Late-Successional Forests and Northern Spotted Owls: How Effective is the Northwest Forest Plan?

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Abstract.—This paper describes the late-successional and old-growth forest and the northern spotted owl effectiveness monitoring plans for the Northwest Forest Plan. The effectiveness monitoring plan for late-successional and old-growth forests will track changes in forest spatial distribution, and within-stand structure and composition, and it will predict future trends. Spatial patterns of forest types will be monitored using remotely sensed imagery. Within-stand structure and composition will be tracked on an extensive set of permanent sample plots established on a grid across the region. Trends in landscape pattern and within-stand structure will be estimated using succession models. A first-instance monitoring report will be available to forest managers in the year 2000. The effectiveness monitoring plan for the northern spotted owl has three primary components. First, an annual rate of population change will be estimated using results of mark/recapture demographic studies on eight large (> 1,000 km^2) study areas distributed throughout the species' range. Second, the rate of change of suitable nesting and foraging habitat will be estimated, as classified from vegetation maps obtained from satellite imagery and assessed at 10-year intervals. Finally, we will attempt to develop predictive models relating changes in owl populations to changes in the amount and distribution of habitat. If these models are successful, we will cut back on the demographic studies and rely on model predictions based on habitat condition. If the models are not successful, we will continue to rely on the demographic studies to track population trends.

The Northwest Forest Plan (ROD 1994) addresses management and conservation of late-successional and old-growth forests on federal lands within the range of the northern spotted owl (*Strix occidentalis caurina*, fig. 1). The plan rests on an assessment of late-successional and old-growth forests and associated species within the range of the northern spotted owl in Oregon, Washington, and northern California (FEMAT 1993) and an ensuing environmental impact statement (FSEIS 1994). Late-successional and old-growth forests provide habitat for northern spotted owls, marbled murrelets (*Brachyramphus marmoratus*), and many other species. The Northwest Forest Plan requires monitoring the status of late-successional and old-growth forests, northern spotted owl, and marbled murrelet over a large landscape (over 10 million ha of federal land) for a long period of time (decades to centuries). Effectiveness monitoring plans provide methods for accomplishing this task (Hemstrom *et al.* in press, Lint *et al.* in press, Madsen *et al.* in press). This paper describes the late-successional and old-growth forest and northern spotted owl monitoring plans. These two effectiveness monitoring plans are part of a larger effort to monitor the effectiveness of the plan (Mulder *et al.* in press).

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Figure 1.—*Physiographic provinces in the Northwest Forest Plan area (Hemstrom* et al. *in press, used by permission).*

LATE-SUCCESSIONAL AND OLD-GROWTH FOREST MONITORING

Two Views of Late-Successional and Old-Growth Forest

Late-successional and old-growth forest can be described from remotely sensed information about upper canopy features "as seen from above," such as canopy cover, the size of tree crowns, and inferences about tree diameter, canopy structure (single versus multiple layers), and, to a very limited extent, tree species (Cohen and Spies 1992). The size class of the overstory, an indication of overstory canopy complexity, and the dominance by conifers or deciduous species will be mapped using Landsat-TM imagery and used to analyze spatial features of late-successional and old-growth forests.

Late-successional and old-growth forest can also be examined from field plot data. Several stand-scale structural elements will be used to characterize late-successional and old-growth forests: live old-growth trees, standing dead trees, fallen trees or logs, canopy layers, smaller understory trees, canopy gaps, and understory patchiness (Franklin *et al.* 1981, FEMAT 1993). Structural characteristics of old forests vary with environment, vegetation type, disturbance regime, and developmental stage. A partial set of stand-scale definitions of old-growth conditions is available (USDA Forest Service 1992, USDA Forest Service 1993a). Note that "old growth" is a subset of late-successional and old-growth forest. Late-successional and old-growth forest, as defined in the FEMAT report (1993) and the FSEIS (1994), includes mature and old forests.

Because definitions, attributes, and scale differ between remotely sensed and plot-based analyses of late-successional and old-growth forest, estimated amounts of late-successional and old-growth forest are also likely to differ. Remote sensing information allows analysis of spatial features, while plot data provide information about stand-scale structure and composition. A uniform grid of permanent field plots for the measurement of stand-level attributes has been established on USDA Forest Service and USDI Bureau of Land Management lands in the plan area (Max *et al.* 1996). Estimates of late-successional and old-growth forest amounts can be derived from these data using stand-based definitions. Because permanent plot methods are easier to repeat over time, they provide the most accurate estimators of late-successional and old-growth forest amount. Although remote sensing and plot views can be compared (Czaplewski and Catts 1992), they are not the same.

Monitoring Approach

The indicators for late-successional and old-growth forest effectiveness monitoring come from a conceptual model (fig. 2) that links ecosystem process and function to stand structure and composition and to biological diversity (Hemstrom *et al.* in press). Because ecosystem process, function, and biological diversity are difficult to monitor directly, several stand composition and structure attributes were chosen as indicators. Monitoring questions hinge on the conceptual model and allow quantitative answers. The monitoring plan also assumes that managers need to understand why changes occur, hence the inclusion of a monitoring question on sources of change.

Monitoring Questions:

1. What are the distribution and amount of forest classes, including late-successional and old-growth forest, from remotely sensed information and from plot data?
2. What is the stand-size distribution, stand interior area distribution, and interstand distance distribution of late-successional and old-growth forest at the large landscape scale?
3. What are the sources (human uses, fire, insects and pathogens, wind, growth, succession, regeneration, exotic species and others) of change?

Indicators

Monitoring indicators were chosen from composition and structure attributes in the conceptual model. Three kinds of indicators will be examined: (1) large landscape-scale indicators that can be addressed through analysis of remotely sensed imagery, (2) stand-scale indicators that can be addressed through analysis of field plots, and (3) change agent indicators.

Large Landscape-Scale Indicators:

1. Amount: The acreage of land meeting forest class definitions by physiographic province by plant community and land management allocation.
2. Distribution: The distribution of land by forest class as depicted in a map.
3. Stand size: The areal extent of stands of vegetation that meet canopy structure and composition criteria for remotely sensed late-successional and old-growth forest classes.

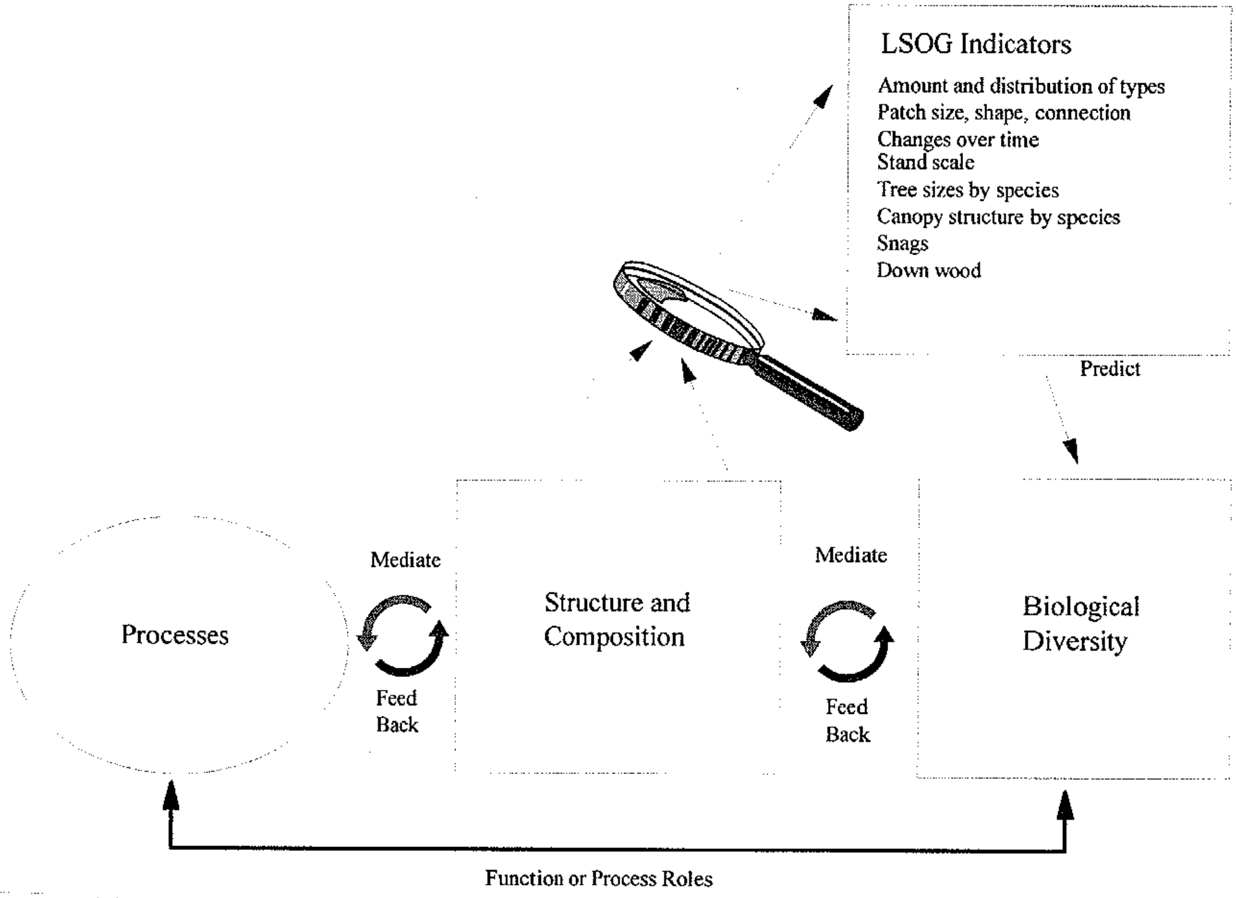

Figure 2.—*Late-successional and old-growth forest effectiveness monitoring conceptual model (Hemstrom* et al. *in press, used by permission).*

4. Stand interior area: Indices of stand shape (edge to area, fractal dimension, and so forth) are often hard to relate to specific habitat issues. Interior core area of stands, after buffering high contrast edges, will be used as an index of stand shape. Interior core area will be analyzed from remotely sensed data using a buffer of 100 m from late-successional and old-growth forest edges with nonforested and small, single-storied forest classes. Other edge conditions may be analyzed, if needed. Chen *et al.* (1992) found edge effects extending more than 400 m in some cases. Most effects seem to occur within 100 m, however.
5. Interstand distance: The distance between late-successional and old-growth forest stands for the region and for each province by plant community will be displayed in a frequency distribution or cumulative distribution function.

Stand-scale structural and compositional attributes summarized from permanent field plots include:

1. The forested area that meets forest class definitions and ground-based definitions of late-successional and old-growth forest (e.g., USDA Forest Service 1992, USDA Forest Service 1993b).
2. Tree diameter class distribution, canopy structure and height class distribution, snag height and diameter distribution, and down woody debris amounts and sizes on a per area basis for different environments within each physiographic province.

Other attributes that may be useful for characterizing late-successional and old-growth forest will likely emerge from research on stand-scale characteristics, ecological process, and function. Stand age, where it can be determined, may be important for some species (Halpern and Spies 1995). Ongoing research indicates that the spatial arrangement of structure at the stand scale may be important for old-growth function (J. Franklin, University of Washington, personal communication). These may be included in future analyses.

Sources of Change

Sources of change will be tracked from both remotely sensed information and permanent grid plot data. Remotely sensed information will not generally allow determination of the change agent, except possibly for timber harvest and large, intense fires. Most information about change agents will come from permanent field plots. Data recorded on each plot include causes of tree damage (such as fire, logging, insects, and disease). These data will be summarized to quantify causes of change.

Change in late-successional and old-growth forest amounts and spatial distribution as detected in remotely sensed images can also come from changes in methods used to process remotely sensed data. It will be important to quantify changes in spatial attributes due to methods alone. In this sense, remotely sensed information about late-successional and old-growth forest attributes is less repeatable than information from permanent field plot remeasurement.

Predictive Models

Changes in late-successional and old-growth forests may take decades or centuries to become evident. Since the time lag between management actions and the development of late-successional and old-growth forest is so long, models would provide an early indication of the need for any adjustments in the plan. Forest growth and development will be projected using stand growth simulation models. Projected trends will provide an early indication, subject to review, about the direction of forest development. Recalibration of existing models and development of new models will likely be necessary.

Baselines

Detection of trends depends on a baseline for comparison. Baselines will be established for remotely sensed and stand scale indicators. A baseline map will be developed using the most recent Landsat thematic mapper imagery available (generally 1996) and will be analyzed for the first monitoring report. Imagery from 1996 will be accepted as approximating the conditions at the start of the Northwest Forest Plan implementation even though some change would have occurred in the 2 years between the date of Forest Plan adoption and the date of the remotely sensed imagery.

A stand-scale baseline will be established from the permanent grid plots distributed across the region by the end of 1998. In addition, maps and descriptions of the strata used in the first report (physiographic provinces, plant communities, land allocations) will be archived for future use. These baseline information sets should be housed in a permanent facility, accessible to anyone who needs to use them.

The FEMAT report (1993) and the FSEIS (1994) also call for comparing existing late-successional and old-growth forest conditions (amounts, distribution, connection, process, function) to long-term averages and long-term average lows. These are defined as the late-successional and old-growth forest conditions in the last several centuries. The FEMAT report and the FSEIS suggest developing this information through fire history studies, stratified by province and plant community, but these studies do not exist for much of the region. A retrospective analysis of conditions before FEMAT is not required for the first monitoring report. Analysis of the long-term averages could be used in subsequent reports as research is completed.

Quality Assurance

Accuracy assessments must be performed on any maps used in late-successional and old-growth forest analysis to understand the confidence interval associated with any results. A random sample of the permanent field plots is remeasured in the field to quantify their accuracy. A random set of permanent field plots will be reserved and used for an accuracy assessment of the vegetation maps (Czaplewski and Catts 1992). Imagery used for developing vegetation maps will be of generally similar vintage across the landscape being analyzed to reduce the effects of changes that might occur within short time frames (fire or logging, for example).

Link to Decisionmaking

A report will be generated every 5 years, more often if needed, detailing the status of threshold attributes and their projected 50- and 100-year trends in comparison to FSEIS (1993) expectations. Attributes that depart significantly from projected trends (more than 10 percent) will be highlighted. Deviations of important attributes from projected trends will trigger a variety of actions, ranging from review of stand succession models and mapping methods, to an examination of the Forest Plan and its implementation. Since results may require interpretation, a panel of scientists, managers, and others will review results and develop interpretations and recommendations for land managers.

How Will We Know if the Plan is Succeeding?

The FEMAT report (1993) and the FSEIS (1994) provide a basis for gauging success. They discuss abundance and ecological diversity, process and function, and connectivity outcomes for late-successional and old-growth forest.

Thresholds provided in these documents are general and regionwide, and they apply only to federal lands. Outcomes in the FEMAT report and the FSEIS link to the likelihood of maintaining both the viability of late-successional and old-growth forest-related species and the likelihood of maintaining a functional, interacting late-successional and old-growth forest ecosystem on federal lands. Current conditions and trends from monitoring analysis will be compared to outcomes and conditions in these documents to provide a basis for judging the success of the Northwest Forest Plan in meeting late-successional and old-growth forest objectives. In addition, models will be used to project forest conditions into the future, since it takes decades or centuries for young stands to develop into late-successional and old-growth forest. Modeled future trends will be compared to projections in the FEMAT report and the FSEIS. A first monitoring analysis and report, generated in 1999-2000, will provide the starting point or first instance summary.

Research Needed

Several important topics should be investigated to refine our ability to monitor late-successional and old-growth forests. These include: (1) more refined uses of, and sources of error in, remotely sensed information to map forest structure and composition; (2) expected rates of transition among forest types over time in different environments; (3) long-term baseline conditions; (4) refined definitions or indices of old-growth forest characteristics; (5) better models to project long-term forest development and spatial patterns; and (6) basic research of the relations between processes, functions, composition, structure, and biological diversity.

NORTHERN SPOTTED OWL MONITORING

The objective of the northern spotted owl effectiveness monitoring plan is to assess trends in spotted owl populations and habitat on federal lands throughout the range of the owl in Washington, Oregon, and California (fig. 1). Before implementation of the Northwest Forest Plan, studies of population trends of the northern spotted owl indicated that the owl's population was declining at a mean rate of 8.4 percent per year (95 percent confidence interval = 0.7 to 8.4 percent) and that the rate of decline had been accelerating (Burnham *et al.* 1996). The forest plan was designed, in part, with the intent to arrest, or possibly reverse, this downward trend. The primary monitoring question is whether the Northwest Forest Plan is successful in halting the downward trend in the spotted owl population (Forsman *et al.* 1996) and in restoring habitat conditions necessary to support a well-distributed and stable population of owls.

Monitoring Approach

Monitoring Questions

Given the overall objectives stated above, the monitoring plan addresses the following general questions:

1. Will implementation of the Forest Plan reverse the declining population trend and maintain the historic geographical distribution of the northern spotted owl?
   A. What is the trend in rates of demographic performance (adult survival, reproduction, turnover, finite rate of population change)?
   B. Can the status and trend in spotted owl abundance and demographic performance be reliably predicted from distribution and abundance of habitat?
2. Is spotted owl habitat being maintained and restored as prescribed under the Forest Plan?
   A. What is the trend in the amount and distribution of habitat?
   B. What is the trend in the amount and distribution of dispersal or foraging habitat?

Conceptual Model

An initial step in designing a monitoring strategy was the development of a conceptual model to help sharpen understanding of the underlying processes that govern the dynamics of the spotted owl population. The conceptual model focuses on habitat change, both in the amount and in its pattern or level of fragmentation. Scale is an important consideration and the design team developed two related models, one at the stand (or home range) level and one at the landscape (or subpopulation) level. As described above for the late-successional and old-growth forest (LSOG) plan, the models have several components including stressors (those processes that act on habitat or individual animals), effects (expected changes on habitat or owls caused by the stressors), and indicators (those attributes of the system that are amenable to measurement and that reflect the effects). The conceptual model developed for the spotted owl focuses on habitat change as well as population change (illustrated in figure 3 for the stand or home range level).

At the home range scale (fig. 3), habitat stressors ultimately affect birth and death rates of individual owls. The proximate responses to disturbance include changes in the density of large living and dead trees and logs as well as changes in the diameter distribution of these features. These attributes affect the density of nest sites and the quality of foraging habitat. These features, in turn, lead to changes in reproductive success and survival of individual owls.

Figure 3.—*Northern spotted owl effectiveness monitoring conceptual model at the home range scale (Lint* et al. *in press, used by permission).*

Indicators

A list of potential indicators was derived from these conceptual models (fig. 3). Desirable attributes of candidate indicators include:

1. The indicator reflects fundamental population processes and changes in stressor levels (habitat change).
2. The indicator is representative of the state of the population.
3. The indicator is measurable and can be quantified at reasonable cost.
4. The indicator demonstrates a low level of natural variability so that changes can be distinguished from background variation.

Primary Components of the Monitoring Strategy

The monitoring strategy for the northern spotted owl has three primary components. First, the team will estimate demographic trends from a sample of marked birds monitored on eight large study areas. Second, the team will estimate trend in amount and distribution of habitat based on analysis of satellite imagery. Third, the team will develop predictive models that relate demographic trends to trends in habitat condition. If these models are successful, predicted population trends based on habitat condition will be emphasized.

Population Monitoring

Three alternative methods for monitoring spotted owl populations were evaluated. The first, based on mark-recapture methods, provides precise estimates of rates of juvenile and adult survival and reproduction (see *Franklin et al.* 1996 and Raphael *et al.* 1996 for methods and rationale). A second alternative would be to estimate population size each year from a set of random calling stations distributed throughout the owl's range. A third method would require a total count of all owls each year in selected intensive study areas. For each of the latter two methods, population change would be estimated directly from changes in estimated population size from one year to the next (or over a series of years).

After evaluating the costs and reliability of each of these alternatives, the spotted owl monitoring team selected the mark-recapture approach. Such studies were already underway and formed the basis for the available estimates of population status (Forsman *et al.* 1996). An additional critical factor in selecting this approach was its utility in supporting development of predictive models. Detailed information on demographic rates would be available for a large sample of spotted owls. For each owl, characteristics of habitat quality and distribution could also be obtained and used as the basis for model development.

Demographic data will be obtained from eight demographic study areas (fig. 4) varying in size from about 1,000 km^2 to over 8,000 km^2. Although these study areas do not cover all of the provinces or ecological conditions across the range of the owl, they do represent a large area that spans a wide range of habitat conditions. Estimates of survival reproductive rates will be analyzed and summarized for individual study areas at the end of each year. A more comprehensive meta-analysis (e.g., Burnham *et al.* 1996) will be conducted every 3 years (starting December 1998).

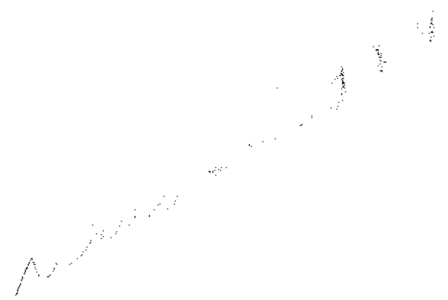

Figure 4.—*Proposed demographic study areas in the Northern spotted owl effectiveness monitoring plan (Lint* et al. *in press, used by permission).*

Habitat Monitoring

The basic information needed for rangewide monitoring of spotted owl habitat is a set of digital map layers that will be managed in a geographic information system. Habitat monitoring will be based on the same vegetation map that will be used by the LSOG monitoring group. Federal land management agencies in the Pacific Northwest Region have committed necessary resources to produce this rangewide map of vegetation. To monitor spotted owl habitat, appropriate structural classes and species of vegetation will be identified and used to classify both nesting and dispersal (or foraging) habitat. Habitat condition and trend will be estimated every 5 years after a baseline map is developed. Monitoring over time will allow estimates of change in the amount and distribution of spotted owl habitat. Habitat reports will be generated showing acres of habitat by land allocation and will include metrics describing landscape pattern. Attributes will include estimates of patch composition, mean patch size, distance between patches, patch shape, and other measures of landscape pattern.

Predictive Modeling

The spotted owl monitoring plan assumes a transition from direct population monitoring to a habitat-based monitoring strategy. This will be possible only if relationships can be established between trends in owl populations and trends in amount and pattern of habitat. Therefore, the monitoring team will focus on developing models that relate relative abundance and/or demographic rates to the amount and distribution of habitat as derived from the habitat monitoring module. Development of these models will take place over the next 5 years. The advantages of moving toward a habitat-based monitoring strategy include:

1. Habitat monitoring can build from existing forest inventory programs as part of ongoing work.
2. Estimating trends in vegetation structure and composition represents a prospective, rather than retrospective, approach to ecological monitoring.
3. Monitoring vegetation change is more cost-effective that directly monitoring owl populations.

We recognize that the expected correspondence between owl trends and attributes of vegetation will have uncertainty. There are a number of possible limitations to this approach, including:

1. Some variation in populations is due to other factors and will be missed if monitoring relies on inferences from habitat change.
2. Changes in habitat may not predict changes in populations with sufficient reliability.
3. Satellite-based habitat maps may not measure the

fine-scale attributes that distinguish higher quality habitat (such as snags for nest sites or logs for prey cover).

These limitations may preclude replacing the demographic approach with the habitat approach. The monitoring team will evaluate the reliability of predictive models and decide whether they will perform as expected. The models will be tested through a series of validation studies in areas outside the demographic study areas. If the validation work indicates the models are not successful, then monitoring will rely on demographic data over the long run, supplemented with estimates of trend in broad habitat attributes.

Research Needs

The distinction between monitoring and research is not as clear as many would think. As part of any monitoring program, a number of research questions and needs are apparent. For the northern spotted owl monitoring plan, we have identified a number of research topics that are key to implementation of the plan. These research needs (in no particular order) include: (1) the relations between habitat structure, prey ecology, individual owl home range, and variation in vital rates of owl populations, (2) owl habitat characteristics and the implications of using vegetation attributes for habitat classifications, (3) role of habitat amount, type, and pattern on the speed, pattern, and survival of dispersing juvenile owls, (4) the use of remotely sensed vegetation information to identify and map spotted owl habitat, and (5) an assessment of a random census plot technique for estimating owl population trends.

CONCLUSION

Monitoring the effectiveness of the Northwest Forest Plan is a long-term process. Decades will pass before land managers know for sure whether or not the plan is producing the intended results. During the next several decades, careful documentation of methods and processes will be necessary if managers of the future are to understand monitoring results. Data will have to be maintained and transformed as computer systems and databases evolve. Land management agencies must be dedicated to a long-term investment in effectiveness monitoring if we intend future managers to understand what happened to late-successional and old-growth forests and related species and why it happened. None of this will be inexpensive, nor will it happen unless effectiveness monitoring becomes a normal, ongoing part of the land management business.

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LITERATURE CITED

Burnham, K.P.; Anderson, D.R.; White, G.C. 1996. Meta-analysis of vital rates of the northern spotted owl. Studies in Avian Biology. 17: 92-101.

Chen, J.; Franklin, J.F.; Spies, T.A. 1992. Vegetation responses to edge environments in old-growth Douglas-fir forests. Ecological Applications. 2: 387-396.

Cohen, W.B.; Spies, T.A. 1992. Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery. Remote Sensing of Environment. 41: 1-17.

Czaplewski, R.L.; Catts, G.P. 1992. Calibration of remotely sensed proportion or area estimates for misclassification error. Remote Sensing of Environment. 39: 29-43.

FEMAT. 1993. Forest ecosystem management: an ecological, economic and social assessment. Report of the Forest Ecosystem Management Assessment Team. Portland, OR: USDA Forest Service, USDC National Marine Fisheries Service, USDI Bureau of Land Management, USDI National Park Service, and USEPA.

Forsman, E.D.; DeStefano, S.; Raphael, M.G.; Gutiérrez, R.J. 1996. Demography of the northern spotted owl. Studies in Avian Biology. 17: 1-12.

Franklin, A.B.; Anderson, D.R.; Forsman, E.D.; Burnham, K.P.; Wagner, F.W. 1996. Methods for collecting and analyzing demographic data on the northern spotted owl. Studies in Avian Biology. 17: 12-20.

Franklin, J.F.; Cromack, K., Jr.; Dennison, W.; McKee, A.; Maser, C.; Sedell, J.; Swanson, F.; Juday, G. 1981. Ecological characteristics of old-growth Douglas-fir forests. Gen. Tech. Rep. PNW-118. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

Franklin, J.F.; Spies, T.A. 1991. Ecological definitions of old-growth Douglas-fir forests. In: Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M., tech. coords. Wildlife and vegetation of unmanaged Douglas-fir forests. Gen. Tech. Rep. PNW-285. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 61-69.

FSEIS. 1994. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth related species with the range of the northern spotted owl. Portland, OR: USDA Forest Service and USDI Bureau of Land Management.

Halpern, C.B.; Spies, T.A. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. Ecological Applications. 5: 913-934.

Hemstrom, M.; Kiester, R.; McDonald, P.; Palmer, C.; Spies, T.; Teply, J.; Warbington, R. 1999. Late-successional and old-growth forest effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-438. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Lint, J.B.; Anthony, R.; Collopy, M.; Forsman, E.D.; Noon, B.R.; Raphael, M.G.; Starkey, E.E. 1999. Northern spotted owl effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-440. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Madsen, S.; Evans, D.; Hamer, T.; Hensen, P.; Miller, S.; Nelson, S.K.; Roby, D.; Stepanian, M. 1999. Marbled murrelet effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-439. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Max, T.A.; Schreuder, H.T.; Hazard, J.W.; Oswald, D.D.; Teply, J.; Alegria, J. 1996. The Pacific Northwest Region vegetation and inventory monitoring system. Res. Pap. PNW-493. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Mulder, B.S.; Noon, B.R.; Spies, T.A.; Raphael, M.G.; Olsen, A.R.; Palmer, C.J.; Reeves, G.H.; Welsh, H.H. 1999. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. Gen. Tech. Rep. PNW-437. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Raphael, M.G.; Anthony, R.G.; DeStefano, S.; Forsman, E.D.; Franklin, A.B.; Holthausen, R.; Meslow, E.C.; Noon, B.R. 1996. Use, interpretation, and implications of demographic analyses of northern spotted owl populations. Studies in Avian Biology. 17: 102-112.

ROD. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl, and standards and guidelines for management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. Portland, OR: USDA Forest Service and USDI Bureau of Land Management.

USDA Forest Service. 1992. Old growth definitions/descriptions for forest cover types. Internal memo dated June 19, 1992. San Francisco, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region.

USDA Forest Service. 1993a. A first approximation of ecosystem health. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 109 p.

USDA Forest Service. 1993b. Region 6 interim old growth definition[s] [for the] Douglas-fir series, grand fir/white fir series, interior Douglas-fir series, lodgepole pine series, Pacific silver fir series, ponderosa pine series, Port Orford cedar series, tanoak (redwood) series, western hemlock series. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.