
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.*

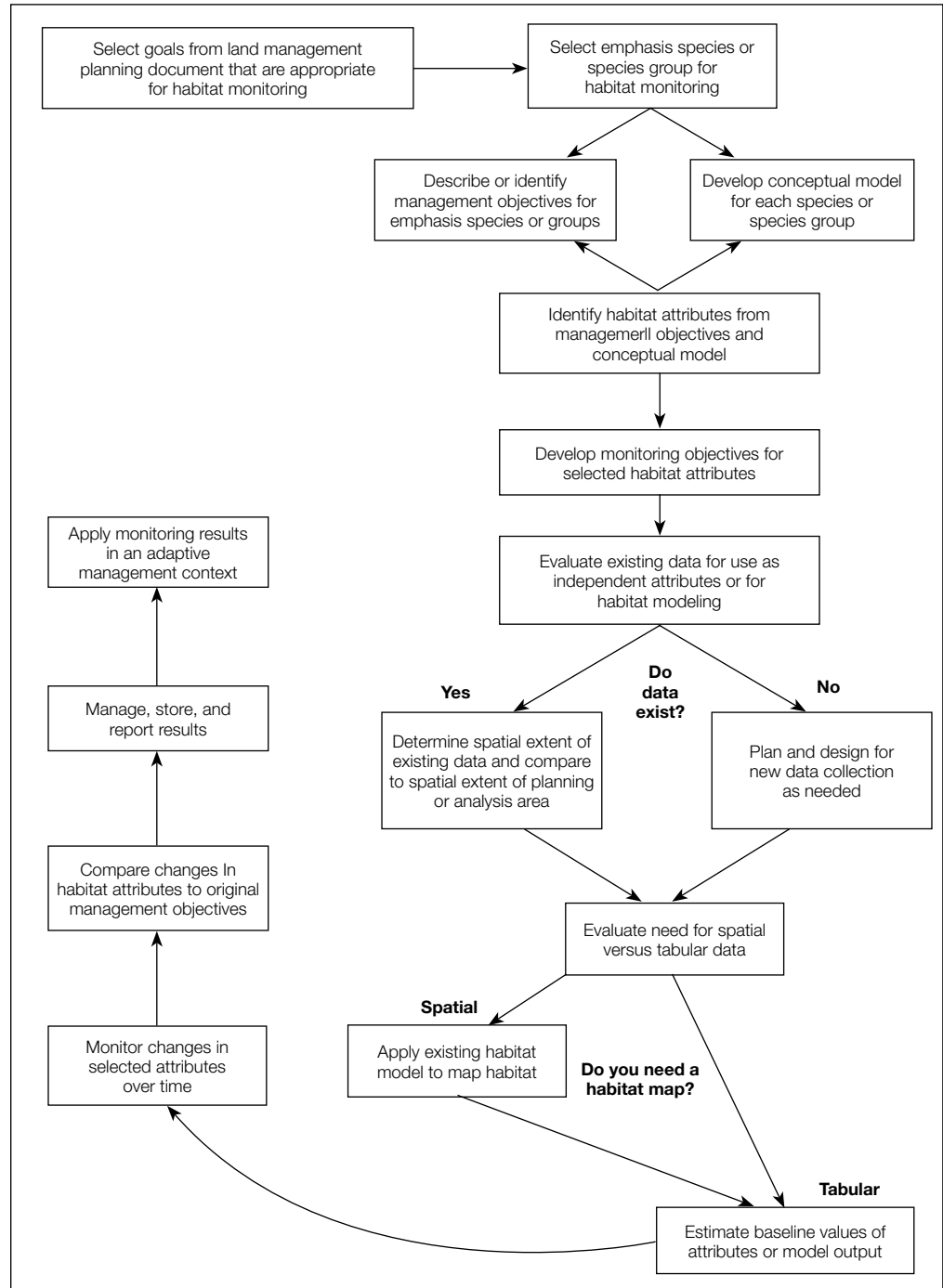


Table 10.1.—*Process steps in developing a habitat monitoring program.*

- 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.

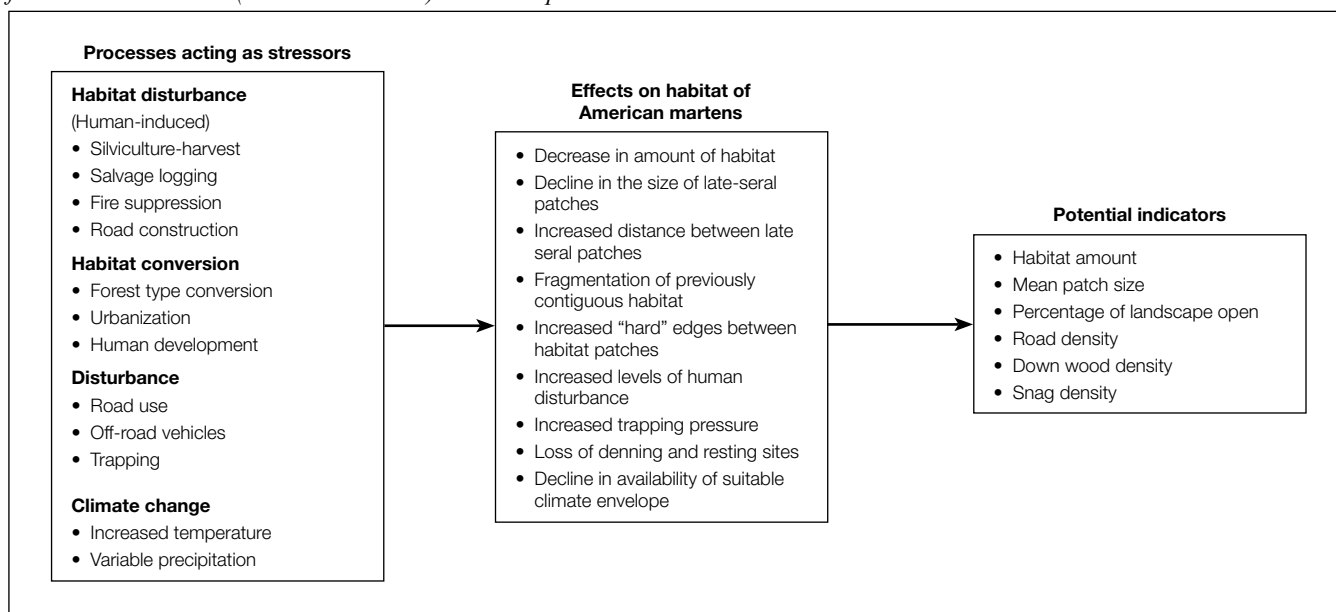
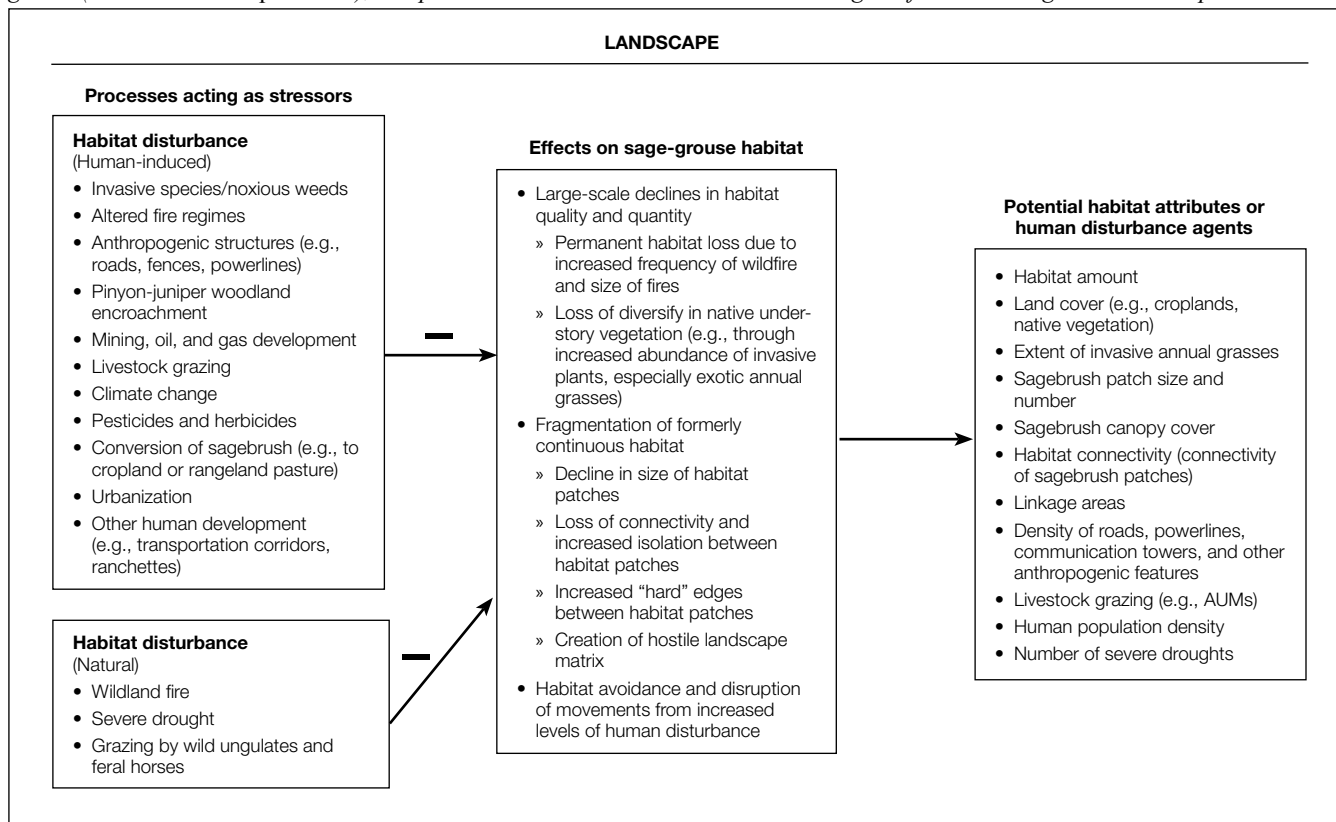
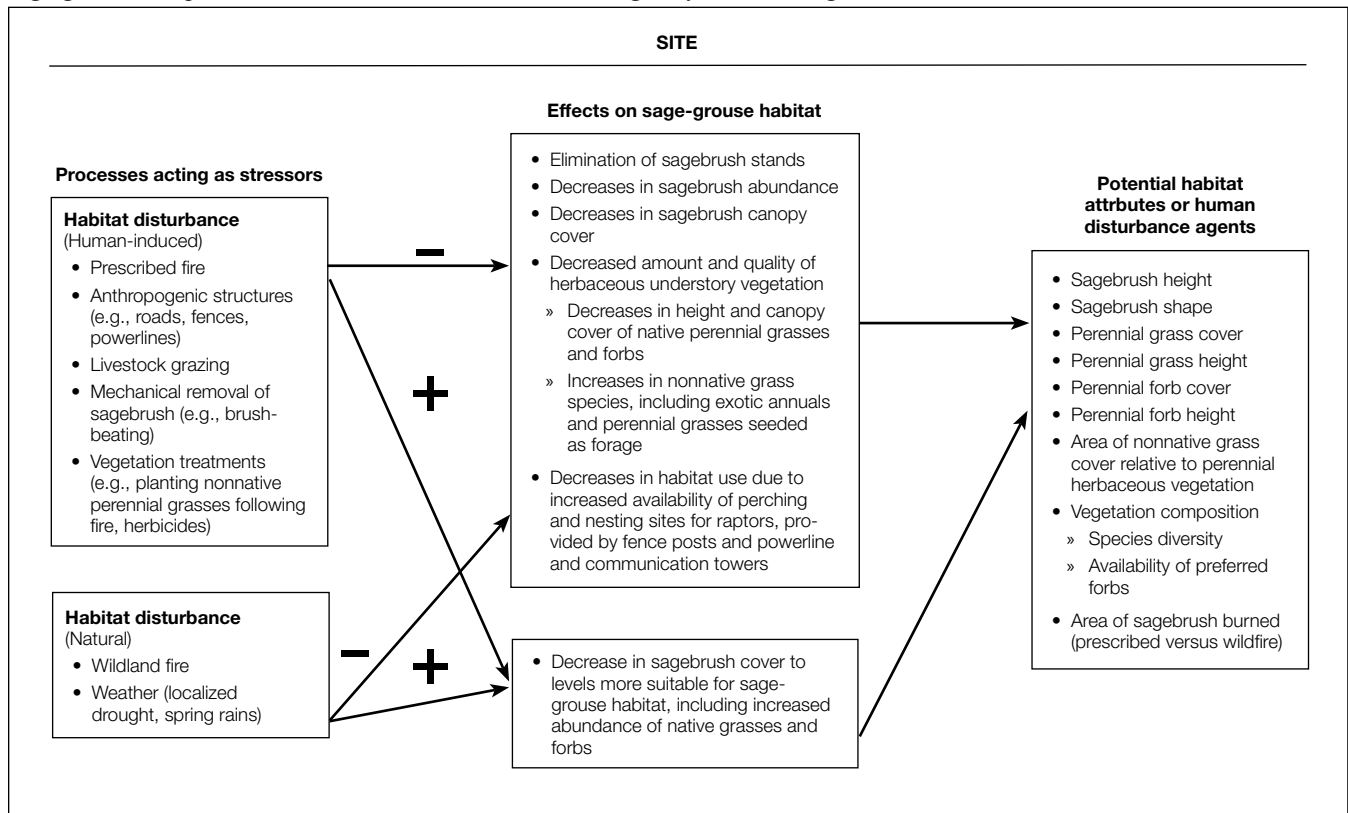


Figure 10.3.—Conceptual model illustrating relationships among natural and human-induced stressors, their effects on greater sage-grouse (*Centrocercus urophasianus*), and potential attributes or human disturbance agents for monitoring at the landscape level.



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 $\geq$ 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 multiscale 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 States³ (<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 midsize 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. Midsize 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/mi² 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 midsize 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, Onyiahialam 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 sub-population 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	Asbury 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 cover⁵ 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 km² [0.39 mi²]) 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 km² (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 attributes⁶ 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 interspersed 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-m² (1.2 yd²) 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

Case Example

Figure 10.5.—Two species of mole salamander—the marbled salamander (*Amphystoma 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 within 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).

Case Example

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 (*Eubbranchipus* 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 midelevation 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 composition 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

Case Example

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.

Case Example

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

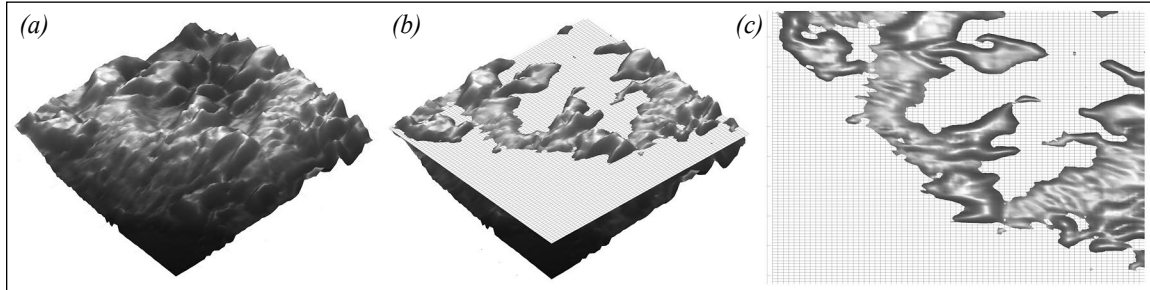
Regional and Neighborhood Levels

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.

Case Example

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

Case Example

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.

Case Example

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.
