

Independent Science Review
Pursuant to a Settlement Agreement
Concerning the Sierra Nevada Forests
Management Indicator Species Amendment
Record of Decision and
Final Environmental Impact Statement

**Recommendations for
Monitoring of Species and Habitats
in Sierra Nevada National Forests**

Prepared for:

Parties to the Settlement Agreement:

Sierra Forest Legacy
Defenders of Wildlife
Center for Biological Diversity
Sierra Club
and
Region 5 of the USDA Forest Service

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Appendix A Biographies of Science Reviewers and Editors

Summary

This report summarizes recommendations from a panel of independent scientists concerning how Region 5 of the U.S. Forest Service should consider performing monitoring of plant and animal species and their habitats within the Sierra Nevada National Forests (SNF). It was motivated by a settlement agreement between the Forest Service and several conservation organizations concerning how the Service had been implementing the Management Indicator Species (MIS) program under the 1982 National Forest Management Act (NFMA). However, a new NFMA planning rule, adopted by the Forest Service in 2012, replaced the MIS approach with new monitoring requirements, changing the context of the panel's review. This report therefore presents general recommendations for how the SNF can develop a scientifically defensible and cost-effective monitoring program that is consistent with the original intent of the MIS program or adapted to fit other regulatory requirements. This report is not intended as a detailed guide to biological monitoring, nor to interpret monitoring requirements under the 2012 Planning Rule or any other particular regulations or guidelines. Rather it presents general scientific advice to be considered by the Forest Service as it prepares and refines monitoring programs under applicable regulations.

The scientists¹ providing these recommendations are fully aware that the Forest Service faces numerous regulatory, financial, and practical constraints in designing and implementing monitoring programs, and that not all of our recommendations may be practicable. Nevertheless, the recommendations represent recent scientific thinking on effective approaches to biological monitoring and they deserve careful consideration by the Service.

Section 1 reviews the regulatory and planning context for this report and recommends that SNF solicit additional scientific input and review as they prepare or revise monitoring programs.

Section 2 summarizes ecological and practical considerations for monitoring programs, which should be (1) grounded in best available science, (2) strongly tied to management goals and objectives, and (3) implementable in light of budgetary and other constraints. It points out that decisions about *what* and *how* to monitor are strongly interdependent and should be driven by monitoring objectives. When possible, the objectives should clearly define desired information outcomes, minimum detectable changes, and levels of confidence in the results. To serve adaptive management, objectives should also define quantifiable standards where possible, such as thresholds in species population metrics or environmental conditions that might trigger a management action. Once objectives are clearly defined, the program should determine what combinations of sampling designs and methods will most efficiently meet the objectives.

¹ The Conservation Biology Institute (CBI) compiled and edited this report with input and review from a panel of independent scientists selected based on their demonstrated expertise in wildlife biology, adaptive management, forest ecology, aquatic ecology, Sierra Nevada ecosystems, and other pertinent topics, as well as to represent a diversity of approaches, types, and theories of ecosystem monitoring. The scientists first individually answered questions about the MIS program crafted by the parties to the settlement agreement, and then discussed similarities and differences in their answers in attempting to craft general, consensus recommendations for scientifically sound monitoring programs. Given that the regulatory context changed during their deliberations, these recommendations are not intended to interpret or apply to any particular planning rule or regulatory context. Brief biographies of the eight reviewers and the CBI facilitator and editor are included in Appendix A.

Section 3 provides guidance for developing objective-driven sampling designs, organized around four generalized monitoring objectives:

1. Monitoring to determine population trends in relation to changes in habitat or environmental condition.
2. Monitoring to determine responses of populations and ecological conditions to management actions.
3. Monitoring to measure progress toward desired conditions.
4. Monitoring to test assumptions or hypotheses that underlie management decisions.

For each of these four general objectives, Section 3 discusses the appropriate monitoring targets, spatial and temporal sampling designs, analytic approaches, and other considerations. We suggest that two basic sampling approaches can address most pertinent monitoring objectives:

1. Systematic sampling across the entire SNF using multi-species occupancy methods to establish status and trends simultaneously for a diverse array of targets (species and environmental conditions). Ideally, sampling plots should be collocated with Forest Inventory and Assessment (FIA) plots to take advantage of the robust environmental dataset this program provides. This sampling design would address most monitoring questions under general objectives 1 and 3 above.
2. Paired sampling, such as Before-After-Control-Impact (BACI) designs, to determine the effects of management actions that are replicated across the bioregion (for general objective 2).

These two approaches may need to be supplemented by other, more specific designs to address general objective 4, because testing assumptions and hypotheses—which is more research-oriented than traditional monitoring—requires each sampling design to be specifically tailored to the assumptions and hypotheses of interest. Addressing all such possible research designs is beyond the scope of this report, and we recommend that monitoring studies intended to test assumptions and hypotheses that underlie management decisions—such as to establish management standards and guidelines or evaluate the impacts of specific management actions on species of conservation concern—be designed in collaboration with researchers and statisticians.

Section 4 provides further guidance on selecting monitoring targets, which can be any aspect of an ecosystem (component, structure, or process) that can be measured and is featured in a monitoring objective. Broad-scale monitoring targets, such as landscape area of specific vegetation cover types, can provide coarse-filter information about ecosystem condition, whereas distribution patterns, occupancy rates, density estimates, or demographic rates of a species can provide fine-filter information about a species' status and trends. We emphasize the utility of using various types of models (e.g., conceptual models of ecosystem structure and function, wildlife-habitat relationships models) to explicitly articulate relationships among potential targets as well as between targets and desired conditions. This can help with prioritizing which targets, of the nearly infinite number of potential options, will yield the greatest information value to cost ratios. We also review considerations for selecting focal species and suggest that

multi-species or omnibus sampling is an efficient approach for many species of interest. We further suggest that some multi-species metrics—such as using assemblages of species that share habitat associations, life-history strategies, or stressors—can be useful monitoring targets for assessing environmental conditions, ecological integrity, and management effects.

Finally, Section 5 briefly presents considerations for efficient implementation and cost control, such as making best use of existing data sources and modeling methods, new data collection technologies, and partnerships with other scientists and citizens.

1 Introduction

This report summarizes recommendations from a panel of independent scientists² concerning how Region 5 of the U.S. Forest Service (Forest Service) should consider performing bioregional monitoring of plant and animal species and their habitats within the Sierra Nevada Forests (SNF)—where *bioregion* refers to a landscape with similar ecological conditions (e.g., climate, physiography, hydrology, and biota) within SNF or within individual national forests, as opposed to the scale of individual projects or sites. The panel was established to meet requirements of a settlement agreement between Sierra Forest Legacy et al.³ and the Forest Service. The settlement agreement concerned how the SNF were implementing the Management Indicator Species (MIS) program under regulations implementing the 1982 National Forest Management Act (NFMA).

As a first phase in developing the recommendations, the panel members answered a set of questions related to the original 2007 SNFMIS Record of Decision (ROD). The scientists then discussed commonalities and differences in their individual answers and attempted to develop general recommendations that all panelists could agree to. However, during these deliberations, the Forest Service adopted a new planning rule (USFS 2012a,b) that no longer uses MIS as a required monitoring element of Land and Resource Management Plans (LRMP). This change in regulatory context and associated uncertainties about the scope of the panel's review complicated the panel's attempt to develop consensus monitoring recommendations. This report therefore presents general recommendations for how the SNF can develop a scientifically defensible and cost-effective bioregional monitoring program—regardless of any particular planning rule, regulations, or guidelines—while remaining generally consistent with the original intent of the MIS program and with some considerations for species-related monitoring under the 2012 regulations. The report is not intended to fully interpret monitoring requirements under the 2012 Planning Rule or any other particular regulations or guidelines; rather it presents general scientific advice to be considered by the Forest Service as it undertakes the difficult job of preparing monitoring plans.

Because several recent publications provide sound guidance for developing population and habitat monitoring programs (e.g., Lindenmayer et al. 2013, Manley et al. 2006, McComb et al. 2010, Noon 2003, Noon et al. 2012, Rowland and Vojta 2013), we summarize key recommendations from this and other recent literature without delving into details. We recommend that the SNF convene additional scientific input and review as they proceed with preparing, revising, and implementing monitoring programs and performing recommended tasks, such as developing and prioritizing monitoring objectives and questions, identifying and

² The Conservation Biology Institute (CBI) compiled and edited this report with input and review from a panel of independent scientists selected based on their demonstrated expertise in wildlife biology, adaptive management, forest ecology, aquatic ecology, Sierra Nevada ecosystems, and other pertinent topics, as well as to represent a diversity of approaches, types, and theories of ecosystem monitoring. Brief biographies of the eight reviewers and the CBI facilitator and editor are included in Appendix A.

³ Sierra Forest Legacy, Sierra Club, Defenders of Wildlife, and Center for Biological Diversity, represented by Earthjustice.

prioritizing monitoring targets, developing conceptual and species-habitat models, performing value:cost analyses, and designing appropriate sampling schemes. Such detail is beyond the scope of this report and would best be developed collaboratively by Forest Service scientists, statisticians, and managers in consultation with additional experts and guided by the recommendations in this report and cited literature.

Pursuant to the settlement agreement, the recommendations in this report are advisory only; the Forest Service is to consider these recommendations as it revises LRMPs and monitoring programs, but has no legal obligation to adopt the recommendations. The scientists providing these recommendations are fully aware that the Forest Service faces numerous regulatory, financial, and practical constraints in designing and implementing monitoring programs, and that not all of our recommendations may be practicable. Nevertheless, these recommendations represent recent scientific thinking of a panel of experts concerning effective approaches to biological monitoring, and they deserve careful consideration. Although panelists expressed some differences of opinion concerning the strengths and weaknesses of alternative monitoring approaches, and about certain details of monitoring designs, they all agree with the general recommendations herein. Most notably, some panelists favored careful selection of a few monitoring targets (species or other ecological components, structures, or processes) based on management objectives, ecological functions, sensitivity to environmental changes, or conservation importance, whereas others favored monitoring a larger suite of easily detected targets to provide broader insights about ecological conditions. The advisors ultimately agreed that these different approaches are complementary and that a hybrid approach should be considered (see Section 2.3).

2 Ecological and Practical Foundations

Any biological monitoring program should be (1) grounded in best available science, (2) tied to management goals and objectives, and (3) implementable in light of budgetary and other constraints. The approach of assigning Management Indicator Species (MIS) as broadly representing the status of habitat types or ecological conditions was designed to be cost-effective, but has been criticized for poor scientific support and lack of clear ties to management goals and actions.

This section summarizes some ecological and practical considerations for establishing a new bioregional monitoring approach that is more reflective of recent science and management goals, while remaining relatively cost-effective. It briefly introduces considerations for establishing monitoring objectives and provides a general overview of what and how to monitor under those objectives. Subsequent sections provide more specific guidance for designing appropriate sampling approaches to address different sorts of monitoring objectives (Section 3), selecting and prioritizing monitoring targets (species and ecological conditions) under each sampling approach (Section 4), and ensuring that the monitoring program is cost-effective (Section 5).

2.1 Developing Monitoring Objectives

Decisions about *what* and *how* to monitor are strongly interdependent and should be driven by clearly stated and quantified monitoring objectives and questions, to the degree feasible with

existing information. A sampling system cannot be designed coherently without knowing what metrics are to be estimated and with what precision. Appropriately stated objectives will allow estimation of cost and feasibility, and these estimates in turn may lead to changes in objectives.

Different monitoring goals generally require different monitoring approaches, and monitoring a few organisms cannot sufficiently determine status or trends of ecosystems, species assemblages, or ecological processes. Monitoring can also be expensive, and not every species or ecological condition can or should be monitored. Therefore, any monitoring program must carefully select a subset of potential monitoring targets (e.g., species, environmental conditions) that are expected to yield the greatest information value for managers, and determine how these targets can be monitored most efficiently to achieve meaningful power and precision. To the degree possible, the necessary power and precision of status and trends estimates should be derived a priori and used to design sampling schemes.

Based on this assessment, we recommend starting with clearly defined monitoring objectives and then iteratively determining what combinations of sampling designs, sampling methods, monitoring state variables, and targets can be monitored most efficiently to answer specific questions relative to those objectives. Section 3 is organized around four generalized monitoring objectives:

- Monitoring to determine population trends in relation to changes in ecological condition
- Monitoring to determine responses of populations and ecological conditions to management actions
- Monitoring to measure progress toward desired conditions
- Monitoring to test assumptions or hypotheses

A clearly defined monitoring objective should state the desired information outcome, the spatial and temporal universe of inference, the desired minimum detectable change, and the desired level of confidence or precision in the results. Ideally, it should also describe a quantifiable standard against which the monitoring results will be compared, such as a threshold that might trigger a management change (Noon 2003, Vojta et al. 2013). We recognize that establishing such thresholds is difficult, especially for poorly studied species or conditions. Where existing information is insufficient to establish them, a specific monitoring or research design could be implemented to establish them, as discussed in Section 3.3.

2.2 Establishing the Spatial Sampling Frameworks

Once the monitoring objectives are identified, appropriate sampling methods can be designed to address them (Section 3). Although it may seem more intuitive to select monitoring targets *before* deciding on sampling design, we reverse this order in the organization of this report to emphasize that a few different sampling designs can be used to address an array of different monitoring objectives and that, for efficiency, multiple monitoring targets can be addressed under each sampling design (Sections 4 and 5). For example, multi-species occupancy or “omnibus” approaches to field sampling—such as the cross-taxonomic Multiple Species Inventory and Monitoring (MSIM; Manley et al. 2005, 2006) for terrestrial systems and River Invertebrate Prediction and Classification System (RIVPACS; Clarke et al. 2003, Hawkins 2006)

for aquatic systems—can be an efficient means of monitoring status and trends simultaneously for a wide array of species and ecological conditions. For monitoring targets or questions that cannot be addressed adequately with these approaches, supplemental monitoring can be designed, such as paired sampling for the effects of management actions or population vital rate monitoring for a species of conservation concern. Important considerations for establishing the spatial sampling framework, regardless of the sampling targets and methods, include: unbiased spatial and temporal representation; power to establish status and detect change; flexibility; and costs (or information value to cost ratios).

We recommend that the monitoring program primarily employ systematic random sampling across the entire bioregion, rather than developing forest-level or local-level sampling designs and attempting to “roll up” or combine the data into a bioregional sample. Given sufficient sampling intensity, this approach allows for stronger inferences about species and ecological conditions across a bioregion as well as within individual forests. However, it may be necessary to increase sampling intensity or supplement the bioregional sampling within particular forests or localized areas to support inferences for narrowly distributed species or ecological conditions.

We also recommend that, to the degree feasible, sample plots be paired with Forest Inventory and Assessment (FIA) plots to take advantage of the valuable plot-level environmental data this program provides. Concurrently collecting habitat and population data in this way can improve program efficiency over time, because it can be used to establish species-habitat relationships, identify which environmental attributes best predict species occupancy patterns, and help focus future monitoring and research efforts (Cushman et al. 2008, Manley et al. 2006, McComb et al. 2010, Mulder et al. 1999). Coordination with the FIA program is sensible and cost-effective because FIA already collects bioregional data and is likely to continue to do so. If sample plots are co-located with FIA plots, the strength and stability of environmental covariates can be assessed and, over time, greater credence given to those habitat relationships that are robust and stable. Additionally, environmental covariates are often critical for modeling detection likelihoods and hence improving population estimates (MacKenzie et al. 2003). Ideally, the collection of covariates can reduce the frequency with which species occupancy needs to be monitored in the field, so long as periodic occupancy sampling is performed to ensure that the habitat metrics remain valid predictors of species condition (Noon et al. 2009, 2012). Additional environmental covariates can be collected based on other regularly scheduled bioregional monitoring. These sources include remotely sensed data such as Moderate Resolution Imaging Spectroradiometer (MODIS) and interpolated climate data. For species where coordination with FIA plots is not practical (e.g., endemic species with highly restricted habitat requirements or distributions), we suggest collecting environmental covariates as a regular part of monitoring.

As detailed in Section 3, we recommend paired-sample designs, such as the Before-After-Control-Impact (BACI) designs (Green 1979, Underwood 1992), when the objective is to detect responses of species to management actions (e.g., vegetation treatments). Additional sampling designs may be required to test specific assumptions or hypotheses that are important to adaptive management decisions, such as to establish or verify assumptions about management thresholds, standards, or guidelines concerning forest structural attributes. These more research-oriented monitoring studies (sometimes called validation monitoring) may best be done in coordination

with the Research and Development division of the Forest Service or other partners, and some of them may be outside the scope of bioregional monitoring as addressed in this report.

2.3 Selecting Monitoring Targets

A monitoring target is any aspect of an ecosystem (an ecosystem component, structure, or process) that is featured in a monitoring objective and can be measured. In practice, monitoring targets are specific monitoring state variables that provide reliable insights into the status and trends in ecological or habitat conditions, focal species, or species of conservation concern. As with sampling designs, the selection of targets should consider temporal and spatial scales and multi-scalar relationships among the targets. Broad-scale monitoring targets, such as landscape area in specific vegetation cover types, can provide coarse-filter information about ecosystem condition, whereas distribution patterns, occupancy rates, density estimates, or demographic rates of a focal species can provide fine-filter information about that species' status and trends.

The list of potential monitoring targets is practically infinite, and not every species or environmental attribute can or should be monitored. We agree with Noon et al. (2012) that it is generally necessary to monitor a small subset of species based on management objectives, their functional roles in the ecosystem, their sensitivity to environmental changes, or their conservation importance. However, because we often know too little to select the “right” subset of such species in this manner, and because bioregional monitoring should provide broader insights concerning ecological or habitat conditions, we recommend also monitoring a larger suite of easily detected species using omnibus occupancy sampling designs (e.g., MSIM and RIVPACS) along with environmental attributes obtained from existing FIA plot sampling data and remote imagery. Although this recommendation may seem at odds with the recommendation to select monitoring targets to answer specific monitoring or management objectives, omnibus sampling is actually complementary to such specific objective-oriented monitoring, because it can help to identify which monitoring components and methods will provide the most meaningful results for question-oriented monitoring. Omnibus methods are efficient at simultaneously collecting data on a suite of species, and the costs do not increase proportionately with the number of species monitored (Manley et al. 2005). Ideally, the full suite of monitoring targets should be relatively comprehensive and complementary to efficiently reflect the suite of management objectives, environmental conditions, and anticipated changes over time at the bioregional and forest levels. In other words, monitoring targets should be useful to informing adaptive management decisions at appropriate scales, without being unnecessarily redundant or cost-prohibitive to obtain.

As detailed in Section 4, we therefore recommend selecting a suite of monitoring targets based on management objectives and hypotheses, using various models to clearly articulate the relationships among targets and between targets and environmental conditions, evaluating whether existing information is already sufficient to meet the monitoring objectives or to test important hypotheses, evaluating which components can be monitored effectively using the bioregional, omnibus sampling approach introduced above, and then selecting additional monitoring targets that would add the greatest information value to cost ratios for forest managers. In some cases, species populations should be monitored directly—mostly using occupancy patterns, rather than more costly population abundance or density estimates; in others,

monitoring habitat extent and condition may be more practical, so long as the species-habitat relationships are well-established and periodically verified to ensure that habitat condition adequately reflects population condition (Rowland and Vojta 2013).

2.4 Sampling Frequency and Duration

Regardless of the spatial sampling approach, the temporal frequency of sampling should be based on the expected rate of change in the monitoring targets to avoid unnecessarily frequent sampling (higher costs) while retaining the ability to detect meaningful changes. Bioregional occupancy sampling requires multiple consecutive visits to estimate detection rates, with the actual frequency of revisits being linked to the ecology of the species or the temporal dynamics of the ecological condition indicators selected, to establish a firm occupancy baseline (Section 3). Thereafter, we recommend that sampling continue perpetually (or at least until it is clear further monitoring of a target is unnecessary), with the sampling frequency dictated by factors such as the rate and magnitude of environmental change and, at the species level, by maximal growth rate, the stability of source habitat, and the temporal variation in population size. Should major changes to a site occur (e.g., severe fire), detection likelihoods are expected to change and need to be re-assessed. As with management-effects monitoring, rapid post-fire vegetation changes probably will affect detection likelihoods. Thus, we recommend including disturbed areas in the subset of sites sampled multiple times per year. As sufficient data accumulate to answer specific monitoring questions and develop occupancy-related habitat relationships models, and as new management questions arise, some targets could be dropped or modified and others added.

3 Objective-driven Sampling Designs

As introduced in Section 2, a defensible monitoring program requires an iterative process that includes development of specific, measurable objectives and identification of targets that answer specific questions relative to those objectives. Section 3 is organized around four generalized monitoring objectives.

- Monitoring to determine population trends in relation to changes in habitat or ecological condition.
- Monitoring to determine responses of populations and ecological conditions to management actions.
- Monitoring to test assumptions or hypotheses about the responses of targets to a management action.
- Monitoring to measure progress toward desire conditions.

By organizing our recommendations around these general objectives, our intent is to provide guidance on possible sampling designs as well as guidance regarding the objectives themselves. For each objective, we include recommendations about spatial extent, sampling frequency, and change detection thresholds, and suggest considerations for selecting the species, habitat(s), or ecological components to be monitored. Section 4 provides more detailed guidance for selecting monitoring targets.

A probability-based sampling design should allow inference to the entire geographic range of the selected targets, or all 10 SNF, even though only subsets of these populations or conditions may be sampled (Thompson et al. 1998). If the sampling design is not appropriate for the monitoring objective or question, the results may contain hidden biases that confound conclusions, or the sample may lack sufficient power to detect meaningful ecological trends.

One reason that MIS monitoring under the 1982 Planning Rule was problematic is that the primary objective—“population trends of the management indicator species will be monitored and relationships to habitat changes determined” (36CFR219.19)—suggests two or more sampling designs that are difficult to carry out simultaneously. An appropriate sampling design for monitoring population trends, whether using abundance or occupancy as the state variable, would be based on a random sample of the target population such that inferences could be made to the entire plan area. In contrast, the sampling design for monitoring the response of a species to specific changes in habitat due to management actions would most efficiently use a special sample of paired plots, in a treatment/control design with pairs representing “changed” (managed) and “unchanged” (not managed) habitat under otherwise similar environmental conditions. The generalized design is unlikely to have sufficient statistical power to detect local treatment effects, and local change detection designs provide limited information on overall population trends or ecological conditions.

We recommend that the SNF articulate monitoring questions so that each question can be answered through a specific sampling design. Systematic monitoring of multiple species and ecological conditions across the entire bioregion can reveal broad-scale patterns, while paired sample designs can help identify likely causal factors. Monitoring to test assumptions or

hypotheses can encompass a wide array of potential monitoring designs, which are best customized, in cooperation with researchers and statisticians, for the specific assumptions or hypotheses to be tested.

3.1 Monitoring to Determine Population Trends in Relation to Changes in Environmental Condition

This section describes the recommended sampling design when the monitoring objective is to establish a correlation between population trend and one or more indicators of habitat or ecological condition for a species or suite of species.

3.1.1 Monitoring targets

A wide array of species, species assemblages, and ecological conditions are suitable targets under this objective, and for efficiency we recommend using multi-species or omnibus sampling methods—such as the Multiple Species Inventory and Monitoring (MSIM) approach for terrestrial species (Manley et al. 2005) and RIVPACS for aquatic ecosystems—rather than limiting monitoring to a select few species expected to serve as indicators of environmental conditions or processes. These multi-species methods provide occurrence data for many species simultaneously and can also produce new location records for rare species (Manley et al. 2005). With this approach, monitoring effort (and cost) is more a function of the number of survey sites and the type and number of survey methods than the number of monitored species. Survey methods that seem consistently efficient and effective are auditory surveys for birds and camera surveys, hair snares, and scat surveys for mammals (see Manley et al. 2005).

While it is sometimes possible to develop correlations between species *abundance* and habitat conditions, for logistical reasons it is almost always more efficient (and therefore less costly) to relate species *occupancy* (the proportion of sample units where the species occur) to habitat conditions. Over about the past decade, occupancy modeling (MacKenzie et al. 2006) has proven to be a highly effective means of monitoring populations compared with more traditional, and costly, monitoring approaches, such as estimating species abundance or population density. The primary statistics are the presence or absence of an organism or species assemblage at a location coupled with an estimate of the likelihood that the organism was present but undetected. Analyzing patterns of co-occurrence among species with the resulting data also provides insights concerning species assemblages or ecological communities, which not only provide information on ecological conditions (e.g., species diversity patterns) but may be used to improve monitoring efficiency over time (e.g., by dropping difficult-to-detect species that are reliably associated with other, easier-to-monitor species or environmental conditions).

Because MSIM is designed to determine occupancy for many species, sample size and the power to analyze the sample will vary across species. For relatively common, widespread, or easily detected species, trend estimation directly from the occupancy data is possible. For others, sample sizes may be insufficient to directly calculate population trends with much precision, but occupancy patterns can at least serve as an early warning of extreme changes in distribution, such as local extirpations or catastrophic population declines. Moreover, even with modest sample sizes (more than about 20-25 localities), the species presence data obtained by MSIM

surveys can be used (perhaps supplemented by other sources of species locality data) to develop empirical habitat relationships models (see Spencer et al. 2011 for an example using Pacific fisher). Once a defensible model is produced, it can be used to track trends in habitat condition over time; with continued surveys, the robustness and predictive power of the models can be evaluated and increased in a Bayesian process (Section 3.1.3).

3.1.2 Sampling design

The bioregion is an appropriate spatial extent for inferring relations between population trends and changes in habitat (e.g., vegetation structure and composition), because sample sizes are sufficiently large and the range of environmental conditions sufficiently variable to infer whether or not a relationship exists. The recommended monitoring state variable (i.e., indicator of a species' population status) is the proportion of sampling sites where the species or multi-species assemblage was detected (occupancy). This proportion is adjusted for imperfect detectability by sampling all or a subset of the sampling sites at least twice during the sampling season to estimate a detection coefficient (MacKenzie 2005). For some species, "detection" can be through genetic sampling of hair or scat rather than visual or aural detections (Noon et al. 2012, Schwartz et al. 2007, Waits 2004).

We recommend developing a systematic sample across the entire bioregion, either by adopting the existing grid used by the Forest Inventory Analysis (FIA) program, or by designing a grid that is minimally offset from the actual FIA points to maintain confidentiality of FIA point locations. Co-locating MSIM samples with FIA points has great advantages due to the large number of high-quality environmental variables recorded at FIA plots, which can be used to establish wildlife-habitat relationships (Zielinski et al. 2006). Individual national forests can increase their local sample, if necessary, by intensifying the sample based on Generalized Random Tesselation Stratification (GRTS; Stevens and Olsen 2004). This method provides for increases or decreases in sampling intensity while maintaining spatial representation across the survey area. (See the Colorado Bird Monitoring Program [Blakesley and Hanni 2009] for a successful application of the GRTS design.) Stratification based on vegetation types or structural stages is not necessary and, in fact, problems can arise when vegetation conditions change due to disturbance events or natural succession. In such cases, the stratified sample would no longer achieve the goal of reducing variability within each stratum, and it is not possible to reassign plots to different strata after monitoring has begun. Rather than stratifying based on vegetation, we recommend evaluating the role of vegetation variables in predicting species occurrences during the analytical process by including them as covariates in predictive models of species occupancy and habitat value (see Section 3.1.3).

Whether or not the sampling design is coupled with FIA plots, we cannot overemphasize the importance of measuring environmental covariates at the same locations that species are sampled. Environmental covariates in this context serve two purposes: (1) they are used to improve estimates of detection likelihoods, because for many detection methods the efficiency of the method is linked to the environment in which it occurs; and (2) to develop statistical wildlife-habitat relationships models using the detection data. Robust, statistical habitat relationship models can serve as monitoring surrogates to a degree (to save monitoring costs), especially for hard to detect species, as detailed more in Section 3.1.3.

The selected indicators of habitat condition must be measured at the same sites where the species is surveyed and within similar time periods to evaluate whether there are correlations between species' presence and habitat attributes over time. This is one of the primary reasons that co-location with FIA sampling plots is desirable: FIA plots provide standardized and detailed vegetation and other environmental data at regular intervals, without cost to the SNF monitoring program, and with direct application to management decisions. See Zielinski et al. (2006) for an example of using FIA plot data to produce a model of fisher resting habitat value that is directly useful to managers.

3.1.3 Analytic approach and thresholds

The power to detect trends in species occupancy will be based on sample size and detection rates. For many species, expected detection rates (the likelihood of detecting an organism given that it is present) associated with specific methods can be estimated a priori based on rates achieved using these same methods elsewhere. For a bioregional grid, the number of sample locations where the species is present will serve as the primary unknown factor when determining the number and locations of survey stations. The only way to determine species detection rates is to survey and subsequently modify the design if necessary. It is important that these initial surveys be as close to the final survey design as possible.

We recommend model selection and multi-model inference (Burnham and Anderson 2002) as an accessible and intuitive analytical approach to identify the environmental variables that best explain the presence or absence of each monitored species. After one sampling cycle, it is possible to identify which species have the strongest affiliations with habitat attributes. However, occupancy trends in relation to habitat change need to be evaluated over longer time scales (e.g., a decade or more). It should be recognized that—in addition to responding to habitat changes due to management, disturbance, and succession—occupancy patterns for some species are likely to change with factors other than habitat. Many populations are naturally highly variable, and their occupancy patterns may be affected by weather, diseases, invasive species, or other factors.

Using species occurrence data to develop empirical wildlife-habitat relationship models can be a powerful tool for designing and refining a bioregional monitoring program. Presence data from existing monitoring data or from Natural Heritage databases like CNDDDB can be linked to environmental covariates using Maxent (Phillips et al. 2006) or other spatially explicit species distribution modeling algorithms that use species occurrence (or presence-absence) data. The resulting probability maps of predicted species distribution (or, by proxy, predicted habitat quality) can be used to inform the initial sampling design. Such species distribution models can also serve as draft habitat relationships models that can be tested and made more robust with subsequent MSIM sampling. For example, Spencer et al. (2011) used the USFS regional fisher monitoring database (fisher detections from camera stations and other detection methods paired with FIA plots) to develop a landscape-scale model (and map) of the probability of fisher occurrence in the Sierra Nevada. Fisher researchers, in turn, have used the predicted probability surface to stratify finer-resolution camera sampling to increase sampling efficiency in a Before-After-Control-Impact (BACI) design (see Section 3.2) to assess the effects of vegetation

treatments on fisher occupancy patterns. Data from the finer-resolution sampling helped validate the fisher habitat model and are providing valuable information about the effects of vegetation management on this species of conservation concern.

We suggest that species occurrence data from MSIM sampling that may be insufficient for direct trend analysis could nevertheless be used to build habitat models that can be used to monitor habitat conditions indirectly for these species. Initial habitat models, based on existing locality data and/or initial monitoring samples, may be weak for some species, and their temporal robustness will be unknown until tested with additional monitoring data. Bayesian statistics provide an appropriate framework for incorporating data from repeated samples. In a Bayesian approach, a habitat model based on previous sampling (or expert opinion) is used as an expectation—in Bayesian terminology, a “prior.” This expectation is modified by new information, and the new model is referred to as a “posterior” model. Using a Bayesian approach, with each sampling occasion, habitat models will improve, and those elements that prove to be temporally stable will be reinforced, whereas those that vary will be removed from the models.

It is important to establish the magnitude of change that is meaningful from a management and ecological perspective prior to sampling, and then adjust as monitoring data inform our understanding of spatial and temporal dynamics of species and habitats. It is also important to identify approximate thresholds for the direction and magnitude of change in occupancy rates that would trigger additional management attention. Setting a target occupancy rate as the management objective or desired condition (e.g., 70% of spruce-fir cover type occupied by Pacific martens) allows us to monitor relative to this target rather than monitor to detect a significant change in occupancy rate (Rowland and Vojta 2013). In addition, posterior thresholds or cut-off points can be established to select species for other monitoring objectives due to their apparent sensitivity to the presence of specific habitat attributes.

3.1.4 Sampling frequency

The sampling design needs to specify the frequency of sampling within a sampling season or year and the number of consecutive years required to achieve a reliable estimate of occupancy for a given time step (where a time step is the number of years over which the objective is to detect a trend). In general, at least two samples are required each sampling season or year (at least initially) to establish detection rates (MacKenzie et al. 2006); species that are difficult to detect may require additional visits per year. Similarly, the more variable a species is in site occupancy between years, the greater the number of consecutive years are needed to estimate occupancy across sites for a given time step. The more precise the desired ability to detect a trend is, the more precise the occupancy estimates need to be for each time step. Precision can be increased by adding more surveys per year, more sample sites, or more consecutive sample years per time step.

For example, if the monitoring objective for a species involves detecting only large changes in occupancy, the species is readily detected, and the species' distribution is highly invariant across time, then it may be reasonable to sample twice within a year, repeated once every time step (for example, sample twice in 1 year and repeat after 5 years to determine trend). Alternatively, if the

monitoring objective requires detecting small changes in occupancy, the species is difficult to detect, or occupied sites are highly variable from year to year, sampling frequency within and among years should be greater to ensure adequate spatial and temporal representation in occupancy estimate (for example, sample three times per year and repeat annually).

If a survey is designed to track a particular focal species, repeated surveys should occur initially at all sample sites to estimate the variability in detection probability and the degree to which these estimates can be improved based on habitat covariates. Once initial estimates are obtained, it is possible to conduct repeated visits for a random subset of locations and single visits at others (Hargis and Woodbridge 2006). The size of the subset should be determined dynamically based on the observed variability in detection probability. We recommend that the survey effort per site generally should target a probability of detection of ≥ 0.5 per year (MacKenzie and Royle 2005); once this is achieved, effort can be reallocated to surveying additional sites and obtaining occupancy estimates across sites within a given year (as opposed to requiring multiple years). This allocation of effort will improve spatial representation, making occupancy data more robust over time relative to changes in species distribution or ecological conditions.

Omnibus sampling can follow more general rules. Initially, survey effort per site per season or year should consist of three visits at all sample sites the first year (MacKenzie and Royle 2005). The number of surveys required in subsequent years will be determined based on detectability of the species of greatest interest. As with individual species, the greater the number of sample points the greater the spatial representation of conditions and potential change over time. In the case of multiple species methods and metrics, a single year should be sufficient to represent a given time step; however, sampling in multiple consecutive years will provide a measure of annual variability, which will improve confidence in detecting directional change over time.

3.1.5 Other considerations

The proposed design should provide estimates of status and trend in occupancy for the entire SNF that cannot be obtained on individual national forests, because the geographic ranges of most species in the SNF are larger than individual national forests. The design also can be used to build or validate species-habitat relationship models and explore the spatial variability in these relations across national forests. While the design can help identify which species are most sensitive to broad-scale changes in vegetation structure and composition induced by management, it will not provide statistically robust information on the location of changes and, therefore, may not inform management actions for individual forests with much precision.

There are two approaches to better understand changes in occupancy as a result of local-scale management actions. The first is to add sampling locations (increase sample density) to decrease uncertainty over causal relations. However, the costs associated with this approach are high. The second is to develop an empirical habitat relationships model to predict the amount and distribution of suitable habitat across the planning area. In this approach local population responses are inferred indirectly from changes in the area of suitable habitat rather than from locally derived occupancy estimates. In most cases, and for most species, we recommend the modeling approach; however, we recognize that local population estimates may be desired for certain high profile organisms and situations.

3.2 Monitoring to Determine Responses of Populations and Environmental Conditions to Management Actions

This section provides general guidance for monitoring to detect changes related to management actions, with primary focus on plan-level and bioregional monitoring.

3.2.1 Monitoring targets

Targets for this sort of monitoring include species, species assemblages, or environmental conditions considered likely to be affected by management actions as opposed to extraneous factors (e.g., environmental changes outside the plan area or unrelated to local habitat changes). To maximize information value to cost ratios, monitoring targets should be easily detectable with sufficient sample sizes to detect changes over relatively small areas and short durations. Target species should therefore have traits like high site fidelity, short to moderate life span (3-10 years), and small home ranges (relative to the size of monitoring plots). Species expected to experience dramatic changes due to factors unrelated to management actions, such as highly eruptive species or those highly susceptible to diseases or weather patterns, should usually not be selected as monitoring targets.

For this objective, we recommend sampling to estimate population size, density, or demographic rates, if feasible, because these variables provide more useful information than occupancy for detecting local effects. However, population estimates can be very difficult and costly for most species, especially those with large home ranges or that are difficult to detect. Therefore we recommend selecting target species and multi-species assemblages for which abundance or density can be estimated easily on sample plots (e.g., understory plants using relevé methods, birds using distance-sampling methods, stream invertebrates based on reach-wide transect methods, fish based on mark-recapture methods).

3.2.2 Sampling design

If the goal is to draw causal inference from monitoring data, we recommend the Before-After-Control-Impact (BACI) design (Green 1979, Underwood 1992). In this design, both managed and control plots are monitored before and after the management action (impact). At a minimum, paired plots of managed and control sites are preferred if it is not possible to monitor sites before implementing the management action. In practice, this approach will be most successful if the monitoring plan and the treatment plan are closely coordinated. The size and shape of treatment blocks will affect the efficacy of post-treatment monitoring, and legitimate control areas need to be left untreated. As such, this approach works best when applied to management prescriptions that are repeated across the landscape. A designed sub-set of these treatment areas can be modified appropriately to allow implementation of BACI designs. While ideally we should formally incorporate change monitoring into project design, this may not be possible due to design constraints and/or scale issues. For example, organisms that occur at low densities may occur within the project area at numbers that are too low to estimate effects.

3.2.3 Analytic approach

Standard frequentist statistics (chi-squared tests, t-tests) can be used to evaluate the effects of management activities on species' abundance or reproductive success. However, for any specific treatment area, these tests will be weak and will likely lead to high rates of Type II statistical errors (Zar 2010)—the conclusion that there was no effect when in fact there was one. As with bioregional occupancy modeling, we suggest that these change statistics be evaluated in a Bayesian framework, where results are aggregated across treatments, forming an expectation which is modified by newly acquired information. Fully detailing the statistical approaches to be used is beyond the scope of our general recommendations, and we recommend that SNF consult with other researchers and statisticians to develop the most effective analytic approach.

3.2.4 Sampling frequency and duration

The frequency and duration of sampling depends on the monitoring targets and what is being measured (e.g., occupancy, population density, reproductive rates). As a general rule when using a BACI design, we recommend at least 2 years of pretreatment surveys to establish a baseline (although we recognize this may not be compatible with some project schedules); the duration of post-treatment surveys obviously will vary with the nature of the targets. Some responses or trends may be immediate and others may take many years to develop (e.g., due to vegetation succession following a management action). For many monitoring targets and activities, it will be necessary to sample repeatedly within a year or season. For example, monitoring herbaceous plant response after prescribed fire will require several visits during the first few growing seasons. Likewise, monitoring reproductive success of breeding birds requires several visits per season to track different stages of the breeding cycle or growth rates of nestlings; occupancy modeling requires multiple visits to estimate detection likelihoods; and many density estimation methods require multiple visits to establish capture patterns.

3.2.5 Other considerations

A significant challenge with monitoring for management effects is the disparity between the scale of a local management action and the scale of the monitoring target's response (Ruggiero et al. 1994), especially for wide-ranging or highly mobile species. This challenge may be somewhat overcome by sampling over large spatial extent (relative to the size of the management action), or by choosing monitoring targets that are affected at the scale of the management action, such as species with small home ranges. However, management interests are increasingly focused on landscape-wide outcomes that are a functions of cumulative effects of multiple types of management actions. This shift in spatial scale of interest and outcome-driven management presents new challenges for understanding the effects of management on species, and applying that understanding to management decisions.

The BACI design does not provide information on population trends, changes in distribution, or occupancy rates over a species' entire range or the bioregion, because the sampling units are limited to sites that are either control or managed sites, often within a narrow range of environmental conditions to reduce variability in population response from factors other than the management activity. Thus, this activity should be viewed as largely separate from bioregional

monitoring, although results of bioregional monitoring may inform this activity. BACI monitoring is most effective for providing immediate feedback on management activities such that the size, timing, or frequency of the management activity can be altered in an adaptive management context.

3.3 Monitoring to Test Assumptions or Hypotheses

Monitoring studies can be designed to test specific assumptions or hypotheses that underlie management decisions, such as snag-retention or canopy closure guidelines, the potential effects on wildlife of creating or decommissioning roads, effects of recreational uses on sensitive species, or the potential impact of smoke on species of conservation concern. Monitoring to test hypotheses is a form of research, and in many cases falls outside the scope of this report, but it can be an important component of an adaptive management program. We therefore provide some general guidance for testing hypotheses that may be pertinent and that require repeated measures (i.e., monitoring) as opposed to “one-off” research studies or experiments.

Sampling design should be developed through formal consultation with a professional statistician to ensure that the design is sufficient to statistically test the hypothesis, and that factors that potentially confuse or bias results are properly controlled. We recommend that the SNF first decide the spatial extent over which the assumption needs to be tested, and then randomly select sites within the universe of suitable environmental conditions. The most efficient approach would be to use data produced by the omnibus monitoring described in Section 3.1 to test hypotheses. The second most efficient would be to select sample plots from the universe of systematic omnibus monitoring sites (or FIA plots), augmenting them if needed to achieve a sufficient sample of conditions and replicates. Pairing with FIA plots provides generous opportunity for validating assumptions because of the unbiased nature of the sample site locations and the breadth of data collected at each site.

In the selection of new sampling sites, it is better to randomly select from the area of inference rather than attempt to combine similar but independently designed and implemented studies. Combining data from multiple independent studies can result in unintended bias if the studies are not representative of the area of inference, and even small differences in data collection methods (e.g., measuring canopy closure from a point on the ground vs. canopy cover as a vertical projection, or using different tree size or density classes) can weaken precision in estimating conditions and relationships.

Although the specific study design should be tailored to most efficiently and robustly test the assumption or hypothesis of concern, in general we suggest three different sampling designs that likely fit most situations:

1. If the assumption is regarding species-habitat relationships, we recommend sampling across a broad range of habitat conditions so that results can be applied broadly to multiple national forests (essentially the same design as described in Section 3.1 but possibly using different monitoring targets and methods).
2. If the assumption concerns a response to management, we recommend paired samples of managed and unmanaged conditions that are located in areas with similar

environmental conditions in other respects (similar to the design described in Section 3.2).

3. If the assumption concerns wildlife responses to human uses or infrastructure such as roads, ski areas, off-road vehicle areas, or oil and gas developments, the sampling design should focus on representative examples of these uses across a range of environmental conditions. For example, distance bands provide a useful design for testing reductions in habitat quality at different distances from infrastructure (Wisdom et al. 2013).

Even though monitoring to test assumptions or hypotheses relies heavily on the contributions of the research community, SNF should consider implementing them as part of the monitoring program, where appropriate. For example, the Pacific Northwest Region of the Forest Service is testing assumptions regarding demographic responses of the white-headed woodpecker (*Picoides albolarvatus*) to fuels treatments in collaboration with the Pacific Northwest Research Station and using funding from several Collaborative Forest Restoration Projects (Mellen-McLean and Saab 2012). Including these activities as a part of monitoring, rather than as a separate effort associated with research, potentially will allow testing assumptions across the planning area, rather than on different forests or regions, as is often the case when research is conducted independently of a bioregional monitoring program.

3.4 Monitoring to Measure Progress toward Desired Conditions

Measuring progress relative to desired conditions is important in adaptive management because it allows for periodic evaluation of whether management actions are meeting plan goals and objectives. Where desired conditions and associated objectives are clearly specified, identifying measures of condition, thresholds, and endpoints should be straightforward.

Historically, silvicultural harvest prescriptions contained a series of testable goals that could be monitored to determine the success of the treatment: a certain number of a specific species of trees growing on the site after a specified number of years, diameter, density, and height specified at various intervals, leading to a specified volume harvested at some future date. While actual validation monitoring of these treatments has been sporadic at best, the process does provide an example of how management should be framed to facilitate validation monitoring. While formally setting numerical and testable goals has been uncommon in planning documents, it is the heart of adaptive management. We cannot adapt unless we have a clear idea of what we were trying to achieve and appropriate monitoring feedback concerning our achievements.

3.4.1 Monitoring targets

The SNF currently monitor vegetation cover types as part of the bioregional monitoring program. This form of monitoring is an excellent component of broader-scale (coarse-filter) monitoring if, collectively, the SNF identify desired conditions for the amount and distribution of vegetation types, structural conditions, and successional stages across the SNF. Further, FIA data can be related to species habitat requirements and therefore can be used to monitor habitat acreage (see Zielinski et al. 2006 for an example).

3.4.2 Sampling design

The spatial extent of the sampling design will be the same as the spatial extent of the desired condition that is being monitored; it could range from a watershed, to an individual national forest, to the entire bioregion. Although broad statements of desired condition may apply bioregion-wide, variability in environmental conditions, productivity, and ecological potential across the bioregion are likely to require developing thresholds and endpoints specific to geographic regions.

For vegetation cover types, successional stages, and/or structural conditions, the indicator will be total area and/or proportional representation of each category, similar to the habitat type monitoring that is already in place in the current SSNF bioregional monitoring program, but with greater value at minimal cost increases (e.g., using remote imagery). DeMeo et al. (2013) present guidelines for monitoring habitat attributes using existing data when possible.

4 Selecting Monitoring Targets

A monitoring target is any aspect of an ecosystem (a component, structure, or process) that can be measured and is featured in a monitoring objective or hypothesis. In practice, monitoring targets are specific monitoring state variables that provide reliable insights into the status and trends in ecological or habitat conditions, focal species, or multi-species metrics. As with sampling designs, the selection of targets should consider temporal and spatial scales and multi-scalar relationships among the targets (Johnson 1980), including scales of population interactions, home range selection, and resource procurement. Broad-scale monitoring targets, such as landscape area of specific vegetation cover types, can provide coarse-filter information about ecosystem condition, whereas distribution patterns, occupancy rates, density estimates, or demographic rates of a focal species can provide “fine-filter” information about that species’ status and trends.

In this section we build on the objectives outlined in Section 3 to guide selection of appropriate monitoring targets, using various models to explicitly articulate relationships among targets as well as between targets and desired conditions. We emphasize that target selection is an iterative process:

- Develop and evaluate objectives, desired conditions, and hypotheses, expressed as conceptual models;
- Review and evaluate the most current data, analytical techniques, and any newly identified environmental stressors to determine whether existing data and techniques are sufficient to meet the monitoring objectives or to test important hypotheses; and
- Evaluate the practical implications of monitoring, i.e., which components would add the greatest value:cost ratios for forest managers.

4.1 Models of Hypothesized Relationships and Conditions

Conceptual models (Noon 2003), as well as species distribution models, occupancy models, etc., can be used to document our understanding of relationships among species and suites of ecological conditions (Lindenmayer and Likens 2010). Articulating these relationships demonstrates our hypotheses for maintaining populations and ecological function and condition. Such models also can serve as tools for interpreting monitoring results in terms of progress toward desired conditions and the contribution of management. To the degree possible, conceptual models should reflect linkages from the broadest stated objectives of desired condition (e.g., maintain or improve ecological integrity and species diversity) down to more specific ecological factors that contribute to these broad conditions, such as drivers, stressors, and specific habitat components for individual focal species.

Figure 4-1 illustrates hypothesized relationships between focal species, species metrics, and ecological condition. Species metrics, whether for individual species or multi-species assemblages, can provide both direct and indirect information about ecological condition, including tree species diversity, rare communities, and key characteristics of ecological conditions. Given the increasing complexity of drivers acting on systems (e.g., climate change,

disease, human disturbance, fragmentation, invasive species), and our inadequate understanding of how species and communities respond to the individual and interactive effects of these drivers, we recommend measuring conditions as directly as possible and avoid surrogacy assumptions to the degree feasible.

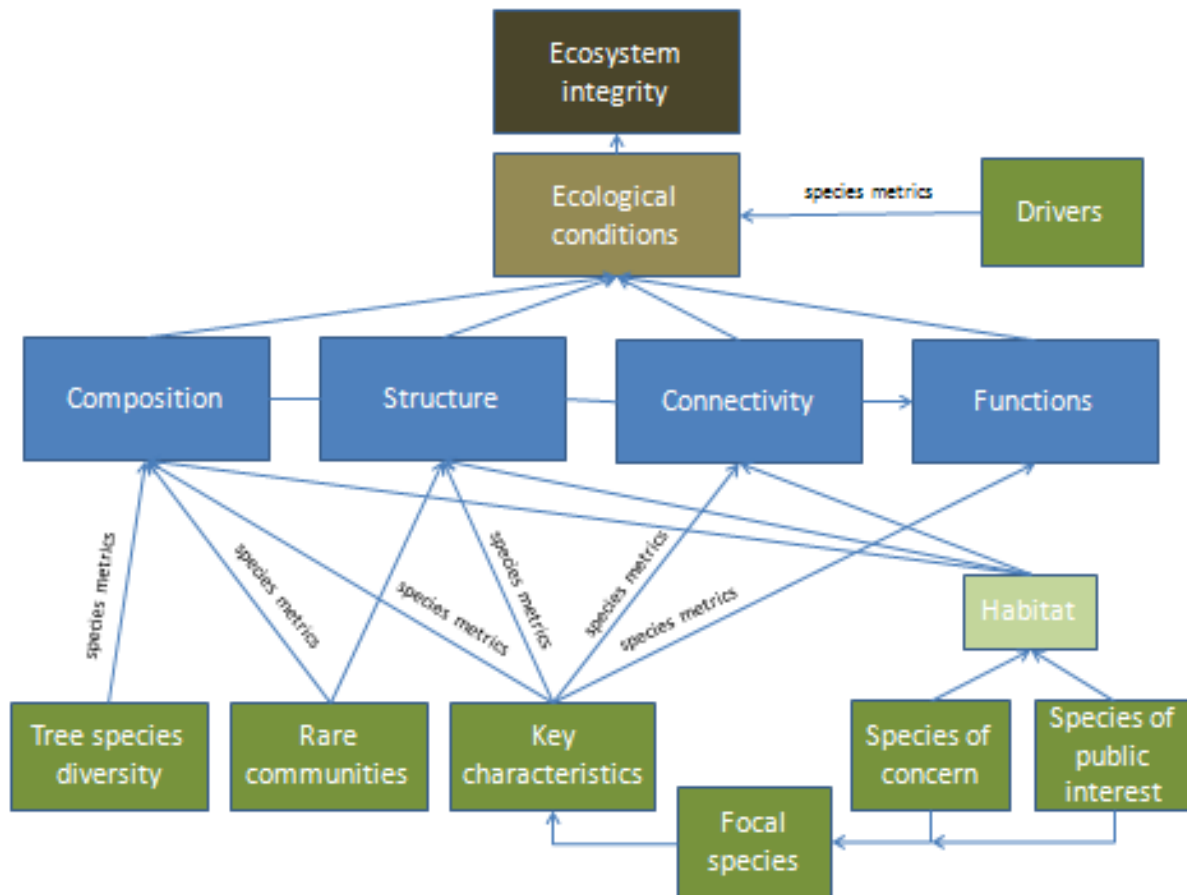


Figure 4-1. Conceptual model of the elements of ecosystem integrity (blue boxes) and specific aspects of these elements that could be addressed in management plans (green boxes).

4.2 Existing and Desired Ecological Conditions

The ecosystems of interest and their existing and desired ecological conditions (as represented by components, structures, and functions that embody them) should be identified and described in measurable terms. Example terrestrial ecosystems might be defined using vegetation communities or land-cover types, vegetation age or structural classes (tree canopy attributes), special features (e.g., large snags, talus slopes), entire life zones (e.g., alpine ecosystems), identifiable landscapes (e.g., the Lake Tahoe basin), and processes (e.g., population changes, nutrient flows, hydrology). Example aquatic ecosystems might include some or all lentic and lotic ecosystem types, special aquatic features (e.g., riverine pools, oligotrophic lakes, seeps), and entire watersheds or drainages (e.g., the San Joaquin drainage, the Clavey River). Desired conditions also may be identified for certain ecosystem services (e.g., water yield, water quality, timber), which in turn are linked to the ecological conditions of some suite of ecosystems.

The ecosystems defined for monitoring purposes need not be spatially discrete or have unique membership. They constitute the suite of constructs—lenses through which we view the status of SNF lands—that are of interest or concern and for which monitoring data can be used to report on their condition. For example, two concerns in the Sierra Nevada that could be translated into monitoring objectives may be (1) condition and trends of red fir forests (all seral stages), and (2) condition and trends of old growth coniferous forests (all species compositions). Desired conditions of these two different but overlapping “ecosystems” could be quite similar—e.g., resilient to climate change, natural range of variability, supporting the full suite of associated plant and animal species, minimal impact of non-native species—but their focal species and other measures of condition would be tailored to address their unique characteristics.

For each ecological condition of interest, the primary drivers of change and system stressors also must be identified. Drivers of change are likely to include a wide range of types and sources, such as planned management activities, urban or recreational development and disturbance, prevalent or threatening diseases, invasive species, and climate change. Identifying the primary agents of change is essential, because at least some measures of condition (including focal species) should target changes expected to result from the primary drivers.

Figure 4-2 provides a partial conceptual model for old-growth conifer forests to illustrate an approach for selecting monitoring targets that are informative about desired conditions. The example shows some conditions relevant to ecological integrity of old-growth conifer forests. It is not a complete model of old-forest conditions, drivers, and monitoring measures, but presents a subset of examples under each category to illustrate how one might represent linkages between a desired condition for an ecosystem of interest, and what data can be collected to determine condition. Ecological conditions are represented first in terms of individual elements associated with components, structures, functions, and drivers. Monitoring targets indicate the characteristics that would be monitored, some of which are direct measures of condition, and others are representative only of condition, because they are either indirect or incomplete measures. We next identify species that would be surveyed to address the characteristics. The model illustrates that individual species and species groups (multi-species metrics) can be used in various combinations to address multiple conditions as direct or indirect measures of

condition. Finally, the monitoring methods are listed to illustrate that, once again, there is a many-to-many relationship between methods, species, and characteristics of conditions.

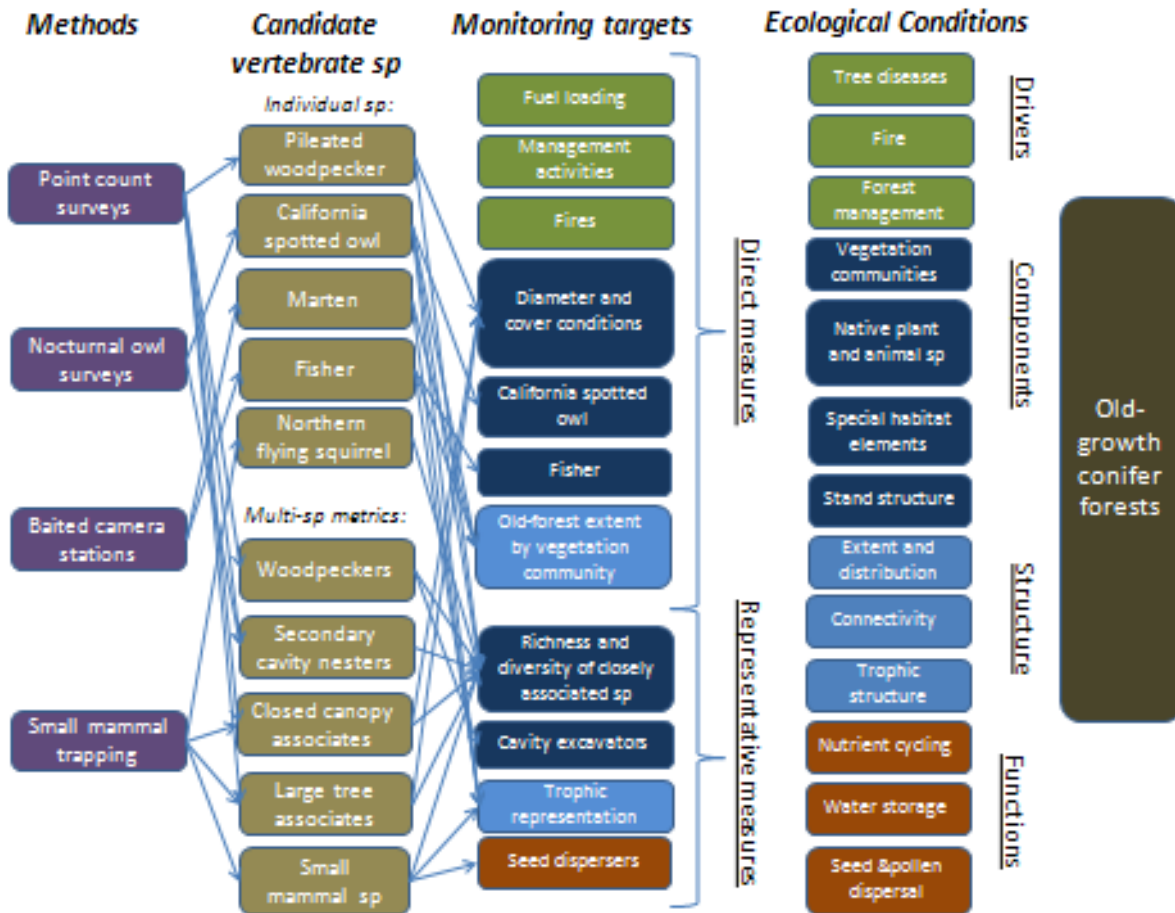


Figure 4-2. Example conceptual model of a monitoring framework directed at desired conditions of old-growth conifer forests.

5 Considerations for Efficient Implementation

As the Forest Service has limited resources for monitoring programs, science advisors were asked to consider innovative and cost-efficient ways for implementation, especially acknowledging the different scales at which management and monitoring must occur. In addition to bioregional monitoring and monitoring at the level of forests or watersheds, the Forest Service has specific monitoring requirements for project-level analysis and endangered species permits, which are not addressed in this report. With the emphasis that monitoring should have clear links to management actions, funding allocation could also be structured to address different scales.

To maximize the information value to cost ratio for implementing a new monitoring framework, science advisors recommended a number of first steps, some of which have been outlined before (e.g., Committee of Scientists Report 1999), but not implemented with a focus on coordinated objectives. The new monitoring paradigm should take advantage of:

- Existing Forest Service data and programs (e. g., FIA, GNN, LandTrendR), including retrospective analyses of existing data to answer questions
- Integration of existing broad-scale data and inventory programs from other agencies (e.g., Breeding Bird Surveys, Landsat, e-Bird)
- New information technologies (e. g. non-invasive DNA and new camera technologies)
- Simulation modelling to explore landscape-level dynamics and effects of landscape change where experimentation is not possible (Noon and Dale 2002)
- Standardization across programs to allow bioregional data pooling
- Collaborative partnerships that provide opportunities and incentives for people to work together and contribute to forest planning
- Increased involvement of the scientific community, linking scientific results and principles to management actions and monitoring
- Economic and social interests in ecological sustainability and productivity of watersheds, forests, and rangelands for present and future generations, recognizing the role of recreation and timber harvest in paying for and achieving sustainability
- Increased civic involvement (citizen science)
- Reducing uncertainty through adaptive management, which requires monitoring the results of management actions so as to make them more effective and cost-efficient
- Management over larger landscapes instead of restricting management to administrative boundaries of national forests, resulting in economies of scale.

This section outlines some of the ways in which these recommendations can be reviewed and implemented with the objective of increasing monitoring efficiency and program effectiveness while at the same time maximizing use of limited funds without sacrificing the validity of monitoring results. The recommendation to co-locate omnibus sampling with extant vegetation

surveys provides an efficient method to monitor many species. MSIM and RIVPACPS are designed to collect data for many species while incurring little additional cost when compared to single species monitoring. Co-location of the resulting occurrence data with measured vegetation and other environmental covariates ensures that useful information for monitoring can be derived for the vast majority of species sampled, either through direct trend monitoring or through the generation of defensible habitat surrogates.

The approach we recommend also includes liberal use of conceptual and quantitative models to make monitoring more efficient. For example, conceptual models of inter-relationships between species and their environment can be used to identify which of several species might yield “biggest bang for the buck” as monitoring components. Identifying “portfolio species” in this way (Section 5.3) can help clarify the conceptual framework of a monitoring program, although it should not be relied on alone to identify the monitoring components or to develop thresholds or triggers for management actions. In addition, species distribution or habitat models built from species locality data and available GIS environmental layers can be highly useful in delineating the monitoring region for a species and stratifying sampling effort for greater cost-effectiveness (Ebenman and Jonsson, 2005 Säterberg et al. 2013).

5.1 Existing Forest Service Data and Programs

Existing Forest Service data and programs could be used to:

- Inform or revise conceptual models.
- Develop initial habitat models using extant species locality datasets.
- Inform or transition to hypothesis-based monitoring for a portfolio of focal species.
- Help identify state variables and covariates.
- Analyze trends.
- Inform decision thresholds or trigger points.
- Populate species occupancy models and couple existing occupancy modeling (e.g., for carnivores) with habitat monitoring.
- Conduct power analyses for developing sampling designs.
- Provide a more robust index of biodiversity (e.g., through co-locating monitoring plots and FIA plots).
- Transition to Multiple Species Inventory and Monitoring protocol (Manley et al. 2006), stressing “omnibus” sampling methods that will provide data for many species and create a more uniform pool of data across all forests.
- Inform forest-level and bioregional programs (e.g., through use of data from project-specific programs).
- Use protocols and classifications that increase value:cost ratios, e.g., Terrestrial Ecological Unit Inventory (Winthers et al. 2005), Existing Vegetation Classification and Mapping (Warbington 2011a,b), relevé methods for vegetation sampling.

5.2 Collaborative Partnerships and Other Data Sources and Protocols

Complementary data from other agencies, collected with protocols that have already been tested, could be incorporated into a new monitoring framework that allows for valid inferences. The following programs are selected examples:

- National Park Service Inventory and Monitoring Program (Fancy et al. 2009)
- State Water Resources Control Board watershed monitoring and assessment
- NASA—remote imagery, cover type, greenness index, and change detection
- Rocky Mountain Bird Observatory—spatially balanced sampling design for birds (Blakesley and Hanni 2009)
- Rocky Mountain Research Station—monitoring strategies for terrestrial animals and habitats that are broader than individual National Forests (Holthausen et al. 2005)
- State Comprehensive Wildlife Conservation Strategies—coarse to medium-scale habitat monitoring techniques (Schoonmaker and Luscombe 2005)
- EPA—Generalized Random Tesselation Stratified (GRTS) Spatially-Balanced Survey Designs for Aquatic Resources (designed to enable Sierra Nevada Forests to increase or decrease the sample size, depending on budget allocations, while maintaining a spatially balanced sample).
- California Invasive Plant Council (Cal-IPC)—publications and databases focused on the Sierra Nevada
- The Southern Sierra Nevada Fisher Conservation Strategy (CBI and a large team of interagency collaborators, in process)

5.3 New Information Technologies

Use of predictive statistical models and remotely-sensed data (versus field measurements) could be incorporated into a new monitoring framework that allows for valid inferences. There have been significant advancements in the last two decades in survey design, statistical methods, the ability to estimate species distribution patterns based on presence/absence data, and in obtaining estimates of animal abundance based on individual animal identities. These advances allow for relatively inexpensive data acquisition, through use of indirect measures and historic data.

- Presence/absence data—temporal and spatial patterns in presence-absence monitoring data also allow inference to changes in animal abundance (MacKenzie and Nichols 2004), the single most important parameter that provides insights into likelihood of species persistence (Lande 1998).
- Changes in species distribution and abundance that presage important state shifts in ecosystems (Säterberg et al. 2013). For example, conceptual models of the inter-relationships among aquatic species can be used to define key monitoring targets at relatively lower monitoring costs (Ebenman and Jonsson 2005).

- Genetic sampling—presence-absence monitoring takes advantage of the ability to confirm the presence of a species at a survey site based on its genetic signature (e.g., in hair or scat) (Schwartz et al. 2007, Waits 2004,).
- Use of digital elevation models and interpolated climate data (e.g., PRISM) in niche models—more predictive than more labor-intensive field measures for aquatic systems.
- Multi-taxon niche models (e.g., River Invertebrate Prediction and Classification System, RIVPACS)—statistical models that enable users to estimate the macroinvertebrate assemblage expected under reference (high quality) conditions based on information on their naturally occurring environmental characteristics. Assessments are based on a comparison of the observed and expected taxa. RIVPACS sampling is specifically designed to provide site-specific data that can be scaled up across multiple sites for a bioregional assessment.
- Occupancy modeling
 - Modeling of climate change in association with stream hydrology, snowpack, prescribed fire and managed wildfire, and species niche models

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Appendix A

Biographies of Science Reviewers and Editors

Facilitator and Editor

Dr. Wayne D. Spencer, Director of Conservation Assessment and Planning, Conservation Biology Institute, San Diego. Dr. Spencer is a conservation biologist and wildlife ecologist with expertise in conservation planning and endangered species recovery. He has worked on regional conservation, land management, and endangered species recovery plans throughout California, and has served as the Lead Advisor or Science Facilitator for numerous independent science advisory processes, including for the Desert Renewable Energy Conservation Plan, the Bay Delta Conservation Plan, and numerous other county-wide or regional habitat conservation plans. Dr. Spencer has also helped develop and apply spatially explicit models of species distribution, habitat quality, habitat connectivity, and population processes to support conservation and land management planning. His research focuses primarily on rare mammal species, including forest carnivores such as the Pacific fisher in the Sierra Nevada. Dr. Spencer is also a Research Associate with the San Diego Natural History Museum.

Assistant Editor

Ms. Jerre Ann Stallcup, Senior Conservation Ecologist, Conservation Biology Institute. Ms. Stallcup has over 20 years of experience in all aspects of endangered species regulations, landscape-scale conservation planning, and monitoring and management of natural resources in the U.S., Europe, and Mexico. She is effective in developing and orchestrating partnerships among the academic community, government agencies, non-governmental organizations, and private landowners to leverage funds and information for achieving conservation goals. She is CBI's project director for *Las Californias Binational Conservation Initiative*, focusing on the border region of California and Baja California, and for the regional planning framework for wind energy development and conservation in the Tehachapi Mountains and eastern Sierra Nevada. She is also involved in developing regional management and monitoring programs for several Natural Community Conservation Planning programs in California and recovery strategies for the coastal cactus wren, island scrub-jay, Florida scrub-jay, and island fox.

Science Reviewers

Dr. Curt Flather, Research Ecologist, U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, CO. Dr. Flather is a landscape ecologist with the Rocky Mountain Research Station's Human Dimensions Program. He holds affiliate faculty appointments with the Department of Fish, Wildlife, and Conservation Biology and the Graduate Degree Program in Ecology at Colorado State University. Dr. Flather is the Forest Service's Wildlife and Fish Specialist for Resource Assessments – an assignment with lead responsibility for completing the agency's national assessments of resource status and trends across all land ownerships as required by the Resources Planning Act. His research is focused generally on understanding wildlife population and species assemblage response to changing landscape patterns driven by

climate change, land use, natural disturbance, and land management activities. There is growing evidence that the distribution and abundance of species may exhibit critical thresholds in their response to reduced habitat amounts, degradation in habitat quality, or increases in habitat fragmentation. His future work will test for the existence of these thresholds and explore their use in setting conservation targets to inform natural resource management.

Dr. Charles Hawkins, Professor and Interim Head, Department of Watershed Sciences and Director of the Western Center for Monitoring and Assessment of Freshwater Ecosystems, Utah State University. Dr. Hawkins is an aquatic ecologist with expertise in the role that landscape setting plays in controlling biodiversity in aquatic ecosystems; survey designs; predictive modeling of community composition; use of aquatic biota to assess and monitor ecological integrity; cumulative effects of watershed alteration on the physical, chemical, and biotic condition of aquatic and riparian ecosystems; and the biology and ecology of freshwater invertebrates, amphibians, and fishes. He has worked extensively with state and federal agencies to develop scientifically defensible indices of ecological condition and regulatory criteria for freshwater ecosystems and ways to simply and directly communicate the results of these technical analyses to the public. His most recent research projects address the effects of climate change on freshwater biodiversity and the indices used in ecological assessments, modeling and assessment of stream water temperature, and modeling the effects of bedrock geology on water chemistry to improve water quality assessments. He served two terms on the editorial board of the *Journal of the North American Benthological Society* (now *Freshwater Science*) and served a 4-year term as Vice-Chair and Chair of the Aquatic Ecology section of the Ecological Society of America. He is currently a member of the Faculty of 1000 with responsibility for Marine & Freshwater Ecology literature. Dr. Hawkins served two terms (2001-2005) on the Ecological Processes and Effects Committee of the USEPA's Science Advisory Board (SAB) and served on the Community Condition Indicators Committee for the H. John Heinz III Center for Science, Economics and the Environment. He has also previously served on a USEPA SAB panel that reviewed the USEPA's Report on the Environment. In addition, he has served on numerous expert panel committees charged with evaluating federal environmental research laboratories, national monitoring needs, and state water monitoring programs. Dr. Hawkins is a member of the technical analysis team that is developing and interpreting biological indices that support the USEPA's national assessments of ecological condition of the Nation's streams, rivers, lakes, and wetlands.

Dr. David Graber, ecologist and science manager working for the National Park Service (NPS). He presently serves as the Chief Scientist for the Pacific West Region of NPS, which includes the 6 western-most states south of Alaska. He has long been based at Sequoia and Kings Canyon National Parks, in the Sierra Nevada of California. During much of his career, Dr. Graber was a field research biologist with NPS as well as USGS, studying species-habitat relationships and exploring the use of extensive field inventories combined with GIS for improved environmental analyses. In more recent years, his efforts have been concentrated on better informing park and reserve conservation and management, as well as the management of broader mixed-use landscapes, through science. This has included the management of plant and animal populations, wilderness stewardship, biotic inventories, and environmental monitoring. In recent years, a large portion of Dr. Graber's efforts have been devoted to the problem of climate change effects,

and how parks can adapt to those changes. Over the years, he has served on a variety of Congressional, agency, and NGO advisory panels, including the Sierra Nevada Ecosystem Project; Giant Sequoia National Monument Science Advisory Committee; National Wilderness Steering Committee; Sierra Nevada Forest Plan Amendment Science Panel; Trust for Public Land Science Advisory Panel. He also serves on several endangered species recovery teams. He was awarded the U.S. Department of Interior Meritorious Service medal in 2000. Dr. Graber graduated from the University of California with a B.A. in Political Science (1970). After several years of work and adventure, he returned to Berkeley's College of Natural Resources to obtain an M.S. (1976) and then Ph.D. (1981) in Wildland Resources Science. His graduate dissertation was *Ecology and management of black bears in Yosemite National Park*.

Dr. Patricia Manley, Supervisory Biological Scientist, USDA Forest Service Pacific Southwest Research Station, Placerville, CA. Dr. Manley is currently the Program Manager for the Conservation of Biodiversity research program at PSW. She has worked on biodiversity management, conservation, and monitoring research in the Sierra Nevada for over 20 years. Her research has focused on natural and human factors affecting biological diversity in a variety of terrestrial, riparian, and aquatic ecosystems in California, with particular emphasis on conservation challenges in the central Sierra Nevada. She has led a number of studies that evaluate the effects of human factors on population and community processes shaping biological diversity, including landscape-scale disturbance and fragmentation effects on species occurrence and abundance, the effects of off-highway vehicles on vertebrate assemblages and their habitats, and spatial and temporal effects of habitat degradation in lentic ecosystems (lakes, ponds, and wet meadows) on associated amphibian and reptile species, and more recently the effects of forest management to reduce fuels and the effects of wildfire on wildlife communities.. She has a strong interest in the design and analysis of landscape-scale ecosystem monitoring, including co-leading the development and testing of a national protocol for monitoring multiple species and their habitats (Multiple-Species Inventory and Monitoring protocol) as a tool to meet national forest obligations to monitor Management Indicator Species. She has published over 50 papers on wildlife and biodiversity management and monitoring.

Dr. Kevin McKelvey, research ecologist with the USDA Forest Service Rocky Mountain Research Station (RMRS) and faculty affiliate at the University of Montana. Dr. McKelvey has worked on endangered species issues for 23 years including the spotted owl, Canada lynx, and wolverine. He was a member of the California Spotted Owl Technical Team and led the Fire Modeling Sub-group of the Sierra Nevada Ecosystem Project. Over the past 13 years he has concentrated research on the large scale monitoring of resources, with an emphasis on carnivores. In this capacity he serves as Team Leader for wildlife monitoring in RMRS. He was the science lead in the National Lynx Survey, which remains the only nation-wide carnivore survey and the largest survey to use non-invasive DNA to identify the target species. He has published extensively on non-invasive sampling methodologies and on landscape genetics. More recently he has lead efforts in Montana and Idaho to evaluate patterns of cutthroat hybridization across over 300 streams; as a side project, the DNA samples collected will likely rewrite sculpin taxonomy in the area. Currently, he is leading an effort to critically evaluate the efficacy using environmental DNA to detect rare salmonids in headwaters streams and is genetically evaluating

rare, endemic organisms including Palmer's chipmunk, several butterfly species, and springsnails in the Spring Mountains, Nevada.

Dr. Barry R. Noon, Professor, Department of Fish, Wildlife, and Conservation Biology, Colorado State University. In collaboration with many outstanding students, Barry has conducted research on the effects of land management practices on wildlife populations for the past 37 years. His focus has primarily been on the conservation of imperiled species in forest ecosystems. During this period, he has published over 120 scientific papers and co-authored 4 book-length reports to the federal government on the sustainable management of public lands. For 11 years, he directed a Forest Service Research Lab in the Pacific Northwest (USA) and served as Chief Scientist of the National Biological Service, Department of the Interior during the administration of President Clinton. During the last 15 years, he has served on federal advisory committees providing recommendations to the Secretary of Agriculture on the management of Forest Service lands to better sustain biological diversity and to the Secretary of the Interior on changes to the Endangered Species Act to encourage conservation on private lands. During this period, he has also provided testimony to the U.S. Congress on numerous occasions on issues regarding the conservation of wildlife in the U.S. and internationally. Dr. Noon has received several academic awards including the Edward T. LaRoe award from the Society for Conservation Biology (1997), an Aldo Leopold Leadership Fellowship from the Packard Foundation (2004), University Distinguished Ecologist (2008-09), and two Senior Fulbright Fellowships to India from the U.S. State Department (2003-04 and 2010-11). In collaboration with his students, his current research focuses on tiger conservation in India, the effects of energy development on imperiled species in the United States, climate change effects on wetland birds, and promoting biodiversity conservation on U.S. Department of Defense lands.

Dr. Martin G. Raphael, Senior Research Wildlife Biologist and Team Leader, U.S. Forest Service Pacific Northwest Research Station, Olympia, Washington. Dr. Raphael received a B.A. (1968) from California State University at Sacramento and B.S. (1972), M.S. (1976), and Ph.D. (1980) degrees from the University of California, Berkeley. He was Project Leader with the Rocky Mountain Station from 1984 to 1989 and has been a Team Leader with PNW Research Station from 1989 to present. He served as Deputy Leader of the Scientific Analysis Team and the Forest Ecosystem Management Assessment Team (1992-1994) and was the leader of the terrestrial science staff for the Interior Columbia Basin Ecosystem Management Project (1996-2002). He is actively involved in the development of monitoring plans for the northern spotted owl and marbled murrelet in the Pacific Northwest. His research includes habitat relationships of forest wildlife, ecology of the marbled murrelet and American marten, and investigations into the roles of riparian habitat for terrestrial and aquatic organisms. He recently led an effort to synthesize information on alternative approaches to the conservation of rare and little-known species. He has published over 150 papers and co-edited 5 books on wildlife habitat relationships and conservation biology.

Dr. Christina Vojta, Senior Faculty Associate, Landscape Conservation Initiative, Northern Arizona University, Flagstaff. Dr. Vojta is a wildlife ecologist with expertise in landscape pattern effects on wildlife species. She provides strategic direction for the Landscape Conservation Initiative, whose mission is the conservation and sustainability of landscapes and

ecosystems in the greater Southwest. Dr. Vojta has worked for three federal agencies in positions at national and regional scales. As the Assistant National Wildlife Ecologist for the Forest Service, she contributed to agency policy related to wildlife management and developed broad scale wildlife monitoring protocols. As Deputy Director for the USGS Southwest Biological Science Center, she oversaw the research programs of 12 scientists located in Flagstaff, Moab, and Tucson. Dr. Vojta was the U.S. Fish and Wildlife's Science Coordinator for the Desert Landscape Conservation Cooperative, a regional multi-agency group whose primary mission is natural resource sustainability in the Mojave, Sonoran, and Chihuahuan deserts. A major theme throughout her career has been promoting the work of scientists and ensuring that their findings are made available to land and resource managers.