so that more than 40 percent of the watershed area is more than 0.5 mi from the nearest route open to motorized use.

The appropriate spatial extent for management is the watershed (step 3) because, in this case, management direction was specified for this extent. The watershed extent is nested within administrative extents of ranger district, national forests and grasslands, and region, allowing for monitoring results across many watersheds to be summarized at larger spatial extents of interest to management. Complicating the monitoring process within all these extents is the mixed ownership of public and private lands (figure 7.3).

Spatial grain in this example is the resolution of the road vector layers available from the national forest or grassland in which the watershed is located. These vector layers, typically included in standardized geospatial formats (e.g., geodatabases, coverages,

or shapefiles), are available for Forest Service regions or for individual national forests and grasslands (chapter 4, table 4.11). Road locations for this example vector layer are assumed to be accurate to within 1 to 2 meters (m) of their true location, based on the accuracy of Global Positioning System (GPS) technologies that were used to inventory all motorized routes in the district.

The selected metric (step 4) is the percentage of watershed area within distance categories (distance bands) from the routes open to motorized travel (table 7.2). This metric was selected because management direction established for the watershed was specified in terms of setting limits on the percentage of area within certain distance bands from routes open to motorized use. A complete roads and trails layer containing all routes open to motorized use in the district is obtained and used as the basis for evaluation (step 5).

The period over which monitoring occurs is 5 years (step 6), which is the length of time in which road management direction is to be achieved under a revised forest plan. The specific road management direction for this watershed is that more than 40 percent of the area needs to be more than 0.5 mi from motorized routes. Evaluation of change in the disturbance over time (step 6) shows that miles of open roads have changed substantially: only 25 percent of the watershed was more than 0.5 mi from motorized routes 5 years ago (figure 7.4a), but currently 46 percent of watershed area is more than 0.5 mi from routes (figure 7.4b, table 7.2). Negative effects on emphasis species that avoid roads or experience increased mortality near roads thus have been reduced over time (step 7, see next section for effects). Consequently, no additional management actions (e.g., additional road closures and obliterations) are deemed appropriate (step 8). Effects on habitats for emphasis species from these monitoring results can then be considered with results from monitoring other human disturbances, such as area-based snowmobile use (figure 7.5) and housing developments on nearby ownerships (figure 7.6). Cumulative effects from monitoring these multiple land uses can be estimated and considered as part of more holistic management of the watershed (step 9, section 7.5.4). Also note that off-road motorized uses that do not follow linear routes are not addressed in this example but are addressed in example 2 on monitoring recreation as a human disturbance.

Table 7.2.—*Percentage of watershed area within distance bands from nearest linear route open to motorized travel and from nearest housing development to National Forest System lands, estimated and mapped for two time points 5 years apart. See examples 1 and 3 in text for details.*

	Distance band (miles)									
	Time point 1					**Time point 2**				
Human disturbance	0.00 to 0.25	> 0.25 to 0.50	> 0.50 to 0.75	> 0.75 to 1.00	> 1.00	0.00 to 0.25	> 0.25 to 0.50	> 0.50 to 0.75	> 0.75 to 1.00	> 1.00
Linear routes	53	22	8	5	12	32	22	14	9	23
Housing	1	3	5	7	84	2	9	16	21	52

Figure 7.5.—*Example landscape used by snowmobiles under area-based use, assuming all areas of less than 30 percent slope can be traversed under current management regulations. Approximately 75 percent of the landscape can be traversed efficiently by snowmobiles in this example.*

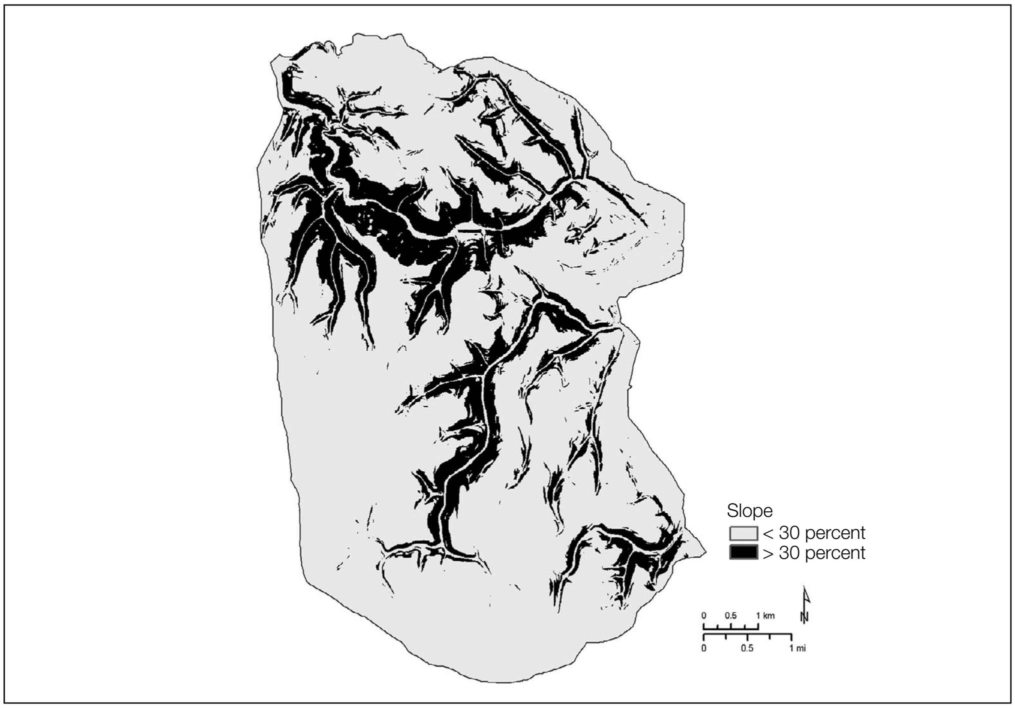
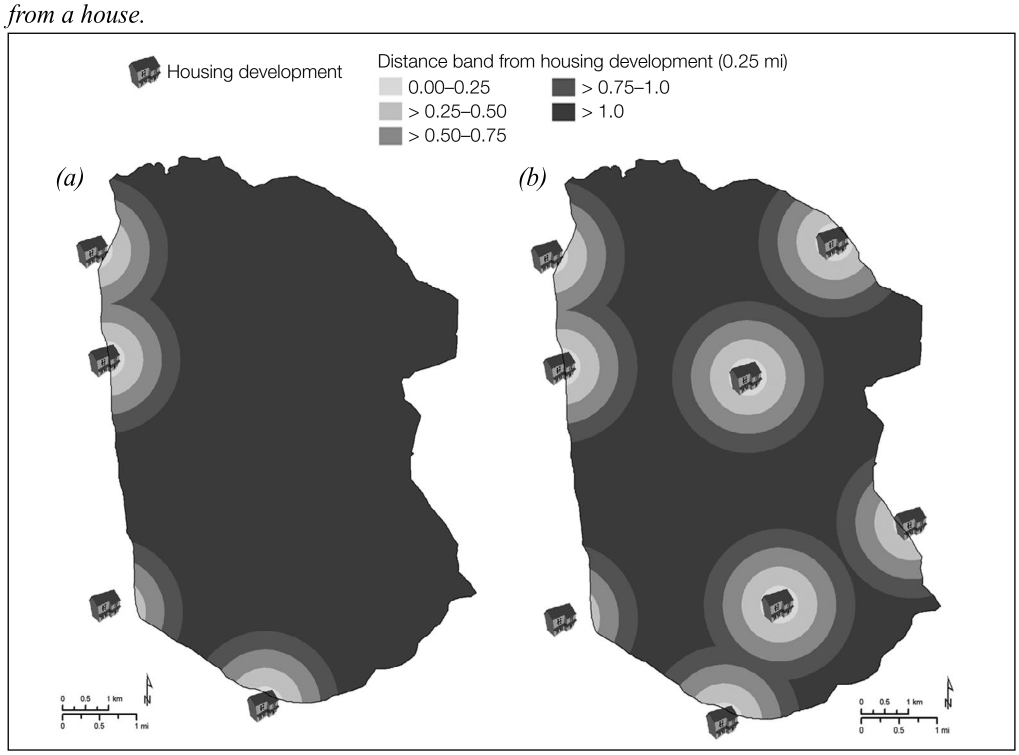


Figure 7.6.—*Example watershed characterized by distance bands buffered from houses, mapped for two time points 5 years apart. At time point 1 (a), 84 percent of the watershed area is more than 1.0 mi from housing. At time point 2 (b), only 52 percent of the watershed area is more than 1.0 mi from a house.*



mi = mile.

Estimating Effects

Linear routes used for motorized travel can be monitored and their effects estimated with use of distance, density, and rate estimates (table 7.3, figure 7.4). In the example in figure 7.4, most (75 percent) of the landscape at monitoring time point 1 (5 years ago) was within 0.5 mi of roads and trails open to motorized use (table 7.3), but this percentage was about 50 percent at time point 2 (current time). Changes in these percentages can easily be monitored in relation to management objectives or proposed management for the period of interest, as demonstrated in this example. In turn, distance bands from nearest linear route can be used as effect zones for species and habitats that are sensitive to human activities associated with routes. For example, invasive plant establishment often occurs within 100 yards (yd) of roads or trails, and this distance band can be considered an area of habitat loss or of severe degradation for native vegetation (Gelbard and Belnap 2003). In the example in figure 7.4a at time point 1, 53 percent of the area is within 0.25 mi of a linear route (all routes, regardless of motorized use regulations), and this zone could contain large areas in which native habitats are eliminated or substantially degraded by invasive plant establishment. A variety of additional edge effects occur at varying distances from roads, with effects that vary widely among species and ecological properties and processes of interest (Forman et al. 2003).

Similarly, elk avoid areas close to roads and trails open to motorized use and select areas at longer distances from such routes (Rowland et al. 2000, 2005; Wisdom et al. 2004b). These patterns can be summarized by distance band and then related to changes in road management (table 7.2). For example, the large area of the watershed within 0.25 mi of a linear route open to motorized vehicles would be expected to receive less than 20 percent of potential use compared with areas more than 1.0 mi from open routes. This large area of low predicted elk use was substantially reduced in area at time point 2 (figure 7.4b) with additional road closures and obliterations.

Although our example uses distance bands away from roads, density estimates also can be used to monitor linear routes and evaluate their effects. For the landscape in figure 7.4, mean density of linear routes open to motorized use was 3.66/mi^2 at time 1 and 1.94/mi^2 at time point 2. Road density is a commonly used metric for setting management direction and monitoring compliance with that direction (Rowland et al. 2005). Many wildlife species are sensitive to effects of roads as measured using road density (table 7.1) (Trombulak and Frissell 2000, Wisdom et al. 2000), and thus the results of monitoring density can be directly related to potential effects on road-sensitive species like brown bear (Graves et al. 2007; Suring et al. 2004, 2006), gray wolf (Mech et al. 1988), wolverine (Rowland et al. 2003), and elk (Lyon 1983).

Although not used in our example, rates also can be used to monitor motorized use on a given linear route, which often is an important indicator of the relative effects on native species sensitive to such use. For example, the rate of motorized traffic on roads and ATV use on trails affects distributions of ungulate species like elk, because one pass of a

motorized vehicle or ATV per day causes increased movement rates and flight responses (Wisdom et al. 2004a, 2004b). Thus, monitoring the rate of motorized use on roads and trails (including ATV use) to assess how many days they are used at least once by vehicles is an effective monitoring approach for predicting effects on elk, a species that increases its avoidance area from roads and trails with increasing rates of motorized uses (Wisdom et al. 2004b).

The potential interactions of climate change with effects of linear routes can be strongly positive or negative. If, for example, climate change is projected to increase the area of wet forest types from dry forest or dry grassland types, then the increased cover associated with the wet forest type may partially mitigate the effects of the linear routes. By contrast, if climate change is projected to decrease the area in wet forest types and increase the area in dry forest and dry grassland types, then the more open conditions will magnify the effects of the linear routes.

7.5.2 Example 2—Recreation

Recreational uses of national forests are increasing rapidly and represent one of the largest, most spatially pervasive sources of human disturbance on public lands (Gutzwiller and Cole 2005, Knight and Gutzwiller 1995, Reed and Merenlender 2008). Recreation consists of two basic forms: (1) linear-based recreation and (2) area-based recreation (table 7.3). **Linear-based recreation** is any form of recreation that follows a linear path, such as roads, trails, rivers, riparian zones, ridgetops, or other linear features that are conducive to human travel. **Area-based recreation** is any form of recreation that is not restricted to a linear route, but is constrained only by varying combinations of technologies, environmental conditions, and management regulations. Area-based recreation typically originates from a specific access point (e.g., a parking lot or drop-off location) and radiates outward from the point over an area conducive for the activity.

Management restrictions often dictate whether a certain type of recreation is linear or area based (table 7.3). For example, snowmobiles might be limited to specific routes, or permitted on all terrain, depending on regulations (figures 7.4 and 7.5). Similarly, backcountry skiing or snowshoeing could follow a particular trail or linear feature, but it often radiates outward from a particular access point to a larger area beyond a narrow line if terrain and travel regulations allow. By contrast, some types of recreation are always linear based or always area based. River rafting is always linear based. Helicopter skiing is always area based. Recreation effects on habitats and species differ with the type of recreation and whether it is linear or area based under the specified travel regulations and particular landscape conditions (figures 7.4 and 7.5). Effects of linear-based recreation on habitats and species resemble effects associated with highways, roads, and motorized trails (Gaines et al. 2003). By contrast, area-based recreation affects habitats and species differently, in that effects typically manifest over a larger area where recreation use is allowed. For example, snowmobiles not restricted to travel on specified trails or

Table 7.3.—*Major types of recreation on national forests and grasslands, categorized as linear-based, area-based, or both, and some example effects and supporting references.*

Type of recreation	Linear- or area-based	Example effects	Supporting references
All-terrain vehicle riding	Both	Increased movement rates and flight by elk near trails.	Preisler et al. 2006, Wisdom et al. 2004a
		Habitat degradation and loss from introduction of nonnative plants.	The Wilderness Society 2006
		Songbird nest desertion and abandonment and reduced predation on shrub nests < 100 meters from off-highway vehicle trails.	Barton and Holmes 2007
		Avoidance of use area by elk.	Preisler et al. 2006
Backcountry skiing	Area	Increased movement rates and energetic expenditure in moose exposed to backcountry skiing.	Neumann et al. 2010
Backpacking	Both	Habitat elimination as caused by development and infrastructure.	Boyle and Samson 1985
Birdwatching	Area	Fewer numbers of fledgling and nestling birds in disturbed areas.	Gehlbach and Gehlbach 2000
Campground use	Area	Increased predation of passerine bird species by jays and corvid species, resulting in population sink.	Neatherlin and Marzluff 2004
Cross-country/Nordic skiing	Both	Ungulate disturbance and flight behavior without habituation or avoidance.	Cassirer et al. 1992, Ferguson and Keith 1982
		Avoidance of use area by native ungulates.	Ferguson and Keith 1982
Downhill skiing	Both	Habitat elimination caused by development and infrastructure.	Kariel and Kariel 1988
		Species avoidance of ski areas or increased stress levels near areas.	Krebs et al. 2007, Thiel et al. 2008
Fishing	Both	Increased mortality of bear species associated with chronic, negative interactions with humans in mutual use areas along salmonid-bearing streams.	Suring and Del Frate 2002
Helicopter skiing	Area	Disruption of wild ungulate behavior.	Frid and Dill 2002
Hiking	Both	Increased movement rates and flight by ungulates near trails.	Brillinger et al. 2004, Miller et al. 1998, Taylor and Knight 2003, Wisdom et al. 2004a
		Decreased use by brown bears in sites close to trails or with higher trail density.	Goldstein et all. 2010, Suring et al. 2006
		Prey handling, maintenance behaviors declined, while contact vocalizations increased (Mexican spotted owls, Strix *occidentalis lucida*).	Swarthout and Steidl 2003
Horseback riding	Both	Increased movement rates and flight by elk near trails.	Brillinger et al. 2004, Wisdom et al. 2004a
Hunting	Both	Increased mortality of bear species associated with chronic, negative interactions in areas of mutual use with hunters.	Peek et al. 1987
		Bear avoidance of areas near to open roads because of the risk of human-caused mortality.	Brody and Pelton 1987
Mountain biking	Both	Increased movement rate and flight by ungulates near trails.	Brillinger et al. 2004, Taylor and Knight 2003, Wisdom et al. 2004a
Mountain climbing	Area	Disruption of cliff-nesting bird and large mammals that use steep topography.	Boyle and Samson 1985, Camp and Knight 1998b
Para-gliding	Area	Displacement of native ungulates.	Schnidrig-Petrig and Ingold 2001
Ocean or lake boating and kayaking	Area	Displacement of nesting shorebirds and marine mammals.	Hockin et al. 1992, Morse et al. 2006
Rock climbing	Area	Disturbance of plant communities, avian nests, bat roosts, and amphibians and reptiles along and adjacent to climbing routes.	Camp and Knight 1998a, b; Goode et al. 1995; Richardson and Miller 1997; Boyle and Samson 1985

Table 7.3.—*Major types of recreation on national forests and grasslands, categorized as linear-based, area-based, or both, and some example effects and supporting references (continued).*

Type of recreation	Linear- or area-based	Example effects	Supporting references
Snowmobiling	Both	Displacement of native ungulates.	Colescott and Gillingham 1998, Poe et al. 2006
Snowmobiling	Both	Increased stress responses in medium to large mammals or increased mortality.	Creel et al. 2002, Persson et al. 2008, Squires et al. 2007
Spelunking	Area	Elimination of bat roosts and potential extirpation of colonies in high-use areas of caves.	Boyle and Samson 1985
Trapping	Both	Overharvest of mammal species that are easily trapped such as marten, fisher, and wolverine.	Douglas and Strickland 1987, Krohn et al. 1994, Squires et al. 2007

snow-covered roads would be limited only by steepness of terrain. Consequently, large areas would be affected by snowmobiles in landscapes dominated by gentle terrain (figure 7.5). Similarly, helicopter skiing would affect all areas that could be skied from the point of access.

Recreation effects are multifaceted and often not easily recognized (Gaines et al. 2003, Knight and Gutzwiller 1995) (tables 7.1 and 7.3; chapter 4, figure 4.4). The increased human contact with many species of wildlife can result in negative interactions, such as increased mortality of brown bears near campgrounds or hiking trails in which contact with humans is more frequent (Merrill et al. 1999), or increased mortality of bats in caves in which spelunking activities occur (Nagorsen and Brigham 1993). Some species are relatively adaptable to recreational disturbance, however. For example, the probability of flushing for vesper sparrows (*Pooecetes gramineus*) was only 0.10 for a pedestrian walking alone on a trail 27 m (89 feet [ft]) away (Miller et al. 2001). Many effects are difficult to recognize, such as increased nest predation by corvids on other birds near campgrounds or human settlements, owing to enhanced survival of corvids in sites with human-subsidized food sources such as garbage (Leu et al. 2008, Luginbuhl et al. 2001, Marzluff and Neatherlin 2006). Consequently, many types of recreation often have been ignored as part of human disturbance monitoring on NFS lands, but they clearly warrant more attention because of their widespread, multifaceted effects on habitats and species (table 7.3).

Monitoring

In this second example, the human disturbance selected for monitoring (step 1) is winter snowmobile use of the same landscape in which summer motorized routes were monitored for example 1 (figure 7.5). Rationale for selecting snowmobile use for monitoring is a combination of factors described previously for process step 1 (section 7.3).

The appropriate spatial extent for management is the watershed (step 2), or 5th hydrologic unit code (Wisdom et al. 2000), because this is the spatial extent at which forest activities are planned, implemented, and monitored in this case. Spatial grain is dictated by the 10-m (33-ft) resolution digital elevation map used to characterize slopes in the watershed and the vector layer of roads available from the ranger district in which the watershed is located. Slope estimates and road locations from these sources are assumed to be accurate to within 1 to 2 percent and 3 to 7 ft of true values, respectively, based on **accuracy assessments** associated with spatial layers.

Past regulations allowed snowmobile use over the entire area, with no restrictions regarding the number of snowmobiles allowed in the watershed. In the past, snowmobile use was sparse, but anecdotal evidence suggests that use has increased substantially since forest plan implementation. Consequently, context and targeted monitoring of actual snowmobile use is warranted (step 3), given the potential effects on habitats and species and new management direction for snowmobile use established in the revised forest plan.

The metrics identified for monitoring (step 4) are (1) the percentage of watershed area over which snowmobiles can traverse and (2) the daily rate at which snowmobiles enter the watershed. These two metrics were selected because management direction in this watershed has established thresholds based on these metrics for managing snowmobile use in watersheds in which emphasis species sensitive to human activities during winter are featured in management. The first threshold is the area within a watershed that can be traversed by snowmobiles; specifically, if more than 50 percent of the watershed can be traversed by snowmobiles, the watershed will be monitored for a second threshold. The second threshold is that snowmobile use will average no more than six to eight machines per weekend day and no more than four to six machines per weekday, as estimated by vehicles and snowmobile trailers in parking lots that provide access to such watersheds. If these two thresholds are exceeded, then snowmobile use will be restricted in the future to designated linear routes to minimize effects on emphasis species sensitive to winter motorized use.

To assess these thresholds as part of monitoring (step 5), a digital elevation map (DEM) is first used to identify all areas with slopes less than 30 percent, which defines areas assumed to be consistently traveled by most snowmobile users (figure 7.5). Results indicate that typical snowmobile users can traverse 78 percent of the watershed (table 7.3). This result, in turn, requires monitoring the number of snowmobiles entering the watershed to evaluate the second threshold.

At least two time points are used to monitor number of snowmobiles entering the watershed (step 6). Time point 1 is the winter during the first year of forest plan implementation, when no restrictions on snowmobile use are in effect because no data related to management have been collected. Time point 2 is 5 years after forest plan implementation. Counts of vehicles with snowmobiles in parking lots that access the watershed during time point 1 indicate that daily use averages one to two machines per weekday and two to three machines per weekend day (step 7). At time point 2, counts of vehicles at the same parking lots average two to three machines per weekday and four to six machines per weekend day. As a result, no change in management direction is warranted. Continued monitoring of snowmobile use is deemed appropriate, however, because counts at time point 2 have increased relative to time point 1 and are slightly less than the second threshold (step 8). Results from this monitoring process can then be considered in tandem with results from monitoring of other human disturbances, such as housing developments on adjacent ownerships (step 9, next sections and section 7.5.4).

Estimating Effects

Monitoring recreation activities and estimating their effects are challenging because of the many types of recreation and different ways in which recreation is managed. Knowledge of whether a certain type of recreation is linear or area based, however, helps guide the choice and use of a monitoring approach. For example, monitoring use

of snowmobiles and estimating effects can be accomplished under two sets of management regulations: (1) all or most areas open to snowmobiles from a specific access point (area-based use, figure 7.5) or (2) all areas closed to snowmobiles except those trails designated as open (linear-based use, figure 7.4). In our monitoring example, snowmobile use was area based but could have changed to linear based had management triggers been exceeded based on monitoring results. In the latter case, the linear-based effects zones for winter snowmobile use would be similar or equivalent to those for summer motorized use, depending on the degree of similarity of linear routes open to motorized uses in the summer versus winter.

In the two contrasting examples shown in figures 7.4 and 7.5, management that restricts summer motorized use to linear routes results in a substantially smaller landscape effects compared with winter area-based travel. Under area-based travel, snowmobile use is restricted only by the technological capabilities of the machine, combined at times with vegetation that restricts travel, resulting in a substantially larger use area and, in turn, a greater area of negative effects on species and habitats, in contrast to linear-based use. Under linear-based summer motorized use, approximately 50 percent of the landscape is within 0.5 mi of a linear route open to motorized vehicles at time point 2 (table 7.3, figure 7.4b). By contrast, area-based snowmobile use in this same landscape results in nearly 100 percent of the landscape within 0.5 mi of areas open to motorized use (table 7.2, figure 7.5). Consequently, resulting effects on wildlife would likewise be different, with a more narrow effect zone under linear-based use and an extremely wide zone under area-based use (figures 7.4 and 7.5). Emphasis species that avoid snowmobiles or experience increased stress associated with snowmobile use are likely to be negatively affected by the higher frequency of snowmobiles entering the watershed, combined with the large area over which snowmobile use is possible, in an area-based management strategy (e.g., Creel et al. 2002).

The contrast between linear-based versus area-based disturbances in the first two examples typifies the use and effects associated with monitoring any motorized travel. That is, use will be restricted to a smaller portion of the landscape under linear-based travel and greatly expanded under area-based travel, with resultant effects that are substantially more negative when travel is area based. The example also applies conceptually to terrestrial, nonmotorized uses such as mountain biking, backpacking, and horseback riding, which are rarely restricted to linear routes, but typically are concentrated along linear routes.

The previous example features additional monitoring to directly estimate snowmobile use or other forms of motorized use at access points such as parking lots (Poe et al. 2006). Further monitoring of actual use can be achieved through surveys of users, aerial counts in use areas, cameras, or traffic counters installed at key use points along the linear routes or common use areas.

The potential interactions of climate change with effects of recreation can be strongly positive or negative. If, for example, climate change is projected to substantially decrease

winter snowpack in the watershed in which snowmobile use occurs, this effect may reduce the length of time that snowmobile use may occur each winter, thus reducing the effect of this recreation activity on emphasis species that may be sensitive to this activity. By contrast, if climate change is projected to increase winter snowpack in the watershed, then snowmobile use is likely to occur over a longer period each winter, increasing the potential effects on sensitive emphasis species.

7.5.3 Example 3—Housing Developments Within and Near National Forests

Loss of open space on private lands near national forests was identified by the Forest Service as one of four key threats to NFS lands (USDA Forest Service 2006b, 2007). Actions that eliminate open space, such as housing and other human developments, can directly affect ecosystem services provided by wildlands, such as wildlife and aquatic habitats, timber, and recreation (Stein et al. 2005, 2007). Housing construction in less populated sites outside urban areas has accelerated in recent years, especially near public lands, and is expected to continue (Hansen et al. 2005, Radeloff et al. 2010, Talbert et al. 2007, Wade and Theobald 2010), especially in Southern and Western States (Hammer et al. 2009). For example, the number of housing units within 50 kilometers (km) (31 mi) of national forests increased from 9.0 million units in 1940 to nearly 35 million units by 2000 (Radeloff et al. 2010). In some areas, however, such as the southern Rocky Mountains, nearly one-half of the lands adjacent to public lands are private grazing lands owned by ranchers holding Federal grazing permits. This juxtaposition offers opportunities for cooperation to retard the conversion of ranchlands to rural housing (Talbert et al. 2007).

Any human habitation and associated structures, such as outbuildings and transmission lines, can lead to habitat loss and degradation. Common effects include (1) elimination and fragmentation of wildlife habitat, (2) spread of invasive or nonnative species into plant and animal communities, and (3) increased risk of wildfire from higher fuel loads and greater potential for ignitions (Butler et al. 2004; Gavier-Pizarro et al. 2010a, 2010b; Hansen et al. 2005; Plantinga et al. 2007; Radeloff et al. 2005; Stein et al. 2005, 2007; Theobald et al. 1997). Human habitation also increases the risk of fire in the wildland-urban interface (WUI), thus adding to the potential loss of habitat. Fire risk in the WUI is likely to increase substantially in the future (Cardille et al. 2001, Syphard et al. 2009).

Human disturbances associated with housing development can also lead to avoidance of otherwise suitable habitat by wildlife (Hansen et al. 2005, Theobald et al. 1997, Vogel 1989). Traditional wildlife migration routes or travel corridors may be altered following construction of housing in rural areas (Sawyer et al. 2005), and human-subsidized predators, such as dogs and cats, near housing developments can alter wildlife behavior, resulting in changes in habitat use patterns or activity levels (Lenth et al. 2008, Maestas et al. 2003). Moreover, many species avoid roads open to motorized use (Forman et al. 2003, Wisdom et al. 2000), which are often constructed as part of housing development

(Hawbaker et al. 2005, Mitchell et al. 2002). Recreational use of public lands near housing developments, in general, is greater than in undeveloped areas and can diminish use of these areas by wildlife species that are sensitive to disturbance (Theobald et al. 1997).

Increases in human population and housing density within or near public lands also may directly reduce or eliminate local populations of wildlife species, with concomitant decreases in biodiversity or biotic integrity (Germaine et al. 1998; Glennon and Porter 2005; Hansen et al. 2005; McKinney 2002, Rottenborn 1999). Negative effects on wildlife population can be caused by predation from domestic cats and dogs; poaching; collisions with vehicles; or human-wildlife conflicts resulting in removing or euthanizing wildlife (Coleman and Temple 1993; Kretser et al. 2008; Lepczyk et al. 2003; Maestas et al. 2003). All of these negative effects occur at a higher frequency on public lands near housing developments, in contrast to public lands with no housing nearby.

Housing density, in particular, affects many other environmental conditions, such as degree of invasion by nonnative plants, area affected by roads, and habitat fragmentation. Moreover, housing density provides a more accurate measure of land use change from human encroachment than does human population density. Household size has been trending lower for 70 years, so that a given increase in population now results in a larger increase in number of homes (Radeloff et al. 2005). In addition, the population census does not count seasonal residents; by contrast, the housing census does count seasonal homes. Taken together, these factors and others make housing counts and trends better suited for measuring human impacts on forest and rangeland resources than do human population counts and trends (Liu et al. 2003).

Housing developments in and near NFS lands can be monitored with the same types of metrics (i.e., distance, density, and frequency or rate) used for other estimates of human disturbance monitoring. For example, distance bands surrounding housing developments can be used to (1) estimate overlap of the bands with NFS lands (figure 7.6) or (2) estimate the density or number of houses within certain distances of NFS lands (Gimmi et al. 2011, Radeloff et al. 2010). In other cases, the frequency of recreational or motorized use of NFS lands within certain distances of houses or associated with different levels of housing density can be monitored as a more direct measure of human activities associated with housing.

Monitoring

The disturbance agent in this monitoring example is housing development on private lands near and within NFS lands (step 1, figure 7.6). This disturbance has been increasing in this national forest, especially in the form of vacation homes, and is of special concern to management because of predicted impacts of increased recreational use on species of concern. In this example, all housing units, whether primary or secondary homes, are included in monitoring. The proposed monitoring is context based (step 2), in that the Forest Service cannot explicitly manage development on private lands. The agency may be able to use knowledge of this type of development (e.g., existing and projected housing

densities), however, to better manage wildlife habitat and populations on NFS lands influenced by this disturbance agent. For example, corridors for movement or connectivity between metapopulations could be identified, established, or enhanced on public lands as mitigation for nearby housing effects on private lands.

The spatial extent for monitoring housing is the watershed (step 3), which is the extent at which forest activities have been planned and implemented in this example. In many cases, a watershed or other large spatial extent contains a mix of public and private lands, as is the case in our example. Monitoring housing development on all private lands, inside and outside the watershed boundary, is therefore important. In our example, any house within 5 mi of NFS lands in the watershed is included in the monitoring. The actual distances chosen for monitoring, however, can be much greater and depend on the specific monitoring objectives. If, for example, the cumulative effects of larger urban areas are of interest, then monitoring the development of housing and different densities and types of developments at greater distances (e.g., 30 mi) from NFS lands may be important to consider as part of the monitoring design.

In our example, spatial grain is dictated by two main data sources used for monitoring housing units: (1) maps based on U.S. Census Bureau data on housing density in the vicinity of the watershed and (2) aerial photographs used to identify houses within the watershed and up to 5 mi from the watershed boundary. A grain of 1 to 2 m (3.3 to 6.6 ft) is adequate for identifying houses from remote sensing imagery, such as National Agriculture Imagery Program (NAIP) photography (Leinwand et al. 2010; also see text in the following section and chapter 4, section 4.5.1). If census block data are used, the block is the minimum mapping unit (Warnick et al. 2005).

The metric selected to assess effects of housing in this example is the area of NFS lands within distance bands surrounding each housing unit (step 4; figure 7.6). This metric is a measure of the proximity of any housing and associated effects in relation to NFS lands in the watershed. Data sources for this metric (step 5) include spatial data on housing density available from the U.S. Census Bureau and a forest-generated map, based on interpretation of aerial photography as described previously. An accuracy assessment of these methods of mapping house locations indicates that most houses can be identified on aerial photographs, but using aerial photographs may underestimate the number of houses. Use of aerial photographs to estimate number of houses is similar to spatial depictions of road locations, which typically underestimate the total number of roads present. Nonetheless, as with road layers, estimates of housing density are highly correlated with the true number of houses present in a given area and, thus, are useful in monitoring trends over time, assuming that houses are mapped with the same level of accuracy over time (i.e., degree of mapping bias remains unchanged over time). This assumption would need to be tested as part of the monitoring effort.

Monitoring in this example is at 5-year intervals (step 6). The first period of data collection, time point 1, was 5 years before the current time. Time point 2 is the current period.

Monitoring results for time point 1 indicate that a large percentage (84 percent) of the watershed is at least 1.0 mi from the nearest house (step 7; table 7.2, figure 7.6a). Results for time point 2 indicate that a much smaller percentage of the watershed is in this distance band, with only 52 percent of the watershed more than 1.0 mi from housing. New housing developments that are located on private inholdings, within the watershed and adjacent to the watershed boundary, account for the increase in area affected by housing (table 7.2, figure 7.6b). These results indicate a trend of increasing rural housing development.

Results from monitoring the area in distance bands relative to the nearest house indicate that continued monitoring of human development is warranted, given the rapid encroachment of housing near NFS lands in this watershed. Management direction in this watershed may need to be altered to accommodate the decreasing habitat quality for emphasis species sensitive to human disturbance (step 8). We combined these results with those for monitoring linear routes open to motorized use and areas used by snowmobiles in the watershed to better understand the cumulative effects from all three human disturbances (step 9, section 7.5.4).

Other methods and larger spatial extents, such as a district or one or more national forests, may also be used to monitor human developments, given that the potential effects are local (e.g., stand and watershed) and regional (e.g., district, forest, and region) in extent. For example, Stein et al. (2007) used three classes of housing density to evaluate trends in housing development adjacent to all national forests in the United States—the rural I class (less than or equal to 16 houses/mi^2), the rural II class (17 to 64 houses/mi^2), and the exurban/urban class (more than 64 houses/mi^2). One approach to using these categories is to quantify the area in each of these three zones within a specified distance; e.g., 15 mi from the boundary between NFS lands and private lands. Shifting proportions of these categories, such as increases in the area in exurban/urban, would indicate the need for more explicit monitoring of housing and associated roads in private lands adjacent to NFS lands. Radeloff et al. (2010) used two buffers or distances, 1 km (0.6 mi) and 50 km (31 mi), to report housing growth near all national forests, in absolute numbers of houses and decadal growth rates.

Estimating Effects

After spatial data on housing are obtained, either from existing data or through imagery, as described previously, estimating the area affected by houses can be accomplished in a Geographic Information System (GIS) by creating circular buffers or distance bands around each point location for houses (figure 7.6). The radius of the buffer reflects the disturbance zone, or distance to which effects of housing developments on habitat or behavior of the emphasis species are believed to occur (Leinwand et al. 2010, Odell et al. 2003, Theobald et al. 2007). The size of the disturbance zone, similar to analyzing road effects, depends not only on the emphasis species but also on housing proximity, housing density, and the spatial pattern of housing; that is, whether houses are clustered

or distributed uniformly throughout the monitoring area (Rowland et al. 2000, 2005; Theobald et al. 1997). Emphasis species will vary in their response to housing development. For example, deer (*Odocoileus* spp.) in Montana avoided houses up to 2,400 m (1.5 mi) away, and relative use by deer declined substantially when housing density exceeded 10/mi^2 or when 1 to 10 houses were within 800 m (0.5 mi) (Vogel 1989). By contrast, gray foxes (*Urocyon cinerioargenteus*) in areas of New Mexico tolerated rural housing densities as high as 50 to 125 homes/km^2 (130 to 325 homes/mi^2) (Harrison 1997). The user must also decide if pixels located within multiple disturbance zones (i.e., influenced by more than one house) need to be weighted more in calculations of total area affected. If little data exist about the disturbance zone for a species, a range of radii can be used to generate maps of various effect scenarios.

The total area of NFS lands affected by housing then can be quantified within an area tailored to the monitoring objectives. For example, if habitat for an emphasis species occurs on a local management unit close to houses on nearby private lands and estimated effects extend up to 1.0 mi from houses, then the analysis area needs to extend inward at least 1.5 mi from the boundary between the local management unit and private lands. The distance from the boundary for which effects are summarized can be adjusted to meet monitoring objectives and account for other potentially synergistic disturbances, such as traffic on roads.

A key challenge for monitoring housing developments and associated effects is to accurately identify the location of all houses. For example the U.S. Census Bureau does not record specific locations of housing units within each parcel or census block; thus, the distribution of housing units within the blocks (e.g., random, even, or clustered) is unknown. The coarse spatial resolution of census data is problematic, because the spatial pattern of development can strongly influence the potential area affected by this disturbance (Theobald and Hobbs 2002, Theobald et al. 1997). Therefore, some knowledge of prevalent housing patterns in the vicinity is useful. Housing density data from county assessor offices, in general, are even more coarsely georeferenced, typically only to the nearest section (i.e., 640 acres) or quarter-section; however, they may provide broad-scale information for baseline monitoring or help stratify the area for sampling housing density. For example, Glennon and Porter (2005) used tax parcel data from the State of New York to determine residential housing density within sampling blocks in Adirondack Park while investigating biotic integrity of bird communities in relation to human development.

Housing density can be monitored with existing data, obtainable from a variety of public sources such as (1) decennial or annual American Housing Survey data collected in conjunction with census block data (http://www.census.gov/housing/ahs/) or (2) information from county assessor offices, which maintain building records for tax purposes (Saving and Greenwood 2002, Theobald et al. 1997, Warnick et al. 2005) (step 4). Census-derived data on housing densities are georeferenced to census blocks (smallest unit), which differ in size across the country and may be too coarse-grained to meet local monitoring

objectives (Warnick et al. 2005). In addition to the decennial census data, estimates of housing density are included in the Census Bureau's annual population survey. If existing and future census data meet the goals of the monitoring program, then no new data on housing are needed.

To obtain new data on density of housing and related structures for a monitoring program, we recommend using a combination of remotely sensed data and GIS software (Warnick et al. 2005). An advantage of obtaining data from remote sensing is that all structures, not only houses, can be accounted for. Remote sensing imagery also can be used for targeted sampling in key areas of concern, in which housing growth is of special interest. For example, NAIP imagery (chapter 4, section 4.5.1) can be used in tandem with either hand-digitizing or image-processing software to count housing units visible on the image (Laes et al. 2007, Warnick et al. 2005; chapter 4, section 4.5.2, Image counts and observations, and figure 4.1). Laes et al. (2007) compared manual digitizing versus semi-automated image-processing software using 1-m (3-ft) natural color NAIP photography to estimate the number of structures and found that manual digitizing was more accurate and repeatable. Semiautomated approaches work well when structures are consistent in color, shape, and surrounding vegetation patterns, as in many suburban subdivisions. Populated areas within the WUI, however, often are characterized by dispersed structures of many types, embedded in a variety of different vegetation patterns. One difficulty in identifying structures with any image source is that trees in densely forested environments can obscure the structure from view, which often occurs in the WUI (Laes et al. 2007, Saving and Greenwood 2002, Warnick et al. 2005). LIDAR (see chapter 4, section 4.5.1) is another potential source of remotely sensed data for locating housing structures (Warnick et al. 2005); however, initial tests using this method with LIDAR Analyst were somewhat unsatisfactory owing to high omission errors (Laes et al. 2007).

The potential interactions of climate change with housing development can be strongly positive or negative on habitats for emphasis species. For example, if climate change is projected to significantly increase the duration of summer drought and warmer temperatures in the watershed, the vulnerability of associated dry forest and grassland communities to wildfires could increase dramatically. Frequency of human-ignited fires is higher in areas of human habitation (Syphard et al. 2009). Thus, an increase in housing near NFS lands under this climate scenario could magnify effects of wildfire on emphasis species whose habitats are not fire-dependent. Species whose habitat requirements include recent burns and early seral stages, however, may benefit from the interactive effects of climate change with housing development.

7.5.4 Consideration of Effects From Multiple Human Disturbances

Monitoring and evaluating the combination of different human disturbances operating in a given area are important because the cumulative effects from multiple disturbances may be substantially greater than the effects from individual disturbances. One method

of analyzing the combination of results from monitoring multiple human disturbances involves a variation of human footprint analysis (Leu et al. 2008, Sanderson et al. 2002). This method includes six steps.

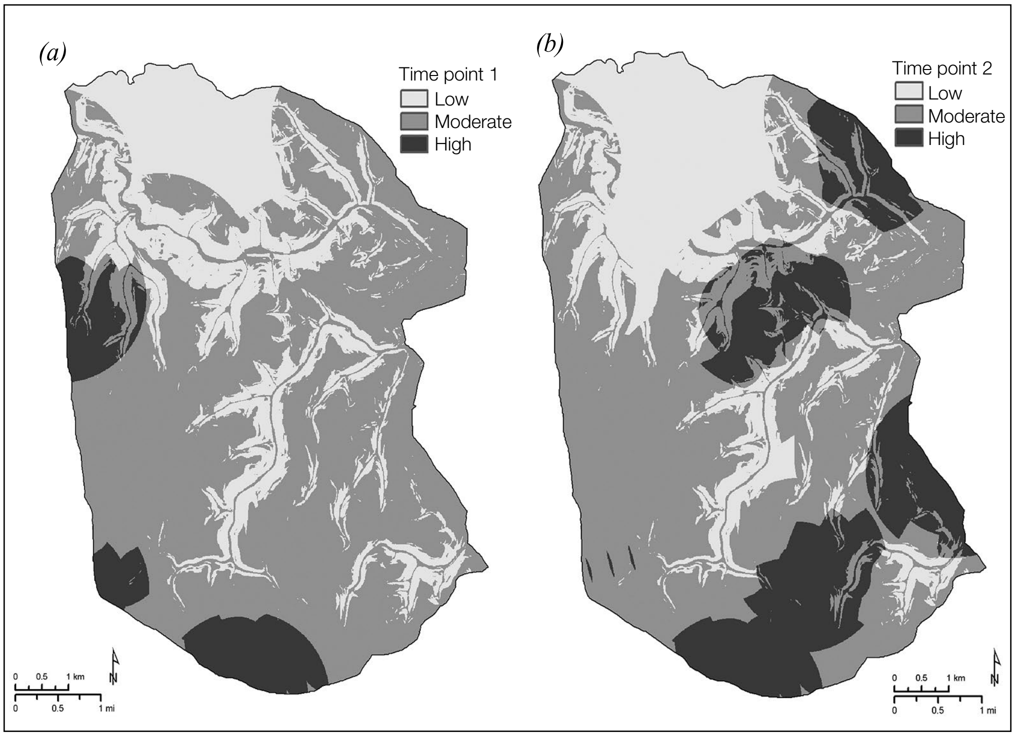
1. Rank conditions from best to worst for a given human disturbance, area, and time. For example, assign ranks to the distance bands buffered from linear routes or housing developments for a specific watershed and time, with the ranks representing different effect zone categories (e.g., category 1 representing the worst scenario; i.e., the distance band closest to a linear route or house, and increasingly higher ranks representing progressively less effect for more distant bands).
2. Overlay maps of the rankings from multiple disturbances on one another for the watershed and time point, such as a watershed map of the ranked distance bands for nearest linear routes with a watershed map of the ranked distance bands for housing.
3. Sum the ranks among all disturbances for each pixel in the landscape. For example, a given pixel may be immediately adjacent to an open linear route and have a ranking of 1 but be more than 2 mi from the nearest house and have a ranking of 5, resulting in a cumulative rank of 6 when considering the combined effects of human disturbance for the pixel.
4. Group the cumulative ranks into categories of environmental conditions or effects for the area and time, and map the categories. For example, pixels with a cumulative rank of 2 through 4 (depending on the number of disturbances considered simultaneously), considering the combination of linear routes and housing development, might be grouped as a condition of high effect, with progressively higher ranks grouped into conditions of moderate or low effect.
5. Calculate the percentage of area in each environmental condition for the time point and repeat the process for one or more additional time points.
6. Evaluate the trend in conditions across time, such as whether the percentage of area in a condition of low or high effect has increased or decreased substantially, indicating whether the cumulative effects from the combination of disturbances have increased or decreased over time.

We applied these steps to evaluate the combined monitoring results from our three examples of linear routes, snowmobile use, and housing developments (table 7.4, figure 7.7).

Table 7.4.—*Combined effects of three human disturbance agents in a hypothetical watershed at two time points. Effect categories are as follows—low (pixels with cumulative ranks ranging from 11 through 15), moderate (cumulative ranks ranging from 7 through 10), and high (cumulative ranks ranging from 3 through 6); see text for details.*

Effect category	Percentage of watershed	
	Time point 1	Time point 2
Low	29	28
Moderate	63	52
High	8	20

Figure 7.7.—*Sum of ranks from effects zones based on linear routes, snowmobile use, and housing developments for time point 1 (a) and time point 2 (b). The highest effect (i.e., greatest disturbance) zone is assigned a rank of 1, with increasing ranks for lower effect (defined by the number of the zone farthest from the human disturbance). The ranks in each pixel were summed, and pixels were then placed into three equal categories of low, moderate, or high effect.*



For each of the two time points, we assigned a rank of 1 (highest effect) to the distance band closest to linear routes, with the next-closest band assigned a rank of 2, and so on, through the farthest (fifth) distance band (rank = 5). We assigned these same ranks to distance bands in relation to housing developments. Similarly, we assigned a spatial rank of 1 (highest effect) for areas traveled by snowmobiles and a spatial rank of 5 for areas inaccessible to snowmobiles. For each time point, we then summed the ranks from the three human disturbances for each pixel in the watershed; grouped pixels into categories of low, moderate, or high cumulative effects; mapped the groups (figures 7.7a and 7.7b); and calculated the percentage of area of the watershed in low, moderate, and high cumulative effects categories for each time (table 7.4).

Trends in the three cumulative effects categories show that area in moderate effect declined and area in high effect increased (table 7.4, figures 7.7a and 7.7b). Thus, cumulative effects have increased over time. This increase in cumulative effects can be attributed to an increased amount of housing development because this disturbance was the only agent that increased in effect from time point 1 to time point 2. By contrast, linear routes declined in effect from time point 1 to 2 and snowmobile use remained the same across the two times.

These results have important management implications. First, housing development occurs on private lands, not public lands, and thus its effects cannot be mitigated directly by the Forest Service. Instead, the increased cumulative effects stemming from increased housing development can be mitigated only through further reductions in linear routes or reductions in snowmobile use, each of which is under management control of the Forest Service. Second, the importance of monitoring the effects from forest management (linear routes and snowmobile use) as well as off-site human activities (housing development) is obvious. That is, without monitoring the changes in housing development in relation to NFS lands, results from monitoring the other human disturbances would have suggested that trends in cumulative effects were positive or benign, with substantially different implications for Forest Service management. Third, many different types of human disturbances warrant monitoring, because a variety of human disturbances now affects most NFS lands. That is, the traditional effects on public lands from silviculture, livestock grazing, mining, and fire management remain as important human disturbances to monitor, but a plethora of emerging or common additional human disturbances are now exerting widespread effects on habitats and species on private and NFS lands in an interactive way (Czech et al. 2000). These additional human disturbances include linear routes open to motorized uses; all forms of recreation; housing developments; energy developments; establishment of NNIS; and power lines, communication towers, and related infrastructure.

Consideration of combined effects from multiple human disturbances, as with monitoring of individual disturbances, typically requires longer periods and more than two time points to accurately document trends. Our examples in this chapter, using two time points for evaluation, illustrate a monitoring process that usually requires estimates over multiple points in time, or over longer periods of continuous monitoring. Without monitoring conducted multiple times and over an appropriate temporal extent, detecting a meaningful trend of the targeted human disturbances may be impossible.

7.5.5 Conclusions

One key responsibility of land management agencies is to monitor and manage human activities. Most wildlife monitoring programs in land management agencies, however, have focused solely on monitoring either populations or the vegetation components of habitat. These past approaches have typically overlooked the significant role played by human disturbance agents in changing the quantity and quality of habitat. Past approaches also have overlooked the many direct effects of human disturbances on populations. This chapter addressed this topic in a manner directly relevant to management. We illustrated, through practical and relevant examples, how metrics of distance, density, and rate can be used to monitor human disturbances of interest in relation to wildlife species and their

habitats. These examples, and the associated methods, can be efficiently incorporated into new monitoring designs for Forest Service management to address potential effects of a variety of human disturbances on species and habitats.

Human disturbance monitoring for management of wildlife species and their habitats, however, is a challenging and complex process. The large number of potential species to be monitored, the varied and many types of human disturbances that affect these species, and the different spatial and temporal scales at which monitoring occurs, all are factors that add to the challenge and complexity. Further complicating these challenges is the lack of resources needed for the work. As with many long-term management issues, it is difficult to implement monitoring programs that must occur over multiple time points that span multiple funding cycles. Despite these challenges, the long-term investment in such a monitoring program is expected to result in more effective, efficient, and defensible management of habitats for emphasis species. Moreover, given the legal, sociopolitical, and economic issues that typically are associated with managing emphasis species, the investment in human disturbance monitoring is well justified.

Chapter 8. Data Analysis

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8.1 Objective

Perhaps the greatest barrier between monitoring and management is data analysis. Data languish in drawers and spreadsheets because those who collect or maintain monitoring data lack training in how to effectively summarize and analyze their findings. This chapter serves as a first step to surmounting that barrier by empowering any monitoring team with the basic understanding of how to get data out of the drawer and onto the management table. Even if a statistician will complete the task of data analysis, monitoring team members need to have sufficient knowledge about the data analysis process to effectively work with a statistician. This chapter outlines the basic steps involved in data analysis at specific milestones in a monitoring effort.

We begin with key concepts related to data analysis and then provide Internet links and references to statistical textbooks and methods that are designed specifically for natural resource data users. A complete discussion of statistical methods is not possible within the scope of this chapter, so we encourage readers to become acquainted with the wealth of assistance that is available online and in well-written texts.

The remainder of the chapter describes the process of data analysis at various stages in a monitoring program, beginning with the evaluation of pilot data. We then follow with sections that address how to analyze inventory and baseline data, compare data between two points in time, and analyze multiyear data. Throughout the chapter, our emphasis is on field-sampled data, whether it originates from an existing program such as the Forest Inventory and Analysis (FIA) Program, or whether it has been collected for a specific habitat monitoring program. This chapter does not reiterate aspects of sampling design that are addressed in chapter 3. Decisions about the sampling design, however, will ultimately affect the type of data analysis. For example, a systematic sampling design may result in spatial dependence among sampling units and may require a **time series** analysis or other analytical technique that adjusts for spatially correlated data.

8.2 Key Concepts

8.2.1 Planning for Data Analysis

In the temporal sequence of a monitoring study, data analysis follows data collection. Discussions about possible data analysis methods, however, are an important part of the

planning phase. Too often, decisions about data analysis methods are left until the data are collected, resulting in highly complex analyses in order to overcome flaws in the initial design. By addressing the data analysis methods and plotting hypothetical data during the planning phase, a monitoring team can evaluate whether the proposed data-collection and data-analysis methods will actually result in the desired information outcome of the monitoring objective. Moreover, by knowing what statistical analyses are planned, the monitoring team can create a sampling design that will meet the assumptions of the statistical methods (Elzinga et al. 1998). Although this chapter on data analysis follows the sequence of process steps for conducting a monitoring study (table 10.1), we encourage monitoring teams to consider data analysis when planning the monitoring design (chapter 3).

8.2.2 Statistical Versus Biological Significance

Over the last century, wildlife research studies have typically used hypothesis testing as the framework for conducting research and reaching defensible conclusions. The basic concept of hypothesis testing is to compare a research hypothesis with a null hypothesis by performing a statistical test and generating a significance level (*p*-value; i.e., probability of observing the data if the null hypothesis is true [Popper 1959]). More recently, wildlife research studies frequently use multimodel inference (Burnham and Anderson 2002) to compare several competing research hypotheses and choose the model that best supports the underlying data. Hypothesis testing and multimodel inference rely on statistical indices to objectively evaluate support for a research hypothesis.

Statistical significance can serve as a baseline quality standard that allows research results to pass a test of research objectivity. Many statisticians have shown that statistical significance can be meaningless (Johnson 1999, Simberloff 1990, Tukey 1969), however, especially if the null hypothesis is nonsensical or known to be false before data are collected (Johnson 1999). For example, the standard null hypothesis that one tries to disprove is that no effect or change occurred over time and that any observed patterns can be explained through random processes. Because one seldom explores phenomena that are unlikely to have an effect, nearly any study can result in statistical significance if the sample size is extremely large (Berger and Sellke 1987). In general, the failure to detect significant results has more to do with small sample size, which results in a low power to detect change (Nunnally 1960). For landscape analyses, it can be easy to find a statistical difference in some landscape pattern metrics for two points in time, simply because of differences in classification and mapping methods used for the two time periods. Even with simulated landscapes that contain no classification error, small differences in land cover proportion can yield statistically significant differences in landscape pattern indices (Remmel and Csillag 2003).

A key aspect of data analysis is to evaluate whether the results of a study are biologically significant and can be used to inform management actions. Monitoring studies, like other research studies, must consider biological significance when evaluating

monitoring results. If the results are statistically significant, the monitoring team needs to ask whether the magnitude of change indicates a meaningful change in either habitat quantity or quality. For example, if the results of a monitoring study indicate a statistically significant increase in canopy cover from 33 to 35 percent, it is important to evaluate whether that difference has changed the quality of habitat for the emphasis species. If the emphasis species can successfully use a vegetation type when canopy cover is 20 percent or greater, the observed increase from 33 to 35 percent does not have biological significance.

Conversely, if the results are insignificant, the monitoring team needs to evaluate whether the sampling design was sufficient to detect a level of change that is biologically meaningful. Elzinga et al. (1998) describe how to calculate the minimum detectable change that is possible for the data, given the sample size, sample standard deviation, threshold significance level for the test, and an acceptable level of power. If the minimum detectable change is larger than a change that is considered to be biologically meaningful, it is possible that a biologically significant change has occurred but that the design was not adequate to detect it and that this change will not be detectable until better methods are devised.

Other options besides conducting significance tests are available for evaluating monitoring data. In section 8.6, we illustrate the use of **confidence intervals** as an alternative to significance tests and describe how confidence intervals can be used to evaluate the biological significance of the data. In chapter 3, we recommend comparing monitoring data with a threshold that is based on ecological information rather than arbitrary statistical considerations.

8.3 Statistical Resources for Monitoring

An excellent source of information is *Measuring and Monitoring Plant Populations* (Elzinga et al. 1998; http://www.blm.gov/nstc/library/pdf/MeasAndMon.pdf). This publication specifically describes monitoring of plant populations; however, the study designs and analysis procedures are directly applicable to wildlife habitat monitoring studies. Chapter 7 addresses sampling design, and chapter 11 describes data analysis methods. In addition, the following appendixes of Elzinga et al. (1998) address statistical analysis: appendix 7 (Sample Size Equations), appendix 8 (Terms and Formulas Commonly Used in Statistics), appendix 14 (Introduction to Statistical Analysis Using Resampling Methods), and appendix 18 (Estimating the Sample Size Necessary to Detect Changes Between Two Time Periods in a Proportion When Using Permanent Sampling Units [based on data from only the first year]).

For complete coverage of basic statistical principles and analyses, we recommend *Biometry: The Principles and Practices of Statistics in Biological Research, 3rd Edition* (Sokal and Rolf 1994), and *Biostatistical Analysis, 5th Edition* (Zar 2010). Both texts

cover a broad range of topics and use numerous natural resource examples. For an overview of design of biological field-sampling procedures and statistical analyses, we recommend two texts: *Wildlife Study Design*, *2nd Edition* (Morrison et al. 2008), and *Statistics for Environmental Science and Management, 2nd Edition* (Manly 2009). Manly's book emphasizes sampling of the environment with special attention to monitoring, impact assessment, reclamation assessment, and basic analysis methods for time series and spatially correlated data. For information on graphical presentation of data, we recommend *Graphical Methods for Data Analysis* (Chambers et al. 1983) and *Creating More Effective Graphs* (Robbins 2005). See also Collier (2008) for examples of using graphs when describing and analyzing wildlife research data and Friendly (1995) for a discussion on the use of visual models for categorical data.

Forest Service statisticians developed a Web site that is internally available to Forest Service employees at http://statistics.fs.fed.us. The link named Statistical How-To's takes readers to a number of statistical analysis procedures prepared by statisticians at each Forest Service research station and listed under the acronym for that research station.

8.4 Evaluating Data From a Pilot Study

A monitoring team can choose to run a pilot study for a number of reasons, such as to test a field protocol, determine logistical constraints, estimate costs, or train field personnel (chapter 3). We recommend that any pilot study gather enough samples (usually more than 20) to evaluate the expected variability associated with each selected habitat attribute. Low variability can suggest that the attribute may not be a good indicator of habitat change, or that it is being measured at a resolution that is too coarse to detect differences over time. High variability can indicate that the attribute has a wide range in potential values because of factors such as elevation, slope, or soil type. High variability can also be a forewarning of possible measurement error, however, and could motivate the need to test for differences among observers in the attribute values measured at the same sites.

In addition, an evaluation of variability is necessary to determine whether it will be possible to meet the monitoring objectives at the desired power and precision. The amount of variability observed in pilot data can lead to important decisions such as changing the resolution of measurements, providing additional training for field personnel, or dropping the habitat attribute altogether and replacing it with one that is more or less sensitive, easier to measure, or easier to interpret.

The team can begin to evaluate spatial variability by displaying the data in a simple three-dimensional scatter plot for each habitat attribute that shows the values obtained for the attribute (vertical axis) plotted against the longitude and latitude of each sampling unit (horizontal axes). Also, the team can visually evaluate the effects of environmental factors in two-dimensional scatter plots by plotting the attribute against individual factors of

interest (e.g., elevation) on a single horizontal axis. This information may come into play as part of adaptive management if changes in habitat are disproportionate across different elevations, management units, or other subunits of the area of interest.

If an evaluation of variability reveals only minor differences among sampling units, the monitoring team needs to address whether sufficient differences are likely between years to make the attribute worth sampling. Each attribute should have some sensitivity related to environmental conditions or management actions for managers to detect meaningful change over time. By contrast, an attribute that manifests high variability among sampling units may warrant further investigation to ensure that the variability is not largely because of measurement errors or differences among surveyors. During the pilot study, we recommend that each surveyor take measurements at the same set of sampling units so that the values obtained from each surveyor can be graphically compared. The monitoring team should avoid field methods that result in unacceptable measurement error or require subjective input from surveyors, because these deficiencies will reduce the value of the habitat attribute for monitoring.

The variability observed in a pilot study can be used in a power analysis to estimate the sample size needed for the full monitoring program (see also chapter 3, section 3.3.3, Estimate the number of sampling units required). In the context of **frequentist statistics,** a power analysis evaluates the power of a given statistical test to reject a null hypothesis when the null hypothesis is false. The generalized null hypothesis for most monitoring efforts is that the monitored attributes will not change between monitoring periods or over the course of a monitoring program. Because the power analysis is based on a specific statistical test, the monitoring team must have a fairly good idea of the type of test that eventually will be used to analyze the data. For example, different forms of power analysis exist for t-tests, paired t-tests, analysis of variance, and comparisons of proportions that take into consideration the sampling design and distribution of the data (e.g., normal, chi-square, Poisson).

Power is a function of four factors: sample size, effect size, variance, and alpha level (the critical value set for rejecting the null hypothesis). By presetting the power to a desired level, the power equation can be rearranged to solve for the estimated sample size needed, using a specified effect size, a selected alpha level, and the variance estimated from the pilot study. In case the variance from the full monitoring program turns out to be greater than the variance from the pilot study, it is always wise to boost the final sample size upward from the estimated sample size derived from the power analysis.

Given that properly designed pilot studies are costly, the desire is often to get as much out of pilot data as possible. A monitoring team should not report descriptive statistics from a pilot study as part of the monitoring results or as preliminary guidance to managers, however, especially if the pilot was based on a much smaller sample size than will be used for the full study. A number of factors could cause pilot study values to differ substantially from the values obtained during a full monitoring effort: (1) insufficient

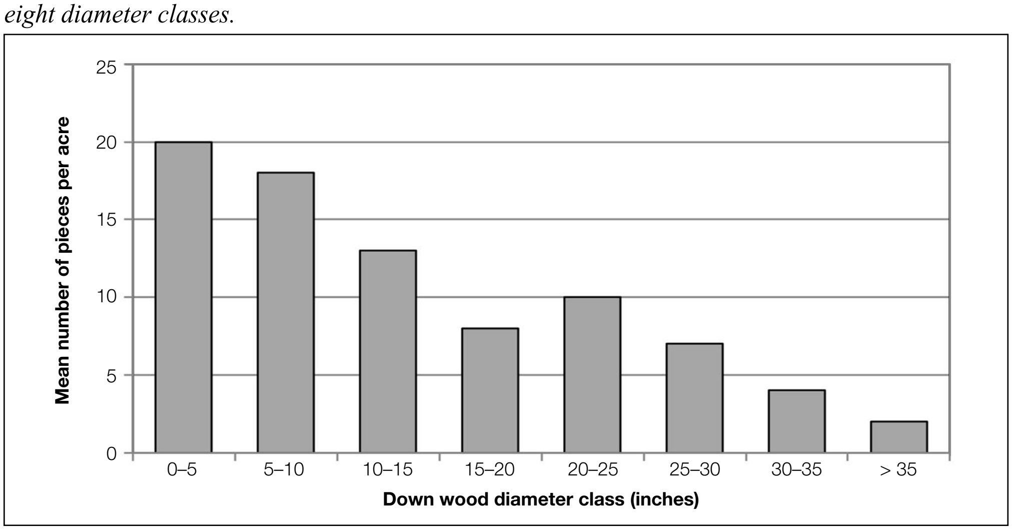
representation of the entire area of interest, (2) inadequate sample size to determine actual variability in the attribute, (3) higher or lower attribute values if collected outside the intended monitoring period (e.g., the autumn or spring before the monitoring period), and (4) either higher or lower attribute values during the training period. Pilot data provide valuable input for refining a monitoring design but should not be treated as monitoring outcomes for adjusting management actions.

8.5 Analysis of Inventory Data and Baseline Monitoring

As with a pilot study, the first step in the analysis of inventory or baseline data is to plot the data so that it can be visually evaluated. Even if the sample size is based on variability estimated from the pilot study, a habitat attribute likely will exhibit greater variability when all sites are sampled, especially if samples are collected over a larger spatial extent than the pilot. As with pilot data, a simple three-dimensional scatter plot of each habitat attribute, plotted against longitude and latitude of sampling units on the horizontal axes and values of the attribute on the vertical axis may quickly reveal a great deal about the properties of the collected data. A second way to visually evaluate the data is to create two-dimensional scatter plots with values of one habitat attribute on the vertical axis and values of another attribute (or other gradient such as elevation) on the horizontal axis.

Another useful exercise is to place continuous data of an attribute into classes (e.g., diameter classes of down wood) and then create a histogram that shows the distribution of the class data across all sampling units (figure 8.1). Often a histogram is more meaningful than a simple average value because it shows the proportion of the total sample that falls into each class. For example, knowing that 50 percent of sampled down wood diameters are in the range of 10 to 20 inches (in) could be more meaningful in evaluating a species' habitat quality than knowing that the average diameter across all plots is 14 in.

Figure 8.1.—*A simple histogram showing the mean number of pieces of down wood per acre in eight diameter classes.*



A way to evaluate whether the full suite of attributes needs to be monitored is to develop a correlation matrix between all combinations of habitat attributes (table 8.1). A high correlation (e.g., $|r|$ is greater than 0.60) between any two attributes could indicate that both are providing similar information, so that it is unnecessary to continue measuring both attributes in the next monitoring period. If two variables are highly correlated, we recommend selecting the attribute that has the least potential for measurement error for continued monitoring, while also considering ease of measurement and understanding by managers. For example, basal area and canopy cover are often highly correlated, and canopy cover based on field estimates can be highly variable. If the first year of data collection confirms a high degree of variability in measures of canopy cover, and if the two attributes are indeed highly correlated, we recommend dropping the canopy cover estimates and measuring only basal area.

The next step in the analysis of inventory or baseline data is to calculate descriptive statistics (e.g., mean, median, standard deviation, coefficient of variation, skewness) for each habitat attribute. The choice of an average statistic will depend on how the data are distributed, and, as mentioned previously, the frequency distribution or **box-and-whisker plots** are more meaningful for some attributes than any form of average value.

If the monitoring program is based on FIA data, the team can generate tabular and spatial summaries based on user-defined inputs using tools available at http://fia.fs.fed.us/tools-data/default.asp (see chapter 4, section 4.4.1). Within the Natural Resource Manager (NRM) environment, a monitoring team can use the Graphical Interface tool to perform queries (referred to as views) that summarize the raw data collected at sites, in fixed area plots, along line intercepts, or in quadrats. Data summaries include descriptive statistics for continuous and categorical variables. These views will extract summary or raw data from NRM into either an Access database or an Excel spreadsheet. From that point, data can be analyzed in any statistical software program.

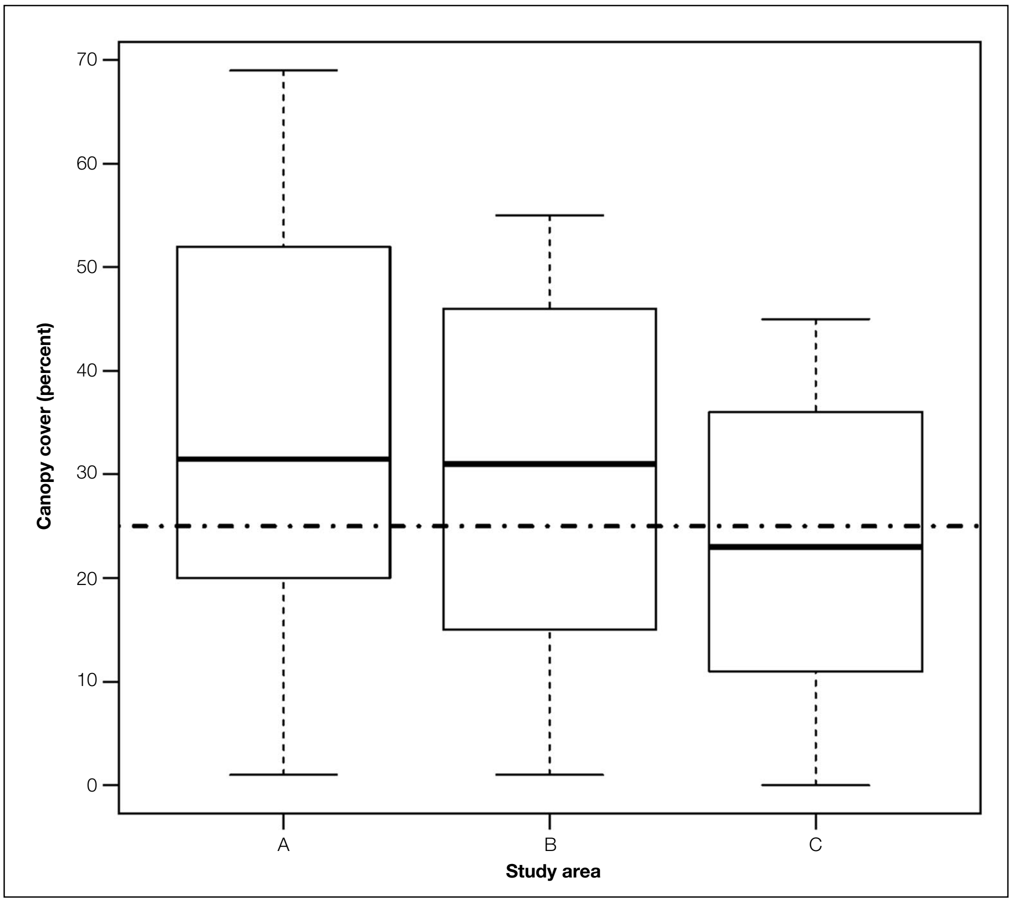
For an inventory or baseline study, descriptive statistics and box-and-whisker plots may be the only form of data analysis and presentation needed. If the objective of a monitoring program is to compare the status of an attribute with a desired condition or threshold, however, the final step of the analysis is to compare the outcomes of the

Table 8.1.—*Correlation matrix of potential habitat attributes for monitoring. Tree canopy cover and basal area have a correlation coefficient (r) greater than 0.60 (shown in bold) and are therefore considered highly correlated.*

Attribute	Elevation	Slope	Tree canopy cover	Basal area	Down wood volume	Distance to road	Distance to well pad
Elevation	1.000	0.273	0.294	0.483	0.327	0.225	0.483
Slope	0.273	1.000	0.201	0.366	– 0.218	0.475	0.530
Tree canopy cover	0.294	0.201	1.000	**0.713**	0.398	0.030	0.162
Basal area	0.483	0.366	**0.713**	1.000	0.366	0.426	0.488
Down wood volume	0.327	– 0.218	0.398	0.366	1.000	0.269	0.287
Distance to road	0.225	0.475	0.030	0.426	0.269	1.000	0.560
Distance to well pad	0.483	0.530	0.162	0.488	0.287	0.560	1.000

sampling effort with the desired condition or threshold value. Using raw data, the relationship of the threshold value to the median and range of the distribution of data can be easily evaluated graphically by plotting the threshold value on a box-and-whisker plot (figure 8.2). Statistically, this comparison is generally accomplished by evaluating the relationship between the threshold value and an approximate 95-percent confidence interval about the mean; i.e., the mean plus or minus two standard errors.

Figure 8.2.—*Relationship of estimates of percentage canopy cover at three study sites to a threshold value of 25 percent. For two of the study sites (A and B), the median values are above the threshold, but for the third study site (C) the median is below the threshold, indicating that at this location a change in management or more intensive sampling is warranted.*



8.6 Comparing Data Between Two Monitoring Periods

Although the ultimate goal of any habitat monitoring program is to be able to detect change in habitat quantity or quality over time, change will usually not be evident after two monitoring periods unless (1) the temporal span between periods is large or (2) habitat has undergone substantial change because of management actions, large-scale natural disturbances, or changes in land use. If the conceptual model (chapter 2) suggests that

habitat will likely change as a consequence of vegetation establishment or growth, a span of 5 or more years may be needed to detect any change. Even when environmental or management factors are expected to cause rapid change (e.g., intensive management actions, wildfire, or insect outbreaks), these factors often affect small spatial extents relative to the monitoring area, and change is therefore difficult to quantify.

In spite of these limitations, the merit in comparing data between two monitoring periods is apparent for several reasons. First, in the context of adaptive management, early evaluation of data can hint at eventual loss of habitat that could be prevented by making immediate adjustments in current management. For example, the establishment of invasive plants after certain types of burn prescriptions may not create a significant reduction in habitat between two monitoring periods, but the immediate implementation of a weed control plan following prescribed fire could prevent invasive species from having a more significant effect on habitat over time.

Second, early evaluation of monitoring data demonstrates to managers that data are indeed being collected for a purpose and that the effort is worth the financial investment. Although data from 2 years should never be overinterpreted, summary statistics and visual graphs can serve to promote the continuation of a monitoring program when it is still in its infancy.

Third, monitoring of land management plan objectives and desired conditions may be fiscally limited to only two time steps, one at the beginning and one at the end of each planning period. Thus, a meaningful approach for comparing these two periods will be necessary as part of the planning process. Even a simple qualitative comparison between monitoring periods that uses graphs and other visual aids can be important for communicating changes in wildlife habitat to the public and stakeholders.

As with pilot and first year data, the first step in comparing data from two monitoring periods is to plot the data. Following up on our previous suggestions, a possible approach is to plot attribute data in three dimensions, with longitude and latitude on the x and y axes and measured values of an attribute on the third axis, using different colors for each year. Alternatively, one could construct scatter plots in two dimensions of two habitat attributes, or one habitat attribute against a gradient such as elevation, with the two time periods in different symbols or colors. All these approaches will qualitatively reveal the amount of overlap and the degree of difference between the 2 years, although, in general, less variation is expected in the scatter plots if data are paired (i.e., repeated measures exist on the same plot for both time periods) relative to variation with nonpaired data. If attribute values from the 2 years overlap substantially on the scatter plots, it is unlikely that statistical tests will show any difference between years. These plots will also show the amount of variability associated with each attribute and whether the variability was similar between years.

Another useful technique, assuming repeated measurements on the same sampling units, is to plot the first year of data (x) against the second year of data (y) and insert a

diagonal line (i.e., y = x). The plotted data will indicate a general increase in values of the attribute if most points fall above the line and a general decrease if most points fall below the line (figure 8.3).

The team should then generate descriptive statistics for each attribute, whether or not these statistics will be used in a formal test comparing the two monitoring periods. The team can visually evaluate differences between years by plotting two box-and-whisker plots side by side, one for each monitoring period, similar to figure 8.2. For some attributes (e.g., attributes derived from the diameters of trees, snags, or logs), a frequency distribution of size classes can be more meaningful than mean values. The team can compare histograms for each monitoring period, either side by side or one inverted under the other in a mirror image (figure 8.4). This comparison will show whether changes in attribute values between monitoring periods were evenly distributed across classes or more pronounced for certain size classes.

If scatter plots indicate that a statistical test is warranted, the team will want statistical assistance to ensure that the test performed is appropriate for the data. We caution, however, that statistical tests of hypotheses are easy to misinterpret and are not as useful for analysis of monitoring data as they are often promoted to be (Johnson 1999). Environmental data tend to have high variance, so the outcome of the test may not show statistical significance, although the change in habitat may be ecologically significant. For example, annual production of forbs is often highly variable across landscapes even with

Figure 8.3.—*A scatter plot of monitoring data from Year 1 and Year 10 for 18 landscapes in which mean patch size was measured. The relationship of attribute values to the diagonal line (x = y) indicates that no change in mean patch size exists for landscapes with smaller patches, but a decline in mean patch size occurred for larger patches in the second monitoring period.*

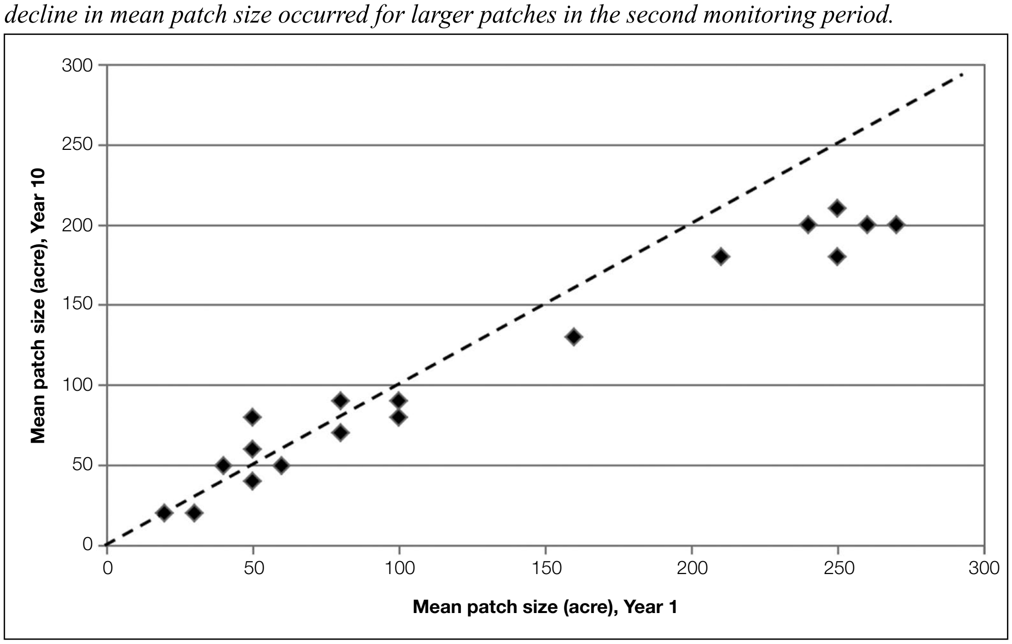
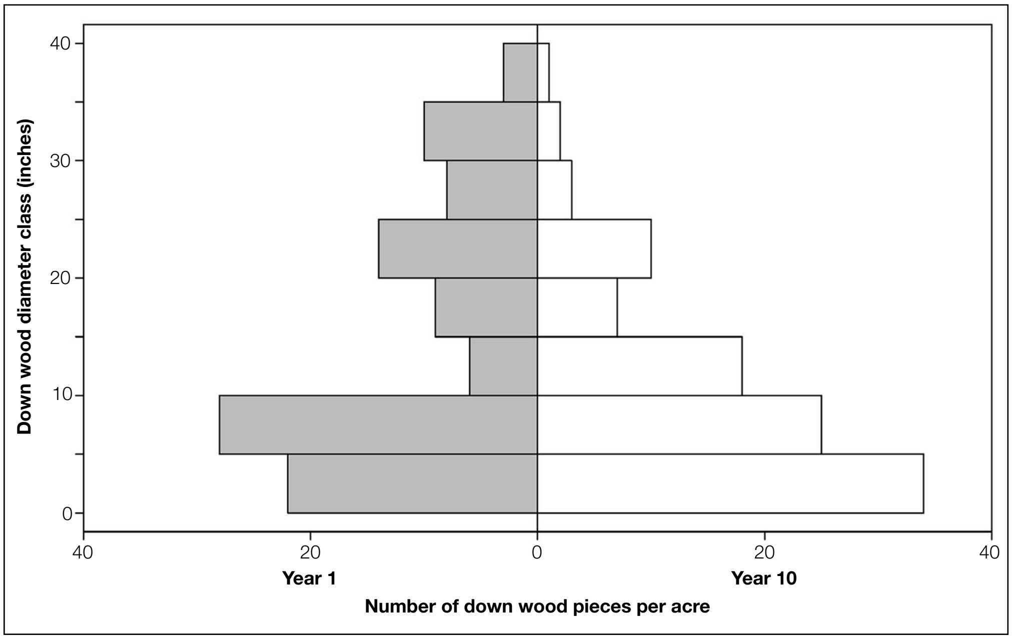


Figure 8.4.—*A comparison of histograms from two monitoring periods showing the distribution of down wood pieces per acre in eight diameter classes. Note that in Year 10 the number of pieces in the larger diameter classes (top of graph) has declined relative to Year 1, whereas the number of pieces in the smaller diameter classes has increased.*



repeated measurements on the same sampling units, so a test for differences may appear statistically insignificant when in actuality the reduction in forbs is ecologically significant for the emphasis species (see sidebar).

In contrast to statistical tests, confidence intervals are hard to misinterpret, both for comparing 2 years and for evaluating change over time. The usual presentation of a confidence interval is a graph showing the full range of possible attribute values on the vertical axis; the mean value of the attribute is indicated on the graph as a small horizontal bar, and the confidence interval is shown as a vertical line extending above and below the horizontal bar. The length of the vertical line is set to the values that represent two standard errors of the mean above and below the mean value.

In the sidebar example, the mean difference between the two monitoring periods was 100 lb/acre (ac) but was statistically not significant. The approximate 95-percent confidence interval on the mean difference is 100 ± (1.96)(300) lb/ac, or from 0.0 to 688 lb/ac.

The failure to reject the null hypothesis (no change in a metric before and after a point in time at a specified *p*-value) does not prove that there has been no important biological change. For example, assuming normality of the data, the estimated difference in production of forbs per acre might be $\overline{X}_1 - \overline{X}_2 = 100$ pounds (lb). If the estimated variance of the difference is 90,000, a z-statistic will be z = 100/√90,000 = 0.333 and the *p*-value will be much larger than the nominal value. A difference of 100 lb/acre, however, might be very important from a biological point of view; therefore, it is misleading to state that no statistically significant difference exists. Likewise, an observed difference can be statistically significant but have no biological significance. Always be skeptical of statistical results stated simply as significant or not significant with a given *p*-value (Johnson 1999).

(Note that the lower value of the confidence interval is 0 rather than -488, because the latter is computationally correct, but biologically implausible.) This confidence interval indicates not only that the mean difference is 100 lb/ac, but also that evidence indicates that the difference may be substantially greater than 100 lb. Ecologically, reporting the confidence interval is more meaningful than reporting that the variance is too great to show a significant difference between the mean values.

Thus, we recommend using confidence intervals rather than statistical tests when comparing two monitoring periods, especially when the data are highly variable and when the actual values of the data are more meaningful than the *p*-value associated with the test. Confidence intervals are also useful for assessing whether attributes are approaching or getting further from a threshold or desired condition value after the second monitoring period. The visual presentation of confidence intervals along with graphical plots of data from both periods provides an excellent tool for communicating with managers.

8.7 Analysis of Multiyear Data

A primary objective for most long-term monitoring studies is to look for a change or trend in either the means or proportions of the selected attribute(s) over a specified time period. A trend is an average annual increase or decrease in the attribute from year X to year Y. Analysis of trend can be challenging because it is difficult to distinguish a directional trend from multiyear cyclical variation, within-year seasonal variation, or erratic fluctuations (Dixon et al. 1998). Moreover, attribute values may show an abrupt increase or decrease caused by a single event (e.g., a management action or natural disturbance) rather than a gradual change over multiple time periods. Therefore, it is sometimes better to think of the multiyear analysis as a detection of change rather than a detection of trend.

A multiyear analysis begins with exploratory data analysis in the form of scatter plots and histograms, similar to that conducted with 1- and 2-year data. Two types of plots will usually be of interest: (1) a scatter plot of all data with lines connecting the dots for each sampling unit (e.g., plot, point, transect) and (2) a scatter plot of average values over time. In addition, we recommend using confidence intervals and box-and-whisker plots to evaluate the variance associated with each monitoring period.

Numerous methods of statistical trend analysis exist, and the use of any given method depends on the nature of the monitoring data. Olsen et al. (1999) distinguish between design-based and model-based statistical inferences. A design-based analysis requires a probability sample and uses properties of the sampling design to make inferences about changes or trend (Edwards 1998, Olsen et al. 1999). For example, long-term changes in the means and proportions of FIA data can be inferred through design-based approaches because the data were (and continue to be) collected with a probability sample. Throughout this technical guide, we have advocated the use of sampling designs for habitat monitoring, so we assume that most analyses of change or trend will be design based.

In contrast, a model-based analysis makes inferences about trend using a model that assumes a relationship between the mean attribute values and a set of covariates. A good example of a model-based analysis of trend is the Breeding Bird Survey, in which data on bird abundance are collected along transects that have been selected through professional judgment and therefore do not constitute a probability sample. The statisticians who analyze these data use complex models that take into account a number of factors that could influence estimates of mean counts of different species of birds (Link and Sauer 1998).

In addition to knowing whether the analysis will be design based or model based, other factors contribute to selection of the analysis method. For example, it is important to know whether the study area was stratified and how sampling units that are inaccessible were handled (McDonald et al. 2009). The statistician will also need to consider whether spatial and temporal correlation will cause problems during analysis.

Randomly sampled units are considered independent, whereas systematically sampled units may be spatially dependent, requiring a form of analysis that accounts for the spatial correlation between adjacent sampling units. If systematically sampled units are treated as if they were randomly sampled (i.e., independent), the analysis will usually be overly conservative, meaning that the reported standard errors may be larger and confidence intervals wider than would be obtained if the spatial correlation were taken into account (Manly 2009). On occasion, systematically sampled units can result in standard errors that are smaller than expected, if the systematic design has inadvertently duplicated a cyclic pattern on the landscape (e.g., every unit falls on a ridgetop). This latter possibility is usually recognized in the design stage and is easily avoided.

Many statistical approaches for detecting **monotonic** trend use the number of time periods as the sample size and fit a linear regression line through the yearly mean values, a strategy that may be appropriate for long time series of monitoring data but is less effective over short periods of time. It is clear that, with only a few time periods of data, the sample size will be small, with little power to make statistical inferences that important changes have occurred on a study area.

For monotonic trends that are assumed to be linear or log-linear, the basic unit analysis (McDonald et al. 2009) is to fit a line to the data collected on each unit. In the simplest form of analysis, **least squares regression** is used to estimate the slope of a line through the data collected on a single sampling unit over time. Each line yields an estimated slope, S_i, for each of the sample units (n), i = 1 through n. After the slopes are estimated, the average slope is computed from the random or systematic sample of size n. The statistician then computes the standard error of the mean slope and a confidence interval on the mean slope. If the confidence interval does not contain 0.0 then the conclusion is that a significant increasing (or decreasing) linear trend exists. This approach is equivalent to testing the null hypothesis that the mean slope is 0.0; however the width of the confidence interval provides more information than a simple yes or no answer from hypothesis testing with a specified *p*-value.

McDonald et al. (2009) refer to this approach as a unit analysis, where unit refers to each sampling unit and a measure of change or trend is obtained on each unit. In the previous paragraph, the measure of trend was the slope computed over time (i.e., average annual increase or decrease in the attribute) for each unit. The measure of change could be the difference in attribute values between two time periods on each unit. Depending on the data, the analyst can then report the mean or median of the measure of change or trend with accompanying confidence intervals and graphical presentations. From these summaries, statements can be made about whether the average or median slope is significantly different from 0, as well as the proportion of units in the population experiencing trends greater (or less) than a specific some standard value.

A unit analysis is clearly inappropriate for more complex study designs and long time series of data; however, it is simple and powerful in the sense that the number of sampling units, rather than the number of monitoring periods, is the sample size used in the analysis. In most studies, the number of sampling units will be fairly large, and the mean statistic for change or trend will be approximately normal. As a result, the confidence interval will be approximately correct.

The unit slope analysis is only one of many approaches to testing for trends. We highly recommend chapter 11 of Elzinga et al. (1998), which contains a wealth of information on statistical analyses of trend data.

8.8 Using Ancillary Data To Interpret Monitoring Outcomes

Every competent habitat monitoring program is designed to eventually produce defensible data that reveal whether the attributes of interest have substantially changed over time. Management decisions are often needed before sufficient time has elapsed, however, to reliably demonstrate results from a monitoring study. Even after the passage of several years, natural variability or issues of scale can inhibit the ability to detect whether changes in habitat have occurred, leaving the manager with the sense that the monitoring data are inconclusive and therefore not valuable.

Two basic understandings can help with the interpretation of monitoring data. The first is that any apparent trend in a habitat attribute is likely not spurious, because it takes a tremendous amount of management and natural disturbances to substantially change most habitat attributes over large spatial scales. Therefore, if data analysis indicates a weak trend, this result should be taken seriously, especially if it is a downward trend in a desired attribute or in habitat quantity or quality as a whole. Changes in management should not wait for a statistically significant trend.

The second understanding is that a lack of change in selected habitat attributes does not necessarily indicate that the habitat of the emphasis species is static. Environmental conditions are continually changing, so it is unlikely that habitat has remained unchanged.

It is possible that the selected attributes are less sensitive to change than originally thought and that other, unmeasured components of habitat are being lost or gained. For example, average tree diameter may show little change over the short term, implying that late seral conditions are still present for the emphasis species. In reality, a loss of older, larger trees may be occurring, but this loss is not captured by the diameter data because of the recruitment of small-diameter trees into medium-diameter size classes.

We recommend using a variety of ancillary data to either support or refute weak results from a monitoring program because this practice will enhance the utility of the monitoring program in an adaptive management context. In general, trends for one attribute do not occur in isolation, so the monitoring team can look for changes in related attributes that were not a part of the original design. The ancillary data may originate from a larger spatial scale, may have been collected for a different purpose, or may be from a data source not used in the original monitoring design. For example, changes in FIA core variables may mirror the changes seen on aerial photos or satellite imagery that were used for the monitoring program. Data collected for several range allotments that are only partially within the monitoring area may indicate similar changes as those found on the probability sample associated with the monitoring design. By aggregating a variety of data, both those directly derived from the monitoring and ancillary data from multiple sources, a monitoring team can arrive at a reasoned position on the likelihood that a weak trend (or conversely, a conclusion of no change) is true and not simply a sampling artifact. The aggregation of data from several sources will often enable managers to consider adaptive approaches early in the monitoring program, rather than waiting for more conclusive results that could come too late for management options.

The preceding discussion brings us to the inescapable conclusion that managers will have to work with levels of uncertainty that are far greater than those associated with scientific standards. The presence of uncertainty does not undermine the value of a carefully designed monitoring program, but managers need to become comfortable with using data of various qualities. Although managers cannot rely on weak data to the extent that they rely on rigorous evaluations of trends or targets, they should not ignore data simply because they are weak. It is often these data that enable managers to evaluate and achieve desired objectives.

8.9 Conclusions

Statistical analyses constitute a fundamental step in making monitoring information useful to management. Unless a monitoring team has conducted a complete census of each habitat attribute, statistical analyses are needed to make inferences from the sampled data to the entire area of interest. It is essential to address data analysis during the planning stage to ensure that the monitoring results will meet the monitoring objectives.

In this chapter, we present recommendations for conducting data analyses and displaying data at various stages of a monitoring program—as part of the pilot study, after the first sampling period (inventory and baseline data), after two points in time, and after a period of years. During each stage, the analysis team needs to use scatterplots and other forms of graphical presentation to become familiar with the data. Early and frequent analyses help build support for a monitoring program and can indicate whether a change in the monitoring design is needed.

When evaluating data at any point in time, it is important to look for biological significance as well as statistical significance. Statistical significance can serve as a baseline quality standard to establish confidence in the monitoring results, but statistical significance does not always imply biological significance and biological significance is what affects management actions. A statistical change in the value of one or more habitat attributes may be interesting, but a biological change can trigger a discussion of whether a change in management actions is warranted.

We advocate the use of confidence intervals to evaluate the data. Often the variance in data is equally or more meaningful than mean values, and the variance could shed light on biological significance. Confidence intervals are useful at all time periods, from the analysis of baseline to multiyear data. The visual presentation of confidence intervals provides an excellent tool for communicating with managers.

We recommend using a variety of ancillary data to either support or refute weak results from a monitoring program. The small spatial extent of most restoration projects, coupled with slow changes in vegetation from natural succession, make it difficult to show significant changes in habitat over short time periods. Ancillary data collected for other purposes may help indicate when an apparent trend has biological significance.

Chapter 9. Data Management, Storage, and Reporting

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Mary M. Manning
Bryce Rickel

9.1 Objective

Data collected for a habitat monitoring program must be managed and stored to be accessible for current and future use inside and outside the Forest Service. Information maintenance and dissemination are important to the Forest Service; they are part of the U.S. Department of Agriculture (USDA) guidelines for information quality (USDA 2002) under the Data Quality Act of 2001. These guidelines state that USDA agencies and offices will treat information quality as integral to every step in their development of information, including creation, collection, maintenance, and dissemination (USDA 2002). The purpose of this chapter is to describe procedures for managing and storing **legacy** and newly collected habitat data in the Forest Service data management system (the Natural Resource Manager [NRM] information system) and in **auxiliary databases** as needed. The chapter concludes by providing recommendations for reporting the results of habitat monitoring programs.

9.2 Key Concepts

9.2.1 Data Preservation

The Forest Service supports the concept of data preservation, whereby data are stored electronically for future accessibility beyond the current use and the local management unit. Decisions and performance accountability are enhanced when resource information is accessible in a standard **corporate database**. Moreover, preserving resource information in a central repository rather than on local servers makes resource data broadly available, easy to use, and relevant to making informed resource management decisions (Heuttmann 2005). For example, key management questions related to Forest Service business requirements and the strategic plan (USDA Forest Service 2007) can be quickly addressed using centralized data.

For wildlife habitat monitoring, data preservation is essential because the intervals between monitoring could be several years, and evaluation of monitoring results may not occur for a decade or more. In the interim, changes in personnel create challenges to maintaining a record of the data and associated **metadata** previously collected for

the monitoring program. Electronic data preservation is generally preferred over paper records because electronic data are easier to maintain, edit, and share with other users. Moreover, an electronic format facilitates standardized data entry (Heuttmann 2005, McComb et al. 2010). Using electronic data also increases the probability that a monitoring program can be maintained through time and through staffing changes. Electronic data can easily proliferate, so that timely and proactive electronic records management is critical (http://www.nascio.org/publications/).

9.2.2 Forest Service Corporate Data Structure

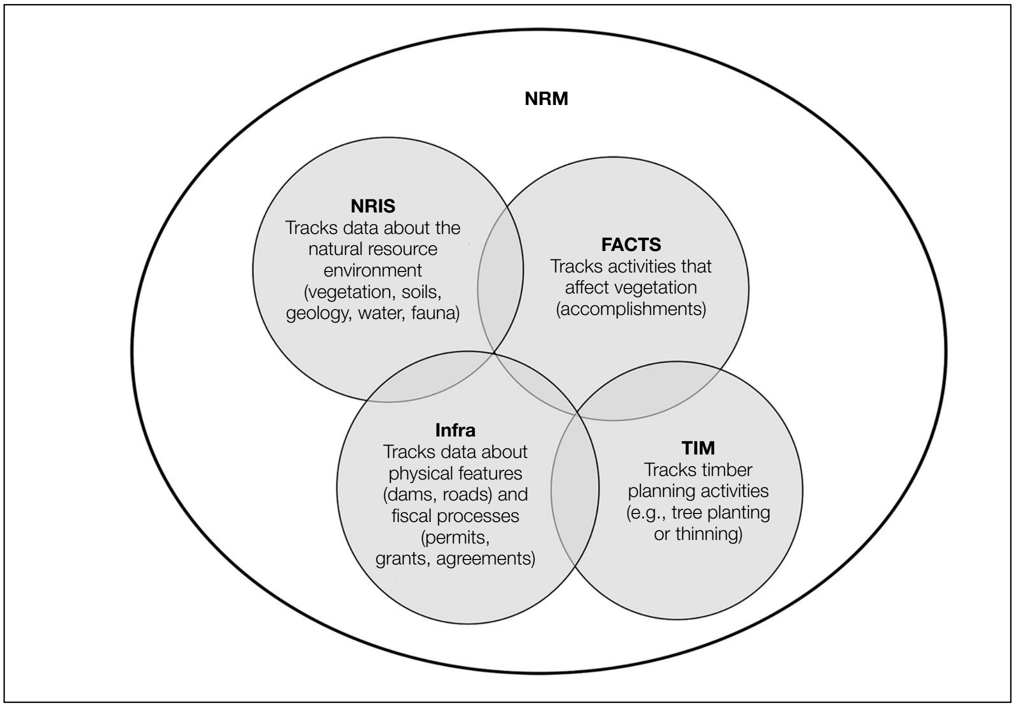
Natural Resource Manager (NRM) (http://fsweb.nrm.fs.fed.us/) is a national Forest Service organization responsible for the management and software development activities of four application groups whose data are accessible through the Enterprise Data Center at the Forest Service National Information Technology Center (FS-NITC) (http://cdb.fs.usda.gov/content/dav/fs/Reference/FSWeb/BusOps/CIO/EGIS/documents/HowToFindData.pdf). (This Web site and others beginning with “fsweb” are internal to the Forest Service and thus not available to outside users.). The principal functions of NRM are to (1) support nationally accepted data-collection protocols, (2) provide the ability to query data through output tools, and (3) store legacy and newly acquired data in editable feature classes called **transactional data**.

All NRM application groups share common components, such as a helpdesk, outputs, and training tools. NRM oversees database development and standardization, which enhances integration of information across resources. The Forest Service designed NRM applications to meet the unique business requirements of the agency, but the applications follow standards of the Federal Geographic Data Committee (FGDC) and are therefore compatible in metadata standards with data compiled by other Federal agencies that comply with FGDC standards (section 9.3.4).

The primary purpose of NRM is to coordinate numerous key application groups (figure 9.1).

- NRM contains the primary applications for habitat monitoring (section 9.3.1; also chapter 4, section 4.4.1) and is part of the corporate database system containing data and information, in conjunction with analysis tools.
- FACTS (Forest Service Activity Tracking System) contains accomplishment and treatment reporting; for example, it tracks and monitors National Environmental Policy Act (NEPA) decisions and invasive species treatments.
- TIM (Timber Information Manager) contains information about timber sales, stewardship contracts, and forest product permits.
- Infra contains information about engineering, heritage, range management, recreation sites, special use permits, grants and agreements, and real property.

Figure 9.1.—*Interaction of the four application groups within Natural Resource Manager (NRM): Natural Resource Information System (NRIS); Forest Service Activity Tracking System (FACTS); Timber Information Manager (TIM); and Infra.*



The Forest Service plans to make many types of data from NRM externally available through the Enterprise Data Warehouse (EDW). Moreover, the NRM platform allows for the use of other data; e.g., from NatureServe (http://www.natureserve.org/). The EDW also provides Forest Service users time-stamped copies of data compiled from external sources, such as Natural Resource Conservation Service (NRCS).

9.2.3 Auxiliary Databases

In some situations, data and map products from a habitat monitoring program may not easily fit in existing NRM applications, either because the applications do not contain the appropriate protocols or they do not have the data fields for entering specific habitat attribute data. The monitoring team may need to create an auxiliary database; if this database is created, first consult the business area manager, program managers, and database stewards at the national forest or grassland and regional office levels to (1) ensure that the proposed database does not already exist, (2) verify that it does not conflict with any existing databases, and (3) track new developments and new business requirements. Also, auxiliary databases may be a long-term management investment. If an auxiliary database is created, use codes and other features published in the corporate databases as much as possible to make them compatible with data supported in NRM.

An auxiliary database can be as simple as a spreadsheet or as complicated as a relational database or Geographic Information System (GIS) project. Whatever the final format for the data, using best data management practices and following FGDC data standards enhance the integrity of the data management, storage, and retrieval system. Martin and Ballard (2010) provide a comprehensive overview of best data management practices for biologists who collect and manage bird monitoring data, and they also provide a list of resources on best data management practices that are published or available on line. Borer et al. (2009) and McComb et al. (2010) provide simple guidelines for effective data management that we highly recommend to habitat monitoring teams.

A key element of best data management practices is documenting all decisions related to data fields through a **data dictionary** and user guide. The NRM *Threatened, Endangered, and Sensitive Plants-Invasive Species (TESP/IS) User Guide* is a good example (http://fsweb.nrm.fs.fed.us/support/docs.php?module=Threatened, Endangered and Sensitive Plants—Invasive Species (TESP/IS)). This guide can serve as a template for creating an effective user guide for an auxiliary database.

We recommend that Forest Service personnel use NRM applications to the extent possible and that they create auxiliary databases only when no other option is available within the Forest Service corporate database structure. Many NRM databases provide a dedicated field (Local ID) that can be used to link databases so that the monitoring team can begin using data in the NRM database and use the Local ID to link to the auxiliary data. In this way, the auxiliary data are directly linked to the corporate database, and the corporate database serves as the main repository for the data.

9.3 Data Management and Storage

Habitat monitoring information can include newly collected vegetation data (e.g., single attributes such as snag density or cover type associated with a particular emphasis species) or output from habitat models created from a formally defined interaction of several key habitat attributes (chapter 5). These data can be stored in NRM databases or in auxiliary databases, or both. Store data products created for habitat monitoring that do not readily fit in existing NRM applications, such as habitat quality maps for an emphasis species, in the appropriate project-level Forest Service electronic filing system (e.g., Content Database or Enterprise Drive).

9.3.1 Database Structure

We recommend that wildlife habitat monitoring be stored in the corporate database applications as much as possible. Wildlife habitat monitoring may require that data be maintained in auxiliary databases, however. Store auxiliary data in the appropriate project-level Forest Service electronic filing system structure. Wildlife monitoring may require data on thinning projects or prescribed burns that are stored in the FACTS database. These data could inform monitoring teams of changes in forest structure at fine

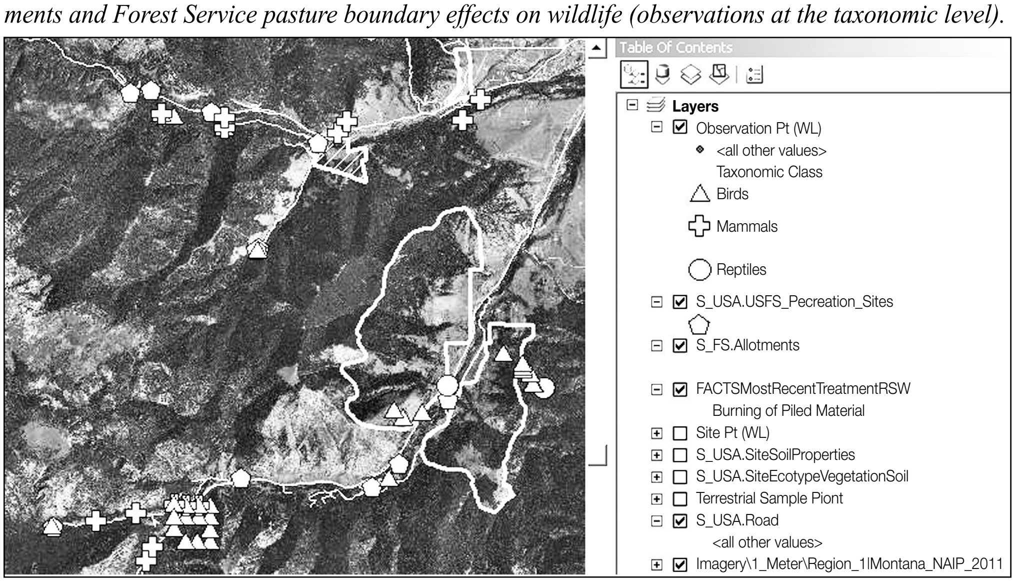
scales; similarly, overlaps of treatments, such as fuels reduction with wildlife observations, could be quantified (figure 9.2). In addition, NRM contains data on land use that could be useful for monitoring human disturbance agents described in chapter 7.

Use NRM corporate databases in habitat monitoring programs as a source of existing data and protocols and as a repository for newly collected data (chapter 4, section 4.4.1). For NRM, the goal is to create a common look and feel across all products. This architecture minimizes repetitive development, simplifies data structure, and provides the same interface across all applications. This streamlined approach to development and standards ultimately results in less user training and an increased comfort level for entering and exporting data (section 9.4.1).

Forest Service employees can access transactional data by requesting a role as either a data steward (for data entry) or a data editor (for data editing) for a specific management unit. Prospective users must have an eAuthentication account and specific user roles and organizational units. Employees can refer to the Quick Guide for an application to get assistance with this process (http://fsweb.nrm.fs.fed.us/support/index.php). The assigned roles enable the employee to edit and query data in NRM from the specific local management unit, through output tools such as the EDW (read-only), NRM **User Views**, and the **Geospatial Interface** (GI).

Although transactional data are available only to Forest Service employees who have assigned roles, the eventual goal of NRM is to make certain types of data available to external parties as published data. When these data are available, interested parties will have access through the Internet and either query the data or download time-stamped data into external databases.

Figure 9.2.—*Example of an ArcMap project incorporating data from several NRM applications (EDW, FACTS, and Wildlife). This map project could be used to examine land management treatments and Forest Service pasture boundary effects on wildlife (observations at the taxonomic level).*



EDW = Enterprise Data Warehouse. FACTS = Forest Service Activity Tracking System. NRM = Natural Resource Manager.

Because of this future capability, any unit that is implementing a habitat monitoring program will need to assess whether monitoring products are ready for publication or should be retained as transactional data in anticipation of further refinement. For example, if a map of existing habitat is based on a regional vegetation-mapping product that the region intends to replace in the near future, it would be best to keep the habitat map transactional until the new regional vegetation data can be incorporated into the habitat map.

NRM Applications

Although an NRM application specifically for managing wildlife habitat data does not exist, similar attributes and sample designs exist in several NRM applications. Documentation for these applications can be found by following the Product links (http://fsweb.nrm.fs.fed.us/products/). In general, a documentation link exists for each application in which information on required fields, spatial standards, and other business rules may be obtained (http://fsweb.nrm.fs.fed.us/support/index.php).

TESP/IS. This application contains records on all taxa of threatened, endangered, and sensitive plant species and invasive species. It is used in planning invasive species surveys, storing field-collected survey and element occurrence data, and analyzing data for consideration in managing the land. It accommodates casual point and polygon observations with basic attributes, such as location, plant code, and observer, but its intended use is for formal, protocol- or program-driven inventories within defined survey areas. For habitat monitoring, one function of this application may be using the locations of threatened, endangered, or sensitive plants selected as emphasis species to help define the monitoring area boundaries, as well as for periodic population monitoring of the selected plant taxa. Another use of this application is the invasive species information, because the presence of invasive species is likely to affect the quality of wildlife habitat. For example, Japanese honeysuckle (*Lonicera japonica*) is an invasive vine that has spread through much of the Southeastern United States, replacing native flora with dense infestations (Miller 2003).

FSVeg. This application contains data about trees, fuels, down woody material, surface cover, and understory vegetation (chapter 4, section 4.4.1). FSVeg supports the business areas of common stand exams, fuels data collection, permanent grid inventories, and other vegetation inventory collection processes. It provides data-collection protocols, codes, entry forms, an Oracle database, and reports for forest vegetation. The application is based on stand polygons defined by local delineation criteria. A spatial application called FSVeg Spatial provides the polygon linkage. This application has high value for monitoring habitat of many species that use forest environments, such as northern goshawk (*Accipiter gentilis*) or flammulated owl (*Otus flammeolus*).

Inventory and Mapping. This application supports classification and mapping of Terrestrial Ecological Unit Inventory (TEUI), geology, non-National Cooperative Soil Survey (non-NCSS) soils, and Potential Natural Vegetation following nationally accepted protocols. Point and polygon features can be created. The application directs

the development of describable, repeatable map units such as ecological land units for a TEUI or potential vegetation map units. These map units can be used to interpret resource values for wildlife habitat on the landscape.

Rangeland Inventory and Monitoring. This application supports vegetation, ground cover, and soil **pedon** sampling using nationally accepted protocols. It accommodates point observations and many sample types. The intended use is for formal, protocol- or program-driven inventory and monitoring for defined projects. This application can be used to monitor vegetation and ground cover attributes in forested and nonforested vegetation communities that are directly related to hiding cover, forage, thermal cover, and other wildlife habitat requirements.

Aquatic Survey. This application is the agency standard for managing information about aquatic surveys. It encompasses data about fish, aquatic insects, reptiles, amphibians, aquatic invertebrates, riparian environment characteristics, and other aquatic features. NRM Aquatic Survey has high value for monitoring aquatic wildlife species.

Wildlife. The NRM Wildlife application supports information about locations of terrestrial wildlife on National Forest System lands, as well as other information about the observation (e.g., observed versus heard, nest sites versus foraging sites). Observations, Sites, and Surveys can be created, and habitat or other attributes can be associated with each. Observations (point or polygon) are either collected during a Visit to a Site or obtained opportunistically. Sites (point or polygon) are typically monitored for wildlife business requirements, including biological, administrative, or use areas. Surveys are searches for certain wildlife species conducted following a specific protocol. Sites and Observations are associated with Surveys. NRM Wildlife enables users to track multiyear surveys by associating the Surveys with specific Sites and entering data for each Visit to a Site. Users enter all survey outcomes, including surveys that did not result in any observations of the targeted species (i.e., negative surveys). Even for species with clearly defined habitat relationships, we recommend periodic monitoring of populations, to ensure that the species occurs in areas defined as habitat for habitat monitoring (chapter 1, section 1.3.2). For wildlife habitat monitoring, a primary value of this application may be using observations of an emphasis species to evaluate a habitat model (chapter 5, section 5.3.4) or for periodic monitoring of populations in conjunction with habitat monitoring to strengthen the relationships defined in the model (chapter 1, section 1.3.2). NRM Wildlife Observation data can be used to meet this need. Habitat monitoring data may be stored in more than one NRM application, or in a combination of NRM and auxiliary databases.

Navigating NRM

The NRM applications reside at the National Information Technology Center (NITC) in Kansas City, MO. Applications can be accessed using Citrix at the Enterprise Data Center. Each application has (1) a required list of roles for editing, (2) a positive spatial requirement (i.e., it must have a spatial feature), (3) an NRM Feature Inspector, (4) a Task

Assistant (specific for each business), (5) online Help, and (6) a set of Output tools. Each application uses ArcMap as a spatial interface and Oracle for tabular data storage. Users can access the applications by running ArcMap software loaded on their personal computers or by using Citrix software to launch ArcMap or the Data Exchange tool at the Enterprise Data Center.

Each NRM application also has its own set of business-related information. This information may contain supported protocols, data requirements, spatial feature datasets, software downloads, documentation about business rules, and lists of acceptable values. This detailed information can be found in the documentation for the specific application on the NRM Support page (http://fsweb.nrm.fs.fed.us/support/index.php).

Data summaries, analyses, reports, and map products are supported through NRM Output tools—EDW; GI; and User Views, Forms, and Reports. The EDW provides read-only, historical, and aggregated data using an Online Analytical Processing (OLAP) design that provides snapshots of the transactional (editable) data repository. Benefits of the EDW include availability of outputs for general use, significantly faster performance relative to the transactional database reports and queries, a variety of formats for data delivery (e.g., reports, maps, raw and summarized data), and data at national spatial extents. Users access the EDW through various database connection methods, including standard ArcMap, the GI, and, in the future, Web services. To display the EDW published feature datasets in ArcMap, users must create a one-time connection to the Citrix (Enterprise Data Center) environment using the SDE (ESRI Spatial Database Engine). The login tool for Forest Service employees is (http://fsweb.nrm.fs.fed.us/support/help/gis/Establish_a_Citrix_Connection.htm).

The GI is an ArcMap extension that NRM applications leverage to simplify loading data, accessing custom products for display, running queries that analyze data, and exporting data. The GI provides a way to load multiple sets of spatial data with or without the tabular data already attached. Presymbolized data can be set up so layers load with the same look for everyone. The GI can be used to run spatial processes like clip, intersect, and identity. The GI enables users to repeat standard analyses on data over and over.

User Views provide support for tabular data exports for specific business requirements. These customizable views allow for direct querying of data tables and provide tabular reports that can be exported to Microsoft (MS) Excel. These views are accessible through the I-Web interface main menu.

Raw data can be summarized using these output tools. Outputs contain various queries, maps, and views that help summarize data collected (1) at the Site, such as aspect, elevation, and slope (e.g., Site General data); (2) in fixed-area plots (e.g., ocular macroplot); (3) along transects (e.g., line intercept); and (4) in quadrats (e.g., cover frequency). Data summaries can include descriptive statistics (e.g., mean, minimum, maximum, count, frequency) for continuous and categorical variables as appropriate. Additional queries, maps, and views are continuously being developed as users' requests

are prioritized. The GI content enables users to create and export maps and tables in MS Excel, Word, and Access, or in text format. User Views generate Excel spreadsheets. These output data can then be imported into and analyzed using the Statistical Analysis System (SAS, available through a Forest Service license) or other statistical software, or a multivariate package such as PC-ORD (McCune and Grace 2002).

9.3.2 Data Quality

Data stewards can ensure data quality by designing and implementing a number of quality assurance and quality control (QA and QC) techniques during program design and execution. Application of principles of effective project management to the design and execution of inventory and monitoring programs can ensure appropriate quality assurance and quality controls are incorporated into all program phases. Data quality and assurance benefit not only from development of an inventory or monitoring plan but also from use of the techniques described in the following paragraphs.

Data Cleaning Methods

A simple checklist of questions can assist in the QA and QC of data. These exercises can be performed in the field and also automated to check data already in the corporate database. While in the field, we recommend you review data entry forms to check that individual land cover types will sum to the total monitoring area. Ensure that field personnel collecting data have the proper skills, adequate training, and periodic oversight, or the field data collected and analyses based on the data will be suspect. If proper skills are not available at the district or forest level, request assistance on project design and implementation, as well as training and oversight, from the regional or national level.

An important component of data quality assurance and control is oversight and monitoring of the collection crew's performance. This oversight may consist of resampling a proportion of sites or specific portions of data collection and error checking. Use of electronic field data recorders will minimize data recording and transferring errors.

Within the database, users can generate reports and maps to identify outliers or extremes that may need to be adjusted or dropped. Users can evaluate if attribute values are reasonable by visually inspecting the data using scatterplots, summarizing the data with simple statistics, or simply sorting the data in ascending or descending order (chapter 8, section 8.5). Some NRM applications include output tools to aid users in QA and QC of their data in the database. For example, the Range business area provides QA and QC visualization in the GI that identifies discrepancies between pasture areas entered in the Forest Service NRM Rangeland Management Unit forms and area calculated from spatial data. A percent difference in area is displayed to notify the specialist of the degree of discrepancy.

Field Data Recorders

Data from the field can be collected on paper forms or entered into a data recorder, depending on the application. In either situation, the user will follow the standards set in

the protocol field guides. These guides, designed for nationally accepted protocols, provide the requirements for data to be housed in the corporate database. NRM application development closely follows defined standards and does not support local modifications (chapter 4, section 4.4.1).

Field data recorder software for several NRM applications implements QA and QC of data through use of code sets and error checking. The validation includes notice of incorrect codes and missing required values. The software also validates measurement formats. Free-form text fields other than Comments and Remarks do not exist. Additional validation occurs when data are uploaded from a data recorder to the corporate database using the NRM Data Exchange (DX tools; http://fsweb.nrm.fs.fed.us/products/nris/).

The DX tool identifies values that are not supported by the lists found in the field guides or at the unit, thus providing a way to correct errors before entering data into the database. With paper forms, users can manually enter data into the DX Tools or the NRM application data entry forms. Both processes provide the same quality control steps, including lists of values and requirements. Other means for data validation include reviewing data on screen within the applications or using outputs such as the GI (section 9.3.1) or I-Web User Views to run reports and create export products, such as tables or maps.

9.3.3 Data Management

At its simplest, data management for habitat monitoring involves reporting on six basic descriptors of the data: (1) what attribute was estimated, (2) the attribute values, (3) where (location in space) the data were collected, (4) when they were collected, (5) how (protocols used) they were collected, and (6) who collected them (McComb et al. 2010). Data management encompasses a broad range of activities from the technical aspects of entering and cleaning data to administrative aspects such as defining user roles and providing for long-term storage. Adhere to best management practices in all aspects of data management (section 9.2.3).

The Forest Service Standard Data Management project is tasked with creating tools and guidance to manage inventory and monitoring data, based on clear standards to collect, manage, use, and report those data (http://fsweb.wo.fs.fed.us/standarddatamanagement/). The overall governance of the corporate database structure is by NRM staff and the directors. At the regional level, resource information coordinators implement and integrate NRM modules across the Forest Service. NRM data stewards oversee regional and local code table maintenance and application use. They may also regulate role assignment and perform data QA and QC. Users enter data and maintain data to meet national and local standards implemented within NRM databases (http://fsweb.nrm.fs.fed.us/support/index.php).

Change requests for software, application interface, and the databases are received throughout the year from users and Forest Service leadership; these requests may become part of the program of work (http://fsweb.nrm.fs.fed.us/about/steeringteam/). Enhancements

or updates to the applications go through the process of evaluation by various stakeholder groups. These requests for enhancements may include new attributes, new business rules, a new look for a form, or data migration. Proposals are submitted using a transparent process. The national program managers and NRM extended team are responsible for reviewing and selecting proposals for inclusion in the NRM program of work. Some enhancements create the potential to move legacy data into the national database. The scope of the need defines whether local, regional, or national programs fund the migration.

Local users may need to maintain auxiliary databases that have attributes that do not fit in the corporate database (section 9.2.3). Store these data, including habitat map products and model data, in a format and location that are accessible to those who need it. The likely repositories for these data are the forest or local management unit's project and program folders at the Data Center (T:\FS\NFS\Forest\Project\). Filing at this location greatly speeds data access, availability, and use with other NRM application data. A GIS analyst and a wildlife biologist will likely manage the auxiliary data. Evaluate archival information, such as maps and photos, attachments, reports, and other documents from the project record, for inclusion in the NRM database periodically.

Software updates, database structural changes, or new business rules may affect stored data. Although database structure or forms may change, data quality is maintained. To minimize impacts to permanently stored data, a thorough analysis is part of every proposal and is incorporated into development and testing cycles. Data protection is achieved through this measure as well as backup procedures.

Specify in the monitoring plan and all subsequent reports where data are stored and which agency, office, or organization is the primary steward. The primary steward is responsible for ensuring that data are transferred correctly as software or applications become obsolete.

9.3.4 Metadata Requirements

Metadata are information about the data (i.e., its history and changes) that are federally mandated by Executive Order 12906 (http://www.archives.gov/federal-register/executive-orders/pdf/12906.pdf). Metadata provide the information people need to understand, trust, and correctly use data. From defining attributes and accuracy to providing information on projection and coordinate systems, metadata provide answers to many questions. Metadata also help to avoid wasteful duplication of effort, direct people to the data they need, and determine how best to use it. The *Forest Service Metadata Users Guide* is designed to provide this information (http://www.fs.fed.us/gac/metadata/step1.html).

Implement the interagency FGDC data standards when creating and disposing of metadata. The Forest Service must archive and dispose of FGDC-compliant geospatial metadata in accordance with its records retention and disposal requirements and schedules as listed in Forest Service Handbook 6209.11 (USDA Forest Service 1996) and with direction issued by the FGDC Historical Records Working Group of the National Archives and Records Administration.

Specific applications enable users to create metadata; for example, the NRM FSVeg Spatial application has implemented a feature level metadata tool. Spatial metadata required by FGDC includes the location revision date (i.e., when the feature was compiled), location source (e.g., aerial photograph or Global Positioning System), and location accuracy. These three feature-level attributes are standard for regional and forest geospatial datasets, such as coverages or feature classes. NRM applications use SDE feature classes stored at NITC. Guidelines of the National Standard for Spatial Data Accuracy (FGDC 1998a, 1998b) and others (ASPRS 1990; U.S. Bureau of the Budget 1947) are followed for geolocational accuracy.

NRM protocols contain requirements for certain tabular and spatial metadata documentation. Some metadata may have to be maintained at the local level, working with the local data stewards. In the corporate database, the revision date and compilation date are maintained for each record. The accuracy of methods used to derive the spatial location is stored in the feature class, in the associated Oracle tables, or as part of the project record. Tabular metadata for the Cover Frequency protocol require that sample design data for transect and frame numbers and sizes be completed before frame-level data are entered.

9.4 Reporting

The monitoring plan will include a section on reporting that describes (1) the type of products the habitat monitoring program intends to produce and (2) the anticipated schedule for availability of these products. The reporting section is essential because the monitoring program can then be designed to efficiently produce these reports and other products. Moreover, by stating the intended outcomes of the monitoring program, the decisionmaking officials are informed about the types of products they can expect to see and when these products will be delivered. A clearly defined reporting plan will also assist in securing funds for creating the monitoring reports. Monitoring plans produced by the Forest Service under the auspices of the Northwest Forest Plan provide excellent examples for those creating habitat monitoring plans and reports (e.g., Hemstrom et al. 1998, Madsen et al. 1999).

9.4.1 Data Products

Tailor the data products specifically to the habitat monitoring questions addressed by the monitoring plan and present data in a style that is meaningful to decisionmakers. The primary data products will be a series of reports describing the monitoring program and its outcomes at different stages of implementation (e.g., 1 year, 5 years, and 10 years). Follow Vesely et al. (2006), section 3.5, for key elements of interim or final monitoring reports. When reporting data results, be sure to describe the sampling design and data quality protocols to provide context for the data. If data are not spatial, ensure that summary tables are uncluttered and interpretable (table 9.1). Consider using bar graphs or pie charts as visual tools for displaying monitoring results.

Wildlife habitat monitoring data will typically consist of spatial databases of habitat attributes and maps for the emphasis species that indicate the location of habitat by some category of quality, such as high, moderate, or low quality. Ensure that spatial products are in a format readily viewed outside of GIS environments (e.g., maps in various graphics formats, such as jpegs or tiffs) so that they are easily accessible to decisionmakers.

Several tools will help prepare habitat data for presentation in a monitoring report. For example, the NRM GI ArcMap extension helps resource specialists work efficiently with their data. It provides tools that simplify loading data and access to custom products for display, analysis, and export of data and maps (table 9.2, figure 9.3). The desired

Table 9.1.—*An example report of sagebrush (*Artemisia *spp.) canopy cover classes for meeting landscape-scale monitoring objectives for greater sage-grouse (*Centrocercus urophasianus*) (chapter 10, sage-grouse case example).*

Monitoring year	Percent total sagebrush by canopy cover class[a]				
	0–5	6–15	16–25	> 25	Total
Year 1	21	39	14	26	100
Year 5	18	32	29	21	100
Year 10	12	25	40	23	100
Goal	< 10	< 30	60[a]	—	100

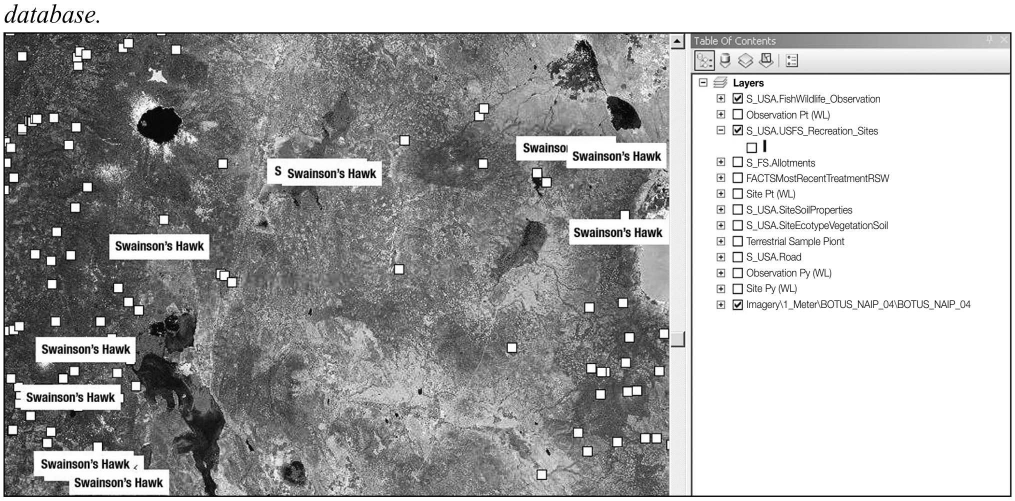
[a] The overall goal is for at least 60 percent of the sagebrush to be either in the 16 to 25 percent or > 25 percent canopy cover classes.

Table 9.2.—*Example of tabular output from the Geospatial Interface for Observations of Swainson's hawk (*Buteo regalis*).[a]*

Observer	Observation date and time	Observation date accuracy	Observation method	Reproductive status	Total detected	Age	Activity
K. Hauge (experienced)	6/20/1990 0:00	Day	Other	Unknown	2	Unknown	Unknown
E. Olmeso (experienced)	6/9/1997 0:00	Day	Camera Set	Unknown	1	Unknown	Moving
Unknown (unknown)	7/11/1974 0:00	Day	Other	Unknown	1	Adult	Unknown
S. High (experienced)	3/31/1995 7:25	Exact	Visual	Unknown	1	Adult	Unknown
S. High (experienced)	8/29/1995 10:00	Exact	Visual	Unknown	1	Adult	Unknown
J. McAlister (experienced)	9/22/1986 15:00	Exact	Visual	Unknown	1	Unknown	Incubating
S. High (experienced)	11/12/1996 0:00	Day	Other	Unknown	1	Adult	Unknown

[a] Data were edited to fit the page.

Figure 9.3.—*Observations of Swainson's hawk (*Buteo regalis*) from the NRM Wildlife observation database.*



products can be preset and made available to all Forest Service users to apply with their local data, or the products can be specific to a Forest Service unit. Products can be easily reproduced over time, and maps and tables can be exported and delivered to cooperators. Tabular data can be exported in many formats: in MS Word, Access, and Excel or as text files.

The GI enables users to—

- Easily upload preset maps that include many features.
- Load layers using a different symbology (such as all roads as a solid black line rather than a different symbol for each road type).
- Combine tabular data with spatial layers.
- Run predefined queries and export maps or layouts to MS Word with a one-button click.
- Access data stored in various places on a local server as well as NITC.
- Run standard spatial analysis using processes such as clip, intersect, dissolve, and identity.

9.4.2 Reporting Schedule

When the habitat monitoring program is part of land management plan monitoring, the reporting schedule will reflect the forest plan reporting schedule. Other habitat monitoring reports may not be tied to the Forest Service planning process, but to specific conservation efforts (e.g., a multiagency monitoring program for a wide-ranging emphasis species). In these cases, the reporting schedule will be a function of the expected rate of change in the monitored attributes, the frequency of management actions affecting the monitoring area, and the anticipated response time. Milestones that could be listed in a reporting timetable include results of the pilot monitoring program and the first full year, subsequent annual reports, and 5- or 10-year reports.

9.4.3 Report Content

Organize reports produced for a habitat monitoring plan to address the specific objectives and the associated sampling design and methods of the monitoring program (McComb et al. 2010). For example, a monitoring objective could be estimating the number of vernal pools with salamanders present in the monitoring area (chapter 10, salamander case example). In this case, the monitoring report should clearly display the results of sampling (e.g., sample sizes, locations, dates) to estimate vernal pools, in either graphic or tabular format, or both. Similarly, objectives may include a threshold statement, such as—*After each monitoring period, any pool neighborhoods with a decline in neighborhood area greater than 15 percent will be evaluated for possible changes in vegetation and road management to prevent further declines or to restore neighborhood size, if*

feasible (chapter 10, section 10.2.4). In the monitoring report, describe the additional evaluation in areas exhibiting declines above the threshold and what management actions are planned to address these declines.

We recommend that reports include a section explicitly describing how the results from the habitat monitoring program can be used in resource management, either to improve current management or affirm current management direction. Report the results of implementing the habitat monitoring program in a separate section from a list of suggested management recommendations. Last, in the management recommendations section, be sure to link recommendations to the business requirements identified in the original monitoring plan.

9.5. Conclusions

It should be apparent that wildlife habitat monitoring data are at risk of being stored incorrectly and possibly lost without a well-designed system of data management including (1) data entry, (2) storage, (3) retrieval, (4) analysis, and (5) reporting. Because a tremendous investment of time and energy is typically made for sample design and data collection, it is critical that this very important last step, data management, is completed properly. The NRM applications provide a system that not only fosters data sharing but also ensures data integrity and transparency and defensible analysis and reports. This chapter provided guidance and links to resources that will help you properly manage the data you collect and thus enable you to generate sound reports from your habitat monitoring data and ensure the efficient and proper use of the data by future monitoring teams.

Chapter 10. Developing a Habitat Monitoring Program: Three Examples From National Forest Planning

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10.1 Objective

This chapter reviews the process steps of wildlife habitat monitoring described in chapters 2 through 9 and provides three case examples that illustrate how the process steps apply to specific situations. It provides the reader an opportunity to synthesize the material while also revealing the potential knowledge gaps and pitfalls that may complicate completion of a comprehensive habitat monitoring program. The chapter strives to clarify questions the reader may have by demonstrating the process of developing a habitat monitoring plan.

The examples provided in this chapter address habitat monitoring for terrestrial vertebrates, although the examples could have included invertebrates and rare plants. Whereas population monitoring is a necessary and critical complement to habitat monitoring (chapter 2, section 2.2.2), this guide does not address population monitoring per se because several excellent, published resources exist on this topic (e.g., Manley et al. 2006, McComb et al. 2010, Vesely et al. 2006). This chapter provides examples that are specifically tailored to habitat monitoring on national forests across North America.

For the examples, we selected two species and one species group—American martens (*Martes americana*), greater sage-grouse (*Centrocercus urophasianus*), and mole salamanders (*Ambystoma* spp.)—that are likely candidates for habitat monitoring because they are frequently emphasized in planning documents as having special conservation interest. These examples are taxonomically diverse (mammal, bird, and amphibian), use different environments, and occupy different geographic areas.

American martens are closely associated with mature and old-growth forests across parts of the Northern United States and in Canada. A great deal of information has been written about their natural history and management across their range, and this species has been broadly identified as a sensitive species and management indicator species (MIS). The greater sage-grouse is a sagebrush (*Artemisia* spp.) obligate for which the U.S. Department of the Interior, U.S. Fish and Wildlife Service recently determined that listing under the Endangered Species Act is warranted, but precluded because of higher

priority listings (USDI USFWS 2010). Of the three examples, this species has the greatest amount of information for developing a monitoring plan, because habitat management guidelines (Connelly et al. 2000) and monitoring guidelines (Connelly et al. 2003) have been published. In addition, a comprehensive book describing the species' ecology, habitat, and conservation needs has been published (Knick and Connelly 2011), as well as a framework for habitat management at multiple spatial scales (Stiver et al. 2010).

The species group case example consists of three species of mole salamanders that breed in vernal pools in proximity to deciduous or mixed-deciduous woodlands in the Northeastern United States. This group includes the Jefferson salamander (*Ambystoma jeffersonianum*), blue-spotted salamander (*A. laterale*), and spotted salamander (*A. maculatum*). Very little has been published about the Jefferson salamander, and some confusion exists in the literature because this species has been misidentified with and hybridizes with the blue-spotted salamander. The Jefferson salamander is a species of conservation concern in several States and, at the time of writing, several national forests had identified the species as an MIS under the 1982 planning rule for the National Forest Management Act (NFMA). The species is also on the National Forest System (NFS) regional list of sensitive species. The biology and status of these salamanders offer a unique set of challenges to managers charged with monitoring habitat for a species about which little is known. We chose to combine (something that managers may need to do) this species with two other mole salamanders for which a larger body of literature exists.

For each species and species group, we developed example habitat monitoring programs that appear at the end of this chapter (American marten, greater sage-grouse, and mole salamander case examples). Using an area in which the species or group occurs, we obtained planning and monitoring documents and available data to identify land management and monitoring objectives, as well as local concerns or habitat threats for the species. We solicited local expert knowledge on species distributions, habitat needs, management issues, and threats to develop a conceptual model for each species (chapter 2, section 2.3.2). We have not stated the specific locations used in these case examples because we aimed to provide a more general overview for each species without comparison with any ongoing efforts in the selected locations. Likewise, the attributes selected for monitoring in each example were for illustration only; local conditions and management issues could result in the selection of different habitat attributes for the same species.

In the examples for American martens and greater sage-grouse, we demonstrated the process steps and described choices and decisions that a monitoring team might make based on a local situation. In contrast, we wrote the mole salamander example as a finished monitoring plan, following the outline recommended in chapter 3, section 3.3.5. We then drew from all three examples to comprehensively illustrate and summarize the process of habitat monitoring described in this guide.

Although our emphasis is on habitat monitoring, not population monitoring, this emphasis does not replace the need to conduct population monitoring to establish population status and trend (chapter 2, section 2.2.2). Situations in which habitat does not strongly influence population dynamics also require population monitoring to adequately address species' responses to management actions or to environmental change other than habitat (O'Neil and Carey 1986). When necessary to meet monitoring objectives, concurrent collection of habitat and population data strengthens wildlife-habitat-relationships models and allows for more valid interpretation of observed changes in populations and habitats (Cushman et al. 2008b, Manley et al. 2006, Morrison et al. 2006, Mulder et al. 1999).

10.2 Habitat Monitoring Process Steps

As a refresher, the primary steps for designing and executing a habitat monitoring program are as follows (figure 10.1, table 10.1):

1. Define general goals that relate management goals to monitoring goals.
2. Select emphasis species for habitat monitoring.
3. Develop a conceptual model for each species or species group and select habitat attributes derived from the model.
4. Develop monitoring objectives for each emphasis species or group.
5. Evaluate the use of existing data sources for meeting monitoring objectives.
6. Plan for new data collection as needed.
7. If spatial output is needed, create a habitat map from existing or modified habitat model.
8. Obtain baseline values of attributes.
9. Monitor changes in values of selected attributes over time.
10. Manage, store, and report data.
11. Apply results of monitoring in an adaptive management context.

10.2.1 Define Goals of the Habitat Monitoring Program

Goals for monitoring habitat should be derived from documented Forest Service business requirements and based on current agency laws, rules, and policies (chapter 1, table 1.1). Effective habitat monitoring often involves many different land ownerships, and therefore the monitoring goals should recognize the influence of adjacent landowners on habitats and populations. Goals derived from land and resource management plans (LRMPs) are often general and do not reference the specific emphasis species or group. For example, the LRMPs for greater sage-grouse and American martens include the following general goals:

- Evaluate the effectiveness of LRMP implementation.
- Monitor to identify needs for possible amendments to the LRMP and other changes in management practices in relation to habitat.

Figure 10.1.— *Simplified diagram of process steps for developing a habitat monitoring program.*

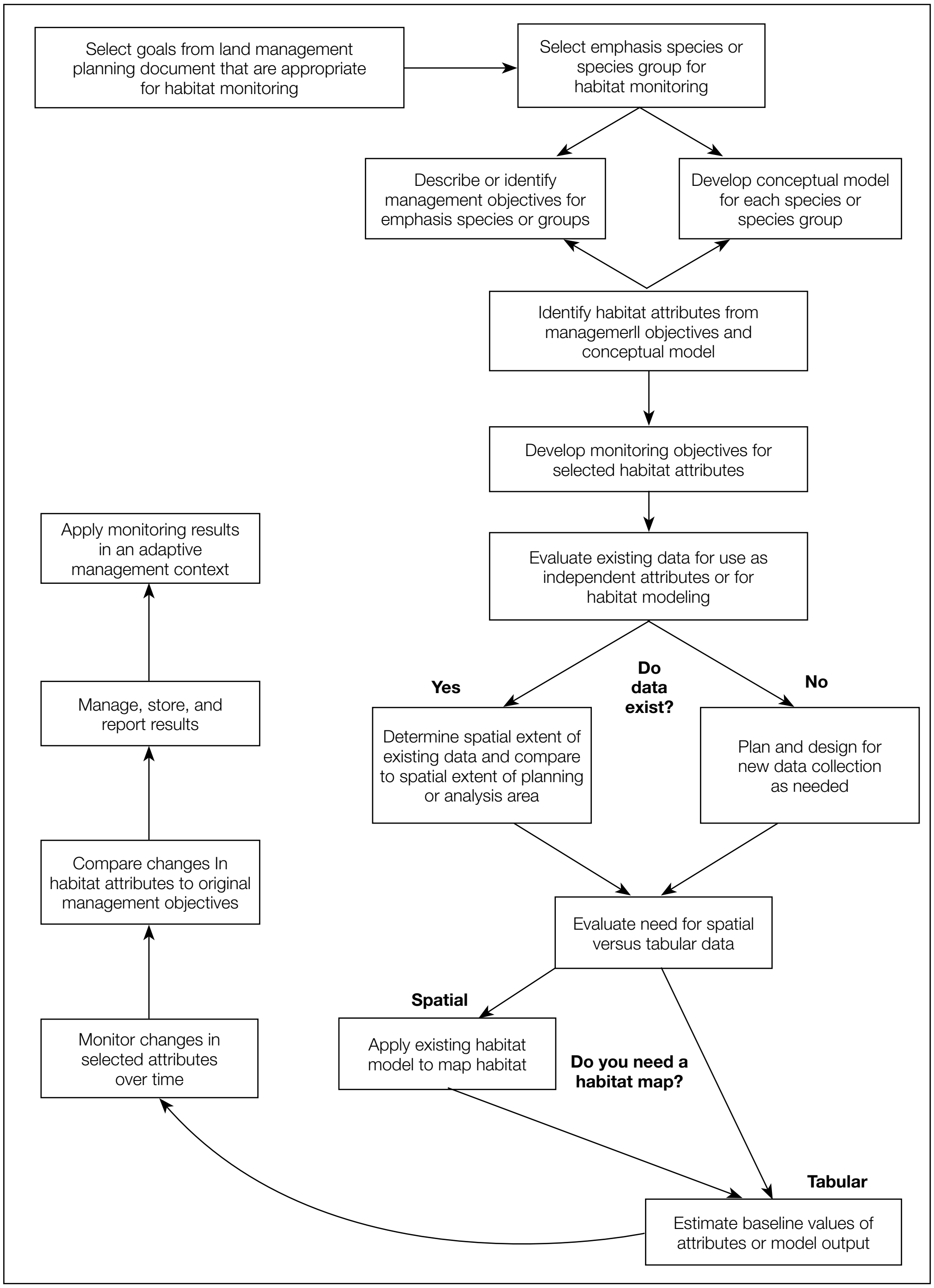


Table 10.1.—*Process steps in developing a habitat monitoring program.*

1. **Define general goals for habitat monitoring program** (chapter 1).
   a. Identify business requirements.
   b. Select habitat monitoring team.
   c. Set broad objectives for habitat monitoring.

2. **Select emphasis species for habitat monitoring** (chapter 2).
   a. Decide whether the species is appropriate for habitat monitoring and document rationale for selection.
   b. Evaluate whether several selected species can be grouped to increase efficiency in monitoring.

3. **Develop conceptual model for each species or species group** (chapter 2).
   a. Review existing wildlife habitat-relationships models.
   b. Identify appropriate levels of habitat selection for emphasis species.
   c. Identify habitat requirements and associated habitat attributes for emphasis species.
   d. Identify stressors (including human disturbance agents and climate change) that may affect habitat for the emphasis species and integrate in conceptual model, with explicit linkages between stressors, effects on habitat attributes, and potential effects on populations.
   e. Transform conceptual model of habitat requirements and stressors into discrete list of potential habitat attributes and human disturbance metrics[a] for consideration in the monitoring program.
   f. Reduce set of all potential attributes to measurable attributes suitable for monitoring.

4. **Develop monitoring objectives for emphasis species or species group** (chapter 3).
   a. Determine desired information outcome at each level of habitat selection.
      i. Identify the management objective or specific goal that motivates specific habitat monitoring objective(s).
      ii. Identify from the list of measurable attributes (Step 3f) those that best meet the management objective and will be carried forward into the monitoring plan.
      iii. Decide whether monitoring objective(s) will be met in a one-time inventory or a multiyear monitoring program. If multiyear, establish monitoring intervals and time points for summarizing results.
      iv. Decide if results will be tabular only (i.e., amount of habitat) or if spatial output is needed (i.e., maps of individual attributes or mapped habitat from a habitat model).
      v. Decide whether to monitor habitat attributes independently or combined in a model.
         (1) If monitored independently, set monitoring priorities among attributes.
         (2) If combined in a habitat model, evaluate whether an existing model is appropriate (step 7). If a suitable model does not exist, develop a model incorporating the selected attributes.
   b. Determine spatial extent and sampling frame over which desired information is needed (e.g., national forest, timber sale area).
   c. For each habitat attribute, identify the standard (threshold value or amount of change) that will trigger a change in management.
   d. Determine desired minimum detectable change and desired precision of monitoring information outcome.
      i. Establish desired minimum detectable change and precision for each attribute or modeled habitat, through an iterative process that includes choosing the level of sampling intensity, evaluation of existing data, and other decisions.
      ii. Decide if monitoring will use new or existing data or a combination of both.
   e. Develop monitoring objective statement(s) for each level of habitat selection, based on decisions listed previously (e.g., desired information outcome, spatial extent).
   f. Document key aspects of the monitoring planning process in a monitoring plan (including decisions from 5 and 6 in the following sections).
      i. Goals, background, business requirements, and rationale for selecting emphasis species.
      ii. Conceptual model.
      iii. Monitoring objectives.
      iv. Sampling design.
      v. Data collection.
      vi. Logistics.
      vii. Data storage and management.

5. **Evaluate existing data for use as independent attributes or for habitat modeling** (chapter 3).
   a. Field-sampled data.
      i. Determine spatial extent of existing data and compare it with spatial extent of the monitoring program.
      ii. Determine whether existing data include measurements of habitat attributes selected to monitor the emphasis species' habitat, and if not, whether these habitat attributes can be derived from other measured variables in the dataset.
      iii. Compute confidence intervals (or run power analysis) on attributes of interest using existing data to determine sample size requirements.
      iv. If existing data are from an area smaller than that being monitored or if existing plot data are less precise than needed to meet monitoring objectives, design an unbiased probabilistic sampling procedure for increasing sample size.

Table 10.1.—*Process steps in developing a habitat monitoring program (continued).*

- b. Remotely sensed data.
  - i. Determine spatial extent of existing data and compare it with spatial extent of the monitoring program.
  - ii. Determine whether the data source will continue to be available over the desired time frame of the monitoring program.
  - iii. Determine whether existing data include the selected habitat attributes of the emphasis species, and if not, whether it is possible to derive the attributes from other analyzed, interpreted, or sampled variables in the dataset.
  - iv. Become familiar with the methods and assumptions of the classification process.
  - v. Determine whether the image resolution is appropriate for one or more levels of habitat used by the emphasis species.
  - vi. Evaluate map accuracy to ensure it is sufficient for the intended analysis objective.

6. Plan and design for new data collection as needed (chapters 3, 4, 5, 6, and 7).

- a. Field-sampled data.
  - i. Define sampling unit.
  - ii. Select sampling unit size and shape.
  - iii. Determine method of sampling unit placement.
  - iv. Decide whether sampling units are permanent or temporary.
  - v. Estimate number of sampling units required.
- b. Remotely sensed data.
  - i. Acquire aerial photos, LIDAR data, or satellite imagery as needed.
  - ii. Ensure coverage across spatial extent of monitoring program.
  - iii. Define relevant grain for monitoring the habitat attributes.
  - iv. For fragmentation analyses, select fragmentation features (e.g., roads, rivers).

7. Apply existing habitat model to map habitat (chapter 5).

- a. Select an appropriate habitat model (if a modeling approach has been chosen).
  - i. Review existing model structures and frameworks.
  - ii. For candidate models, determine whether model variables include the full complement of selected habitat attributes.
  - iii. Examine range of values for model input variables and adjust model as necessary.
  - iv. Conduct meta-analysis to compare models if several are available from different geographic areas.
- b. Compile extant data required by selected habitat model.
  - i. For models with only midscale or broad-scale attributes, compile existing Geographic Information System (GIS) data if appropriate and available.
  - ii. For models with fine-scale attributes, use existing field-sampled data and acquire new data as needed.
- c. Apply selected habitat model to determine amount, quality, and spatial distribution of habitat, using one of two approaches—
  - i. Apply the model using appropriate GIS databases.
  - ii. Apply the model using plot data and create a habitat map through statistical modeling—
    - (1) Assign each plot as habitat or nonhabitat based on model and attribute values for the plot.
    - (2) Develop a statistical mapping model to relate predictions of habitat to broad-scale attributes.
    - (3) Predict habitat presence or quality across monitoring area.
- d. Create final habitat maps.
- e. Validate model and provide measures of uncertainty.
  - i. Collect independent data on occurrences of emphasis species in monitoring area.
  - ii. Compare model predictions of habitat with species occurrence and abundance.
  - f. Formally document source of model, input data, spatial scale, and accuracy.

8. Estimate baseline values of attributes (chapters 4, 5, 6, and 7).

- a. Nonspatial analysis.
  - i. Estimate attribute values (e.g., snags per hectare) across monitoring analysis area.
  - ii. Explore the data in terms of measures of central tendency, dispersion, and error.
- b. Spatial analysis.
  - i. Using maps created under 7(d), estimate amount, quality, and spatial distribution of habitat.
  - ii. For spatial analysis of human disturbance agents, quantify disturbance in distance bands or other spatial representations of distance, density, or rates of disturbance.
  - iii. For landscape pattern analysis—
    - (1) Identify an area larger than the monitoring extent to incorporate an appropriate landscape context.
    - (2) Define a reference framework if relevant to the monitoring objective.
    - (3) Determine level of analysis (e.g., focal patch, global landscape, or local landscape).
    - (4) Calculate landscape pattern metrics.

Table 10.1.—*Process steps in developing a habitat monitoring program (continued).*

9. Monitor changes in selected attributes over time (chapters 4, 5, 6, and 7). a. Nonspatial analysis. i. Acquire new estimates of each attribute value. ii. Explore the new data in terms of basic statistics (e.g., measures of central tendency and variability). iii. Compare new values with baseline values, thresholds, or desired conditions, as appropriate. b. Spatial analysis. i. Acquire new data for vegetation, other biotic and abiotic features, and human disturbance agents. ii. Obtain new estimates of amount, quality, and spatial distribution of habitat. iii. For spatial analysis of human disturbance agents, create distance bands or other spatial representations of distance, density, or rates of disturbance and compare with baseline values, thresholds, or desired conditions as appropriate. iv. For landscape pattern analysis, calculate new values of the selected landscape pattern and compare with baseline values, thresholds, or desired conditions as appropriate.
10. Manage, store, and report data (chapter 9). a. Error-check field data. b. Use existing agency databases for data storage when appropriate (e.g., Natural Resource Manager). c. When necessary, create auxiliary databases for storage of habitat monitoring data. d. Complete metadata documentation for all data collection and analysis (spatial and tabular). e. Report results using standard scientific reporting structure (e.g., Introduction, Methods, Results, Discussion). f. Use monitoring results to inform management decisions.
11. Apply results of monitoring in an adaptive management context. a. Compare monitoring results with original management direction and monitoring program objectives. b. Respond by selecting one of four approaches. i. Modify monitoring approach to improve trend detection and evaluation of management objectives. ii. Modify management to respond to noncompliance or undesired effects. iii. Modify monitoring and management direction. iv. Document that no change in monitoring or management is required at this time.

[a] *"Habitat attributes" or "attributes" include both habitat attributes and human disturbance agents/regimes identified as part of a habitat monitoring program.*

The goals of the monitoring plan should also make specific reference to the emphasis species. The following three specific goals are from each of the examples, as stated in the LRMP from which each example was drawn:

1. Determine the degree to which management is maintaining or making progress toward desired conditions and objectives relevant to habitat of American martens.
2. Monitor conditions in key sagebrush areas, such as nesting habitat, important for specific life history requirements to determine if they are moving toward desired conditions for greater sage-grouse and its habitat.
3. Evaluate whether habitats of mole salamanders are being maintained under current management direction.

10.2.2 Select Emphasis Species, Document Rationale, and Group Species When Possible

An LRMP may already contain the rationale for selecting an emphasis species for habitat monitoring. If the planning document listed the species but did not clarify intent, then the rationale for species selection should be described and agreed upon before developing the monitoring program (chapter 2, section 2.3.1).

All three examples used the conservation status of the emphasis species as part of the rationale for selection (e.g., sensitive, MIS, State species of concern). Each example also provided additional rationale related to specific aspects of habitat that could be affected by management and that warrant monitoring.

For American martens, the rationale was that this species is closely associated with mature and old-growth forests and structural features such as snags and down wood, and that forest management in the local management unit has already impacted the amount and quality of these seral stages and structural features. For greater sage-grouse, the rationale for selection was that this species may serve as an umbrella species for other sagebrush-associated species, and that sagebrush systems have declined in quantity and quality (Hanser et al. 2011, Knick and Connelly 2011, Rowland et al. 2006). The mole salamander example used the rationale that management of vernal pools alone may be insufficient to sustain mole salamander populations, and that monitoring of upland habitat is needed at neighborhood and regional scales to ensure landscape connectivity between vernal pools. The mole salamander example also illustrated how several species can be grouped into one habitat monitoring plan, because they require similar environmental conditions and are vulnerable to similar threats (chapter 2, section 2.2.5).

10.2.3 Develop a Conceptual Model

The monitoring team will develop a conceptual model of known and suspected ecological relationships to predict possible changes in habitats over time and to identify habitat attributes to monitor (chapter 2, section 2.3.2). A well-developed conceptual model qualitatively links the environmental processes, human-induced and natural, that act as stressors on populations and habitats with affected resources (e.g., structure and composition components), and graphically illustrates the ecological relationships among these complex, interacting components (figures 10.2, 10.3, 10.4; Hemstrom et al. 1998, Lint et al. 1999, Madsen et al. 1999). Several examples in the literature address the framework for a conceptual model (Gentile et al. 2001, Manley et al. 2000, Noon 2003).

Part of the process of creating a conceptual model is locating and reviewing habitat relationships models that have previously been developed for the emphasis species. In the case example for American martens, a literature review yielded 20 wildlife habitat relationships models in North America (table 10.2 in marten case example). We categorized those models by framework type, listed the habitat attributes used in those models, and identified which attributes to consider for monitoring (e.g., land cover is included in 15 of the 20 models).

The use of local empirical data, if available (e.g., from U.S. Department of Agriculture, Forest Service, Research and Development), should be emphasized to inform the conceptual model and to help evaluate existing habitat-relationship models to render both more relevant to local conditions.

Figure 10.2.—*Conceptual model illustrating relationships among natural and human-induced stressors and their effects on habitat for American martens (*Martes americana*) at landscape and site levels.*

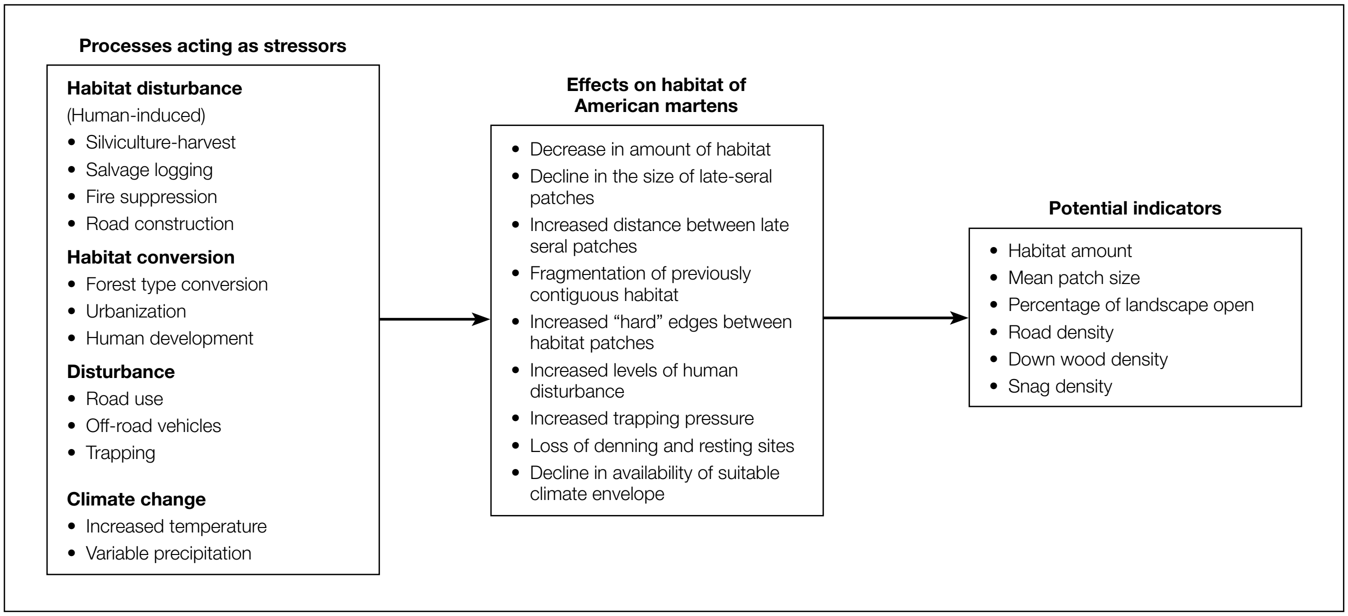
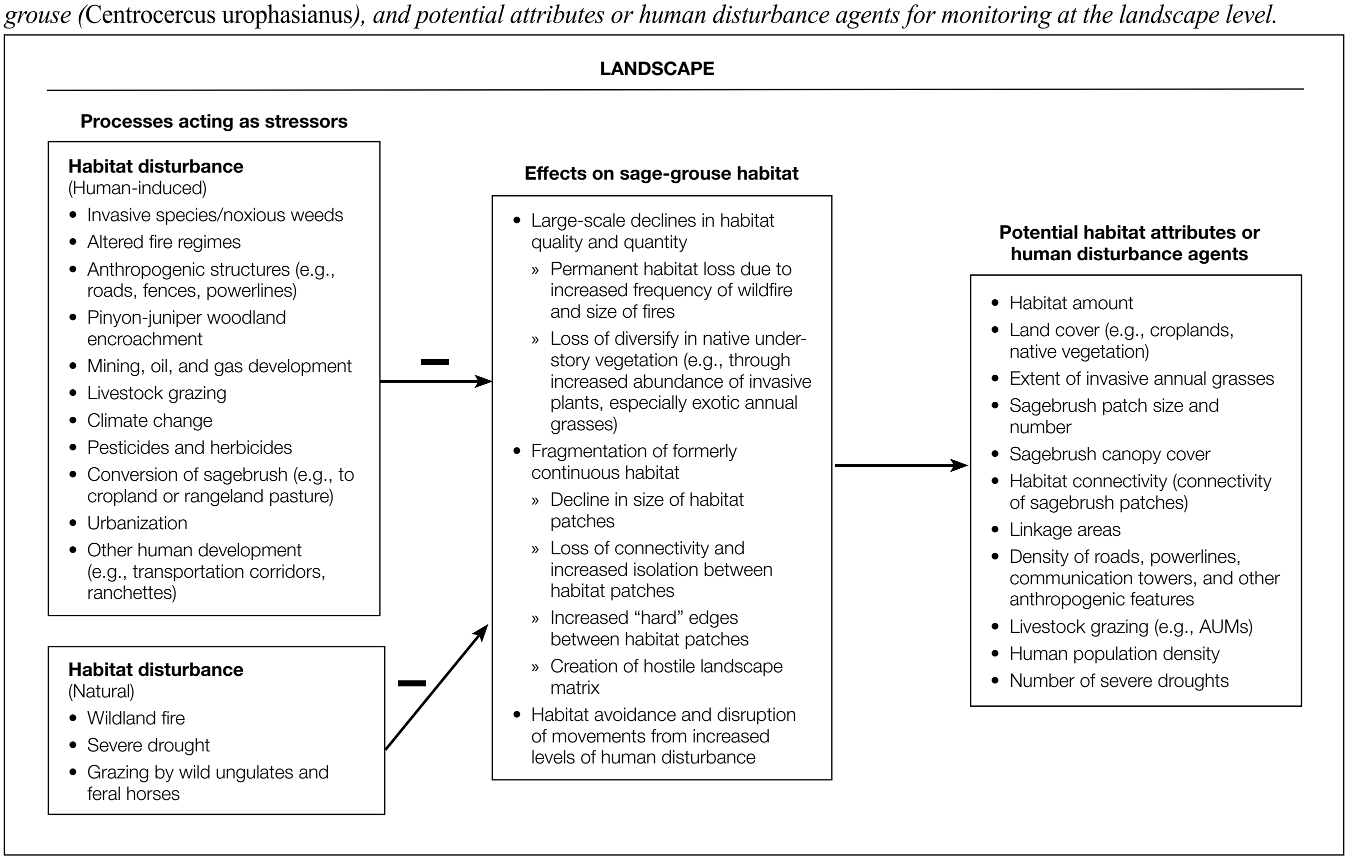
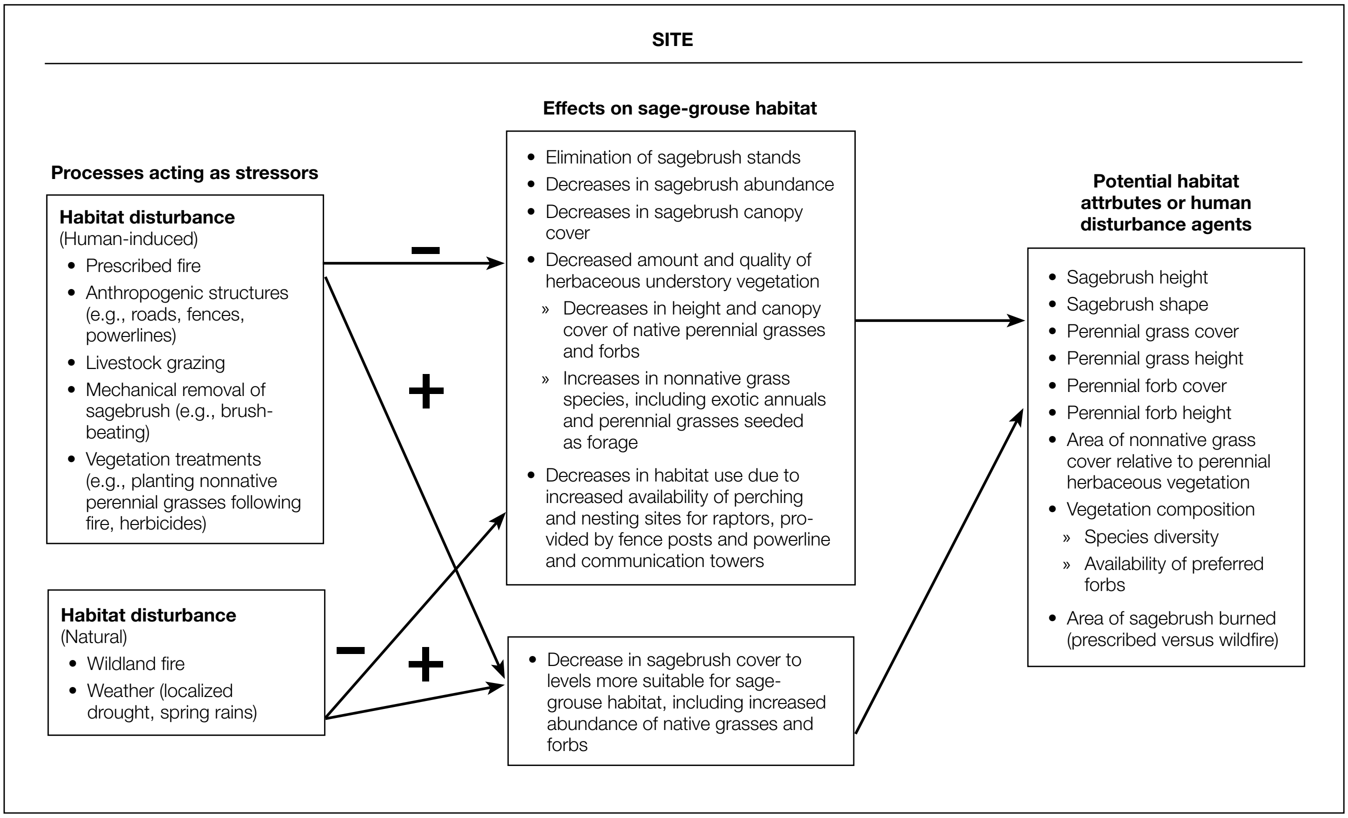


Figure 10.3.—*Conceptual model illustrating relationships among natural and human-induced stressors, their effects on greater sage-grouse (*Centrocercus urophasianus*), and potential attributes or human disturbance agents for monitoring at the landscape level.*



AUM = Animal Unit Month.

Figure 10.4.—*Conceptual model illustrating relationships among natural and human-induced stressors, their effects on greater sage-grouse, and potential attributes or human disturbance agents for monitoring at the site level.*



In all three examples, the conceptual models were structured around multiple spatial scales that reflect the different orders of habitat selection of the emphasis species (chapter 2, section 2.2.6). Each example listed the species' habitat requirements and key stressors at two or more spatial scales and then described the expected relationships and outcomes. In addition, the examples for American martens and greater sage-grouse made effective use of figures to visually illustrate these relationships (figures 10.2, 10.3, and 10.4). At the end of each conceptual model description, the examples showed how the models lead to the selection of specific habitat attributes to monitor.

10.2.4 Develop Monitoring Objectives

Stating a clear set of objectives is essential to developing a successful monitoring program (chapter 3). The monitoring objectives should be closely tied to relevant management objectives in either the LRMPs or other pertinent documents within the area of interest. The objectives should use metrics that measure progress toward meeting the objectives as well as metrics that reflect habitat needs and stressors from the conceptual model.

Table 10.2.—*Habitat relationships models developed for American martens (*Martes americana*).*

Model framework	Geographic area	Level	Season(s)	Components	Variables	Spatial application	Method of model evaluation	Reference
HSI	Columbia Highland and Rocky Mountain Forest provinces (Bailey 1995)	Stand; home range	Winter	• Foraging habitat • Cover	• Habitat type (proxy for soil moisture) (Cooper et al. 1991, Pfister et al. 1977) • Mean DBH of overstory trees • Canopy closure • CWD density (> 15 cm [5.9 in]; > 25 cm [9.8 in]) • Land cover	Nonspatial	Expert review	Patton and Escano 1983, 1990
HSI	California	Landscape	All	All	• Land cover	Spatially explicit	None	Timossi et al. 1995; Green 2007
HSI	West-Central Alberta	Landscape	Winter	• Foraging habitat • Cover	• Tree canopy closure (percent) • Spruce and fir in tree canopy (percent) • Tree canopy height • Pine, spruce, and fir in tree canopy (percent)	Nonspatial	None	Takats et al. 1999
HSI	North Columbia Mountains, British Columbia	Watershed	All (with emphasis on winter)	• Food • Cover • Den sites • Resting sites • Foraging sites	• Land cover • Canopy closure (percent) • Stand age (seral stage) • Site class • Biogeoclimatic zone	Spatially explicit	Trapping data	Kliskey et al. 1999
HSI	Sierra Nevada, California	Stand	Winter	• Food • Cover • Den sites	• Land cover • Canopy closure (percent) • Mean DBH of overstory trees • Volume of CWD > 23-cm (9-in) diameter • Soil moisture class • Distance to foraging habitat • Distance to denning habitat • Distance to cover	Spatially explicit	Field data (baited track-plate cubbies)	Barrett and Spencer 1982
HSI	Western United States	Stand	Winter	All	• Tree canopy closure (percent) • Spruce or fir in tree canopy (percent) • Percent cover of CWD ≥ 7.6 cm (3 in) • Stand age	Nonspatial	Peer review	Allen 1982; Laymon and Barrett 1986
HSI	Northern Maine	Landscape	Winter	• Food • Cover	• Land cover	Spatially explicit	Trapping data	Ritter 1985
HSI	Idaho	Plot level, home range, multiscale	Winter	• Food • Cover	• Land cover and seral stage • Road density • Elevation • Moisture index • Landscape metrics	Spatially explicit	Classification accuracy and bivariate scaling	Wasserman 2008
Rule-based	Western Montana, northern Idaho	Landscape	All	All	• Tree diameter and basal area • Canopy closure (percent) • Land cover	Spatially explicit	None	Samson 2006
Rule-based	New Brunswick	Landscape	All	All	• Land cover • Patch size	Spatially explicit	None	Betts et al. 2003

Table 10.2.—*Habitat relationships models developed for American martens (*Martes americana*) (continued).*

Model framework	Geographic area	Level	Season(s)	Components	Variables	Spatial application	Method of model evaluation	Reference
Rule-based	Ontario	Landscape	All	All	• Land cover • Patch size	Spatially explicit	None	Rempel and Kaufmann 2003
Rule-based	Northern Wisconsin	Landscape	All	All	• Stand age • Land cover • Patch size	Spatially explicit	None	Zollner et al. 2008
Rule-based	Northern California	Single and multiple home ranges; landscape	Spring, summer	Breeding	• Land cover • Canopy closure (percent) • Mean DBH of overstory trees • Percent habitat in landscape • Number of habitat patches	Spatially explicit	Field data (detections)	Kirk 2006
Rule-based	Ontario, Canada	Stand	All	All	• Tree canopy closure (percent) • Spruce, fir, and cedar in tree canopy (percent) • Tree canopy height • Stand age	Nonspatial	Field data (snow tracks) and empirical model	Naylor et al. 1999
Rule-based	Southeast Alaska	Landscape	Winter	All	• Timber volume • Stand age • Proximity to beach and streams • Elevation • Road density	Nonspatial	Field data (radio telemetry)	Flynn 2004, Suring 1993
Matrix	Black Hills, South Dakota	Landscape	All	All	• Land cover • Canopy closure (percent) • Mean DBH of overstory trees • Proximity to streams • Elevation	Spatially explicit	Field data (track plates)	Fecske 2003; Fecske et al. 2002
Matrix	Ontario, Canada	Stand	All	All	• Stand age • Land cover	Nonspatial	Field data (snow tracks) and empirical model	Holloway et al. 2004
Matrix	Central Rocky Mountains	Landscape	All	Food	• Stand age • Land cover	Spatially explicit	None	Hoover and Wills 1984; Schulz and Joyce 1992
Matrix	Northern Minnesota	Landscape	All	All	• Stand age • Land cover	Spatially explicit	None	Nichols et al. 2000
BBN	Northeast Washington State	Watershed and landscape	All	All	• Departure of habitat amount from natural range of variability • Patch size • Riparian habitat • Percent cover in landscape • Road density	Spatially explicit	Field data (observations, track plates, cameras)	Gaines et al., in press

BBN = Bayesian Belief Network. cm = centimeters. CWD = coarse woody debris. DBH = diameter at breast height. HSI = Habitat Suitability Index. in = inch.

The following two management objectives are for greater sage-grouse (sage-grouse case example) at two different spatial scales; the first objective was in the LRMP, whereas the second was derived from Connelly et al. (2000):

Landscape

- Manage vegetation to maintain at least six large patches (more than 320 acres [ac]) of sagebrush with greater than 15 percent canopy cover.

Site

- In areas with potential greater sage-grouse nesting habitat (i.e., 16 to 25 percent canopy cover of sagebrush), manage understory vegetation to meet habitat guidelines for greater sage-grouse, which include total perennial grass-forb canopy cover greater than 15 percent in arid sites and greater than 25 percent in mesic sites and grass-forb height greater than 7.1 inches (in).

The monitoring objectives should be organized first by level of habitat selection and then by the habitat attributes applicable at each level. In all three examples, we began with the highest level and ended with local levels, but this order can be reversed.

The monitoring objectives of each example contained similar components. They all described the spatial extent of the monitoring program, provided a statement of the desired information outcome (e.g., minimum detectable change that would trigger management action), and specified the level of precision, (confidence level) desired for that information. It can be difficult to specify a level of desired precision without previous knowledge of potential error rates associated with estimating values of each habitat attribute. This statement is ideal rather than real, and the monitoring team may need to rephrase the objective in the second or third year if initial results indicate that it is not possible to obtain the desired precision to detect important levels of change.

The examples also included statements about how reaching a standard or threshold can trigger a change in management. Threshold statements were based on best available science and on expert opinion, if necessary, because we rarely know if there is an actual, biological threshold in habitat that could result in a substantial change in population size. The intent is to ensure that managers begin incorporating monitoring results through adaptive management before reaching unacceptable declines in habitat. An example threshold statement from the mole salamander monitoring plan follows.

After each monitoring period, any pool neighborhoods with more than a 15-percent decline in neighborhood area will be evaluated for possible changes in vegetation and road management to prevent further declines or to restore neighborhood size, if feasible.

This statement does not mean that mole salamander populations would be in jeopardy at the stated threshold, but it provides a trigger for evaluating whether vegetation or road management, or both, needed to be changed.

The threshold statement can be based on percentage change in an attribute without knowing *a priori* the expected value of the attribute. In the previous illustration, the

monitoring team will not measure vernal pool neighborhood area until the monitoring program begins, so the threshold is expressed as a relative rather than absolute value. This approach is more explicitly used in one of the greater sage-grouse threshold statements, which reads as follows:

Habitat connectivity. *No baseline data exist on* ***correlation length*** *for sagebrush patches; thus, estimating this metric during the first year of monitoring will provide a basis for comparisons at Year 5 and beyond. A decline in mean correlation length of more than 10 percent of the baseline value at Year 5 merits closer examination of sagebrush connectivity to understand potential causes for the decline.*

10.2.5 Design the Monitoring Program Using Existing or New Data as Needed

The monitoring team will make decisions about suitable sources of data concurrent with the process of developing monitoring objectives because these steps influence each other, the desired precision and desired minimum detectable change affects the type of data selected, and, conversely, the type of data that are available affects the precision and change detection that is achievable.

We recommend using existing data sources as much as possible to minimize the costs of the monitoring program (chapter 4). Because the original purpose for collecting the existing data might be quite different than the monitoring objectives, however, the monitoring team must carefully evaluate the sampling design and protocols, as well as accuracy, of the existing data to ensure that the data are actually useable for this purpose (chapter 3, section 3.3.2).

In the case example for American martens, we decided to use the national forests' spatial vegetation database for monitoring area of potential habitat. The schedule for updating the map appeared to be compatible with the objectives for monitoring habitat for American martens. We decided to use road density data from the Government Service Center and U.S. Census Bureau (i.e., Topologically Integrated Geographic Encoding and Referencing [known as TIGER] database, http://www.census.gov/geo/www/tiger). The monitoring plan would call for reviewing, editing, and updating the spatial road database to include delineation of closed roads. We found Forest Inventory and Analysis (FIA) program data useful for monitoring snag density, with a sufficient number of plots to be able to detect change over time. For down wood density, however, we discovered that it would be necessary to supplement the FIA data with additional plots.

When evaluating existing data for the greater sage-grouse habitat monitoring program, we found a classified map of sagebrush polygons from 2004 through 2005, as well as a variety of rangeland plot data in the area of interest. Although the existing data cover the entire area of interest for monitoring, none were collected with a sampling design that allowed for inference to other areas, so we recommended using the existing spatial sagebrush database for preliminary mapping only and suggested waiting for the planned

update of the sagebrush database for the actual (hypothetical) monitoring program. For the landscape analysis, the greater sage-grouse example used an existing map of sagebrush canopy cover depicting cover classes, associated land ownership, and patch size that was developed from Landsat satellite imagery and ground-truthed in the mid-1990s. We suggested supplementing this map with spatial databases of fire history, lek sites, fence locations, tilled versus no-till areas, and management activities.

The mole salamander example used three different sets of data for monitoring landscape attributes versus monitoring site-level attributes. The landscape habitat map was created using a combination of expert opinion on mole salamander dispersal capabilities, land cover types from a State vegetation map, and a spatial road database. For the site level, we recommended using the spatial vegetation database from the Example National Forest for estimating canopy cover. Field plots would be needed for obtaining down wood cover, however.

Thus, for all three case examples, most of the habitat attributes will be monitored from maps derived from remotely sensed data that will be periodically updated on a cycle that fits with each habitat monitoring schedule. Attributes that will be field-sampled are (1) down wood density or cover, as part of the habitat monitoring programs for American martens and mole salamanders, and (2) sagebrush canopy cover (to assess accuracy of canopy cover estimates from aerial photography), height and cover of perennial grasses, and bulbous bluegrass (*Poa bulbosa*) cover for the greater sage-grouse example. In the mole salamander example, field sampling will enable biologists to concurrently check for the presence of mole salamanders in vernal pools so that changes in any of the monitored habitat attributes can be evaluated in relation to changes in mole salamander presence.

10.2.6 Plan and Design for New Data Collection as Needed

New data may be needed for a habitat monitoring program for several reasons (chapter 3, section 3.3.3); for example, when—

- The area of interest is fairly small.
- The habitat attributes cannot be derived from existing data.
- The existing data were not derived with an appropriate sampling design.
- The sample size of existing data is inadequate to meet monitoring objectives.

Although collection of new data for a habitat monitoring program may be justified, it is important to provide a good rationale for the expense of collecting these new data to demonstrate that the additional costs are necessary.

In the greater sage-grouse example, we recommended acquiring new satellite imagery to delineate sagebrush patches, because existing data were not collected using random or systematic sampling and therefore may not represent the complete area of interest. Moreover, the shrub canopy cover database is more than 10 years old and does not represent current conditions, especially in light of numerous recent fires. We suggest acquiring recent satellite imagery and low-elevation aerial photography. These remotely sensed data

can also be used to facilitate an understanding of the relationship between metrics that may offer new insight into sage-grouse habitat selection but have not been previously calculated, such as correlation length.

In the examples for American martens and mole salamanders, the only identified need for new data was the collection of field-sampled data for down wood. In the example for American martens, these new data would supplement existing FIA data on down wood. In the mole salamander example, insufficient FIA plots existed in forest stands associated with vernal pools, so all of the down wood data must be collected specifically for mole salamander habitat monitoring.

10.2.7 Create a Habitat Map From an Existing or Modified Model

Wildlife habitat monitoring does not necessarily require a spatial depiction of habitat, although we strongly recommend this approach. A monitoring team can report changes in habitat quantity in tabular form (e.g., snags per acre by existing vegetation type, the size distribution of habitat patches). If habitat attributes are combined in a habitat model, however, the monitoring team will typically display the model outputs as a habitat map (chapter 5, section 5.2.3). Moreover, if the monitoring team is using existing maps such as LANDFIRE or Gap Analysis Program products, the attributes (e.g., existing vegetation type) will usually be derived from the maps themselves (chapter 5, section 5.3.2).

In the example for American martens, we planned to monitor all of the attributes from existing vegetation maps that were already available for the local planning area. The monitoring team will create a habitat map for American martens by classifying the various vegetation types and structural stages into categories of differing habitat quality.

In the greater sage-grouse example, the team will use a combination of existing data from prior vegetation mapping and new data collection. Classification of newly acquired remotely sensed imagery (e.g., Landsat scene, low-elevation aerial photography) will allow for delineation and mapping of sagebrush patches, a portion of which can be sampled to estimate sagebrush canopy cover using line transect methods. No existing habitat model for sage-grouse was suitable for this example; however, the consistent inclusion of specific model variables (e.g., sagebrush canopy cover, grass and forb canopy cover and height) across the suite of models we found guided our selection of attributes for monitoring.

In the mole salamander example, modeled maps provided the basis of the monitoring program at the broad scale (statewide) and midscale (national forest-wide). A spatial analyst will generate a new map for each monitoring period and will use FRAGSTATS (chapter 6) to derive landscape metrics that represent habitat attributes needed by mole salamanders for dispersal and gene flow.

10.2.8 Obtain Baseline Values of Attributes

The first monitoring period will yield baseline values of the selected habitat attributes at each of the selected levels. A monitoring team will generally obtain fine-scale attributes of vegetation composition and structure from existing field-sampled data, through either current FIA or Common Stand Exam (CSE) data or from data collected at new sampling units. In the mole salamander example, baseline values of down wood cover will be obtained from line transects in mature forests associated with vernal pools.

For midscale analyses, a monitoring team will obtain baseline values primarily from current spatial databases. The monitoring plan for American martens will specify obtaining area of specific vegetation type-structural stage combinations from an existing spatial vegetation database. The greater sage-grouse monitoring example describes estimation of values such as area dominated by bulbous bluegrass or percentage of existing sagebrush habitat patches in various canopy cover classes. For mole salamanders, baseline data for the midscale analysis will consist of a map showing all known vernal pools, delineated into pool neighborhoods that are connected by proximity of land-use types that are suitable for mole salamander dispersal. The baseline data will also consist of summary tables of the regional, neighborhood, and stand level habitat attributes such as average pool neighborhood size, an index of pool neighborhood complexity, average dispersal resistance value for each pool neighborhood, and average canopy cover of pool neighborhood forest stands.

10.2.9 Monitor Changes in Selected Attributes Over Time

The essence of monitoring is the ability to obtain new measurements of each attribute at scheduled monitoring periods with sufficient precision to be able to detect a change in attribute value over time. When using existing sources of data, the ability to remeasure is dependent on the remeasurement cycle of the databases used in monitoring. In the American marten example, the ability to recalculate potential area of habitat and to obtain new values for the landscape metrics is entirely dependent on the update schedule for the national forest's spatial vegetation database. We assume that the national forest staff will choose to update the map at or near the end of the current planning cycle, and that this update will be sufficient for evaluating changes in habitat area and landscape pattern over the planning period. The FIA snag density data are on a 10-year remeasurement cycle, which does not correspond to the 15-year planning cycle but is assumed adequate for the monitoring purposes. The greater sage-grouse and mole salamander examples are also dependent on update schedules for spatial data (i.e., the sagebrush base map for greater sage-grouse and road and land cover maps for mole salamanders).

10.2.10 Manage, Store, and Report Results

Each case example provided a general illustration of data storage and reporting. Because all three examples relied heavily on existing data, very little new data needed to be entered into the Forest Service Natural Resource Manager (chapter 9). Each example will, however, produce a habitat map that will be added to the spatial databases for the relevant planning area. In the case of American martens, the habitat map will simply be a reclassification of the current vegetation type and structural stage map into polygons that describe habitat requirements of American martens. For mole salamanders, the map product will be output from a model that is based on mole salamander dispersal capabilities through previously classified land use categories.

The results of all three examples will be reported as part of the local management units' monitoring plans and compared with predetermined threshold values for individual attributes. In the greater sage-grouse example, monitoring results will be compared with a reference landscape to evaluate whether a greater degree of habitat connectivity is achievable in the planning area. Based on the monitoring results, the management practices of each example area can be adjusted, as needed.

10.3 Conclusions

To the extent possible, the three examples we created were as realistic as possible to emulate the process of developing a habitat monitoring program in support of land management planning on national forests and grasslands. We based all three examples on actual LRMPs in which the emphasis species or species group was identified as sensitive, an MIS under the 1982 planning regulations, or both. In addition, we identified data that were currently available to each example planning unit and that could be used for monitoring. The attributes we selected, however, were not the only possible ones. For example, a national forest could choose to use canopy cover for monitoring marten habitat, although our example did not. Therefore, we encourage monitoring teams to evaluate existing sources of data and choose what is appropriate for meeting their monitoring objectives.

In the process of consulting actual management plans and searching for useable data, we encountered challenges and difficulties that a habitat monitoring team might also face. The first major challenge was that the LRMPs we used often did not specify management objectives in sufficient detail to facilitate development of habitat monitoring plans. For example, the national forest from which the mole salamander example was drawn had guidelines for protecting riparian and wetland habitat, but it did not specifically identify objectives or desired conditions related to the management of mature forests adjacent to vernal pools, which are an essential attribute of mole salamander habitat. Also, some planning documents focused exclusively on one segment of the species' life history requirements and therefore did not address other key aspects of the species' habitat requirements that may require specific monitoring.

Second, the amount of information available for developing useful conceptual models varied considerably for the species we selected. The mole salamander group had the least amount of information and only sparse information was available for Jefferson salamanders. In this case, we relied on expert opinion of herpetologists who were conducting research on mole salamanders and vernal pools in the example area. In contrast, the wealth of literature pertaining to American martens made the task of creating a conceptual model more complex. When literature on a species is abundant, each monitoring team may arrive at a different set of attributes for the same emphasis species, depending on local issues and habitat and population stressors. Much published information exists for greater sage-grouse as well, although opinions differ regarding how the species responds to changing habitat conditions. Because of the complexity of the land management issues and potential habitat stressors occurring in the example area for greater sage-grouse, selection of attributes for this species was the most complicated. In this case, more specific management objectives in the planning documents would have clarified our direction.

In spite of these challenges, we arrived at habitat monitoring plans that we believe are realistic for each example area and that illustrate several themes of this technical guide. First, all three examples used literature to create a conceptual model that described the habitat needs and habitat stressors for the emphasis species or group and that served as the framework for the selection of attributes to monitor. Second, all three examples illustrated the process of translating a species' order of habitat selection into relevant spatial scales that could be used in a multiscalar monitoring program (Johnson 1980). Third, the examples demonstrated the various aspects of the planning phase, like setting objectives (including the desired minimum detectable change), specifying the area of inference, stating the desired level of precision (confidence level), and creating a sampling design. Next, the examples created scenarios of data collection with field-sampled and remotely sensed data, and they provided examples of attributes that were either measured (greater sage-grouse) or modeled (mole salamanders). Two of the examples incorporated aspects of human disturbance monitoring—road density for American martens and changes in land use for mole salamanders.

All three examples revealed how monitoring can be designed across multiple spatial scales. Through this illustration, we hope to encourage biologists to expand beyond the traditional emphasis of site-level characteristics, which tend to be the focus of most monitoring and management activities. It is important to ensure that lands, including non-NFS lands, be managed holistically to provide sufficient area and juxtaposition of requisite vegetation types for a species or species group.

These examples also illustrate that a monitoring design can be very simple, such as in the example for American martens in which we were able to use an existing vegetation map and existing FIA data to meet most of the monitoring objectives. On the other hand, a monitoring design can be fairly complex, as in the mole salamander example, requiring

the modeling skills of a spatial analyst. We suggest that biologists use external contractors to meet monitoring objectives when necessary (for example, when agency skills are unavailable).

Finally, we have used these case examples to reiterate the value of using existing sources of data that are periodically updated and that have value for wildlife habitat modeling and monitoring. In addition, close collaboration between forest biologists and research scientists will help leverage existing data so that research results can be integrated into forest-level habitat monitoring (e.g., Saenz et al. 2001; Witt 2009; Zielinski et al. 2006, 2010). Field-sampled data are becoming increasingly available throughout the Forest Service through FIA and CSE (chapter 9). Moreover, the FIA program now offers tools that enable users to specify an area of interest and generate summary statistics from data on any variables that FIA collect. Remotely sensed data offer the ability to not only monitor into the future but to perform retrospective monitoring and analysis through archived data. Using the process steps described in this technical guide and the suite of data that is readily available, it should be possible to monitor wildlife habitat effectively and efficiently so that management can be tailored to sustain wildlife habitats over time.

Case Example

American Martens

Introduction

To develop this example, we began by selecting a national forest in which American martens are a management indicator species (MIS) under the 1982 National Forest Management Act (NFMA) planning rule, which, at the time of publication, was the rule under which most land and resource management plans (LRMPs) were written. We used the Example National Forest's current LRMP to identify goals and objectives that would motivate the need or desire to design a habitat monitoring plan for this species, and we proceeded as if we were a habitat monitoring team that had been charged to design and implement the monitoring program. Ideally, the habitat monitoring team that would be created for this purpose would consist of the forest and/or district biologists, a silviculturist, a State furbearer or nongame biologist, the forest planner, and a statistician.

Goals of Habitat Monitoring

The following broad goals for monitoring habitat of American martens are based on laws and agency policy (chapter 1, table 1.1).

- Provide information on habitats needed to maintain well-distributed populations of American martens within each planning area to meet the viability requirement under the 1982 rule for implementing the NFMA.
- Determine the degree to which management is maintaining or making progress toward the LRMP's desired conditions and objectives relevant to habitat of American martens.
- Avoid Federal listing of American martens under the Endangered Species Act.
- Provide information for environmental analysis of the potential effects of proposed projects on habitat of American martens, as required under the National Environmental Policy Act.
- Work cooperatively with States in the conservation of American martens and their habitats (as described in the Sikes Act).

In addition, the following specific goals related to the LRMP used for this example could be achieved in part through monitoring of the habitat of American martens.

- Provide data for enabling an evaluation of the coarse filter and fine filter approach for the conservation of biological diversity.
- Evaluate the effectiveness of implementation of the LRMP.
- Monitor to identify needs for possible amendments to the LRMP and other changes in management practices.
- Monitor changing conditions in key areas for American martens to determine if desired conditions are being achieved.

Rationale for Selection as Emphasis Species for Habitat Monitoring

American martens are closely associated with mature and old-growth forests across their range and have experienced population reductions as a result of silvicultural modifications of their habitat and overexploitation of populations through trapping (Buskirk and Powell 1994, Buskirk and Ruggiero 1994). As a result, four regions of the Forest Service have identified the American marten as a sensitive species, a formal management designation of the Forest Service (Forest Service Manual) 2670.32, USDA Forest Service 2005a). An even greater number of national forests have selected American martens as an MIS for the development of their LRMPs under the 1982 planning rule because of the close association of martens with specific vegetation types. American martens were listed as a species of greatest conservation need in comprehensive wildlife conservation strategies (wildlife action plans) for 14 States[3] (http://teaming.com/state-wildlife-action-plans-swaps).

In the planning area for this hypothetical monitoring program, American martens are an MIS and on the Regional Forester's Sensitive Species list. American martens are an appropriate emphasis species for habitat monitoring, given that they are closely associated with mature and old-growth forests and require structural features such as snags and down wood for denning, resting, and foraging (Buskirk and Powell 1994, Buskirk and Ruggiero 1994). Moreover, American martens appear to be highly sensitive to forest fragmentation, requiring a landscape pattern dominated by forest interior rather than one that provides small isolated patches of forest. A vegetation monitoring program that tracks only area of vegetation types would be insufficient for measuring the amount and quality of habitat for American martens because it would not address the fine-scale structure and broad-scale landscape configuration required by American martens. A monitoring program specifically designed to assess habitat for American martens would target these additional attributes to ensure that (1) the preferred vegetation types contain sufficient logs and snags and that (2) the stands are sufficiently large to function as habitat. By monitoring habitat for American martens, we also ensure that the local planning unit is maintaining habitat of other species associated with mature and old-growth forests, thereby increasing monitoring efficiency.

Conceptual Model for American Martens

Existing Wildlife Habitat Relationships Models

We identified 20 wildlife habitat relationships models for American martens in North America that were developed from 1982 through 2008 (table 10.2). The frameworks used to develop the models included Habitat Suitability Index (40 percent), rule-based (35 percent), habitat matrix (20 percent), and Bayesian Belief Network (5 percent). These models included more than 20 variables; predominant

[3] Alaska, California, Maryland, Michigan, Nevada, New Hampshire, New Mexico, New York, Oregon, Utah, Vermont, Washington, Wisconsin, and Wyoming.

were land cover (75 percent of the models), canopy closure (45 percent), and stand age (45 percent). In general, earlier models were not spatially explicit, included primarily variables for which data were collected during field surveys (e.g., down wood), and were designed to be applied at the stand level. Contemporary models were generally designed to be spatially explicit, included primarily variables for which data are available from remote sensing, included landscape metrics (e.g., number of patches, patch size), and were applied at watershed and broader scales. When habitat relationships described by these models differed across regions, we used those in proximity to the planning area. We also recommend using local presence and absence data, if it is available, to link conceptual and empirical models in model validation.

Orders of Habitat Selection

American martens select habitats at multiple levels, including home range, site, and microhabitat (Baldwin and Bender 2008, Bissonette et al. 1997, Potvin et al. 2000, Slauson et al. 2007). For monitoring, we identified two spatial extents that were relevant to habitat selection by American martens—the landscape (a few hundred acres), which represents the level at which American martens establish home ranges, and the site (fewer than 150 acres [ac]), which represents the level at which American martens select habitat for foraging and denning.

Habitat Requirements

Landscape. American martens are strongly associated with late successional forests of a variety of vegetation types, as long as the forests contain sufficient vertical diversity and structure. In the Western United States, they occur in lodgepole pine (*Pinus contorta*) and red fir (*Abies magnifica*) (Spencer et al. 1983), Douglas-fir (*Pseudotsuga menziesii*), redwood (*Sequoia sempervirens*), and white fir (*Abies concolor*) (Slauson et al. (2007), and mature Englemann spruce—subalpine fir (*Picea engelmannii—Abies lasiocarpa*) (Koehler et al. (1990). Poole et al. (2004) found that although American martens preferentially used mature coniferous forests in boreal forests of northeast British Columbia, however, they apparently used all forested stands relative to their availability, including extensive deciduous and mixed coniferous and deciduous stands less than 40 years of age. In western Alberta, Proulx (2006) indicated that American martens used young forests and mature and old coniferous and deciduous forests according to their availability, but preferred mature and old mixed coniferous and deciduous stands. American martens in the Great Lakes Region primarily selected deciduous forests (i.e., mature, upland hardwoods) (Dumyahn et al. 2007, Gilbert et al. 1997, Wright 1999).

American martens have been reported to prefer riparian areas (Anthony et al. 2003, Buskirk et al. 1989, Martin 1987) and sites close to water (Bull et al. 2005, Hargis and McCullough 1984, Simon 1980, Spencer et al. 1983). Prey availability is likely higher in riparian settings than elsewhere, either because prey densities are higher (Doyle 1990, Geier and Best 1980, Getz 1968, Gomez and Anthony 1998) or because structural features in riparian areas, including down wood, provide additional foraging substrates.

Regardless of the vegetation type, the primary landscape requirement is sufficiently large areas of mature forest for establishing home ranges. Although American martens may use edges adjacent to late-successional forest, forest edge in general increases risk from avian predators (Drew 1995) and provides less thermal cover during winter (Buskirk and Powell 1994, Buskirk et al. 1989). During winter, American martens rarely cross large, open areas (Hargis and McCullough 1984), such that home range quality decreases with an increase in open areas. Several studies reported that American martens rarely established home ranges in landscapes containing more than 25 to 30 percent in openings (Chapin et al. 1998, Hargis et al. 1999, Potvin et al. 2000).

Site. American martens require a high degree of horizontal and vertical structure for nearly all aspects of their life history at the site level, and this requirement is thought to be the primary driver leading to their close association with late-successional forests (Buskirk and Powell 1994). When American martens were found in sites other than late-successional forests, elements of horizontal and vertical structure were present. For example, Chapin et al. (1997) found American martens using forested stands infested with spruce budworm (*Choristoneura fumiferana*), despite the loss of the mature overstory. In these stands, a regenerating understory of deciduous and coniferous vegetation, an abundance of snags, and a high volume of fallen dead trees and root mounds provided vertical and horizontal structure. American martens also used blow-downs and old burn sites when fallen trees provided abundant horizontal structure.

The primary components of forest structure that are important to American martens are multiple tree canopy layers (including tall trees), snags, and down wood. Tree height was reported by Katnik (1992) and Payer and Harrison (2003) to be the most important variable for discriminating between areas that were used versus unused by American martens. Tall trees provide elevated resting sites, which are important to American martens during warm weather (Bull and Heater 2000, Buskirk 1984, Raphael and Jones 1997). Trees probably also provide escape cover from mammalian predators such as fisher (*Martes pennanti*), coyotes (*Canis latrans*), and red foxes (*Vulpes vulpes*) (Hodgman et al. 1997, Payer 1999).

Snags provide resting sites, escape cover, and den sites. In all geographic areas and vegetation types reported, snags used by American martens were always larger in diameter relative to available snags (Bull and Heater 2000, Martin and Barrett 1991, Ruggiero et al. 1998, Spencer 1987). Large-diameter snags are more likely to have sufficiently large cavities in decayed heartwood to provide denning and shelter (Gilbert et al. 1997, Martin and Barrett 1991, Payer and Harrison 1999, Ruggiero et al. 1998).

Down wood is likely the most critical component of habitat for American martens, because without it, they cannot efficiently obtain prey. Voles (*Clethrionomys* spp.), a primary food item for American martens (Buskirk and Ruggiero 1994), use down wood for runways and nest sites (Nordyke and Buskirk 1991, Tallmon and Mills 1994). The primary foraging strategy used by American martens is to search around down wood for voles and other mammals. In the winter, down wood branches and boles provide American martens with access to the subnivean zone, the layer of air between the ground and snowpack in which small mammals move during the winter (Corn and Raphael 1992).

In addition to vertical and horizontal structure, American martens are associated with closed-canopy forests throughout their geographic range (Bateman 1986, Koehler and Hornocker 1977, Soutiere 1979, Spencer et al. 1983), (i.e., American martens require overstory canopy closure greater than 30 percent but prefer canopy closure greater 50 percent [Allen 1982, Thompson and Harestad 1994). This degree of canopy closure provides American martens with escape cover and complex horizontal and vertical structure. Adequate overhead canopy closure may be critical to American martens to decrease risk of predation from avian predators and fishers (Buskirk and Ruggiero 1994, Drew 1995, Fuller and Harrison 2005, Hargis and McCullough 1984, Hodgman et al. 1997).

Habitat Stressors

Landscape. The primary broad-scale stressors to habitat for American martens are activities and processes that create large open areas lacking horizontal and vertical structure (e.g., clearcuts, large wildfires, ski runs, highways). These stressors reduce the quality of home ranges by interjecting patches of nonhabitat within home ranges. Open areas increase risk to American martens from avian predators (Buskirk and Ruggiero 1994, Drew 1995, Fuller and Harrison 2005, Hargis and McCullough 1984, Hodgman et al. 1997). Hargis et al. (1999) reported very little use of landscapes having more than 25 percent in open areas (e.g., meadows, clearcuts). American martens are sensitive to the effects of habitat fragmentation; population declines have been reported in areas in which clearcutting occurred (Snyder and Bissonette 1987, Soutiere 1979, Thompson and Harestad 1994). American martens may respond positively to creation of a limited amount of openings, however, because they have been reported to forage in clearcuts containing structure in the form of regenerating deciduous or coniferous vegetation during summer (Katnik 1992, Steventon and Major 1982) and along forest–meadow edges (Simon 1980, Spencer et al. 1983). This initial positive response rapidly becomes negative, however, as the amount of open area increases within a landscape.

Roads are an additional stressor because they increase mortality of American martens through vehicle collisions as well as contribute to habitat fragmentation and increased trapping pressure. Robitaille and Aubry (2000) noted that use of habitats by American martens increased as distance from roads increased, presumably to avoid traffic. Alexander and Waters (2000) also observed an avoidance of areas less than 50 meters (m) (55 yards) from roads. American martens are harvested for fur in the State in which the selected planning area is located, and many trappers use roads to gain access to their trap lines. Expanding road networks for forest management can increase trapper access in remote areas (Soukkala 1983, Thompson 1988) and may accelerate declines in populations of American martens (Hodgman et al. 1994). Thompson (1994) reported that trapping mortality rates were higher in logged forests (with road development) than in uncut forests.

An additional stressor of habitat for American martens may be climate change. Predicted increases in temperature could mean that American martens would not find the climate envelope of their current habitats anywhere in the contiguous United States by the end of the current century (Lawler et al. 2012). Future precipitation is more difficult to model accurately than temperature, and therefore the projected effects of changes in precipitation on habitat of American martens are highly variable.

Precipitation is expected to increase over much of the current range of American martens, which would favor the forest structure that is characteristic of marten habitat (Lawler et al. 2012). Areas in which precipitation is expected to decrease (e.g., the Sierra Nevada of California), however, the drier moisture regime could result in loss of habitat of American martens because of an increase in the frequency of large wildfires (Westerling et al. 2006), followed by conversion to drier woodlands (Miller and Urban 1999) that are not suitable for martens. Cushman et al. (2011) modeled the interactions of fire management, vegetation management, and climate at a watershed scale and concluded that climate variables had a greater potential effect on habitat capability for American martens than either active fire management or vegetation management.

Site. The primary stressors to habitat for American martens at the site level are activities that reduce the abundance of snags and large-diameter down wood below a threshold (currently unknown) in which potential denning and resting sites become rare or unavailable. Activities include all forms of timber harvest if the harvest method results in total removal or severe loss of snags and down wood or excessive reduction in canopy cover. In addition, excessive removal of down wood by firewood cutters can reduce habitat quality at the site level.

Conceptualized Effects of Stressors on Habitat of American Martens

The habitat requirements and stressors described previously led to the following conceptual model of how habitat for American martens might be altered over time (figure 10.2). The combination of natural disturbances, climate change, silvicultural practices, and increased development and use of roads could affect habitat for American martens by—

- Reducing the amount of habitat.
- Reducing the size of habitat patches.
- Increasing the distance between late seral patches.
- Increasing the amount of habitat edge.
- Increasing levels of human disturbance.
- Increasing trapping pressure.
- Reducing the availability of denning and resting sites.

Habitat Attributes Derived From the Conceptual Model

From this conceptual model, we identified six landscape attributes and two site attributes that would be important to monitor to ensure that habitat of American martens is maintained on this national forest. We then evaluated these attributes in terms of their relationship to forest plan management objectives, and whether the attributes would demonstrate a response to management actions (table 10.3). From this evaluation, we selected the following four landscape attributes and two site attributes for monitoring.

Landscape

- Vegetation type and structural stage combination.
- Large patches of contiguous habitat.
- Habitat connectivity.
- Secondary roads.

Site

- Down wood.
- Snags.

Our next step was to translate the habitat attributes into measurable metrics (table 10.4). We selected two metrics to represent habitat connectivity, resulting in seven metrics altogether—five associated with landscapes and two associated with sites. Each of the following attributes will be monitored independently (i.e., not as variables within a wildlife-habitat–relationships model) throughout the extent of vegetation type and structural stage combinations that serve as potential habitat for American martens.

Table 10.3.—*Evaluation of habitat attributes and disturbance agents identified from the conceptual habitat model for American martens (*Martes americana*).*

Habitat attribute or disturbance agent	Management objective that relates to this attribute	Is the attribute or disturbance agent responsive to management?	Attribute selected
Landscape			
Vegetation type and structural stage combination[a] Late	Maintain 10 percent of each vegetation type in the mature and late-seral structural stage classes	Yes	Yes
Proximity to riparian	No specific management objective	No	No
Large patches of contiguous habitat	Provide large, contiguous, well-distributed blocks of habitat	Yes	Yes
Habitat connectivity	Avoid activities that fragment or alter interior late-succession or old-growth forest characteristics	Yes	Yes
Roads, paved	No specific management objective	Yes	No
Roads, secondary	No specific management objective	Yes	Yes
Site			
Tree height	No specific management objective	No	No
Canopy cover	No specific management objective 12-in diameter	Yes	No
Down wood	Maintain > 1 log/ac > 12-in diameter in late seral of each vegetation type[a]	Yes	Yes
Snags	Maintain > 1.5 snags/ac > 10-in DBH in all three vegetation types	Yes	Yes

ac = acre. DBH = diameter at breast height. in = inch.

[a] This attribute includes three vegetation types: spruce-fir (dominated by Engelmann spruce), subalpine fir, and cool-moist mixed-conifer forest (dominated by white fir and Douglas-fir).

Landscape

- Percentage of each vegetation type in the mature and late-seral structural stage classes.
- Median patch size for each vegetation type and structural stage class identified as habitat for American martens.
- Distance and connectivity between patches of habitat.
- Percentage of each midsized watershed (40,000 to 250,000 ac) that is in a nonforest vegetation or cover type.
- Density of secondary roads open to vehicular travel.

Site

- Density of down wood larger than 12-inch (in) diameter at breast height (DBH).
- Density of snags larger than 10-in DBH.

Table 10.4.—*Metrics used to measure selected habitat attributes for American martens (*Martes americana*) in the Example National Forest.*

Habitat attribute	Metric	FRAGSTATS metric[a]	Classes and thresholds	Sources for classes
Landscape				
Vegetation type and structural stage combination	Total acres of each vegetation type/ structural stage combination for highest two structural stage classes	PLAND	Three vegetation types and five structural stage classes	Forest Service regional classification system of forest structural stages
Large patches of contiguous habitat	Area-weighted mean patch size of vegetation; type/structural stage polygons identified as habitat for American martens	AREA_AM	Low: < 15 ha (37 ac) Moderate: 15–100 ha (37–247 ac) High: > 100 ha[b]	Chapin et al. (1998), Potvin et al. (2000), Snyder and Bissonette (1987)
Habitat connectivity	Percentage of each midsize watershed in nonforest vegetation or land cover	PLAND	Low: 0.0–10.0 percent Moderate: 10.1–30.0 percent High: > 30 percent[b]	Chapin et al. (1998), Hargis et al.(1999), Potvin et al. (2000)
Habitat connectivity	Amount of connectedness between habitat patches	GYRATE_AM	No classes identified	
Roads, secondary	Road density (mi/mi^2 of open roads) by midsize watershed[c]	NA	2 mi/mi^2 [b]	Forest plan guidelines
Site				
Down wood	No./ac per DBH class within each vegetation type/structural stage combination	NA	1 log/ac > 12-in DBH[d]	Forest plan guidelines
Snags	No./ac per DBH class within each vegetation type/structural stage combination	NA	1.5 snags/ac > 10-in DBH[d]	Forest plan guidelines

ac = acre. DBH = diameter at breast height. ha = hectare. in = inch. mi = mile. NA = not available. No. = number.

[a] Acronyms are the metrics calculated by FRAGSTATS (see chapter 6).

[b] Threshold—exceeding this value triggers an evaluation of management practices on the reporting unit.

[c] Watersheds (Seaber et al. 1987) provide a systematic means of identifying and subdividing river-basin units. Midsized watersheds range in size from 40,000 to 250,000 ac.

[d] Threshold; falling below this value triggers an evaluation of management practices on the reporting unit.

Management Objectives for American Martens and Late-Seral Forests

To ensure that our monitoring measures and objectives were related to management objectives, we consulted the forest plan for all management objectives pertaining to late-seral forests and American martens and found the following listed under forestwide objectives:

- Over a 10-year period, determine if harvest of 500 ac of spruce-fir forest and 1,200 ac of cool-moist mixed-conifer forest has produced stands of uneven size and age class trees within the spruce-fir and cool-moist mixed-conifer types to perpetuate effective habitat for American martens over time.
- Avoid activities that fragment or alter interior late-succession or old-growth forest characteristics, or could increase edge effects (e.g., timber harvest, salvage logging, fuels treatments, and road construction) unless these activities have either a short- or long-term benefit to American martens.
- Design timber removal to support sustainable populations of American martens.
- Maintain habitat effectiveness for American martens by providing large, contiguous, well-distributed blocks or smaller, closely interconnected patches of late-succession and old-growth spruce-fir habitat (including minimization of edge effects).
- Maintain connectivity among habitat blocks with closed-canopy corridors to facilitate dispersal and population interaction of American martens.
- Maintain a complex vegetation understory and forest floor structure, including coarse woody material, to facilitate reproductive success in American martens and to maximize the microtine and pine squirrel (*Tamiasciurus* spp.) prey base.

Habitat Attributes Derived From Management Objectives

After evaluating the forestwide objectives, we concluded that the seven metrics we selected from the conceptual model were closely aligned with metrics that could have been derived from the management objectives. The management objectives focused on habitat attributes that we identified for landscapes (e.g., interconnected patches of late-succession and old-growth spruce-fir) as well as for sites (e.g., coarse woody material). Additional attributes mentioned in the management objectives included canopy cover and understory vegetation. Canopy cover was one of the initial habitat attributes derived from the conceptual model, but we eliminated it from our final list because the national forest did not have reliable canopy cover information. Understory vegetation is a habitat attribute that we did not identify from the conceptual model, but we chose not to add it to the final list because it would substantially increase monitoring costs with little value added.

Other choices exist for habitat attributes to monitor for American martens. We selected these attributes based on our review and evaluation of models for American martens, but also on forest plan objectives, data availability, cost, and efficiency considerations.

Monitoring Objectives

Landscape

The LRMP identified desired conditions for specific cover types, landscape pattern, and road densities that suggested the following three monitoring objectives for landscapes.

1. Monitor changes in the amount of mature and late-seral structural stages of the following three vegetation types: (1) spruce-fir, dominated by Engelmann spruce; (2) subalpine fir; and (3) cool-moist mixed-conifer forest, dominated by white fir and Douglas-fir. The spatial extent to be monitored is all areas of the national forest in which these three vegetation types currently occur, regardless of their current structural stage. The minimum detectable change that we want to be able to observe is a 20-percent change in amount of habitat, if one occurs, over the 15-year planning cycle, using one monitoring period at the beginning and one at the end of the planning cycle. To ensure that the magnitude of habitat loss does not approach critical levels (e.g., 60 percent [Rompré et al. 2010]) before appropriate changes in management can be made, 20 percent will also serve as the threshold. We currently do not know what degree of habitat reduction would affect population viability of American martens, so for the current planning cycle, we will use a 20-percent reduction in mature and late-seral structural stages as the threshold that would trigger a change in management.
2. Monitor changes in landscape pattern of the habitat of American martens, using median patch size, patch connectivity and the percentage of each midscale watershed in nonforest vegetation or cover types. The spatial extent is the same as that defined for monitoring objective 1. Two monitoring periods will exist—one at the beginning and one at the end of the 15-year planning cycle. We will set our minimum detectable change at 10 percent for median patch size, 20 percent for change in patch connectivity, and 10 percent for change in the percent of midscale watershed in nonforest vegetation or land use types. These levels of detectable change are believed to be adequate to ensure that if negative changes in habitat quality or amount occur, management practices can be altered before populations of American martens decline or are extirpated. We anticipate that for patch connectivity, we will be able to detect only a 20-percent change at best, because this metric is calculated from three values and hence, the error could also be compounded. For threshold values, we consulted the published literature and found that Potvin et al. (2000) recommended that uncut forest patches be greater than 100 hectares (247 ac) to maximize core area and to minimize edge for American martens. We currently do not know if our median patch size is near 247 ac, but we will use 247 ac as a target value for which we will compare our actual value after 1 year of baseline data and set a threshold value based on what appears to be achievable in the planning area. For the percentage of landscape in nonforest vegetation or land use types, we will set a minimum threshold of 30 percent, using the tolerance to open areas reported in Chapin et al. (1998), Hargis et al. (1999), and Potvin et al. (2000).
3. Monitor changes in density of secondary roads that are open to vehicular use. The spatial extent will be the entire national forest, but we will also estimate road density in the three vegetation types identified as potential habitat for American martens to compare changes in road density

across the entire national forest with changes that occur in habitat for American martens. We will use 10 percent as the minimum detectable change in road density within habitat for American martens over the 15-year planning cycle, using one monitoring period at the beginning and one at the end of the planning cycle. The LRMP identifies 2 miles (mi) of roads/mi^2 as a high road density for secondary roads, and we will use this threshold as a maximum for road densities in any midsize watershed containing habitat for American martens. Densities above this value would trigger a need to reduce road densities within the affected watersheds.

Site

The LRMP identified two guidelines that motivated the following two monitoring objectives at the site level.

1. Monitor changes in density of snags larger than 10-in DBH within all combinations of the three vegetation types and mature and late-seral structural stages identified as potential habitat for American martens. The spatial extent is all areas of the national forest in which these three vegetation types currently occur, regardless of their current structural stage. We will use 10 percent as the minimum detectable change in snag density over the 15-year planning cycle, but because we plan to use Forest Inventory and Analysis (FIA) program data, we will need to conduct a power analysis to estimate the additional number of plots needed to observe this amount of change. FIA data are collected every 10 years, so we will need to compare snag densities between the two FIA monitoring years that most closely fit the current 15-year planning cycle. The forest plan guidelines call for a minimum of 1.5 snags/ac that are larger than 10-in DBH, so we will use this value as a threshold. If monitoring indicates that snag density has dropped below this value, we will recommend a change in management.
2. Monitor changes in density of down wood larger than 12-in DBH within all vegetation type and structural stage classes identified as potential habitat for American martens. The spatial extent for monitoring is all areas of the national forest in which these three vegetation types currently occur, regardless of their current structural stage. At a minimum, we want to be able to detect a 10-percent change in down wood density over the 15-year planning cycle, but because we plan to use FIA data, we will need to conduct a power analysis to estimate the additional number of plots needed to observe this amount of change. FIA data are collected every 10 years, so we will compare down wood densities between the two FIA monitoring years that most closely fit the current 15-year planning cycle. The forest plan guidelines call for at least 1 log/ac larger than 12-in DBH, so we will use this value as a threshold, and if monitoring indicates that down wood density has dropped below this value, we will recommend a change in management.

It should be noted that monitoring changes in density of snags and down wood will add to our ability to manage these attributes for American martens, but the degree of change may not represent degree of change in habitat for American martens as a whole.

Evaluation of Existing Data Sources

Field-Sampled Data

We searched through the Natural Resource Manager (NRM) to find vegetation data on the national forest that were fairly current and ongoing. We found FIA data for the forested areas of the national forest and several datasets associated with past inventory activities. The data we located included—

- Vegetation data collected under the FSVeg protocol.
- Goshawk nest survey data.
- Ground-truthing plots for the forest vegetation layer that is in the national forest's Geographic Information System (GIS).
- FIA phase 2 (P2) and phase 3 (P3) plot data.

Other than the FIA data, these datasets did not cover the entire area of interest and were collected once only for a specific purpose. We evaluated the FIA data for their potential to provide information on snag and down wood density in our example area. The national forest has approximately 740,000 ac of potential habitat for American martens with 125 P2 plots and eight P3 plots. All living and dead trees are measured on the 125 P2 plots, so our hypothetical power analysis indicates we will be able to derive estimates of snag density from this sample. Down wood measurements are made only on the P3 plots, however, and eight plots do not provide an adequate sample for estimating change in down wood density over time. Based on our hypothetical power analysis, we will use the eight P3 plots and augment them with 22 additional plots that are randomly selected from all available stands of potential habitat for American martens, to create a sample size of 30 plots for estimating down wood density. The sampling frequency of FIA plots is 10 years and the P2 and P3 plots were measured 2 years before the plan was completed. Therefore, we will use that sampling period and compare it with the sampling that will take place 8 years after plan completion.

Remotely Sensed Data

The national forest has an existing vegetation data file for the entire national forest developed from Landsat7 imagery that is at 30-m (98-foot) resolution. Each polygon represents an existing vegetation type and structural stage, using the regional structural stage classification system. The data file is updated as necessary when management activities and natural processes occur and as new information becomes available.

As addressed in chapter 3, it is important to assess the accuracy of spatial data to determine whether it is possible to detect a stated minimum amount of change with a desired amount of precision to achieve the monitoring objective. We are fortunate to have ground-truthing data that has already been collected for the vegetation data, so we will estimate the error rate of the existing vegetation data before using it, and adjust our minimum detectable change and desired precision if the mapping accuracy is too low to achieve our initial targets. The national forest has digital data of roads and trails for the planning area from the Census Bureau's Topologically Integrated Geographic Encoding and

Referencing (known as TIGER) database that they have subsequently reviewed, edited, and updated (including delineation of closed roads). These files are sufficient for monitoring road densities over time because the national forest plans to keep them updated.

Summary of the Evaluation of Existing Data

As summarized below, we determined that the selected attributes could mostly be measured using existing data sources. Update schedules for all data sources were considered adequate to meet the monitoring objectives.

Landscape

- ***Vegetation type and structural stage combination.*** We will calculate acres from the existing vegetation database.
- ***Large patches of contiguous habitat and habitat connectivity.*** We will calculate the three metrics from the existing vegetation database using FRAGSTATS (McGarigal et al. 2012; see chapter 6).
- ***Secondary roads.*** We will calculate miles of road per square mile of potential habitat for American martens from the current national forest roads database.

Site

- ***Down wood.*** We will use the eight existing FIA P3 plots and supplement with new data.
- ***Snags.*** We will calculate density from FIA P2 plots.

Planning for New Data Collection

Landscape

Although we are using an existing vegetation database from the national forest, the need to calculate landscape pattern metrics constitutes new data collection. The landscape metrics will be derived in a GIS, so we will not need to generate a random sample for estimating metric values. We will use midsize watersheds as units for reporting each of the landscape metrics to better understand the variance in habitat quantity and quality for American martens among watersheds. Using the midsize watershed will enable us to identify specific watersheds that have not met threshold values and target them for management actions. Moreover, a spatial extent or boundary must be selected for calculating percentage of open areas, and the midsize watershed provides a useful scale for this calculation.

Site

We will not need to collect new data for snag density because it will be obtained from FIA P2 plots. In essence, we are adopting the FIA sampling design of one plot per 6,000-ac hexagon. The down wood data collection will combine the FIA sampling design with a random selection of 22 midsized watersheds within the planning unit that contain potential habitat for American martens. We will use a stratified (by watershed) random sample as a way of ensuring the data are representative of the area of interest.

Estimating Baseline Values of Attributes

We will begin by creating a map of potential habitat for American martens for the entire national forest showing all areas that meet the vegetation type and structural stage combinations. We will then generate baseline values for each of the four landscape attributes and the two site attributes, as follows.

Landscape

- ***Percentage of each vegetation type in the mature and late-seral structural stages classes.*** We will calculate this percentage from the baseline area values that we derived from GIS.
- ***Median patch size for each vegetation type and structural stage class identified as habitat for American martens.*** We will use a metric called AREA in FRAGSTATS (McGarigal et al. 2012) to calculate the area of each patch, and then derive the median value for each watershed as well as an overall median value for each vegetation type and structural stage combination.
- ***Connectivity between patches of habitat.*** We will use a metric called GYRATE-AM, which is the area-weighted mean radius of gyration across all patches in the class or landscape (AM is the acronym for area-weighted mean) (McGarigal et al. 2012). Values range from zero to infinity and become meaningful in a comparative sense (e.g., when comparing values calculated from maps of similar extent and resolution, or when comparing values calculated over sequential time periods). Higher values of GYRATE-AM represent higher degrees of connectivity within a class of patches.
- ***Percentage of each midscale watershed that is in nonforest vegetation or land use type.*** We will use a metric called PLAND in FRAGSTATS (McGarigal et al. 2012). This metric calculates the proportion of a map in each type of patch, and we will use midsize watersheds as the area in which to calculate these proportions. We will then calculate the mean proportion of nonforest land cover across all watersheds.
- ***Density of secondary roads open to vehicular travel.*** We will calculate the total miles of roads per square mile for the entire national forest and for each of the vegetation type and structural stage combinations that comprise habitat for American martens.

Site

- ***Density of down wood larger than 12-in DBH.*** We will combine data from 8 FIA P3 plots with 22 random plots stratified by midsize watershed. For the new data, we will use the same sampling protocol as is used at FIA P3 plots, which is the FIA Field Methods for Phase 3 Measurements (http://fia.fs.fed.us/library/field-guides-methods-proc). This process will enable us to easily combine the existing data with our new data.
- ***Density of snags larger than 10-in DBH.*** We will obtain baseline values from 125 FIA P2 plots in the three vegetation types identified as potential Habitat for American martens. We will use tools available under FIA tools at http://fia.fs.fed.us/tools-data/default.asp.

Monitoring Changes in Selected Attributes Over Time

At the end of the 15-year planning cycle, we assume that the national forest will have updated its existing vegetation map and roads database, and we will use these products to generate another forestwide habitat map for American martens. We will then calculate a new set of values for each of the four landscape metrics and two site metrics, and we will compare these with the baseline values. For landscape metrics, we will use mean and median values from all midsize watersheds to identify watersheds that may warrant changes in management. For the site-associated metrics, the sample size may be insufficient to detect changes on a watershed basis, but we can use overall means and standard deviations to determine whether forestwide changes are significant.

It will be important to establish and document clear definitions and rule sets for what forest areas are considered in the mature and late-seral structural stages so that changes in habitat are not because of changes in definition. The monitoring team will also need to establish a rule set for what defines a "patch" so that the same criteria would be used for the next monitoring period.

Data Storage and Reporting

The local management unit will be the repository of all data collected for this monitoring program. The habitat map for American martens for each sampling period will be incorporated into the national forest GIS database. The new data on down wood will be stored in NRM FSVeg. The baseline values of all metrics will be stored as tabular data in the national forest's repository for land management planning data.

We assume that this monitoring will be conducted in support of the land management plan, so results of the baseline data collection will be reported at the first 5-year monitoring period and at the end of the 15-year planning cycle. If the national forest updates their vegetation and road layers at 5-year intervals, we will be able to offer the national forest more frequent assessments of any changes in quality or quantity of habitat for American martens so that changes in management, if needed, can occur more quickly.

Case Example

Greater Sage-Grouse

Introduction

We developed our example monitoring plan for greater sage-grouse in an administrative unit of about 47,000 acres (ac) of National Forest System (NFS) lands that occur within a larger boundary (74,000 ac) of intermixed private and other public lands; we refer to this larger extent as our analysis area. Our analysis area in turn occupies about 10 percent of a valley of mixed land ownerships, including substantial acreage managed by the Bureau of Land Management (BLM). Because this broader land base is considered regionally important in sage-grouse management, the entire valley is a logical reference framework for our analysis (see "Estimate Baseline Values of Attributes" and chapter 6, section 6.3.3). This larger area was also used by the Forest Service as context for determination of proper functioning condition for vegetation in the administrative unit. Greater sage-grouse occur throughout our analysis area, and habitat conditions on intermixed, non-NFS lands are of interest, as are conditions on federally managed lands.

The habitat monitoring team assigned to develop a monitoring program for greater sage-grouse should include a wildlife biologist, planning specialist, and range ecologist, and involve cooperators such as other Federal and State upland game bird biologists.

Goals of Habitat Monitoring

We identified three sources of goals for monitoring habitats of greater sage-grouse. The first is current agency laws, rules, and policies (chapter 1, table 1.1); these goals resemble those presented in the case example for American martens. The second is specific business requirements related to the land and resource management plan (LRMP) addressed in this example, including—

- Evaluating the effectiveness of implementation of the LRMP.
- Tracking conditions in key sagebrush areas, such as nesting habitat, to determine whether they are moving toward desired conditions for greater sage-grouse and its habitat, especially in relation to restoration activities for sage-grouse.

The third source of goals is a publication focused on habitat and population monitoring for sage-grouse (Connelly et al. 2003). These goals generally fall within one of the following four categories.

1. Documenting current habitat condition and trend.
2. Evaluating impacts of land management.
3. Assessing the success of habitat restoration projects.
4. Evaluating habitat capacity for supporting a transplanted population.

Of these categories, the first three apply to our example monitoring area.

Rationale for Selection as Emphasis Species for Habitat Monitoring

The greater sage-grouse has long been considered synonymous with the sagebrush ecosystem (Paige and Ritter 1999, Patterson 1952, Schroeder et al. 1999). Recent declines in quality and quantity of this ecosystem (Knick 1999, Knick and Connelly 2011, Wisdom et al. 2005) have been paralleled by declines in sage-grouse populations (Connelly and Braun 1997; Knick and Connelly 2011; Schroeder et al. 1999, 2004). In response to these declines, multiple petitions have been submitted to the U.S. Fish and Wildlife Service (USFWS) to list the species as endangered across its range (USDI USFWS 2005, 2008). The USFWS determined that listing the species is warranted, but precluded because of higher priority listings (USDI USFWS 2010). Population declines in this species vary regionally, but ultimately are related to loss of suitable sagebrush habitat because of stressors such as invasive plants, altered fire regimes, and invasion of woodlands into sagebrush ecosystems (Knick and Connelly 2011). Greater sage-grouse is a sensitive species on many national forests and at least one national grassland in the five western regions (Alaska, Pacific Northwest, Pacific Southwest, Rocky Mountain, and Southwestern) of the Forest Service. It is also considered a management indicator species on several national forests and grasslands in these same regions, including our example planning area. Similarly, the BLM ranks it as a sensitive species at State and district levels, and it is designated as a species of greatest conservation need in many State wildlife action plans (http://teaming.com/state-wildlife-action-plans-swaps.). Through the umbrella of the Western Association of Fish and Wildlife Agencies, greater sage-grouse habitat is a primary focus of several State-level local working groups (Stiver et al. 2006).

Greater sage-grouse is ranked as vulnerable to apparently secure globally (G3G4) and nationally (N3N4); State ranks range from extirpated (SX; Arizona, Kansas, New Mexico, Oklahoma) to apparently secure (S4; Colorado, Wyoming) (NatureServe 2012). Internationally, the species is ranked Near Threatened (NT) by the World Conservation Union, representing an increase in risk from its rank of Least Concern in 2000 (BirdLife International 2011). Monitoring habitat for greater sage-grouse is especially appropriate because the species is widely recognized as a sagebrush obligate (Paige and Ritter 1999, Rowland 2004, Schroeder et al. 1999).

The greater sage-grouse is considered a landscape species in that life history requisites (e.g., for breeding, nesting, and brood-rearing) must be met at several spatial and temporal scales (Knick and Connelly 2011, Rowland et al. 2006, Stiver et al. 2010). It has also been considered an umbrella species, in that management directed at conserving habitats for this species may also benefit other species of conservation concern that have similar habitat requirements (Hanser and Knick 2011, Rich et al. 2005, Rowland et al. 2006). Thus, if other sagebrush obligates are designated as emphasis species in the monitoring program, they may be grouped with sage-grouse and thereby increase monitoring efficiency (Hanser and Knick 2011, Rowland et al. 2006, Wiens et al. 2008; chapter 2, section 2.2.5). Careful evaluation of consistencies in habitat requirements among species is necessary, however, before grouping approaches should be followed.

Conceptual Model for Greater Sage-Grouse

Existing Wildlife Habitat Relationships Models

A diverse array of habitat models for greater sage-grouse has been published, spanning the geographic range of the species (table 10.5). All seasons of habitat use are represented, such as nesting and brood rearing, and models are equally divided between landscape and site levels. All models except two **lek** models (Aspbury and Gibson 2004, Onyeahialam et al. 2005) contain variables representing either land cover type or specific attributes of sagebrush.

Orders of Habitat Selection

Greater sage-grouse select habitats at multiple levels, from first order selection at the geographic range of populations to fourth order selection at nesting, foraging, roosting, and brood-rearing sites (Connelly et al. 2003, Johnson 1980, Schroeder et al. 1999, Stiver et al. 2010; see sidebar on orders of habitat selection in chapter 2, section 2.3.2).[4] Because of this hierarchical selection, and the use of distinct seasonal habitats by sage-grouse, most authors recommend evaluating habitat for sage-grouse at multiple spatial scales and seasons (e.g., Connelly et al. 2003, Crawford et al. 2004). We follow that guidance as we describe habitat attributes associated with greater sage-grouse and recommend protocols for monitoring selected attributes.

Stiver et al. (2010) described greater sage-grouse habitat indicators within physical and geographic areas at three scales—midscale, fine scale, and site scale—corresponding to (1) population and subpopulation ranges, (2) seasonal habitat within a home range and movement between seasonal ranges, and (3) seasonal use areas and movement between daily use sites, respectively. Midscale extents for sage-grouse encompass groups of subbasins (fourth order Hydrologic Unit Codes [HUCs]), whereas fine-scale evaluations are appropriate across watersheds (fifth order HUCs) or a subbasin. Site-scale evaluation is conducted across smaller areas on the order of a few to several hundred acres. We combined the two larger scales and refer to them as the landscape level throughout the remainder of this example. Accordingly, we describe attributes and monitoring at two levels of habitat selection—landscape and site. These levels correspond to Johnson's (1980) levels of selection as follows: second and third order levels = landscape, fourth order level = site.

Habitat Requirements

Habitat requirements for sage-grouse have been well described in several comprehensive publications (e.g., Connelly et al. 2000, 2003; Knick and Connelly 2011; Schroeder et al. 1999). Effective management for sage-grouse focuses on maintaining (1) large expanses of contiguous sagebrush shrublands, primarily big sagebrush (*Artemisia tridentata*) varieties; (2) a diverse understory of perennial native grasses and forbs for food and cover; (3) a complement of well-connected seasonal habitats that includes adequate sagebrush cover extending above the snow during winter; and (4) relatively

[4] Discussion about sage-grouse habitat requirements and their evaluation at multiple scales in this section of the example relies heavily on the document, "Sage-grouse Habitat Assessment Framework" (Stiver et al. 2010).

Table 10.5.—*Example habitat relationship models developed for greater sage-grouse (*Centrocercus urophasianus*).*

Model framework	Geographic area	Level	Season(s)	Habitat Components	Variables	Spatial application	Evaluation	Reference
BBN	Interior Columbia Basin	Landscape	All	All	• Land cover • Departure from historical range of variability • Livestock grazing • Road density • Human population density	Spatially explicit	Comparison of extirpated versus occupied areas (Wisdom et al. 2002)	Raphael et al. 2001
DFA	Idaho (southeast)	Site	Summer	Brood rearing	• Sagebrush density • Shrub density • Forb frequency	Nonspatial	None	Klebenow 1969
GLM	Wyoming (Natrona County)	Site, home range	Spring	Leks	• Slope • Distance from human development • Elevation • Distance to water • Distance to roads • NDVI	Spatially explicit	None	Onyeahialam et al. 2005
HEPM	Not specified	Landscape	Spring	Nesting	• Land cover (sagebrush) • Sagebrush height • Herbaceous cover • Slope	Spatially explicit	None	Edelmann et al. 1998
HEPM	Not specified	Landscape	Summer	Brood rearing	• Land cover (sagebrush) • Sagebrush height • Herbaceous cover • Slope	Spatially explicit	None	Edelmann et al. 1998
HEPM	Not specified	Landscape	Winter	Winter	• Land cover (sagebrush) • Sagebrush height • Slope	Spatially explicit	None	Edelmann et al. 1998
Landscape simulation (STELLA)	Central Washington	Landscape	All	All	• Sagebrush cover • Grass cover • Aspect • Elevation • Slope • Human disturbance	Spatially explicit	None	Westervelt et al. 1995
Logistic regression	Wyoming (central and southwest)	Site	Spring	Nesting	• Sagebrush density • Shrub canopy cover • Dead sagebrush canopy cover • Sagebrush height • Residual grass height • Residual grass cover	Nonspatial	None	Holloran et al. 2005

Table 10.5.—*Example habitat relationship models developed for greater sage-grouse (*Centrocercus urophasianus*) (continued).*

Model framework	Geographic area	Level	Season(s)	Habitat Components	Variables	Spatial application	Evaluation	Reference
Logistic regression	Utah (Strawberry Valley)	Site	Summer	Adult habitat	• Sagebrush canopy cover • Grass cover	Nonspatial	None	Bunnell et al. 2004
Logistic regression	North Dakota	Site	Spring	Active leks versus inactive leks	• Big sagebrush height • Visual obstruction at 0.25 m (0.82 ft) • Herbaceous forb cover • Herbaceous grass cover • Bare ground	Nonspatial	None	Smith 2003
Logistic regression	South Dakota	Site	Spring	Active leks versus inactive leks	• Sagebrush cover • Big sagebrush height • Visual obstruction at 0.25 m (0.82 ft)	Nonspatial	None	Smith 2003
Maximum entropy	Oregon	Landscape	Spring	Nesting	• UTM coordinates • Elevation • Slope • Aspect • Integrated moisture index • Vegetation cover type	Spatially explicit	Subset of presence records	Yost et al. 2008
RSF	Southern Alberta	Site	Spring	Nesting	• Land cover	Spatially explicit	Field data (independent dataset)	Aldridge and Boyce 2007
RSF	Southern Alberta	Landscape	Summer	Brood rearing	• Land cover • Plant community • Topography • Distance to energy well site • Visibility of energy well site • Distance to water impoundment	Spatially explicit	Field data (independent dataset)	Aldridge and Boyce 2007
RSF	Wyoming, Montana (Powder River Basin)	Landscape	Winter	Winter	• Land cover • Topographic roughness • Slope • Density of natural gas wells	Spatially explicit	Field data (independent dataset)	Doherty et al. 2008
Rule-based	Nevada, Utah (Pine Valley)	Landscape	Spring	Leks	• Land cover • Slope • Rainfall • Distance to water	Spatially explicit	None	Nisbet et al. 1983
Rule-based	Utah (Rich County)	Landscape	Winter	All	• Land cover (shrub class)	Spatially explicit	Field data (grouse sightings, tracks)	Homer et al. 1993
Rule-based	California (Mono County, Long Valley)	Landscape	Spring	Leks	• Topography (visibility)	Spatially explicit	None	Aspbury and Gibson 2004

Table 10.5.—*Example habitat relationship models developed for greater sage-grouse (*Centrocercus urophasianus*) (continued).*

Model framework	Geographic area	Level	Season(s)	Habitat Components	Variables	Spatial application	Evaluation	Reference
Rule-based	Nevada	Site	Spring, summer	Nesting, brood rearing	• Sagebrush recruitment • Pinyon and juniper invasion • Human disturbance • Livestock grazing • Sagebrush canopy cover • Perennial grass cover • Forb cover • Spring grass height • Forb species richness	Nonspatial	None	USDA NRCS 2007
Rule-based	Nevada	Site	Winter	Winter	• Sagebrush recruitment • Pinyon and juniper invasion • Human disturbance • Livestock grazing • Sagebrush canopy cover	Nonspatial	None	USDA NRCS 2007

BBN = Bayesian Belief Network. DFA = discriminant function analysis. ft = feet. GLM = generalized linear model. HEPM = habitat effectiveness population model. m = meter. NDVI = Normalized Difference Vegetation Index. RSF = resource selection function. UTM = Universal Transverse Mercator coordinate system.

open sites for lekking that are undisturbed by human activities. No overarching limiting factors have been identified for sage-grouse habitats, although several interacting stressors have negatively impacted the species' habitats, such as invasions by nonnative grasses, encroaching woodlands, and oil and gas development (Knick and Connelly 2011). No evidence shows that lek habitat is limiting (Crawford et al. 2004, Schroeder et al. 1999).

In identifying habitat requirements and associated attributes to monitor for greater sage-grouse, we considered the distinct seasons of use—breeding (including lekking, nesting, and early brood-rearing), summer (late brood-rearing), and fall and winter. A monitoring program, however, could target only one of these activity periods or a subset of them, especially if the species did not occur year round in the monitoring area.

Landscape. Across large landscapes, sage-grouse require "access to well-connected sagebrush patches that provide dispersal and movement among subpopulations" (Stiver et al. 2010: II-1). Knowledge of many aspects of broad-scale requirements for sage-grouse is lacking, however, including optimal spatial patterns of habitat attributes (Aldridge et al. 2008, Wisdom et al. 2011), total area requirements (Schroeder et al. 1999), and threshold values for many broad-scale metrics (addressed further in the following section).

The amount of sagebrush in subpopulation and seasonal use extents is a key requirement for sage-grouse. Aldridge et al. (2008) reported that sage-grouse population persistence across the species' range was associated with greater than 25 percent sagebrush cover[5] within a 30-kilometer (km) (19-mile [mi]) radius of sampling locations in extirpated or occupied range, with a 90-percent probability of persistence in circles with at least 65 percent sagebrush. Similarly, Wisdom et al. (2011) found that large areas (100,000 hectares [ha] [247,100 ac]) with more than 50 percent sagebrush cover were associated with high probability of population persistence.

Sage-grouse are associated with large patches of sagebrush. Sage-grouse in Alberta selected nesting and brood-rearing habitats characterized by large (1 km^2 [0.39 mi^2]) heterogeneous patches of moderate sagebrush cover; the most dense sagebrush patches (about 50 to 60 percent canopy cover) were not selected (Aldridge and Boyce 2007). In an extirpation analysis across the range of sage-grouse, mean sagebrush patch size was 4,173 ha (10,310 ac) in occupied range versus 481 ha (1,189 ac) in extirpated range (Wisdom et al. 2011). Core area of sagebrush patches was 11-fold greater in occupied versus extirpated ranges, although patch density did not differ between extirpated and occupied range (Wisdom et al. 2011).

Sage-grouse require areas between habitat patches that are suitable for movement or dispersal; in general, the greater the shrub cover in the landscape matrix, relative to forest or grassland cover, the more suitable the matrix (Stiver et al. 2010). Edges between sage-grouse habitat and nonhabitat also influence sage-grouse distributions. Sage-grouse avoided nesting in areas with a high proportion of

[5] Cover in this study refers to sagebrush as a land cover type, not field-sampled canopy cover.

anthropogenic edge, such as edges associated with roads, oil well sites, and croplands, within 1 km^2 (Aldridge and Boyce 2007). Nest sites had an average of 2.9 percent edge within this distance versus 10.1 percent in the larger landscape.

Site. Connelly et al. (2000) described site requirements for productive lekking, breeding, brood-rearing, and winter habitats, primarily in terms of composition and structure of sagebrush and perennial grasses and forbs. A meta-analysis of greater sage-grouse nesting and brood-rearing studies confirmed values for these attributes in the published guidelines (Hagen et al. 2007). These vegetation attributes relate to needs of sage-grouse for food, shelter, and security within seasonal habitats. Connelly et al. (2000) recommended that more than 80 percent of breeding and winter habitats, and more than 40 percent of brood-rearing habitats, meet the site conditions specified in their publication, summarized in the following section.

Canopy cover of sagebrush should range from 10 to 30 percent, depending on season of use; shrub heights from 9.8 inches (in) (winter) to 31.5 in (breeding) are optimal. Sagebrush cover of less than 5 percent, in general, is not suitable during any season except lekking (Stiver et al. 2010). Sagebrush cover conceals nests and young chicks, helps protect sage-grouse from predators, and ameliorates effects of weather on grouse, especially during winter. Nearly all sage-grouse nests are located under sagebrush shrubs (Schroeder et al. 1999). Unlike other seasonal use sites, leks typically support low, sparse vegetation, if any at all, but are adjacent to sagebrush with adequate cover for nesting hens (Autenrieth 1981, Klebenow 1985, Petersen 1980).

A diverse understory of native, perennial herbaceous plants provides additional cover for sage-grouse, especially during nesting and brood-rearing periods. Greater grass cover is associated with greater chick survival (Aldridge and Boyce 2008) and selection of brood-rearing sites (Hagen et al. 2007). Connelly et al. (2000) recommended a combined grass-forb canopy cover of more than 25 percent (15 percent in arid sites), depending on season and site characteristics; height of perennial grasses and forbs should typically exceed 18 centimeters (cm) (7.1 in) during the breeding season.

Sage-grouse feed almost exclusively on sagebrush in winter (Connelly et al. 2000, Schroeder et al. 1999). Required height and canopy cover of shrubs during winter depend on site conditions, but typically 10 to 30 percent canopy cover of sagebrush shrubs ranging from 25 to 35 cm (9.8 to 13.8 in) in height are suitable. These values apply to the portion of shrubs exposed above snow (Connelly et al. 2000).

Forbs are key foods for sage-grouse chicks and prelaying hens (Crawford et al. 2004). During brood-rearing, sage-grouse select areas of greater forb cover (Hagen et al. 2007). Forb cover exceeding 10 percent (5 percent in arid sites) is recommended in breeding habitats (Connelly et al. 2000), with a diverse mix of forb species available.

Habitat Stressors

Habitat stressors for greater sage-grouse can be human-induced and natural, and result from a variety of environmental processes and disturbances (figures 10.3 and 10.4). Stressors of sage-grouse habitat across large landscapes can be summarized in three broad categories: (1) declines in habitat quality and quantity, (2) fragmentation of habitat and loss of connectivity, and (3) decreases in habitat

effectiveness because of increased human disturbance (figure 10.3). Most stressors that affect sage-grouse habitat across landscapes also operate at the site level; however, their effects may differ at smaller spatial extents (figure 10.4). Several of these stressors operate within our example administrative unit.

Landscape

Invasive species. Lack of a robust, native herbaceous understory in sagebrush communities is a key concern in the example planning area. Current understory vegetation is characterized by large populations of nonnative and invasive plant species, especially crested wheatgrass (*Agropyron cristatum*) and bulbous bluegrass, which compete with native herbaceous species. These species were planted decades earlier to stabilize soils in this unit and have persisted in the herbaceous plant community. Cheatgrass (*Bromus tectorum*) is also increasing in this area but does not compete well with bulbous bluegrass.

Altered fire regimes. A substantial portion (more than 30 percent) of this management unit has burned in recent wildfires, destroying large patches of woody sagebrush that, in general, is fire intolerant and increasing fragmentation of remaining sagebrush. Severe habitat degradation in sagebrush steppe and other native shrublands often occurs because of the invasion of cheatgrass and other nonnative vegetation following wildfires and results in conversion of sagebrush shrublands to annual grasslands largely unsuitable for sage-grouse (Crawford et al. 2004, D'Antonio and Vitousek 1992, Knick 1999, Miller et al. 2011). In the past, unregulated livestock grazing facilitated an increase in cheatgrass and a shift in the sagebrush fire regime to more frequent fires. Currently, cheatgrass-mediated fires are far more severe than historical fires in sagebrush ecosystems (Miller et al. 2011).

Livestock grazing. Grazing by domestic livestock is the most ubiquitous land use across the sagebrush biome (Knick et al. 2011) and is a primary land use in our example administrative unit, in which forage resources for domestic livestock are a key management focus. Improper grazing can lead to loss of habitat quality through shifts in understory composition, such as seeding of nonnative perennial grasses to improve livestock forage and increases in nonnative annual grasses on heavily grazed rangelands (Crawford et al. 2004). Moreover, livestock grazing can alter water, vegetation, and soils past thresholds from which systems cannot return (Pyke 2011).

Habitat conversion. Much of the sagebrush in landscapes surrounding and within our administrative unit has been highly altered—only one-fourth of the unit remains in native vegetation that has not been plowed or farmed. Within the unit, managers have worked to replace crested wheatgrass and bulbous bluegrass with species more suitable as livestock forage as well as sagebrush and other native species important for sage-grouse. Removal of sagebrush to create cropland or rangeland pasture historically has resulted in broad-scale loss of sagebrush habitats, especially on more productive sites with deeper soils and greater precipitation (Knick et al. 2011). Across its range, sage-grouse persistence was negatively correlated with the percentage of cultivated cropland in 2000 (Aldridge et al. 2008), and sage-grouse broods in Canada avoided sites close to cropland (Aldridge and Boyce 2007).

Anthropogenic structures. In addition to fragmentation from removal of sagebrush by processes such as wildfire or mechanical treatments, greater sage-grouse habitat in this administrative unit is fragmented by a variety of anthropogenic features, such as roads, powerline corridors, and fences, contributing to decreased connectivity and smaller habitat patches. Powerline posts and communication towers also serve as roosts for raptors and corvids that may prey on sage-grouse or disturb lekking birds (Knick et al. 2011). Roads are frequently associated with greater densities of invasive or noxious plants, further leading to decreases in habitat quality (Trombulak and Frissell 2000). Roads are also considered a disturbance factor when leks are active, and human uses near leks can lead to their abandonment. Connelly et al. (2000) recommended that human activities be limited to distances greater than 0.5 km (0.3 mi) from leks during the breeding season.

Climate change. Climate change can be a key stressor in sagebrush and other native shrubland ecosystems and acts synergistically with invasive plant species and fire to affect habitats of greater sage-grouse; this stressor will create challenges for future management of sagebrush (D'Antonio and Vitousek 1992, Hansen et al. 2001, Miller et al. 2011, Neilson et al. 2005). Specific effects include the potential for (1) increased levels of carbon dioxide, promoting growth of nonnative annual grasses; (2) warming temperatures across much of the sagebrush ecosystem, leading to replacement of sagebrush with other woody vegetation and restricting sagebrush to higher elevations and northern latitudes, possibly completely outside of the conterminous United States; and (3) increased frequency of drought, resulting in high mortality rates in sagebrush plants (Hansen et al. 2001, Miller et al. 2011).

Site

Prescribed fire. Prescribed fire has been used in the planning area to increase forage production for livestock in areas with dense (more than 15 percent) sagebrush canopy cover; however, recent wildfires have been so extensive that prescribed fire is no longer used. Effects of fire on sagebrush are highly variable, depending on local site conditions, the taxon of sagebrush involved, and fire characteristics (Knick et al. 2011). Fire can be especially detrimental in sagebrush shrublands because of the lack of fire tolerance in woody sagebrush species, however, and in some areas fire has been associated with long-term population declines, declines in lek attendance, and habitat loss (Connelly et al. 2000, Nelle et al. 2000). Prescribed fire may reduce sagebrush canopy cover below levels considered suitable for sage-grouse nesting or wintering habitat, especially on a short-term basis, and can also lead to increases in nonnative grasses as described under the subheading on altered fire regimes previously.

Livestock grazing. Providing local water sources for livestock increases access of livestock to sites remote from natural water sources, thus expanding the area affected by livestock, as described previously for landscapes.

Wildland fire. In the short term, wildfires at site levels may negatively impact seasonal habitats used by sage-grouse by killing sagebrush shrubs and increasing prevalence of nonnative grasses. Sage-grouse may abandon the area until shrubs are reestablished through natural succession or active restoration.

Conceptualized Effects of Stressors on Habitat

We developed graphical representations of the conceptual model at two levels, landscape and site (figures 10.3, 10.4). We also illustrated the relation between potential habitat attributes[6] to monitor and applicable management goals for our analysis area (table 10.6).

From the conceptual model, potential effects of stressors on sage-grouse habitat include—

- Broad-scale declines in habitat quantity and quality.
- Fragmentation of formerly contiguous habitat.
- Habitat avoidance and disruption of movements.
- Decreases in sagebrush canopy cover to unsuitable levels.
- Reduced quality of understory vegetation.

Changes in habitat quantity and quality are expected to ultimately affect population performance (e.g., by altering adult survival rates or numbers of young fledged). Explicit linkages from specific habitat characteristics to individual population indicators can be described, if desired, in a conceptual model (see Madsen et al. 1999). The relative role of habitat in influencing populations will vary depending on the species and locale, the scale of analysis, and other factors (chapter 2, section 2.2.2). For greater sage-grouse, an obligate of the sagebrush ecosystem, sagebrush quality and quantity have been linked to nest location, breeding success, occurrence, distribution, and population status in many studies (e.g., Aldridge and Boyce 2007, Johnson et al. 2011, Leu et al. 2008, Wisdom et al. 2011).

Habitat Attributes Derived From Conceptual Model

From the conceptual model, we identified 20 habitat attributes that could be monitored to assess changes in sage-grouse habitat—11 landscape attributes and 9 site attributes (table 10.6). All of the attributes are measurable, but management cannot influence all attributes. In particular, local management generally cannot affect drought frequency but can only respond through prudent management of livestock grazing in drought years to decrease deleterious effects on understory vegetation. We recommend that the interactions of annual weather patterns with vegetation and disturbance (e.g., fire cycles) be carefully evaluated when reviewing monitoring results for the selected habitat attributes. Similarly, human population density can affect greater sage-grouse habitat and populations, but is not governed by management of public lands.

From the attributes identified in the conceptual model, we selected for monitoring the following six attributes because of their (1) emphasis in planning documents from the area (e.g., LRMP, monitoring reports, Final Environmental Impact Statement [FEIS]), (2) relation to stated or implied management objectives, (3) demonstrated importance to sage-grouse in published literature, and (4) feasibility of monitoring (table 10.6).

[6] We use the term "habitat attributes" in this example to refer not only to habitat features but also to human disturbance agents that may be monitored to assess their effects on habitat.

Table 10.6.—*Evaluation of potential habitat attributes and human disturbance agents identified from the conceptual model for greater sage-grouse (*Centrocercus urophasianus*) at landscape and site levels.*

Habitat attribute or disturbance agent	Management objective that relates to this attribute	Is the attribute or disturbance agent responsive to management?	Attribute selected
Landscape			
Habitat amount	No specific management objective	Yes	No
Land cover (e.g., croplands, native vegetation)	Account for adjacent land-use patterns in managing for sage-grouse habitat	Partially	No
Extent of invasive annual grasses	Reduce extent of invasive annual grasses through active restoration, maintain extent of native-dominated understory	Yes	No
Sagebrush patch size	Manage sagebrush community to reduce fragmentation and restore and maintain habitat connectivity; maintain large (> 320 ac) patches of sagebrush with > 15 percent canopy cover	Yes	Yes
Sagebrush canopy cover	Maintain current extent (60 percent) of sagebrush in > 15 percent canopy cover	Yes	Yes
Habitat connectivity (connectivity of sagebrush patches)	Manage sagebrush community to reduce fragmentation and restore and maintain habitat connectivity	Yes	Yes
Linkage areas	Manage sagebrush community to reduce fragmentation and restore and maintain habitat connectivity	Yes	No
Density of roads, powerlines, communication towers, and other anthropogenic features	Manage sagebrush community to reduce fragmentation and restore and maintain habitat connectivity	Partially	No
Livestock grazing (AUMs)	Monitor potential effects of livestock grazing on sage-grouse habitat	Yes	No
Human population density	No specific management objective	No	No
Drought frequency	No specific management objective	No	No
Site			
Sagebrush height	No specific management objective	Yes	No
Sagebrush shape	No specific management objective	No	No
Perennial grass cover	Maintain or increase extent of native-dominated understory	Yes	Yes
Perennial grass height	Maintain or increase extent of native-dominated understory	Yes	Yes
Perennial forb cover	Maintain or increase extent of native-dominated understory	Yes	No
Perennial forb height	Maintain or increase extent of native-dominated understory	Yes	No
Area of nonnative grass	Reduce extent of nonnative grasses through active restoration	Yes	Yes
Vegetation composition, especially understory diversity in sagebrush communities	Reduce extent of nonnative grasses through active restoration, maintain extent of native-dominated understory	Yes	No
Area of sagebrush burned (distinguish wildfire versus prescribed fire)	Document and map natural and anthropogenic disturbances	Partially	No

ac = acre. AUM = Animal Unit Month.

Landscape

1. ***Sagebrush patch size*****—**to ensure maintenance or creation of large habitat patches.
2. ***Sagebrush canopy cover*****—**to maintain or manage for desired distribution of sagebrush canopy cover classes outlined in the LRMP.
3. ***Habitat connectivity*****—**to ensure spatial continuity of sage-grouse habitat across the unit.

Site

1. ***Perennial grass cover*****—**to maintain or increase extent of perennial-dominated understory to meet guidelines for sage-grouse breeding and brood-rearing habitat. Goals for the planning unit do not specifically mention the published guidelines for understory conditions of suitable breeding and brood-rearing habitat (Connelly et al. 2000), but do emphasize managing sagebrush to improve understory diversity.
2. ***Perennial grass height*****—**same rationale as for perennial grass cover.
3. ***Area of nonnative grass*****—**to diminish the area in nonnative vegetation.[7]

We selected the following six specific metrics to monitor the selected habitat attributes (table 10.7).

Table 10.7.—*Metrics used to measure selected habitat attributes for greater sage-grouse (*Centrocercus urophasianus*) in example analysis area.*

Habitat attribute	Metric	FRAGSTATS metric	Classes and thresholds	Sources for classes
Landscape				
Sagebrush patch size	Mean size of sagebrush patches	AREA, AREA_AM	< 320 ac, > 320 ac, > 15 percent canopy cover	LRMP; Aldridge and Boyce 2007
Sagebrush canopy cover	Percent canopy cover of sagebrush by class	PLAND	0–5 percent, 6–15 percent, 16–25 percent, > 25 percent,	Connelly et al. 2000; FEIS, LRMP
Habitat connectivity	Correlation length	GYRATE_AM	NA	NA
Site				
Perennial grass cover	Percent canopy cover of grasses, by class	PLAND	0–15 percent, > 15 percent (mesic sites); 0–10 percent, > 10 percent (arid sites)	Connelly et al. 2000
Perennial grass height	Height (inches) of perennial grasses ("droop height"), by class	PLAND	< 7.1 in, > 7.1 in (all sites)	Connelly et al. 2000, Hagen et al. 2007
Area of nonnative grass	Acres of land dominated by bulbous bluegrass	NA	NA	LRMP

ac = acre. in = inch. FEIS = Final Environmental Impact Statement. LRMP = Land and Resource Management Plan. NA = not applicable.

[7] Although listed as a site-scale attribute, due to the necessity of measuring this attribute in field-sampled plots, the total area in bulbous bluegrass across the analysis area could be considered a landscape attribute.

Landscape

1. Mean sagebrush patch size.
2. Percentage canopy cover of sagebrush patches (by cover class).
3. Correlation length (connectivity between habitat patches).

Site

1. Percentage canopy cover of perennial grasses (by cover class).
2. Height of perennial grasses (by height class).
3. Area of land (ac) dominated by bulbous bluegrass.

Monitoring Objectives for Greater Sage-Grouse

Management Objectives

To clearly define monitoring objectives, a series of decisions must be made, such as the type of information needed and the spatial extent of the monitoring program, in addition to examination of the local management objectives that ultimately drive the monitoring program (chapter 3, section 3.3.1). The overarching management objective described in planning and monitoring documents in our example area that pertain to greater sage-grouse is to restore well-connected, functional nesting and brood-rearing habitat. This objective can be met by reducing sagebrush fragmentation and maintaining or restoring understory habitat quality and habitat connectivity. Assessing habitat fragmentation and connectivity is especially important because of the interspersion of private lands (in which sagebrush is mostly absent) and State lands with NFS lands within the analysis area. Sage-grouse are nonmigratory in this area, and breeding and brood-rearing habitats occur across the administrative unit.

We identified the following specific management objectives that apply to the NFS lands in this administrative unit following implementation of the LRMP (by Year 10). These objectives were either explicitly stated or implied by the language used in the document.[8]

- Manage vegetation to maintain at least six patches of sagebrush, each larger than 320 ac and with at least 15 percent canopy cover.
- Manage sagebrush communities across the unit so that around 10 percent is in cover class 0 to 5 percent, 30 percent in cover class 6 to 15 percent, and 60 percent exceeds 15 percent cover.
- Replace at least 2,500 ac of vegetation dominated by bulbous bluegrass with vegetation dominated by native grasses, forbs, and sagebrush.
- In areas of potential sage-grouse nesting habitat (i.e., 16 to 25 percent canopy cover of sagebrush), manage understory vegetation to meet habitat guidelines for sage-grouse during the breeding season—total grass-forb canopy cover that is more than 15 percent in arid sites and more than 25 percent in mesic sites, and grass-forb height greater than 7 in.

[8] For brevity, we present only a subset of the potential suite of management objectives and associated attributes for monitoring in our example area.

Monitoring Objectives

The habitat attributes we selected for our monitoring program will adequately address the management objectives and direction in planning documents. The selected attributes will be monitored individually, rather than in a modeling framework. Although some existing sage-grouse habitat models include several of the selected attributes (e.g., Bunnell et al. 2004, Holloran et al. 2005; table 10.5), we know of no existing habitat model that captures the specific conditions for sagebrush canopy cover and patch sizes as described in the LRMP for this administrative unit. If the skills of a modeler were available, however, a multivariate habitat model could be constructed with the selected metrics and the lek data available in this unit (chapter 5). Model evaluation could be conducted using a portion of the empirical data held back from model development.

Planning documents and local conditions require ongoing, multiyear monitoring of sage-grouse habitat in this unit, rather than a one-time inventory, especially in light of the increasing frequency and size of wildfires. Effects of habitat alteration or disturbance may not be detectable in sage-grouse populations for several years (Crawford et al. 2004, Edelmann et al. 1998). Moreover, because sagebrush community dynamics are variable in time and space (Miller and Eddleman 2000, Miller et al. 2011), effects of habitat change may not be distinguished from natural variation for several years.

The overarching objective of the monitoring program is to estimate for the baseline year and every 5 years afterward the amount, distribution, and quality of sage-grouse habitat in the administrative unit as reflected in the selected attributes, over the life of the land management plan, which is approximately 15 years. We developed the following specific monitoring objectives at landscape and site levels, based on our selected attributes.

Landscape

1. Monitor changes in landscape pattern of sage-grouse habitat, using mean size of sagebrush habitat patches within the administrative unit (NFS lands) and the larger analysis area (74,000 ac). Patches will be defined by the 8-neighbor rule, that is, by including all contiguous and diagonal pixels of sagebrush cover. A grain of 30 meters (m) (98 feet) is adequate to map remotely sensed landscape attributes for this analysis (Stiver et al. 2010). For habitat patches, the targeted minimum detectable change is a 10-percent change in mean patch size with 90 percent confidence over the 15-year monitoring period. (Given that the data are drawn from a map of all sagebrush patches rather than from a random sample, mapping error rather than sampling error affects the minimum detectable change and confidence estimates.) We recommend a target threshold of at least four patches within the administrative unit meeting the management objective criteria (i.e., larger than 320 ac and with more than 15 percent canopy cover) at Year 5, and a threshold of six such patches at Year 10. This sagebrush patch size resembles that selected by sage-grouse in breeding and brood-rearing habitats (i.e., around 250 ac; Aldridge and Boyce 2007).
2. Within all delineated sagebrush habitat patches, monitor canopy cover by using the four canopy cover classes defined by management and relevant to sage-grouse habitat requirements during the breeding season (table 10.7) and calculating the acreage in each cover class. The spatial extent

is the same as that for objective one (i.e., the entire 74,000 ac of the analysis area). The desired minimum detectable change is a 10-percent change in the proportion of the analysis area in each sagebrush canopy class with 90 percent confidence. At Year 5, the percentage of sagebrush in canopy class 0 to 5 percent should be less than 20 percent, and in class 6 to 15 percent should be greater than 20 percent. These values represent modest improvements from current conditions, and achieving stated goals for these classes by Year 10 (i.e., 10 percent in cover class 0 to 5 percent, 30 percent in cover class 6 to 15 percent, and 60 percent with more than 15 percent cover) requires clear trends toward desired conditions by Year 5.

3. Monitor changes in landscape pattern by measuring connectivity of habitat patches. The spatial extent is equivalent to that for objectives one and two. For this analysis, any sagebrush patch with less than 5 percent canopy cover will be excluded. The targeted minimum detectable change is a 20-percent change in patch connectivity with 90 percent precision, using the metric of correlation length to index connectivity. No baseline data exist on correlation length for sagebrush patches; thus, estimating this metric during the first year of monitoring will provide a basis for comparisons at Year 5 and beyond. A decline in mean correlation length of more than 10 percent of the baseline value at Year 5 merits closer examination of sagebrush connectivity to understand potential causes for the decline.

Site

The spatial extent for monitoring the selected site attributes will be the administrative unit. A grain of 100-m (109-yards [yd]) transects or 1-m^2 (1.2 yd^2) plots is appropriate at this level (Stiver et al. 2010).

1. Monitor changes in understory quality within sagebrush patches by measuring perennial grass cover and height relative to classes defined as suitable for sage-grouse breeding habitat (table 10.7; Connelly et al. 2000). During the baseline monitoring year, determine what proportion of sampled sagebrush patches meet these criteria for understory vegetation (i.e., height greater than 7 in, with more than 15 percent canopy cover in mesic sites or more than 10 percent in arid sites; see the following section that describes new data collection). The desired minimum detectable change is a 10-percent change in this proportion with 90 percent confidence. At Year 5, determine if this proportion has increased. If not, investigate further and amend management direction if necessary. By Year 10, 75 percent of sampled sagebrush patches should meet the guidelines for these understory attributes. (The preferred alternative approved for the unit states that habitat guidelines for greater sage-grouse will only be partially met.)
2. Monitor changes in area occupied by nonnative grasses by measuring the area dominated by bulbous bluegrass. The desired minimum detectable change is a 10-percent change in area with 90 percent confidence. A decrease of at least 1,250 ac of bulbous bluegrass-dominated understory by Year 5 of plan implementation, compared with baseline conditions, is desired, and of 2,500 ac by Year 10. If the acreage of bluegrass remains the same at Year 5, revisit management treatments designed to eliminate this species and amend activity as required.

3. Monitor annual population of greater sage-grouse, through lek counts or surveys, recognizing that current population status may reflect habitat conditions of prior years (Connelly et al. 2003, Johnson and Rowland 2007). Although a large body of evidence exists relating habitat and population status, especially in birds, understanding the strength of the relationship between the two is often difficult to determine (chapter 2, section 2.2.2).

Evaluation of Existing Data Sources

Field-Sampled Data

A variety of rangeland plot data exist in the example area, such as estimates of stubble height in fall and nested frequency plots for measuring vegetation in treatment sites. Of particular relevance for sage-grouse habitat monitoring is a classified map of sagebrush polygons created in 2004 to 2005, intended to serve as a base layer for further habitat mapping for sage-grouse. Transects (nonrandom) were established in many of the polygons; polygons not sampled were assigned values of similar polygons. Private and State lands intermixed with the unit were not sampled or mapped for this effort; thus, vegetation information is available only for the lands managed by the Forest Service. Variables in the spatial database from the field sampling include—

- Existing vegetation type (e.g., *Artemisia tridentata tridentata/Agropyron cristatum*).
- Potential natural vegetation (e.g., *Artemisia tridentata tridentata/Stipa comata*).
- Dominant sagebrush species or variety.
- Total herbaceous canopy cover (including nonnative species).
- Total forb cover.
- Sagebrush shape (e.g., upright, or bushy).
- Percentage of sagebrush by height class (less than 15.7 in, 15.7 to 31.5 in, and greater than 31.5 in), obtained by measuring 100 sagebrush shrubs in each polygon.
- Estimated age (years) of the dominant sagebrush and oldest sagebrush shrubs in the polygon.
- Locations of active and recently active leks.

Remotely Sensed Data

A large suite of relevant spatial data layers exist, including—

- A map of sagebrush canopy cover by cover class (0 to 5 percent, 6 to 15 percent, 16 to 24 percent, and greater than 25 percent) and associated land ownership and stand size, developed from Landsat satellite imagery and ground-truthing in the late 1990s.
- An actively updated fire history layer that includes prescribed burns and wildfires, fire size, and year.
- Fences (pastures), land ownership, and roads.
- Tilled versus no-till areas.
- Management treatments (e.g., plowing, prescribed fire, and seeding).

Overall, existing plot and remotely sensed data cover the desired spatial extents for site monitoring (i.e., the administrative unit), but some data are lacking for the intermingled lands not managed by the Forest Service. Moreover, no data appear to have been collected using random or systematic sampling, but rather by using convenience sampling (i.e., sampling along roadsides and other easily accessed locales; Anderson 2001). Existing data within the analysis area are insufficient to monitor most of the selected landscape attributes, owing primarily to the lack of a current map depicting sagebrush canopy cover. Most management objectives for the area rely on knowledge of the percentage of sagebrush occurring in various canopy cover classes, and the existing canopy cover layer is not current (approximately 1999), especially in light of recent fires. The administrative unit is creating a new sagebrush canopy cover layer, using low-flying aerial photography to map sagebrush. Until an updated sagebrush layer is available, the older layer must be used to map habitat for sage-grouse, recognizing that sagebrush cover will be overestimated. This layer can be used to stratify sagebrush patches by canopy cover class and then randomly select patches within each stratum for field sampling.

A second key gap in field-sampled data is the lack of detailed information about the herbaceous understory within the sagebrush communities. The planning documents emphasize sagebrush canopy cover rather than understory composition, but sagebrush that lacks a diverse understory of native herbaceous plants, especially perennial species, will be inadequate to support viable sage-grouse populations in the long-term (Connelly et al. 2000, Knick and Connelly 2011). Information on scheduled updates of data layers is unknown.

New Data Collection

Given the existing data on greater sage-grouse populations and habitats in the planning area and the level of planned collection of data by the Forest Service to meet monitoring requirements, new data collection is necessary, especially to meet the landscape-level monitoring objectives. Obtaining current remotely sensed imagery (e.g., Landsat scene, low-flying aerial photographs) will allow for delineation and mapping of sagebrush patches. This map can then be used to randomly select habitat patches to field sample for sagebrush canopy cover using line transect methods (chapter 4, section 4.4.2). Height and cover of perennial grasses can be measured along transects sampled for sagebrush canopy cover, using modified line-point intercept methods (chapter 4, section 4.3.2). Sampled stands can also be used to validate the map of sagebrush patches created from the remotely sensed imagery. The monitoring team will use a small pilot effort followed by a power analysis to determine the sample size needed to meet the desired minimum detectable change stated in the monitoring objective.

Estimate Baseline Values of Attributes

Landscape

The initial product required for monitoring sage-grouse habitat is a base map of sagebrush habitat, which can be created in a Geographic Information System by using recent digital satellite imagery or aerial photographs and delineating all patches of woody sagebrush vegetation types within the larger

analysis area in which the NFS lands of this unit are embedded (74,000 ac). Ideally, a map of greater sage-grouse breeding habitat would form the basis for landscape analysis. This map would have been derived from a spatial model that included parameters such as sagebrush height and canopy cover and understory diversity, height, and canopy cover (Connelly et al. 2000). Because such a map is unavailable for our area, we defined habitat for this analysis as all patches of woody sagebrush vegetation types, such as basin big sagebrush (*A. t. tridentata*), classified from either aerial photography or satellite imagery.

No established reference framework (chapter 6) exists in this area for context. Thus, we recommend establishing a reference framework within the larger spatial extent described in the introduction (i.e., the entire valley) and using maps of biophysical settings or potential natural vegetation (such as those available from LANDFIRE; see chapter 4, section 4.5) to map sagebrush. If available, historical photographs and documentation of vegetation in this landscape may provide a more accurate reference framework than that available from national layers such as LANDFIRE. By using a reference framework, current sagebrush distribution in this highly altered and fragmented landscape can be compared with potential sagebrush; however, canopy cover values for the reference framework must be estimated by applying knowledge of shrub cover in similar sagebrush communities (by taxon, elevation, precipitation regime, etc.) that are relatively undisturbed by livestock grazing or other anthropogenic disturbances.

The proposed landscape assessment for our area is a combination of two levels of analysis (chapter 6, section 6.3.4). Patch analysis is required initially to define the patches of interest (e.g., all woody sagebrush patches) and their attributes (e.g., canopy cover class of the patches). Next, a landscape pattern analysis will be used to provide measures of connectivity. The general objective of landscape pattern analysis is to quantify the amount and configuration of habitat in a landscape of interest to compare these values with desired future conditions or previously measured conditions (i.e., a reference framework). For comparisons of results of landscape analysis to be legitimately used for monitoring greater sage-grouse habitat, the following caveats should be noted (chapter 6, section 6.3.9).

- Use the same thematic resolution of sagebrush maps among years.
- Use comparable sources for maps (e.g., imagery type) at each time point.
- Use consistent methods for determining sagebrush canopy cover, because results can vary widely depending on rules (e.g., canopy gaps, use of line transects vs. plots).
- Calculate metrics the same way at each time point.

We recommend estimating baseline values of the landscape attributes as follows:

- ***Mean sagebrush patch size.*** With the base map, we will use a metric called AREA in FRAGSTATS (McGarigal et al. 2012) to calculate the size of each sagebrush habitat patch (using the 8-neighbor rule), and then derive the area-weighted mean (AREA_AM) of these patches for the administrative unit (i.e., NFS lands) and for the analysis area that encompasses the administrative unit.
- ***Percentage canopy cover of sagebrush (by class).*** When all sagebrush patches have been mapped, we will randomly select 20 percent of the patches occurring on NFS lands in the administrative

unit. In these patches, we will measure sagebrush canopy cover along four line transects. Canopy cover will be averaged across the four transects, and we will assign each patch to one of the four previously defined canopy cover classes (table 10.7). We will then calculate the percentage of the total analysis area in each of these cover classes (PLAND).

- ***Correlation length (connectivity between habitat patches).*** We will calculate correlation length of habitat patches with more than 5 percent sagebrush canopy cover across the analysis area using a metric called GYRATE_AM, which is the area-weighted mean radius of gyration across all patches in the landscape (McGarigal et al. 2012). Higher values of GYRATE-AM represent higher degrees of connectivity within a class of patches.

Site

For site attributes, the sampled area will be the randomly selected habitat patches for sampling sagebrush canopy cover.

- ***Percentage canopy cover and height of perennial grasses (by class).*** We will measure canopy cover and height of perennial grasses, using the line-point intercept method, on four transects in each of the randomly selected sagebrush patches. We will then calculate the proportion of sagebrush patches meeting breeding habitat requirements for these attributes, as stated in monitoring objective 2, using PLAND in FRAGSTATS.
- ***Area of land dominated by bulbous bluegrass.*** We will record bulbous bluegrass cover on the line transects measured for perennial grass attributes. For any sagebrush patch in which bulbous bluegrass is the dominant herbaceous species (as measured by canopy cover), that patch area will be considered dominated by bluegrass. We will obtain a baseline estimate of area dominated by bulbous bluegrass by (1) calculating the proportion of sampled sagebrush patches with understory vegetation dominated by this species, (2) multiplying this fraction by the total number of sagebrush patches in the administrative unit, and (3) multiplying the product obtained in step 2 by the mean size of the sagebrush patches dominated by bluegrass.

The measurements will produce a spatially based, quantitative evaluation of current condition of greater sage-grouse habitat within the example unit as well as within the larger reference landscape. The broadly stated desired future condition statements for greater sage-grouse habitat in the planning and monitoring documents can then be rephrased to incorporate the more specific outcomes of the landscape analysis, through an adaptive management process.

Monitor Changes in Attributes Over Time

At the end of the 15-year planning cycle, we assume that the administrative unit will have obtained new imagery to estimate sagebrush cover, and we will use this product to generate another sagebrush habitat map. We will then calculate a new set of values for each of our metrics at landscape and site levels and compare these with the baseline values. For landscape metrics, we will use the described targets and thresholds for area-weighted mean sagebrush patch size, density, and canopy cover

class, in addition to area dominated by bulbous bluegrass, to determine what changes in management are required. For the metrics associated with sites, we will evaluate proportion of habitat patches meeting understory criteria for perennial grasses and area dominated by bulbous bluegrass at years 5, 10, and 15, and recommend corrective actions as necessary to meet management objectives of this unit.

Data Storage and Reporting

Data produced from the monitoring program will be spatial and tabular. For landscape composition attributes, we recommend reporting the distribution of sagebrush habitat patch sizes for the administrative unit and larger analysis area. We also suggest reporting the proportion of patches in each of the predefined sagebrush canopy cover classes at each time point and the number of all habitat patches that are larger than 320 ac and have more than 15 percent canopy cover. A table of patch characteristics can easily be constructed for summaries, including patch ID number, patch size, and sagebrush canopy cover class. Likewise, graphics of patch size distribution can be created. We will report correlation length and create a map of all sagebrush patches with canopy cover greater than 5 percent, to be used in tandem with measures of correlation length, for the baseline estimates and every 5 years thereafter.

Output for site attributes will be reported in tabular and spatial formats. For perennial grass cover and height, we will create a table with plot ID, sampling date, and percent canopy cover and height of perennial grasses for each transect measured for these attributes. This information can also be used to attribute the map of sagebrush patches; that is, to classify patches as meeting or not meeting standard guidelines for grass cover and height in breeding or brood-rearing habitat (Connelly et al. 2000). For nonnative grass cover, report acres dominated by bulbous bluegrass before and after any management treatments potentially affecting abundance of this species; mapping of bulbous bluegrass distribution is not required.

Case Example

Terrestrial Habitat Monitoring Plan for Mole Salamanders on an Example National Forest

Introduction

This example is a hypothetical monitoring plan that illustrates many of the process steps addressed in the Technical Guide for Monitoring Wildlife Habitat and that provides a sample format for writing a wildlife habitat monitoring plan. No national forest or State has adopted this plan. It is, however, based on actual guidelines from a State wildlife action plan and a national forest land management plan and is written as if it were an actual monitoring plan. To avoid inappropriate adoption of this plan without input by local managers and stakeholders, we will refer to the national forest and the State in which it is located by the generic names of Example National Forest (ENF) and State. An actual monitoring plan would likely contain more literature references, but in the interest of brevity, we have kept natural history details and literature references to a minimum.

Goals of Habitat Monitoring

The goals of this habitat monitoring program are as follows:

- Evaluate whether habitats of three species of mole salamanders (family Ambystomatidae) are being maintained on the ENF under current management direction.
- Evaluate the contributions of the ENF to statewide habitat availability for these three species.

Rationale for Monitoring Habitat of Mole Salamanders

Within the State, three species of mole salamanders use **vernal pools** for breeding and require forest lands within migration distance of these pools for most of their habitat needs—the Jefferson salamander, blue-spotted salamander, and spotted salamander (*Ambystoma maculatum*) (figure 10.5). Of these species, the Jefferson salamander is of highest conservation concern because its terrestrial habitat is primarily restricted to mature forests. It has a State Conservation Status Rank of S2 (imperiled; NatureServe 2011), and is listed in the State Wildlife Action Plan as a species of highest conservation concern. The blue-spotted salamander is more tolerant of disturbed habitats (Klemens 1993), but is a species of medium priority on the State's list of species of greatest conservation need. This species has a State rank of S3 (vulnerable). The Jefferson and blue-spotted salamanders are listed as Regional Forester Sensitive Species for the ENF. The spotted salamander is the most widespread of the three species and has a rank of S5 (secure), but is still included in the State's Wildlife Action Plan as a species of medium priority in northern hardwood forests. The State Wildlife Action Plan lists several

Figure 10.5.—*Two species of mole salamander—the marbled salamander (*Abystoma opacum*) and spotted salamander (*A. maculatum*). Species in this family use vernal pools for breeding and use adjacent upland forests during other seasons. Photo credit: Lloyd Gamble.*

management recommendations for each of these salamanders. Most notable from the standpoint of habitat monitoring is the recommendation to protect uplands up to 200 meters (m) (656 feet [ft]) from vernal pools, and to maintain connectivity between breeding pools.

The ENF land management plan does not provide specific management for these salamanders, but does provide forestwide standards and guidelines for wetlands under the section describing soil, water, and riparian area protection and restoration. These standards and guidelines are as follows:

- A protective strip of predominantly undisturbed soil (having plant and organic matter cover) shall separate soil-disturbing activities from all water sources (streams, lakes, ponds, wetlands, and vernal or seasonal pools).
- Tree cutting and harvesting should not occur with 25 ft of a perennial stream or high water mark of a pond.
- Revegetation of critical bare soil areas shall be completed on all projects as soon as practical within 25 ft of water sources (ponds, streams, wetlands, or vernal pools).
- Within 100 ft of wetlands and seasonal pools, activities should be limited to those that protect, manage, and improve the condition of these resources.

It is unknown whether this management direction is sufficient for maintaining habitat of mole salamanders. Faccio (2003) reported that radio-tagged Jefferson and spotted salamanders travelled as far as 219 m (718 ft) from vernal pools to overwintering sites, with an average distance of 113 m (370 ft) for both species. Semlitsch (1998) recommended a protected buffer of 164.3 m (534.0 ft) between pools and upland habitat for a suite of salamander species. The 100-ft buffer identified in the ENF land management plan leaves most upland habitat open to other management uses. Moreover, this management direction does not ensure landscape connectivity among pools that is needed for dispersal, gene flow, and sustainability of salamander metapopulations (Hanski 1998). It is possible that current restoration and management practices on the ENF will maintain current habitat quality of upland forests and current levels of landscape connectivity for salamanders, but this outcome is unknown without a monitoring program that specifically addresses both of these factors.

Conceptual Model

The conceptual model for the targeted mole salamanders describes habitat requirements and stressors for all three species, but focuses on the Jefferson salamander for specific details because it has the most restrictive habitat requirements. It is built around the concept of multilevel habitat selection.

Orders of Habitat Selection

Mole salamanders select habitat within a nested hierarchy that follows the generalized order of habitat selection of Johnson (1980). First order habitat selection is the geographic range of the species, which differs for each of the three salamander species. For the purpose of this monitoring plan, we have identified the geographic extent as the entire State in which the ENF is located, and will call this area the regional level. A subset of the regional scale is the ENF.

For mole salamanders, the second order of habitat selection is an assemblage of vernal pools that are within dispersal distance of each other and therefore allow for gene flow between populations in individual vernal pools. We follow the terminology of Compton et al. (2007) and refer to this order as a neighborhood of pools, or the neighborhood level. The size of each neighborhood varies because of pool proximity and the dispersal ability of salamanders through various land cover types and across fragmenting features, such as roads.

The next level in the hierarchical order of habitat selection is the range of individual salamanders, which consists of the vernal breeding pool and upland forests that are within a migration distance of approximately 700 ft, based on radio-telemetry studies of Jefferson salamanders (Faccio 2003). Because this monitoring plan focuses on the terrestrial habitat of adult salamanders, we will refer to this order as the stand level. The monitoring plan could be expanded, however, to include aquatic aspects of the vernal pools (e.g., seasonal persistence, water temperature, pH, and contaminant levels).

Habitat Requirements

Regional Level

Throughout their geographic range, mole salamanders require landscapes that contain vernal pools and forest uplands within migration distance of the pools. Although all three species occasionally use wetlands other than vernal pools for breeding, reproduction in these habitats, in general, is low or subject to failure.

A vernal pool is a contained basin lacking a permanent aboveground outlet (Kenney and Burne 2000). Vernal pools typically occur in upland forests over a relatively impermeable substrate layer, but they also may be found in the depressions of some forested wetlands. They contain water for a few months in the spring and early summer, but by late summer, a vernal pool is usually dry (Kenney and Burne 2009).

Herpetologists do not know the percentage of a regional landscape that needs to be occupied by vernal pools to sustain mole salamanders. Vernal pool abundance is physically limited by geologic features and is difficult to determine without field validation, which includes water testing along with surveys to verify the presence of vernal pool biota, such as fairy shrimp (*Eubranchipus* spp.), wood frog (*Rana sylvatica*), and one or more of the mole salamanders. Although vernal pool abundance is currently unknown, the State has mapped wetlands in general and currently estimates that 4 percent of the State land area is in wetlands. The ENF estimates that 1 to 2 percent of the national forest land area is in wetlands. These numbers give an approximate representation of the regional landscape in which mole salamanders currently occur and apparently persist. Jefferson salamanders are restricted to mideleva- tion northern hardwood forests and therefore use only a subset of available vernal pools in the State.

Successful post-metamorphic dispersal is critical to viability of mole salamanders across regional landscapes (Cushman 2006). Salamanders prefer to travel through forests and streams to disperse to pools other than the natal pool (Cushman 2006). Other land cover types (e.g., old field, orchard, low-density residential, unpaved road) can be traversed, although at higher costs in terms of effort and mortality rates (Compton et al. 2007). Regional population viability is highly related to the composi- tion of the regional landscape mosaic because the spatial pattern of breeding pools affects success of post-metamorphic dispersal as well as survival rates of adults in their terrestrial activity phase. Thus, a second habitat requirement at the regional level is connectivity among pools, through the presence of upland forest habitats and streams.

Neighborhood Level

A neighborhood is one cluster of pools and associated upland forests having a higher probability of salamander dispersal among them than to pools outside of the cluster (Compton et al. 2007). Although an isolated pool surrounded by forest may serve as salamander habitat, it has less ability to sustain salamander metapopulations over the long term than a cluster of pools that are interconnected. Forests and streams that provide connection between pools enable dispersal, recolonization of extinct populations, and maintenance of genetic diversity within the metapopulation.

Stand Level

Mole salamanders require a moist, structured forest floor typically associated with mature forest stands and well-developed canopy cover. Forest floor structure provides overwintering sites and foraging areas, and includes leaf litter, down wood, stumps, upturned roots, understory vegetation, and the presence of rodent burrows (deMaynadier and Hunter 1999, Faccio 2003, Ford et al. 2002).

Habitat Stressors

Biologists have identified several threats to mole salamanders including pond pollution or acidity, fish stocking, change in wetland conditions or loss of wetlands because of development, habitat fragmentation from roads and forest conversions, climate change, and collection of salamanders by humans as pets and for sale. Because this monitoring plan is designed to evaluate land management on the ENF as it pertains to salamanders, we focus on threats to upland forests that can affect regional and neighborhood connectivity or the quality of upland sites.

Regional and Neighborhood Levels

The primary stressors affecting regional and neighborhood connectivity include road developments and land-use changes that degrade, fragment, or eliminate existing habitats. Expressways and major highways cause mortality and can be barriers to dispersal. Unpaved roads lack protective vegetative cover which results in increased predation rates and decreased dispersal rates. Conversion of forests to farmlands or residential areas reduces dispersal potential by removing habitat. Timber harvest also may temporarily reduce dispersal potential if the concomitant reduction in canopy cover of harvested stands increases mortality rates.

Stand Level

The primary stressors at the stand level are activities that reduce the quantity or quality of forest uplands in proximity to vernal pools. Land-type conversions to farmlands, residential areas, or other uses cause long-term loss of habitat. Timber harvest and recreational use can compact soils, open the forest canopy, and change forest floor structure. Although habitat changes associated with silvicultural activities (e.g., thinning, prescribed burning) are usually short-term, these activities could result in a temporary, local extirpation of salamanders, and if the neighborhood landscape lacks habitat connectivity, the probability of recolonization could be low.

Habitat Attributes Derived From the Conceptual Model

The relationships listed previously indicate that connectivity is an important habitat attribute at the regional and neighborhood levels, and that connectivity can be monitored through the amount and distribution of forest land types and the density and condition of roads, evaluated in relation to the dispersal ability of each species of salamander. The conceptual relationship between these attributes and salamander persistence is as follows—as land uses change and road densities increase or are converted from unpaved to paved roads, overall sustainability of salamander metapopulations could

become increasingly difficult because of reduced gene flow among populations. Individual populations could be reduced to small, isolated demes that are vulnerable to genetic loss, inbreeding depression, or extinction through demographic stochasticity.

In addition to regional connectivity, the size of pool neighborhoods is an important attribute because it affects local population size and carrying capacity. Changes in land use, as well as increased road densities and road upgrades, could reduce the number and size of pool-upland units and subdivide a single pool neighborhood into two or more disjunct neighborhoods.

At the stand level, a well-developed forest floor structure composed of leaf litter, down wood cover, presence of burrows, and aerated soils, is highly important for foraging and overwintering. Vegetation management and recreational activities could change the quality and quantity of upland sites by removing woody debris, compacting soils, and possibly reducing the density of rodent burrows.

To quantify these attributes for monitoring purposes, we have selected the measurable attributes listed in the following section. For regional and neighborhood attributes, the acronym in parentheses is the name of the metric as calculated by FRAGSTATS (McGarigal et al. 2012). These metrics are further defined under Data Collection.

All of the attributes require fairly complete knowledge of the location of vernal pools. Although this information is currently not available, the State is currently conducting a statewide inventory of vernal pools and, ideally, their map would serve as the basis of the salamander habitat monitoring effort.

Regional Level

- Proportion of region composed of pool neighborhoods (PLAND).
- Correlation length (extensiveness and connectivity of pool neighborhoods) (GYRATE-AM).
- Index of patch aggregation (CLUMPY).

Neighborhood Level

- Area of the pool neighborhood (AREA).
- Core area of the pool neighborhood (area inside of a 300-ft buffer) (CORE).
- Index of pool neighborhood complexity (SHAPE).
- Average dispersal resistance value per neighborhood (from resistant-kernel estimator described in Data Collection section).

Stand Level

- Average canopy cover (percent) of pool neighborhood forest stands.
- Cover (percent) of down wood larger than 3-inches (in) diameter within a sample of mature forest stands.

Monitoring Objectives

Regional Level

This monitoring plan establishes regional monitoring objectives for two areas (i.e., spatial extents): the State and the ENF. For each of these areas, we will identify and map vernal pool neighborhoods

through a modeling approach that is based on salamander dispersal capabilities through various land cover types and road classes (see Data Collection). The initial model will be based on the most recent land cover data and will represent the first monitoring period. We will generate a new map every 5 years, or as soon thereafter when updated coverages of land cover types and roads are available. All metrics described in the following section will be calculated at approximately 5-year intervals over a 30-year monitoring period.

For both regional areas, the first objective is to monitor changes in the proportion of the region that is composed of pool neighborhoods. The desired minimum detectable change over a 30-year period is a 20-percent change in the proportion of the region in neighborhoods with 80 percent confidence. Given that the data are drawn from a map rather than from a random sample, mapping error rather than sampling error affects the minimum detectable change and confidence estimates. Any observable change between monitoring periods in the proportion of regional area composed of pool neighborhoods should be used as a trigger for evaluating the degree of mapping error within and between maps used for each monitoring period, and for evaluating the need to maintain or increase forest representation in targeted areas.

The second objective is to monitor changes in correlation length of all pool neighborhoods in each region. Correlation length measures the extensiveness of patches (neighborhoods) and how well they are connected (described in more detail under Data Collection). The desired minimum detectable change is a 10-percent change in correlation length with 80 percent confidence. A 10-percent decrease in any 5-year monitoring period would be sufficient to trigger changes in vegetation and road management in the affected areas.

The third objective is to monitor changes in the spatial distribution of pool neighborhoods across the regional landscape, using the CLUMPY index (McGarigal et al. 2012). Given the generally low range of variability in this index in natural landscapes (Neel et al. 2004), a decline of 0.1 unit of the CLUMPY index between two monitoring periods would be a trigger for changes in vegetation and road management in the affected areas.

Neighborhood Level

We selected four metrics for monitoring mole salamander habitat at the neighborhood level. The first objective is to monitor changes in the area of each pool neighborhood, with a minimum detectable change of 10 percent with 80 percent confidence. After each monitoring period, any pool neighborhoods with a decline in neighborhood area greater than 15 percent will be evaluated for possible changes in vegetation and road management to prevent further declines or to restore neighborhood size, if feasible.

The second objective is to monitor changes in the core area of each pool neighborhood, excluding a 300-ft-buffer distance to estimate the area of core habitat unaffected by edge effects. The desired minimum detectable change is a 10-percent change in core area with 80 percent confidence. A decline of greater than 15 percent in pool neighborhood core area would be a trigger for changing vegetation and road management in the affected areas.

The third monitoring objective at the neighborhood level is to monitor changes in the spatial configuration (shape) of vernal pool neighborhoods. The desired minimum detectable change is a 20-percent change in the index of vernal pool neighborhood shapes with 80 percent confidence. A 20-percent increase in the shape index of any vernal pool neighborhood would indicate that the neighborhood has become more fragmented and would trigger a change in vegetation and road management in the affected area.

The fourth objective is to monitor changes in average dispersal resistance across each pool neighborhood landscape. As described under Data Collection, resistance values are assigned to each 30-m (98-ft) pixel, based on the dominant land cover type and road class for the pixel and on expert opinion of salamander dispersal capabilities. These values are used to delineate pool neighborhoods, but for monitoring changes in average dispersal resistance, we will estimate the average resistance value from all 30-m (98-ft) cells within each pool neighborhood landscape. This metric will be calculated with the desired minimum detectable change of 10 percent in mean dispersal resistance between any two monitoring periods for each neighborhood. An increase in average dispersal resistance of 20 percent will be a trigger to change vegetation and road management.

Stand Level

At the stand level, the first objective is to monitor changes in average canopy cover of all forest stands within vernal pool neighborhoods on the ENF. Canopy cover will be estimated every 5 years (or as soon thereafter when new vegetation data are available) over a 30-year monitoring period, with the desired minimum detectable change of 20 percent in average canopy cover at 80 percent confidence. In the absence of information regarding a threshold canopy cover value that is important to mole salamanders, we will use a 20-percent decline in average canopy cover over any given monitoring interval as a trigger for change in vegetation management.

The second objective is to monitor changes in percent cover of down wood larger than 3 in diameter as an indicator of forest floor structure. This objective will be accomplished by field measurements for a random sample of forest stands within vernal pool neighborhoods on the ENF, with a sample of forest stands that is of sufficient size to detect a 20-percent change in percentage cover with 90 percent confidence. The metric will be measured at 5-year intervals over the 30-year monitoring period. A 20-percent decline in the percentage cover of down wood between any two monitoring periods would trigger a more thorough evaluation of whether this decline represents a significant change in other aspects of forest floor structure that are important to mole salamanders.

Although the focus of this monitoring plan is on habitat, field visits for down wood sampling could enable the ENF to also sample for presence of salamanders in the vernal pools associated with the sample of stands. Thus, the monitoring plan could be expanded to include a third objective of estimating the proportion of sampled pools with salamanders and would enable managers to evaluate habitat attributes in relation to salamander presence. Site visits also enable expansion of the monitoring plan to include water quality sampling.

Sampling Design

Regional Level

The regional level has two areas of analysis—the entire State and the ENF. For each of the regional attributes, the sample design is a complete census of all 30-m (98-ft) pixels in each analysis area, with an error rate (currently unknown) associated with the assignment of a land cover type to each pixel. The measurement cycle will be every 5 years, or as soon thereafter when updated coverages of land cover types and roads are available.

Neighborhood Level

The neighborhood level uses the same areas of analysis as the regional scale—the entire State and the ENF. The sampling units are vernal pool neighborhoods, which vary in size and shape according to pool proximity and the distribution of low-resistance land cover types. For each of the neighborhood-scale attributes, the sample design is a complete census of all vernal pool neighborhoods. In other words, we will calculate each of the four neighborhood attributes for each pool neighborhood. The error associated with calculating these attributes is the same as the regional error because the same land cover map is used to delineate vernal pool neighborhoods.

Stand Level

Canopy cover. The area of analysis is all vernal pool neighborhoods for only the ENF because of limitations in acquiring fine-scale data for the entire State. The sampling design is a complete census of all forest stands within the vernal pool neighborhoods, but an error rate exists (currently unknown) that stems from the assignment of canopy cover classes to the ENF existing vegetation layer. The measurement cycle will be approximately every 5 years, or as soon thereafter when new data on canopy cover are available.

Down wood. The area of analysis is the same as for the canopy cover data, but because the data will be acquired through field sampling, the sampling design will be a random sample drawn from all available stands within the vernal pool neighborhoods. Sample size will be sufficient to detect a 20-percent change in percentage cover with 90 percent confidence, based on the power analysis from a pilot study. We will use line transects to estimate down wood cover, and transect length will be optimized to reduce variance, based on a pilot study (Bate et al. 2008).

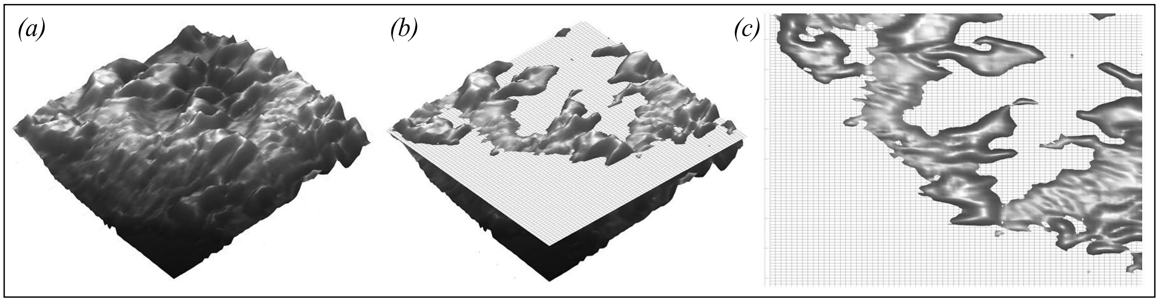
Data Collection

Regional and Neighborhood Levels

We will delineate pool neighborhoods using the methods described in Compton et al. (2007) as outlined in the following section. We will accomplish this work through a contract with a university or individual who has the required modeling skills. Estimated time to complete the initial map of vernal pool neighborhoods is approximately 6 weeks.

1. ***Map vernal pools across the State.*** This monitoring design is dependent on fairly accurate knowledge of vernal pools. Although we will use a map of potential and known vernal pools from the current statewide survey, habitat monitoring would not begin until field surveyors have provided substantial field-validation of pool locations. Updated vernal pool maps can be incorporated into the monitoring program, however, as described in the data analysis section.
2. ***Select a minimum dispersal distance for modeling dispersal resistance.*** Following Compton et al. (2007), we will use 318 ft as the minimum dispersal distance for modeling salamander movements, which is the 66th percentile (i.e., greater than the average) value of dispersal distances for eight Jefferson salamanders (97 m [318 ft]), determined by radio-telemetry (Faccio 2003).
3. ***Create a regional map of all major land cover types and road classes.*** For land cover types, we will use the 2006 National Land Cover Data (NLCD; chapter 4, table 4.6) land cover map for the State. For the road layer, we will use the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) database.
4. ***Assign resistance values to land cover types and classes of roads.*** Each map pixel is assigned a resistance value based on its dominant land cover type or road class and on salamander dispersal capabilities. We will begin with the resistance values assigned to 18 land cover types and 6 road classes by a group of salamander experts working on a dispersal resistance model for the State of Massachusetts (Compton et al. 2007). We will use expert opinion to extend these resistance values, if needed, to land cover types and road classes in our State that were not evaluated in Massachusetts. Examples of land cover types used in the Massachusetts resistance model are forest, old field, pasture, salt marsh, and low- and high-density residential. Examples of road classes are expressway, minor street, and railroad.
5. ***Create a map of local connectivity (a breeding pool and associated forests) and neighborhood connectivity (several pools and associated forests).*** We will use the resistant-kernel estimator described by Compton et al. (2007) to map local and neighborhood connectivity. The kernel estimator creates a three-dimensional surface that represents the probability of a salamander moving from each pool pixel to any other pixel in the landscape, given the species' dispersal limitations and the resistance value of each pixel. By summing the movement probabilities of all modeled salamanders across the map, we can develop a cumulative kernel surface, in which high peaks in this three-dimensional surface represent locations with high probability of salamander dispersal.
6. ***Slice off the peaks of the cumulative kernel distribution at the 75th percentile to create discrete pool neighborhoods (figure 10.6).*** Since this cutoff point is arbitrary, it can be altered to whatever percentile will create discrete neighborhoods while still displaying neighborhood connectivity. In general, the lower the cutoff point, the more connected a landscape appears, thus diminishing the ability to distinguish pool neighborhoods. The cutoff percentile chosen in the first year of the monitoring program must be used in subsequent monitoring periods to obtain standard maps for measuring changes in each of the regional and neighborhood metrics.

Figure 10.6.—*The process of identifying pool neighborhoods, beginning with (a) a cumulative kernel distribution, (b) the cumulative kernel sliced at a 75-percent probability of salamander dispersal, and (c) the resulting two-dimensional map surface. (Figure developed by Samuel A. Cushman.)*



7. ***Calculate regional and neighborhood metrics.*** We will calculate all landscape pattern metrics using FRAGSTATS (McGarigal et al. 2012). Each pool neighborhood becomes a patch, and all pool neighborhoods become a class of pool neighborhood patches. The habitat map will consist of only two classes—the pool neighborhoods and all areas that do not fall into pool neighborhoods.

PLAND and GYRATE-AM are class metrics because they calculate values for each class on a map. Because PLAND calculates the proportion of total map area occupied by each class, we will use PLAND to generate the proportional representation of all pool neighborhoods for the State and the ENF. As with any proportion measure, values range from zero to one.

Correlation length is a measure of landscape connectedness, based on the average length of connected pixels within a patch or class. In FRAGSTATS, correlation length for each class is calculated using GYRATE-AM, which is the area-weighted mean radius of gyration across all patches in the class or landscape (AM is the acronym for area-weighted mean). Values range from zero to infinity and become meaningful in a comparative sense (e.g., when comparing values calculated from maps of similar extent and resolution, or when comparing values calculated over sequential time periods). Higher values of GYRATE-AM represent higher degrees of connectivity within a class of patches. We will use the initial value of GYRATE-AM to represent the current degree of connectivity among pool neighborhoods, and compare this value with values obtained at each of the subsequent monitoring periods.

CLUMPY is an index of the amount of aggregation found within a specific (focal) class of patches in comparison with a spatially random distribution of a class of patches on a **neutral landscape** (McGarigal et al. 2002). The index values range from -1 to +1, with zero representing a spatially random distribution of the patch class, which in the current scenario is the class of pool neighborhood patches. Values approaching -1 indicate a disaggregated class, whereas values close to +1 indicate aggregation. Natural landscapes tend to have values larger than 0.7, so the range of actual values is less than the range of potential values.

The three landscape metrics calculated at the pool neighborhood (patch) scale are AREA, CORE, and SHAPE. AREA is simply the area of each patch, whereas CORE is the area of the patch core after

the analyst specifies a buffer distance from the patch edge inward. We will specify a 100-ft buffer when calculating core area. CORE provides a more sensitive measure of fragmentation than AREA because it is more sensitive to patch shapes. Patches that are convoluted, oblong, or linear have less core area than round patches. SHAPE is a measure of patch complexity. It has a value of one when patches are maximally compact (square) and increases without limit as patch shape becomes more convoluted (McGarigal et al. 2012).

Stand Level

Canopy cover

1. ***If one is available, use a vegetation coverage of the ENF that estimates canopy cover for each forest pixel or forest polygon.*** If the vegetation layer for the ENF does not have canopy cover values, we will model canopy cover with a nearest-neighbor method, using stands that have been surveyed as reference sites for the model. Canopy cover estimates will be mapped at 30-m (98-ft) resolution and at canopy cover intervals of 10 percent.
2. ***Overlay the pool neighborhood map with a forest stand map to identify all forest stands found within pool neighborhoods.*** The selection will include all seral or structural stages of all forest cover types.
3. ***Calculate the mean tree canopy cover and standard deviation for each pool neighborhood on the ENF.*** This statistical summary will be calculated using existing data tables associated with the vegetation layer.

Down wood cover

1. ***Conduct pilot studies to determine sample size and potential need to stratify by cover type.*** We will randomly select five pool neighborhoods, and then randomly select three stands per neighborhood to conduct a pilot study of down wood cover. Given that no Forest Inventory and Analysis (FIA) P3 plots occur in upland sites associated with vernal pools, we will use the line intercept log sampling protocol developed by Bate et al. (2008), including the protocol for determining optimal transect length from pilot data. This protocol requires measuring log diameter and length and then uses an algorithm to estimate percentage cover.
2. ***Estimate sample size required to obtain the desired precision and desired minimum change.*** We will use a power analysis for a single point estimate to determine the sample size needed for estimating down wood cover. The estimated sample size will then be inflated by 10 percent to allow for the ability to detect changes in down wood cover over time.
3. ***Stratify if needed, to improve precision and accuracy.*** We will evaluate results from the pilot study to determine whether the observed variance in down wood cover percentages suggests a need to stratify the total sample by either cover type association or elevation or by any other factors.
4. ***Randomly select a complete set of sampling units based on one transect per stand and conduct sampling.*** Each monitoring interval will be completed within one season between the months of June and September.

5. ***Sample for salamander presence and collect water samples if the monitoring plan is expanded to include population and water quality objectives.*** An expanded monitoring plan would describe specific protocols for these activities. Salamander sampling would need to occur at the appropriate season, which would influence the timing of down wood surveys so that they could be conducted concurrently.

Logistics

Regional and Neighborhood Levels

For the purpose of brevity, we do not describe logistics in detail here. At this point in a monitoring plan, however, determine whether data collection will require a contract with a Geographic Information System (GIS) analyst and describe any other logistics associated with acquiring a regional map of pool neighborhoods, including the estimated start and completion dates, and milestones in between. We anticipate that if a vernal pool inventory were in place and vegetation and road layers were available, the analytical work could be accomplished in 4 to 6 weeks.

Stand Level

This section would describe the logistics of field data collection, including the number of surveyors, their qualifications, and a list of required field equipment including vehicle(s), radios, GPS units, diameter tapes, safety equipment, and other supplies. The section might be subdivided into logistics for the pilot study and logistics for each monitoring period.

Data Storage

The ENF will assume the role of data steward for this monitoring program. The map of statewide pool neighborhoods will be shared with the State, and the extent that covers the ENF will be incorporated into the Forest Service Enterprise Data Warehouse (EDW) through Natural Resource Manager (NRM) FSVeg. Down wood data also will be incorporated into the EDW through NRM FSVeg.

Data Analysis

Regional and Neighborhood Levels

During the initial year and at approximately 5-year monitoring periods, we will develop a habitat map of vernal pool neighborhoods using the resistant-kernel estimator developed for mole salamanders in Massachusetts by Compton et al. (2007) and using updated land cover and road maps for each monitoring period. We will use FRAGSTATS (McGarigal et al. 2012) to calculate, for the State and the ENF, landscape metrics for the region and neighborhoods. We will use GIS to calculate the average resistance value for each pool neighborhood. At the end of each monitoring interval, we will compare the values between monitoring periods for each metric to see if any observable change in regional or neighborhood connectivity has occurred, given an assumed error in mapping.

An underlying assumption of this monitoring program is that mapping resolution, classification, and error rates will not change with each revision of the NLCD land cover type map and with updates on the TIGER road database over the 30-year monitoring period. In actuality, however, mapping resolution is likely to become finer and classification systems could change to reflect changing social needs. Although error rates could decrease with better technology, the sources of error could be different than previous maps. The challenge associated with monitoring is to separate differences in salamander habitat because of actual changes in land use from differences because of the mapping process.

We will evaluate sources of change by comparing the trend in forest vegetation that we derive from the modeled habitat maps with trends in forest attributes at FIA plots for the same time period across the State. The refreshing and remeasurement cycles for FIA, NLCD, and TIGER will not be synchronous, but should somewhat match within a 3- to 5-year window. From FIA data, we will use changes in basal area, stand size class, and the number of overstory trees per acre as indicators of change in the forest land cover type. We will consider the monitoring results valid if the direction and magnitude of change is similar for the habitat maps and the FIA variables.

As biological information about salamander dispersal increases, a monitoring team in future years has the option of changing resistance values and generating a revised model. The revised model would result in new pool neighborhoods, differing in shape, size, and degree of fragmentation from the first model. The future team would then run the new model on archived maps from the initial time period and each subsequent time period to compute valid change statistics. This approach enables the future team to incorporate new information about salamander dispersal capabilities into the ongoing monitoring program.

Similarly, as information about vernal pools increases, a future monitoring team would have the option of updating the vernal pool map. An update would result in a different set of pool neighborhoods, so the team would need to overlay the new vernal pool map with the land cover and road maps from the initial time period and recalculate the landscape attributes to interpret change in any attribute over time. By archiving vegetation and road data from each time period, it is possible to recalculate the landscape metrics at any time and maintain continuity of the monitoring program.

Stand Level

At the end of the each field season, we will use SnagPro (Bate et al. 2008) to estimate mean percent cover and standard deviation of down wood for each sampled stand, for each pool neighborhood, and for the ENF regional extent. After each monitoring interval, we will conduct a *t*-test between the initial year and the current year to look for statistically significant changes in down wood cover. At the end of the 30-year monitoring period, we will graph values for each of the six monitoring intervals and look for significant trends through regression analyses.

Reports

In collaboration with the State's department of fish and wildlife, the ENF will prepare a monitoring report at the end of each approximately 5-year monitoring interval, and findings from this report will be included in the forest plan monitoring information. The report will include information on the methods used to derive pool neighborhoods to maintain continuity and consistency between monitoring methods over the 30-year time frame of the monitoring program. The report will also make recommendations for any needed corrections in the monitoring design.

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Appendix B. Glossary

accuracy assessment. The process by which the correctness of an image, map, or other spatial layer is evaluated (Winthers et al. 2005).

adaptive management. A system of practices based on clearly identified outcomes and monitoring to determine if management actions are meeting desired outcomes, and if not, to facilitate management changes that will best ensure that outcomes are met or reevaluated. Adaptive management stems from the recognition that knowledge about natural resource systems is sometimes uncertain (Forest Service Manual [FSM] 1940) (USDA Forest Service 2009).

alliance. A vegetation classification unit of low rank (7th level) containing one or more associations, and defined by a characteristic range of species composition, habitat conditions, physiognomy, and diagnostic species, typically at least one of which is found in the uppermost or dominant stratum of the vegetation (Jennings et al. 2006). Alliances reflect regional to subregional climate, substrates, hydrology, moisture or nutrient factors, and disturbance (FGDC 2008).

area-based recreation. Any form of recreation that is not restricted to a linear route, but is constrained only by varying combinations of technologies, environmental conditions, and management regulations, such as snowmobiling (chapter 7).

association (plant). The finest level of the (vegetation) classification standard; a physiognomically uniform group of vegetation stands that share one or more diagnostic (dominant, differential, indicator, or character) overstory and understory species and reflect topo-edaphic climate, substrates, hydrology, and disturbance regimes (FGDC 2008); a vegetation classification unit defined on the basis of a characteristic range of species composition, diagnostic species occurrence, habitat conditions, and physiognomy (Jennings et al. 2006).

auxiliary database. A repository for data that is created and maintained outside of a corporate database structure, such as outside the Forest Service Natural Resource Manager (NRM). In the Forest Service, tabular and spatial data that do not meet national published NRM protocols are considered auxiliary and are either maintained at a local unit or with a contributing partner.

basal cover. The area occupied by plant stems as they extend into the soil; calculated as the percent of the soil surface covered by plant stems, using a point-intercept method, such as line-point intercept (adapted from Herrick et al. 2005).

Bayesian belief network. A graphical model based on Bayesian inference that uses a combination of empirical data and knowledge from experts to graphically express complex relationships and address uncertainties in a structured way to evaluate alternative scenarios and their outcomes (McCann et al. 2006).

bias. A persistent statistical error associated with parameter estimates whose source is not random chance (Thompson et al. 1998).

Box-and-whisker plot. A convenient method of graphically displaying the distribution of data in which five numbers are typically shown, including the minimum, maximum, and median values. The upper and lower lines of the box represent the upper (75th percentile) and lower (25th percentile) quartiles of the data. The middle line within the box represents the median value.

business requirements. A need identified as necessary for successful achievement of business goals or objectives, (including strategic, tactical, legal, or operational objectives). May be represented in a variety of contexts and are most often defined in response to establishing requirements for processes, compliance to business direction, and to identification of information technology functionality requirements (FSM 1940) (USDA Forest Service 2009).

cause-and-effect monitoring. An approach for investigating the mechanisms that underlie habitat and species response to management and other forms of disturbance (Holthausen et al. 2005).

canopy cover. The percentage of the ground obscured by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings in the canopy are included (SRM 1989, cited in Warbington 2011).

classification (vegetation). Grouping of similar vegetation types according to physiognomic and floristic criteria, using objective rules that are established before being applied so that the outcome is theoretically independent of individual perceptions. (adapted from FGDC 2008).

classification accuracy. The degree to which a derived image classification agrees with reality (Foody 2002).

climate change vulnerability assessment. A method to evaluate the potential responses of species, habitats, and ecosystems to changes in climate resulting from elevated greenhouse gasses in the atmosphere, to carry out adaptation planning and support decisionmaking (Glick et al. 2011).

clinometer. Handheld instrument used to measure slope, height, and vertical angles, especially of vegetation or structures.

coarse filter. One of two major conservation strategies developed by The Nature Conservancy to efficiently capture and conserve as much biological diversity as possible. Focuses on communities and is expected to capture approximately 85 to 90 percent of the species found in a State, whereas the fine filter focuses on individual species that are not adequately captured by the coarse filter (Noss 1987).

coefficient. In statistics, a constant as distinguished from a variable; also used to denote a dimensionless description of a distribution or a set of data (Lincoln et al. 1998).

Common Stand Exam (CSE). Nationally consistent protocols for acquiring terrestrial vegetation information, especially in forested sites, to meet site-specific analysis needs. The CSE provides procedures for describing vegetation composition, structure, and productivity in an ecological framework and is intended as a dynamic set of guidelines to be responsive to the changing needs of the various resources.

conceptual model. A method to outline the interconnections among ecosystem processes, structure, composition, and function, the strength and direction of those links, and the attributes that characterize the state of the ecosystem (Mulder et al. 1999).

confidence interval. Distance between upper and lower limits around a population parameter. Represents a range of potential values for the parameter given the model used and multiple repeated surveys or samples. For example, a 95-percent confidence interval shows the range of values that are expected to include the parameter in 95 percent of repeated surveys using the same model under the same survey or sampling conditions.

connectance. In landscape analysis, the number of functional joinings, in which each pair of patches is either joined together or not.

connectivity. Spatial continuity of habitat or a cover type across a landscape (Turner et al. 2001).

contagion. Tendency of patch types to be spatially aggregated; that is, to occur in large, aggregated distributions.

context monitoring. An approach to tracking a broad array of ecosystem components at multiple scales without specific reference to influences of ongoing management (Holthausen et al. 2005).

contrast-weighted edge density. Standardizes the number of instances within a raster-based map that two adjacent pixels are of different types. The standardization involves dividing the total number of instances by the total number of pixels on the map.

convenience sampling. Act of collecting data where they are easy to obtain, such as along roads, trails, utility corridors, and in areas of high abundance and hence, not representative of the population of interest (Anderson 2001).

core area. Area unaffected by the edges of the patch; represents the interior area of patches after a user-specified edge buffer is eliminated.

core variable. An element of forest structure such as tree diameter that is routinely measured at all sampling points in the Forest Inventory and Analysis (FIA) program. Each FIA region may choose additional data elements to measure, but may not change the core requirements.

corporate database. Enterprise-wide information management systems using a common information structure and processes to store, maintain and access shared automated inventory, monitoring, and assessment data (FSM 1940) (USDA Forest Service 2009).

correlation length. Average distance an organism can traverse a map from a random starting point and moving in a random direction, while remaining in a specific patch type.

cover type. A designation based upon the plant species forming a plurality of composition and abundance; typically based on the dominant species in the uppermost stratum of vegetation (e.g., oak-hickory) (adapted from Brewer et al. 2011b, FGDC 2008).

data dictionary. A compilation of information that describes how one or more databases are structured, including information on data element names, data type, list or range of values, sources, accessibility, and the systems or applications that use the data.

desired conditions. A description of specific social, economic, and ecological characteristics of the plan area, or a portion of the plan area, toward which management of the land and resources should be directed. Desired conditions must be described in terms that are specific enough to allow progress toward their achievement to be determined, but do not include completion dates (U.S. Department of Agriculture, Forest Service 2012; 36 CFR Part 219, RIN0596-AD02; National Forest System Land Management Planning).

distance band. A method of characterizing effects of landscape elements, often disturbance related, such as roads or cellular towers. Concentric strips of equal width (e.g., 100 yards) are drawn around the element, such that the landscape of interest can be quantified in relation to what proportion of the area is located in each band. Often animal locations also are quantified in the bands to estimate selection (avoidance or preference) in relation to the feature.

dominance. Extent to which a given species influences a community because of its size, abundance, or coverage (Warbington 2011), typically estimated by calculating relative cover.

ecotone. The boundary or transitional zone between adjacent communities (Lincoln et al. 1998).

effect size. The expected difference among means of groups that are subjected to different treatments (Gotelli and Ellison 2004).

emphasis species. Any plant or animal that warrants specific attention in planning or analysis, regardless of its formal or legal designation (e.g., Federal or State listed species, species of public interest, focal species, or keystone species).

Enterprise Data Warehouse (EDW). A Forest Service corporate data storage structure providing read-only, historical, and aggregated data; formerly called the Corporate Data

Warehouse. Benefits include availability of outputs for general use, many formats for data delivery (such as reports, maps, raw and summarized data), data in national extents, the ability to alter published outputs without changing applications, and reduced impacts to the server system by updating data in off-peak hours. Accessed through various database connection methods including standard ArcMap and the Geospatial Interface (GI).

existing vegetation. The floristic composition and structure occurring at a given location at the current time (adapted from Tart et al. 2011).

exurban. Areas with very low-density development, including" ranchette" development in the Western United States, which occurs typically at 1 unit per 35 to 45 acres (Theobald 2001).

focal patch. In landscape ecology, the landscape element that is of interest in the analysis, such as a particular vegetation cover type. Landscape metrics are calculated for the focal patches (e.g., patch density or isolation).

focal species. A suite of plants or animals whose requirements for persistence define the attributes that must be present if a landscape is to meet the requirements for all species that occur there (Lambeck 1997). A small subset of taxa whose status permits inference to the integrity of the larger ecological system to which it belongs and provides meaningful information regarding the effectiveness of the plan in maintaining or restoring the ecological conditions to maintain the diversity of plant and animal communities in the plan area. Focal species would be commonly selected on the basis of their functional role in ecosystems (USDA Forest Service 2012).

foliage height diversity (FHD). An index of canopy complexity derived by measuring the proportion of total foliage that occurs in each of several pre-defined horizontal canopy layers (MacArthur and MacArthur 1961); more generally, a measure of how evenly foliage is vertically distributed among vegetation layers (Cooperrider et al. 1986).

foliar cover. The percentage of the ground obscured by the vertical projection of the aerial portion of plants. Small openings in the canopy and intraspecific overlap are excluded. (from SRM 1989, cited in Warbington 2011). Note: foliar cover never exceeds canopy cover.

frequentist statistics. An analysis framework that uses probability statements based entirely on the hypothetical distribution of the estimate of the fixed parameter generated under the model and repeated sampling.

Geospatial Interface (GI). An ArcMap extension that provides (1) tools to simplify loading data, accessing custom products for display, and analyzing and exporting data; and (2) the ability to export data and maps to Microsoft Excel, Access, and Word or a text format. Data located in several different locations can be preset for quick access; can be used to run spatial overlays like clip, intersect, and identity, enabling users to repeat standard analyses on data.

grain. The resolution at which spatial patterns are measured, or the plot size used to measure characteristics (Wiens 1989).

habitat. A physical location with the resources and conditions present that produce occupancy—including survival and reproduction, or both—by a given organism. Habitat is organism-specific; it relates the presence of a species, population, or individual (animal or plant) to an area's physical and biological characteristics. Habitat implies more than vegetation or vegetation structure; it is the sum of the specific resources that are needed by organisms (modified from Hall et al. 1997).

habitat abundance. The amount and distribution of resources in an area used by an animal (modified from Hall et al. 1997); not synonymous with habitat availability.

habitat attribute. Any living or nonliving feature of the environment that provides resources necessary for a species in a particular setting (chapter 2, section 2.1).

habitat effectiveness. A measure of the reduction in the potential for an environment to meet the needs of a species, often due to the influence of direct human disturbance, such as traffic on roads.

habitat quality. The ability of the environment to provide conditions appropriate for individual and population persistence; a continuous variable, ranging from low to high, and based on resources available for survival, reproduction, and population persistence. Ideally measured by examining demographic characteristics of individuals or populations and not numbers of organisms (Hall et al. 1997); used conceptually in this document to represent habitat conditions believed to influence population persistence, but for which demographic data relating to those conditions may be unavailable.

habitat requirements. Elements that must occur for the species to meet a life requisite (Peek 1986:83). This term should not be confused with preferred habitat attributes.

habitat selection. A hierarchical process involving a series of innate and learned behavioral decisions made by an animal about what habitat it would use at different scales of the environment (Morrison et al. 2006).

habitat type. The vegetation association in an area or the area that will be occupied by that association as plant succession advances (Daubenmire 1952).

human disturbance agent. Any anthropogenic factor that affects native habitats or species in either a positive or negative way.

imputation. In statistics, the substitution of an estimated value for missing data. In spatial data analysis, imputation is the estimation of a cell value using information from other, similar cells. Many imputation techniques are available. After all missing values have been imputed, the dataset can then be analyzed using standard techniques

for complete data. The analysis should ideally take into account that a greater degree of uncertainty is present than if the imputed values had actually been observed, which generally requires some modification of the standard complete-data analysis methods.

inventory. To survey an area or entity for determination of such data as contents, condition, or value, for specific purposes such as planning, evaluation, or management. An inventory activity may include an information needs assessment; planning and scheduling; data collection, classification, mapping, data entry, storage and maintenance; product development; evaluation; and reporting phases (FSM 1940) (USDA Forest Service 2009).

keystone species. A species whose impact on the community or ecosystem is disproportionately large relative to its abundance (Mills et al. 1993).

land unit. The finest planning analysis scale in the Forest Service's National Hierarchy Framework of Ecological Units (Cleland et al. 1997). It includes two ecological unit levels: landtype (from hundreds to thousands of acres) and landtype phase (less than 100 acres). Used for activities such as delineating ecosystems, assessing resources, conducting environmental analyses, and managing and monitoring natural resources.

least squares regression. A method for estimating the relationship between one dependent variable and one or more independent variables by reducing the error term associated with all dependent values used in the equation.

legacy. Refers to natural resource information that was generally collected before the establishment of the corporate database; must meet minimum standards and metadata requirements, including a description of data collection protocols, to be entered into the corporate database.

lek. An assembly area for communal courtship display (Lincoln et al. 1998).

lidar. Acronym for light detection and ranging. A technology that involves the use of pulses of laser light to calculate distances between the sensor and various surfaces detected by the pulses (Lillesand and Kiefer 2000).

life form. Characteristic structural features and processes of a plant species, both genetic and environmental, including growth structure, physiognomy, phenology, and methods of surviving unfavorable periods outside of the growing season. Typical life forms include trees, shrubs, grasses, and forbs (adapted from Warbington 2011).

limiting factors. Environmental features or conditions that exist at a suboptimal level and prevent a population from increasing (Lincoln et al. 1998) (Law of the Minimum; Taylor 1934). These conditions may not be continuously effective but only occur at some critical period during the year or perhaps only during some critical year in a climatic cycle.

linear-based recreation. Any form of leisure activity that follows a narrow landscape feature, such as roads, trails, rivers, riparian zones, and ridgetops that are conducive to human travel.

local management unit. The scale at which local Forest Service planning is done, e.g., national forest, grassland, prairie, or recreation area.

logistic regression. Form of statistical analysis, most commonly with a dependent variable that can take on only two possible categories (i.e., binary), such as presence or absence, or used or not used; assumes the residuals (or error terms) follow a binomial distribution.

macroplot. Relatively large areas with sampling units such as quadrats, lines, or points randomly located within them (Elzinga et al. 1998).

management indicator species (MIS). Plant and animal taxa, communities, or special habitats selected for emphasis in planning, and which are monitored during forest plan implementation to assess the effects of management activities on their populations and the populations of other species with similar habitat needs which they may represent (FSM 2620.5) (USDA Forest Service 1991).

metadata. Information that describes the content, quality, condition, and other characteristics of a given dataset (FGDC 2008).

metapopulation. Several groups of individuals of the same species within some larger area, where migration from one local group to at least some other patches typically is possible (adapted from Hanski and Simberloff 1997). These groups are sufficiently separated so that each group experiences different environmental events, resulting in each group having a unique potential for extinction, which may be followed by recolonization from a neighboring group.

minimum detectable change. The smallest size or percent change that a monitoring team hopes to detect, given a specific sampling design and sampling effort. The minimum detectable change should represent a biologically meaningful quantity, given the likely degree of natural variation in the attribute being measured. Values for minimum detectable change greatly influence statistical power (Elzinga et al. 1998).

minimum map unit. Smallest feature delineated; requirements vary for different map levels (Warbington 2011).

monitoring. The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a resource or management objective.

monotonic (function). A mathematical function that preserves the given order; as x (independent variable) increases or decreases, y (dependent variable) increases or decreases or stays the same.

moosehorn. Handheld tubular device for estimating forest canopy cover with a narrow (10°) angle of view and a 25-dot matrix etched in glass at one end; often used as an unbiased standard for comparing estimates of canopy cover from other methods (Cook et al. 1995).

moving window. In landscape pattern analysis, used to calculate landscape metrics for focal landscapes continuously across a landscape.

multiple logistic regression. An extension of logistic regression in which more than one predictor variable is used; similar to multiple linear regression in having multiple predictor variables, but with a binary response variable.

multispectral data. Information that is obtained through sensors that simultaneously capture multiple, narrow wave length ranges located at various points ranging from the visible through the thermal spectral region (adapted from Lillesand and Kiefer 2000).

neutral landscape. A landscape generated as a random map against which effects of the processes that structure actual landscapes can be tested (Turner et al. 2001).

patch (habitat). A recognizable geographic area that contrasts, in structure or occurrence of resources, with adjacent areas and has definable boundaries (Morrison et al. 2006).

patch mosaic model. A landscape model that recognizes three major landscape elements: patch, corridor, and matrix. Also known as the patch-corridor-matrix model (McGarigal et al. 2012).

pedon. A three-dimensional unit sometimes referred to as a soil profile. Consists of a succession of layers (horizons) in a more-or-less vertical section down into loose weathered rock; a describable unit composed of mineral and organic matter as well as air and water. Layers differ from one another by mineralogy, chemistry, physical or morphological characteristics.

physiognomic. Term referring to vegetation type as defined by the visible structure or outward appearance of a plant community expressed by the dominant growth forms, such as their leaf appearance or whether leaves or deciduous or not (adapted from FGDC 2008).

platform. In remote sensing, the physical object (e.g., balloon, rocket, or satellite) that carries the remote sensor (Rees 1999).

point frame. A rigid vegetation sampling structure that organizes pins in either a rectangular or square grid pattern. The pins are lowered and intercept recorded for each pin in the frame. Multiple frame designs are available (Bonham 1989, Elzinga et al. 1998).

potential natural vegetation (PNV). The plant community that would become established if all successional sequences were completed without human interference under the present environmental and floristic conditions, including those created by man (Tüxen 1956, as cited in Winthers et al. 2005).

power analysis. A method based on the number of observations for determining the likelihood of detecting a statistically significant effect (Dytham 2011).

process variation. General term for the inherent stochasticity of changes in the population level, which includes demographic, spatial, temporal, and individual variability; also referred to as environmental variation (White 2000).

protocol. A detailed study plan that explains how data are to be collected, managed, analyzed, and reported and a key component of quality assurance for natural resource monitoring programs (Oakley et al. 2003).

proximity index. An isolation metric that is calculated for individual patches as the size of and distance to all neighboring patches of the same class, within a specified search distance. The enumeration of size and distance provides the index. A patch with many large patches in close proximity will have a large index value (i.e., low isolation) (McGarigal et al. 2012).

raster. A spatial data structure that uses an array of values in which each cell in the array is a separate unit that can be located spatially by its row and column coordinates (Campbell 1996).

reference framework. In landscape pattern analysis, a landscape used in comparison with another landscape; provides a measure of landscape composition and configuration that is typically used to provide a goal for restoration.

relevé method. An approach developed in Europe to describe the vegetation of an area together with appropriate environmental data (adapted from Lincoln et al. 1998); based on subjectively placed representative standard plots whose size varies depending on the vegetation type and associated size and spacing of the species or plant life form of interest (Barbour et al. 1987).

remote sensing. The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer 2000).

remotely sensed data. Information that is obtained about an object without actually coming into contact with it (Rees 1999).

residual. In a regression model, the difference between an observed value and the value predicted from a model (Zar 2010).

resolution. The fineness with which an instrument can distinguish between different values of some measured property (Rees 1999); analogous to grain (defined above).

Root Mean Square Error (RMSE). A frequently used measure of differences between values predicted by a model or an estimator and the values actually observed from the attribute being modeled or estimated. It is a good measure of precision.

sampled population. The subset of the target population that is actually surveyed (Morrison et al. 2001).

sampling frame. A complete list or map of units that are surveyed (adapted fromThompson et al. 1998).

sampling unit. An individual object within a population about which inferences will be drawn; the basic component of study.

sampling variation. The range of values contributed by attempts, always inexact, to estimate population parameters, in contrast to variation inherent in populations (see process variation; can be estimated) (White 2000).

sensitive species. Plants and animals identified by a regional forester for which population viability is a concern, as evidenced by (1) significant current or predicted downward trends in population numbers or density, or (2) significant current or predicted downward trends in habitat capability that would reduce a species' existing distribution (FSM 2670) (USDA Forest Service 2005).

sensor. Instrument that remotely collects electromagnetic radiation and converts it to some other form, usually a digitized electronic signal (Rees 1999).

seral stage. A temporal and intermediate state in the process of plant succession (Helms 1998).

spatial extent. (1) The area over which observations are made (e.g., the boundaries of a study area, a species range); (2) the area of a geographic dataset specified by the minimum bounding rectangle (i.e., xmin and ymin, and xmax and ymax) (Vesely et al. 2006).

spatial resolution. A measure of the smallest distance between two objects that can be distinguished by a sensor (Rees 1999); the measure of sharpness or fineness in spatial detail (Helms 1998).

spatial scale. Characterized by extent and grain (see definitions for "spatial extent" and "grain"). From a cartographic perspective, the extent is the area of the landscape encompassed within the boundaries of a map, and grain is determined by the size of the minimum mapping unit (e.g., 1 acre) (Vesely et al. 2006).

spherical densiometer. A hand-held instrument used to measure canopy closure of vegetation from the ground.

standard error. The square root of the variance of a sample; the standard deviation of a sampling distribution of sample estimates (Thompson et al. 1998).

stratification. Process of grouping sampling units by some unifying characteristic to decrease the variance within the stratum and increase variance across the strata.

stressor. Any physical, chemical, or biological perturbations to a system that are either (1) foreign to that system or (2) natural to the system but applied at an excessive (or deficient) level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include water withdrawal, pesticide use, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

structural stage. Stand classification based on the horizontal and vertical distribution of components of a forest stand including the height, diameter, crown layers, and stems of trees, shrubs, herbaceous understory, snags, and down woody debris (Helms 1998).

subshrub. A perennial plant having woody stems, typically less than 20 inches (in) tall, except for the terminal part of the new growth which is killed back annually; distinguished by its ground-hugging stems and lower height. Does not include shrubs that are less than 20 in tall because of young age or disturbance.

surrogate (species). Species that are used to represent other species or aspects of the environment to attain a conservation objective (Caro 2010).

target population. The collection of all sampling or experimental units about which one would like to make an inference (Morrison et al. 2001).

targeted monitoring. An activity to track the condition and response to management of species and habitats that are identified as being of concern or interest (Holthausen et al. 2005).

temporal grain. The smallest unit selected for measuring time, i.e., day, month, year, decade, century, or geologic period.

thematic resolution. The level of categorical detail present within a given map unit; increased thematic resolution results in an increased number of classes in the map legend. Whereas thematic resolution is often implied by geographic or spatial resolution, a direct relationship is not inherent (adapted from Helms 1998).

threshold. A value selected before a monitoring program indicating the point at which management changes would be considered or go into effect; point at which a substantial or rapid change in a response variable occurs, given a marginal change in environmental conditions (Sonderegger et al. 2009). Also known as a trigger.

time series. A sequence of data points measured typically at uniform time intervals; analyses use methods that account for the fact that observations close in time will be more closely related than will observations taken farther apart.

transactional data. In the Forest Service, the storage structure for tabular and spatial information that is designed for short, online uses. Data are entered and edited by users who are closely involved with collection of the data and have the appropriate authorizations. Data entered into this secure repository are related to protocol-driven, day-to-day activities.

trigger. See definition for threshold.

Type I error. In statistical tests, the rejection of the null hypothesis when it is in fact true.

Type II error. In statistical tests, the failure to detect a false null hypothesis.

umbrella species. An organism, usually a mammal or bird, whose conservation confers protection to a large number of naturally co-occurring organisms; the umbrella species concept is used in conservation planning as a shortcut method for maintaining biodiversity (Roberge and Angelstam 2004).

User Views. Functionality that allows for direct querying of data tables and provide tabular reports that can be exported to Microsoft Excel; accessible through the I-Web interface main menu and focused on specific business area needs.

variance. A measure of precision; average of squared differences between a set of values and the mean of the distribution of those values (Thompson et al. 1998).

vegetation type. Named class of plant community or vegetation defined on the basis of selected shared floristic and physiognomic characteristics that distinguish it from other classes of plant communities or vegetation. Can refer to units in any level of the National Vegetation Classification hierarchy (FGDC 2008, Tart et al. 2011).

vernal pool. A seasonal water body, usually originating in autumn, filling from spring rains on snowpack and drying by early summer to mid-summer.

zenith angle. The number of degrees between a direction of interest and the local direction of reference.

z-statistic. A value whose distribution under the null hypothesis can be approximated by a normal distribution; has a single critical value for a given significance level (e.g., 5 percent).

Appendix C. List of Scientific and Common Names of Animals and Plants Mentioned in the Text[a]

Animals	
Allen's hummingbird	*Selasphorus sasin*
American marten	*Martes americana*
American pika	*Ochotona princeps*
barred owl	*Strix varia*
bighorn sheep	*Ovis canadensis*
black swift	*Cypseloides niger*
black-backed woodpecker	*Picoides arcticus*
blue-spotted salamander	*Ambystoma laterale*
boreal owl	*Aegolius funereus*
Carolina northern flying squirrel	*Glaucomys sabrinus coloratus*
common raven	*Corvus corax*
coyote	*Canis latrans*
deer	*Odocoileus spp.*
dog	*Canis familiaris*
eastern meadowlark	*Sturnella magna*
Edith's checkerspot	*Euphydryas editha*
elk	*Cervus canadensis*
fairy shrimp	*Eubranchipus spp.*
fisher	*Martes pennanti*
flammulated owl	*Otus flammeolus*
gray fox	*Urocyon cinerioargenteus*
gray-crowned rosy finch	*Leucosticte tephrocotis*
gray wolf	*Canis lupus*
great gray owl	*Strix nebulosa*
greater sage-grouse	*Centrocercus urophasianus*
grizzly bear	*Ursus arctos*
hooded warbler	*Wilsonia citrina*
Indiana myotis	*Myotis sodalis*
Jefferson salamander	*Ambystoma jeffersonianum*
marbled salamander	*Ambystoma opacum*
Mexican spotted owl	*Strix occidentalis lucida*
mole salamander	*Ambystoma spp.*
mountain bluebird	*Sialia currucoides*
northern goshawk	*Accipiter gentilis*
northern pygmy-owl	*Glaucidium gnoma*
northern spotted owl	*Strix occidentalis caurina*
pheasant	*Phasianus spp.*
pine squirrel	*Tamiasciurus spp.*
pronghorn	*Antilocapra americana*
red fox	*Vulpes vulpes*
red-cockaded woodpecker	*Picoides borealis*
ruffed grouse	*Bonasa umbellus*
sachem skipper butterfly	*Atalopedes campestris*
Sitka black-tailed deer	*Odocoileus hemionus sitkensis*
snowshoe hare	*Lepus americanus*
southern red-backed salamander	*Plethodon serratus*
spotted owl	*Strix occidentalis spp.*
spotted salamander	*Ambystoma maculatum*
spruce budworm	*Choristoneura fumiferana*

Common name	Scientific name
vesper sparrow	*Pooecetes gramineus*
Virginia northern flying squirrel	*Glaucomys sabrinus fuscus*
vole	*Clethrionomys spp.*
white-headed woodpecker	*Picoides albolarvatus*
wolverine	*Gulo gulo*
wood frog	*Rana sylvatica*
woodland caribou	*Rangifer tarandus caribou*
worm-eating warbler	*Helmitheros vermivorus*
yellow-bellied marmot	*Marmota flaviventris*
Plants	
aspen	*Populus tremuloides*
basin big sagebrush	*Artemisia tridentate tridentata*
basswood	*Tilia americana*
bulbous bluegrass	*Poa bulbosa*
cheatgrass	*Bromus tectorum*
crested wheatgrass	*Agropyron cristatum*
Douglas-fir	*Pseudotsuga menziesii*
Englemann spruce	*Picea engelmannii*
huckleberry	*Vaccinium spp.*
Japanese honeysuckle	*Lonicera japonica*
Jeffrey pine	*Pinus jeffreyi*
loblolly pine	*Pinus taeda*
lodgepole pine	*Pinus contorta*
longleaf pine	*Pinus palustris*
mountain big sagebrush	*Artemisia tridentata vaseyana*
northern pin oak	*Quercus ellipsoidalis*
oak	*Quercus spp.*
Pacific ponderosa pine	*Pinus ponderosa var. ponderosa*
paper birch	*Betula papyrifera*
pine	*Pinus spp*
pinyon-juniper	*Pinus spp.-Juniperus spp.*
ponderosa pine	*P. ponderosa*
red fir	*Abies magnifica*
red oak	*Quercus rubra, Q. coccinea, Q. velutina, and Q. marilandica*
red spruce	*Picea rubens*
redwood	*Sequoia sempervirens*
sagebrush	*Artemisia spp.*
sensitive fern	*Onoclea sensibilis*
shield fern	*Dryopteris spp*
spruce-fir	*Picea spp.-Abies spp.*
stinging nettle	*Urtica dioica*
subalpine fir	*Abies lasiocarpa*
sugar maple	*Acer saccharum*
sweetgum	*Liquidambar styraciflua*
tuliptree	*Liriodendron tulipifera*
western hemlock	*Tsuga heterophylla*
western redcedar	*Thuja plicata*
white fir	*Abies concolor*
white oak	*Quercus alba*

[a] *Animal names are from NatureServe Explorer (NatureServe 2012). Plant names are from the U.S. Department of Agriculture, Natural Resources Conservation Service PLANTS database (USDA NRCS 2012).*


GRANGER
STATE REFORESTATION AREA
GROVE
ALLEN
BIRDSALL