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Ecological and Financial Assessment of Late-Successional Reserve Management

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Abstract

This paper documents methods for assessing the potential effects of variable-intensity management in late-successional reserves (LSRs) and provides an example (the Gotchen LSR) from the Cascade Range in eastern Washington. The Gotchen LSR study investigates changes in forest vegetation associated with silvicultural treatments, and how different treatment combinations may affect landscape patterns, LSR habitat objectives, fire hazard, and the characteristics and value of wood removed over space and time. The study contributes to the conceptual and technical development of a decision-analysis tool, the northeastern Cascades landscape analysis, management, and monitoring system (NOCLAMMS), for land management. Landscape evaluation of the Gotchen LSR reveals that since the 1930s, forest structures have become more homogeneous; area and average patch size of young, multistoried forest stands have decreased; and spatial patterns of late-successional forest have changed. These changes alter vegetation response to disturbances like fires, insects, and diseases, and suggest that different structures and patterns may better support LSR objectives over space and time. Study results aid in identifying candidate treatment areas, in developing prescriptions to maintain or restore desired stand structures and patterns, and in understanding the financial commitment necessary for different management actions. Silvicultural treatments are applied by using the forest vegetation simulator (FVS). The financial evaluation of ecosystem management activities (FEEMA) software is used to calculate net revenues associated with different treatments. Results from one stand illustrate these methods.

Keywords: Forest reserves, northern spotted owl, restoration silviculture, habitat management, western spruce budworm, fire hazard.

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Introduction

A network of late-successional reserves (LSRs) within the range of the northern spotted owl (*Strix occidentalis caurina*) extends east of the Cascade Range in the Pacific Northwestern United States. This research considers how achieving LSR objectives over time may be influenced by current forest conditions, administrative boundaries, disturbance dynamics, and costs of silvicultural treatments. Our study area, the 15,000-acre Gotchen LSR, illustrates the problem of maintaining a specific successional stage within fixed boundaries without clear guidance on the legal role of active management. An overview of issues in forest reserve establishment and management sets the context for our research questions and is followed by a description of the study area, methods, some initial findings, and an example.

Background on Forest Reserves

Land classification terms are intertwined with land use. The way land is classified influences both how it is managed over time (Burgi 1999) and how it is valued (Abbott et al. 1994). Ambiguity in classification terms can create confusion in land management. The land classification term “reserve” has a history of different international, national, and local definitions (Congressional Record 1907, Fagergren 1998, Green and Paine 1997, IUCN 2000, Schama 1995). These differences affect federal forest reserves in the Pacific Northwestern United States. For example, the Northwest Forest Plan (NWFP) established late-successional reserves within the range of the northern spotted owl but did not specify which historical definition was to be used.

A debate about the role of passive vs. active management in LSRs currently exists, in part, because land classified as a reserve may, depending on the definition, be eligible for either type of management. Adding to the debate, documents underlying the NWFP contain untested assumptions about forest development and the costs of LSR management, particularly on the eastern slope of the Cascade Range (FEMAT 1993). We explore these assumptions by investigating the potential ecological and financial effects of passive vs. active management in the Gotchen LSR.

Issues in Reserve Management

Dynamic Systems

Forest ecosystems are dynamic in space and time (Harper 1977, Koslowski et al. 1991, Watt 1947). Plants and animals continuously reproduce, grow, and die. Some plants, such as trees, can live for centuries, whereas others have annual life cycles. Over time, different combinations of plant and animal life histories and architectures create community structures that support different groups of organisms and processes. In a forest, for example, the animals using early-successional communities differ from those in later seral stages (Harris et al. 1982). The role of dead plants like snags and logs also differs as the community changes (McComb and Lindenmayer 1999). How plants and animals are arrayed within a particular forest stand—the horizontal and vertical structure—influences what other plants and animals may thrive there over time (Spies 1998). Similarly, the relation of that forest stand with neighboring land creates influential structures and patterns (Franklin and Forman 1987, Reiners and Lang 1979, Turner 1989). A “landscape” refers to groups of smaller land units and, like these smaller units, changes continuously. Landscape dynamics have important implications for the potential risks associated with different types and intensities of forest management and land use.

Land use patterns resulting from human activities (e.g., roads, cities, and logging) are superimposed over landscape patterns resulting from disturbance events (e.g., landslides and wildfires) and biophysical factors (e.g., soils and pathogens). If land use patterns differ significantly from landscape patterns, changes may occur in soil productivity, fire regimes, and species extinction rates (Christensen et al. 1996). The risk of these changes is uncertain but potentially high, and thus an ecosystem-based approach to land management has been adopted for federal forests in the Pacific Northwestern United States (Anon. 1999). In ecosystem-based management, the primary objective is maintaining ecosystem structure, organization, and function rather than producing commodities (Woodley et al. 1993). Currently, there is no agreement on either how to assess the risks of ecosystem change or how to manage forests for ecosystem function, but different approaches have been proposed. They include:

- Using historical disturbance patterns to guide land use decisions (Cissel et al. 1999)
- Using range and variation of historical vegetation patterns (Morgan et al. 1994, Swanson et al. 1994, Hessburg et al. 1999a, Landres et al. 1999)
- Establishing reserves to protect key ecosystems, organisms, and processes (e.g., Diamond 1975).

Static Boundaries

Forest reserve boundaries generally are fixed around an area chosen for specific reasons. Late-successional reserves, for example, were established to address biological and social concerns about the persistence of species associated with late-successional forests. Fixing administrative boundaries around dynamic ecosystems may, paradoxically, undermine reserve objectives, especially if:

- Reserve size is inconsistent with key processes and organisms (Everett and Lehmkuhl 1996, 1997; Pickett and Thompson 1978),
- Forests within the reserve were significantly modified before boundary establishment (Peluso 1992), or
- A nonmodified forest reserve is an “island” surrounded by heavily modified land (Curran et al. 1999).

Norton (1999) reviews the biogeographic origins of, and arguments surrounding, reserve designs including the relative merits of several small reserves connected by corridors vs. large reserves.

Potential Role of Management

Human activities permitted in forest reserves differ by country and with reserve objectives (Parviainen et al. 2000). Relations between current conditions and reserve objectives influence how forest reserves are established and maintained. Passive management may be all that is needed if the successional dynamics of current forest conditions are consistent with the conditions and processes desired for the future. In contrast, active management could be required to achieve future objectives. If, for example, a species like ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is desired but no seed source is available on site, or if seeds are available but conditions for germination, establishment, and growth are not, then favorable conditions for regeneration and competitive advantage would need to be created. Hence, the role of active management depends on reserve objectives and the extent to which current and predicted future conditions support these objectives at appropriate scales. If conditions and objectives are inconsistent, or if methods to make them consistent are not available or are too costly, then the risk increases that reserve objectives may not be met. Failure to achieve reserve objectives could weaken support for a system of reserves, especially if the system restricts or eliminates access to public land.

There are many federal and state parks, wilderness areas, and reserves in the Pacific Northwestern United States. The NWFP created additional types of reserves on federal land, including riparian reserves and LSRs. It is uncertain whether the objectives for these reserves can be achieved, given current ecological and regulatory conditions. This uncertainty is documented in the Forest Ecosystem Management Assessment Team (FEMAT) report and in the record of decision (ROD) for the NWFP (USDA and USDI 1994). The FEMAT report noted, for example, the presence of young stands in LSRs and asked, "Should these young stands be silviculturally treated to accelerate their attainment of a condition that mimics late-successional forest conditions . . . or should there be no silvicultural treatment . . . under the assumption that such stands will evolve, given enough time, into the desired habitat conditions?" (FEMAT 1993). The topic was thus left open with the idea that scientific studies could develop and investigate testable hypotheses (USDA and USDI 1994). Another assumption of FEMAT recast in this study as a testable hypothesis, is that silvicultural treatments could both reduce fire hazard and maintain and develop late-successional forest conditions.

Late–Successional Reserves and The Northwest Forest Plan

Definition

The NWFP established LSRs on 30 percent of the federal land area within the range of the northern spotted owl (USDA and USDI 1994). The ROD, which jointly amended the planning documents of 19 national forests and seven Bureau of Land Management Districts, adopted seven land allocations. Objectives for the LSR land allocation are to "protect and enhance conditions of late-successional and old-growth forest ecosystems, which serve as habitat for late-successional and old-growth forest related species including the northern spotted owl (USDA and USDI 1994)." These objectives are similar to those of International Union of Conservation of Nature (IUCN) category IV (Habitat/ Species Management Area), which suggest global standards to ensure the maintenance of habitats and meet the requirements of particular species (IUCN 2000). The NWFP objectives may, arguably, be clear, but the methods to achieve them are not, especially on the eastern slope of the Cascade Range, where both disturbance dynamics and previous land use patterns complicate maintaining a specific seral stage within fixed boundaries (FEMAT 1993).

Issues

The range of the northern spotted owl extends east of the Cascade crest, where dense, multilayered canopies and down wood create suitable habitat (Buchanan et al. 1995, Gaines et al. 1997, Thomas et al. 1990) but also increase susceptibility to fire (USDA and USDI 1994) and to insects that cause defoliation (e.g., western spruce budworm (*Choristoneura occidentalis*))(also see Brookes et al. 1987). Stand replacement fires are part of the historical disturbance regime (Agee 1990, 1993, 1994; Camp et al. 1997), yet such fires may be socially unacceptable because of actual or perceived risk to human life or property, wildlife habitat, riparian systems, and tourism. Due in part to previous federal fire suppression policies, mixed-conifer forests currently have more small to intermediate shade-tolerant trees than would have survived under historical fire regimes (Covington et al. 1994, Hann et al. 1997, Huff et al. 1995, Lemhkuhl et al. 1994). This increased biomass is distributed on many small-diameter trees, rather than on fewer, larger ones (GAO 1999). Silvicultural treatments in such conditions are often expensive, owing to the high cost of removing small trees and the generally low market value of wood removed. These conditions are prevalent throughout the interior West (Everett et al. 1997), and budget allocation methods in the National Forest System may mean that stands with the highest fire hazard are left untreated (GAO 1999). As stated in FEMAT (1993), "some habitat modification activities in Late-Successional Reserves will generate enough revenue to pay for themselves . . . Others will not and need to be supported by appropriated funds.” This research evaluates what silvicultural treatments may fall in which category and the potential subsidies needed for habitat management.

Land managers responsible for LSRs on the east slope of the Cascade Range are concerned about potential risks to existing late-successional habitat associated with passive management and about the ecological and financial implications of active management. The northern spotted owl is federally listed as an endangered species, and thus the primary concern in the LSRs is for owl habitat. Accordingly, we focus on owl habitat but recognize that the requirements of other species associated with late-successional forest ecosystems also must be considered.

The NWFP acknowledges a potential need for active management in LSRs by specifying that silvicultural systems allowed within them should “prevent large-scale disturbances by fire, wind, insects, and diseases that would destroy or limit the ability of the reserves to sustain viable forest species populations” (USDA and USDI 1994). The NWFP also explicitly recognizes the challenges associated with maintaining suitable owl habitat east of the Cascade Range, where there is an “increased risk of fire . . . due to xeric conditions and the rapid accumulation of fuels as the aftermath of insect outbreaks and drought” (FEMAT 1993). Management guidelines are offered in the ROD that permit “risk-reduction” activities in LSRs on the eastern slope of the Cascade Range, provided such activities are “clearly needed” and assure “long-term maintenance of habitat” (USDA and USDI 1994). There is lack of agreement, however, among management and regulatory agencies, advocacy groups, and citizens on acceptable levels of risk and on the best management practices to provide habitats over the long term at scales appropriate for species associated with late-successional forests. The situation seems urgent because passive management of current conditions may instead result in the “large-scale disturbances” the ROD seeks to avoid. Active management, however, raises both technical and philosophical questions. “On one side of the debate are those who, cognizant of past successes, believe that management can and will produce desired results. On the other side are those who, cognizant of past failures, are more cautious. They believe that proof should precede any silvicultural activities in reserves” (FEMAT 1993). Silvicultural treatments could have mixed effects over the short term (decades), long term (centuries), and differing spatial scales. Actions taken now to avoid or minimize large-scale disturbances might have direct or indirect consequences for Native American treaty rights or habitats of rare or endangered species (USDA and USDI 1994). Nonfederal landowners are concerned about potential implications of passive management on adjacent private property rights and uses. Lack of information about the potential effects of passive and active management fuels the debate. This research addresses the technical, rather than the philosophical, aspects of LSR management by considering the following general questions:

- What are the potential consequences of passive LSR management on the eastern slope of the Cascade Range?
- How might an understanding of landscape pattern-process interactions guide LSR management?
- What human activities support LSR objectives?
- Do the activities generate revenues that offset the cost of habitat management and monitoring?

Gotchen Late-Successional Reserve Study

Objectives

This study addresses these four general questions in the Gotchen LSR by (1) characterizing recent changes in vegetation structure and composition at both stand and LSR levels; (2) evaluating associated changes in fire and western spruce budworm hazard; (3) testing if silvicultural treatments can simultaneously reduce fire hazard, maintain existing late-successional habitat, and recruit future habitat attributes; and (4) calculating net revenues associated with different combinations of passive and active management.

Analyses of both Gotchen LSR vegetation conditions and patterns of potential responses to alternative treatments contribute to the northeastern Cascades landscape analysis, management, and monitoring system (NOCLAMMS), currently being developed by the authors. The Gotchen LSR is the pilot area for NOCLAMMS, a decision tool that enables land managers to simultaneously analyze the effects of alternative management strategies on several resources. The goal of NOCLAMMS is to integrate information on landscape pattern and process interactions, key habitats and species, and economics.

The three-step NOCLAMMS process uses the USDA Forest Service ecosystem management decision support (EMDS) software (Reynolds 2000). The EMDS is the integrative framework for structuring ecological and management data. The first step in the iterative process uses EMDS to evaluate whether current vegetation patterns (e.g., late-successional forest) fall within a range of landscape reference variation (Hessburg 1999a, 2000a). Current conditions in the Gotchen LSR illustrate inputs to this first step. If current conditions are outside this range, the second step uses the data, processes, models, and output described in this paper to develop silvicultural treatments and to evaluate their potential contribution to future landscape patterns. The final step uses EMDS to evaluate if these future patterns meet the objectives established for owl habitat, fire and budworm hazard, and reference variation. Net revenues are estimated for treatment combinations that meet these objectives to evaluate the potential cost of habitat management. These methods could be adapted for similar analyses in other locations where information on a range of potential costs associated with developing and maintaining specific forest structures is desired.

Study Area

The Gotchen LSR is in south-central Washington (T. 7 N., R.10 E.) in the Gifford Pinchot National Forest. The northern boundary of the LSR is the Mount Adams Wilderness Area, the eastern is the Yakama Indian Reservation, the southern is a mile inside the Klickitat County line, and the western boundary follows the White Salmon River (fig. 1). The Gotchen LSR was included in planning areas of both the NWFP (USDA and USDI 1994) and the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (Quigley and Arbelbide 1997) but excluded from the analysis of the Eastside Forests Scientific Society Panel (Henjum et al. 1994). In this study, the LSR administrative boundaries define the landscape analysis unit.

Most of the Gotchen LSR falls within the grand fir (*Abies grandis*) series (Franklin and Dyrness 1988, USDA Forest Service 1997). Elevation ranges from about 3,000 to 6,000 feet and estimated annual precipitation from 35 to 65 inches (Topik 1989). There are six documented spotted owl activity centers in the Gotchen LSR (USDA Forest Service 1997).

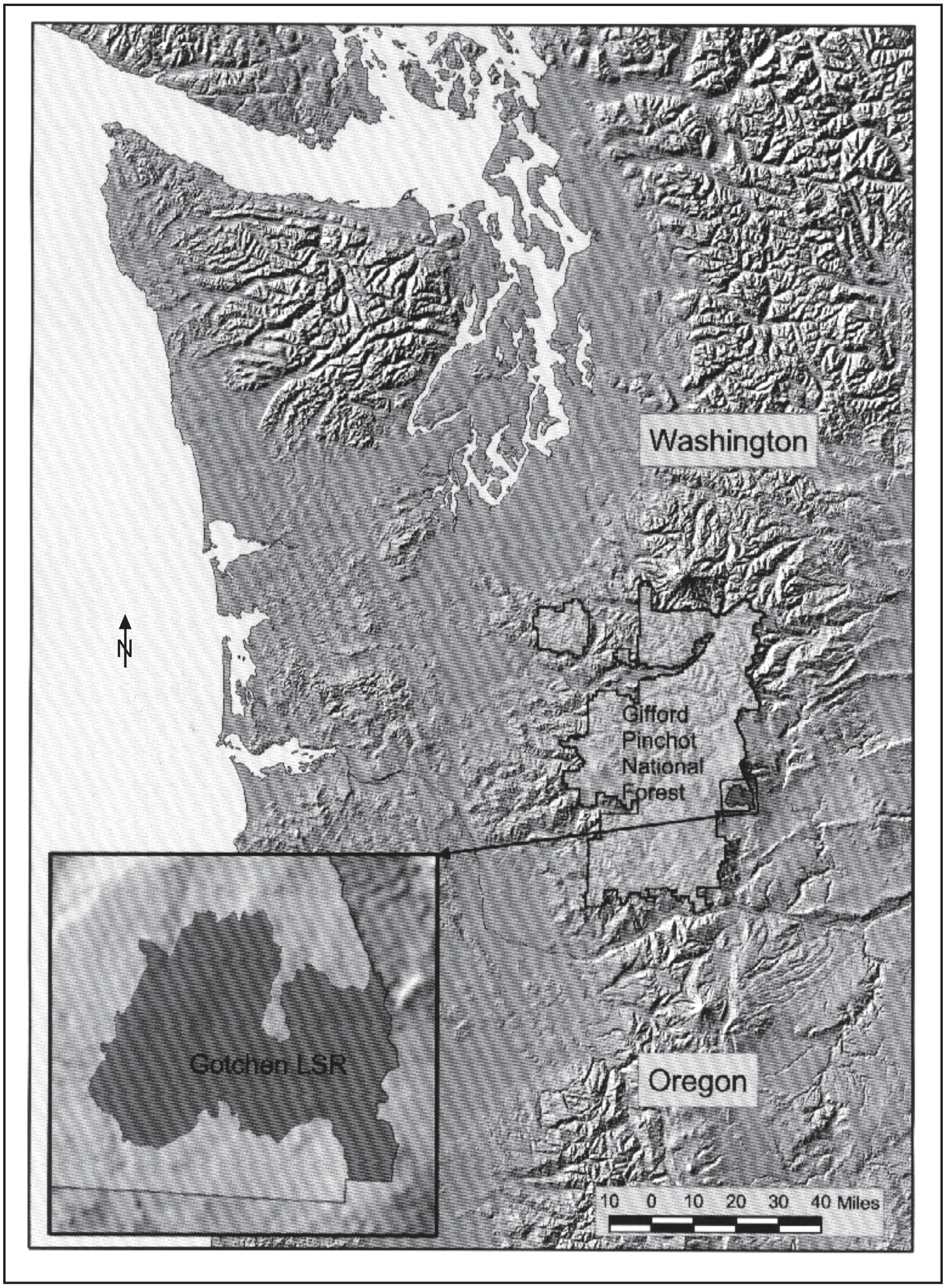

Figure 1—Location of the Gotchen Late-Successional Reserve.

Conditions in LSRs on the east side of the Cascade Range are generally drier than those on the west side (FEMAT 1993, USDA and USDI 1994), which means that increasing stand density also increases competitive stress and makes all trees more susceptible to insects and pathogens (Anderson et al. 1987, Edmonds et al. 2000, Seidel and Cochran 1981). A continuing western spruce budworm outbreak began in the Gotchen LSR in 1994 (Willhite 1999). Budworm defoliation may affect owl habitat suitability both directly, by reducing canopy cover, and indirectly, by reducing habitat availability through increased tree mortality and fire hazard.

Methods

In the first phase of this study, we characterize changing vegetation patterns in the LSR and investigate relations among these changing conditions, late-successional habitat, and vulnerability to fire and budworm disturbance at both the stand and landscape scales. Phase one addresses the first general question on the potential consequences of passive management. Some of the results from phase one are included in this paper. In the second phase, we will address the three remaining general questions (see "Issues") by evaluating changes in untreated vs. treated stands over space and time and assessing the potential effects of associated landscape patterns on owl habitat, fire and budworm hazard, and characteristics of wood removals. Results from the second phase will be reported in future publications.

Phase 1: Characterizing recent change—We will use empirical and simulation methods to investigate stand-level structural and compositional changes in owl habitat associated with budworm defoliation in the current outbreak. A grid of randomly allocated sample plots, installed in 1992 prior to the current outbreak, will be remeasured in 2000. Plots are arranged in a systematic sampling grid near the Smith Butte owl activity center. Each plot consists of three nested subplots and a down wood transect. The largest plot, in which data will be collected on overstory trees and snags >10 inches diameter at breast height (d.b.h. or 4.5 feet), is a 40 basal area factor variable radius plot. Inside the variable plot are two fixed plots: one 1/20th-acre and the other 1/50th-acre. In the fixed plots, data on understory trees, snags <10 inches d.b.h., shrubs, herbs, and conifer regeneration will be collected. A 330-foot down wood transect will include measurements on duff layer depth and wood in all size classes (Brown 1974).

The forest vegetation simulator (FVS) (formerly PROGNOSIS Stage 1973) will be used with the stand visualization system (SVS) (McGaughey 1997) to portray structural and compositional characteristics of the plots in 1992 and 2000. The fire and fuels extension to FVS (FFE-FVS) will be used to model changes in fire hazard between the two measurement periods for three fire behavior parameters: surface fire behavior, torching potential, and active crown fire potential. The potential contribution of different stand attributes to fire hazard will be modeled by using the FVS-FFE extension. Comparisons of 1992 and 2000 plot data will be completed in 2001 and reported elsewhere. Results will be used to calibrate the FVS base model and extensions for local conditions to improve subsequent model projections in phase 2.

Current vegetation in the LSR will be mapped and characterized at the mid-scale (1:12,000) by using photo-interpretation methods and vegetation classifications developed in the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (Hessburg et al. 1999b). Vegetation patches resulting from photo interpretation will be populated with both interpreted and derived attributes in a geographical information system (GIS). Minimum patch size will be 10 acres. Two of these attributes, structural class and potential vegetation type, will be used to stratify the LSR patches in a matrix of “stand types.” The structural class attribute is based on stand development phases identified by Oliver and Larsen (1990) and modified by O’Hara et al. (1996) for forests of the interior West, which include the eastern slope of the Cascade Range. The potential vegetation type attribute describes environments similar in climate, landforms, and geomorphic processes. Timber stand exam and forest inventory (CVS)(USDA Forest Service 1995) plot data will be stratified by stand type, georeferenced, and linked as a GIS database. Plot data will be obtained from existing inventory information and through additional sampling. All data will be organized and formatted for use in FVS. Plot data will be used to provide estimates of variation within patches, to add additional plots, and to test the robustness of the stratification methods. The plot data will provide information on tree-level variables (e.g., species, height, and d.b.h.) at a scale appropriate for estimating potential financial effects of silvicultural treatments. If sufficiently fine-scale data were available, the same process could be used to substratify the patches to estimate plant biomass of nontimber forest products or other scale-appropriate variables.

Vegetation reference conditions for the Gotchen LSR will be developed from a random sample of 18 subwatersheds within the same ecological subregion (ESR4) (Hessburg et al. 2000a). For each selected subwatershed, spatially continuous maps of historical (1930s-1940s) vegetation conditions will be developed from aerial photo-interpreted attributes following the same ICBEMP methods (Hessburg et al. 1999b). Raw vegetation attributes of patches within the historical vegetation maps will be reconstructed statistically by using the most similar neighbor algorithm (Moeur and Stage 1995). Reference variation in spatial patterns of patch types will be estimated for ESR4 from the reconstructed historical maps by using the FRAGSTATS (McGarigal and Marks 1995) spatial pattern analysis program. Current conditions of the Gotchen LSR will then be compared to reference variation estimates (the sample median 80-percent range of any class or landscape metric) to identify key “departures” in the structure, composition, and pattern of forest vegetation (e.g., Hessburg et al. 1999a). This process is called “departure analysis.”

Classification and regression tree (CART) models will be built by using the 18 subwatersheds maps of reconstructed historical vegetation conditions in ESR4. These models will predict the distribution and environmental settings of historical, late-successional, old multistory, and old single-story forest patches (Camp et al. 1997). The CART models derived from the ESR4 analysis will be used to identify the land areas in the Gotchen LSR that likely supported these structures under historical fire regimes. Changes in ground fuels, fire behavior attributes, crown fire potential, and vulnerability to budworm will be identified by comparing current conditions with reference variation in ESR4 for the same attributes.

Phase 2: Assessing potential management effects—In phase 2, we will use results from phase 1 to identify candidate management areas, develop silvicultural treatments, simulate potential changes in vegetation associated with the different treatments, and estimate the precision of the projections. The projected effects on forest structural patterns in the Gotchen LSR will be compared with habitat objectives defined over space and time. Outcomes from silvicultural treatments designed to maintain or restore key forest structures within the LSR will be compared to expected outcomes associated with passive management. Treatments that provide patterns of suitable habitat and reduce patterns susceptible to fire and budworm disturbance within a range of reference variation will be optimized by using heuristic programming and evaluated with NOCLAMMS.

Results will be reported in future publications.

Both stand- and landscape-based approaches for identifying candidate management areas and developing alternative treatments will be used. No hypotheses about interactive effects are being explicitly tested, but use of both approaches will result in observations or preliminary results that can lead to future studies on whether the scale at which management areas are identified influences the treatment selected.

Stand conditions throughout the Gotchen LSR will be stratified according to structural complexity and environmental setting. These stand types will provide a basis for projecting change in forest structure, composition, and growth associated with different treatments. A plot from each stand type will be selected at random, silvicultural treatments applied using FVS, and stand development projected in 10-year increments over a 50-year analysis period. The resulting projections will be distributed to all polygons classified as the same stand type and each alternative future landscape evaluated to determine the effects of different treatments on key forest structures and patterns associated with susceptibility of owl habitat to fire and budworm. The process of selecting a plot and projecting change over time will be repeated to provide estimates of variability associated with projected structural and compositional attributes. The FVS output files will be entered into the interior West variant of the financial evaluation of ecosystem management activities (FEEMA) software package (Fight and Chmelik 1998). Manufacturing and harvesting data for specific forest operations provided from area mills will be used to estimate a net stumpage value. Financial analyses will identify the extent to which operational and administrative costs are recouped through different treatments and estimate the range of associated wood product characteristics over time.

Initial Findings and Example

A preliminary evaluation of the potential effects of active management on Gotchen LSR objectives used timber stand exam data from the Mount Adams Ranger District and the landscape management system (LMS) (McCarter et al. 1998, Mendez-Treneman et al. 2001). The Gotchen LSR was stratified into six groups of similar age and the site attributes of elevation, aspect, and slope. Silvicultural treatments were applied to a “representative” stand chosen from each group. Treatment results were then applied to the whole group and summarized by decade to display the potential development of stands within the LSR. This evaluation influenced the design of our research by suggesting improvements for stratifying stands, selecting stands for analysis, collecting additional data, and characterizing variation in initial conditions and in model results.

In phase 1, we characterized the current distribution of vegetation patches in the Gotchen LSR and used departure analysis to learn how landscape patterns may have changed relative to a set of reference conditions. One hundred fifty-seven patches were delineated in the Gotchen LSR and summarized according to the potential vegetation type and structural class; figure 2 displays the distribution and characteristics of these patches. The structural classification rule is in appendix 1. The matrix in figure 3 summarizes the same information by stand type. Each matrix cell displays the land area (both total acres and percentage of LSR) represented by the stand type. The areas in figure 2 correspond with the cells in figure 3. The area in figure 2 labeled understory reinitiation in the warm-dry Douglas-fir/grand fir potential vegetation type, for example, corresponds to the cell in figure 3 with bold type. The summary information for this cell reveals that this stand type covers 50 percent of the Gotchen LSR. A cell with summary information means the stand

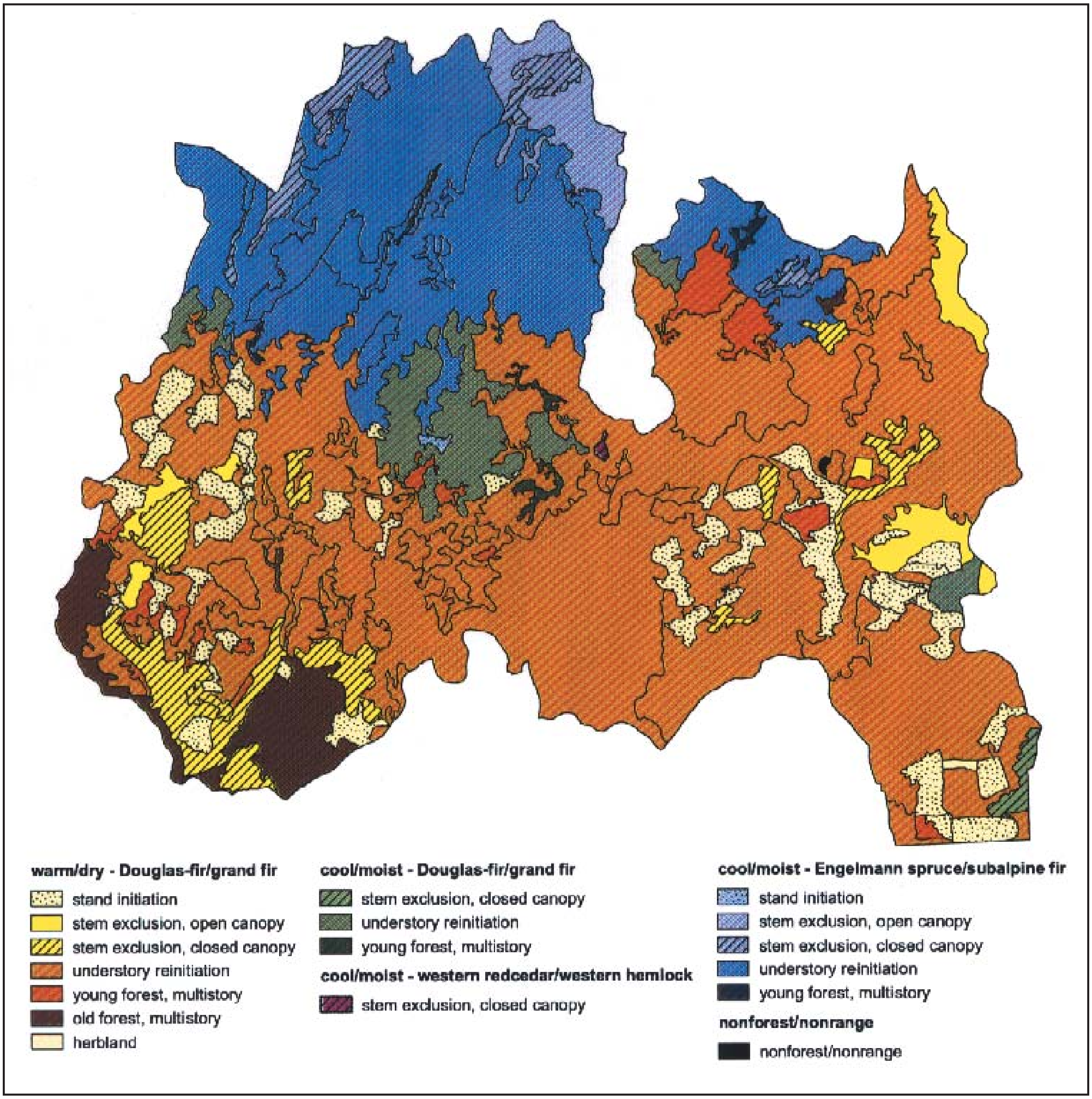

Figure 2—Vegetation patterns in the Gotchen Late-Successional Reserve (1995 aerial photos; 1:12000). Structural class definitions in appendix 1.

Wet ↑ ↓ Dry	si	seoc	secc	ur	yfms	ofms
	0	0	7 ac (0.05%)	0	0	0
Wet	10 ac (0.07%)	349 ac (2.3%)	7 ac (1.83%)	139 ac (21%)	38 ac (0.25%)	0
Dry	0	0	49 ac (0.32%)	652 ac (4.3%)	41 ac (0.3%)	0
	1115 ac (7.4%)	343 ac (2.3%)	694 ac (4.6%)	**7582 ac** **(50%)**	354 ac (2.3%)	515 ac (3.4%)

Structural class (horizontal and vertical complexity) →

Figure 3—Matrix of stand types in the Gotchen Late-Successional Reserve by structural class and potential vegetation type (a temperature, moisture gradient). Structural class definitions are in appendix 1.

type is represented in the Gotchen LSR. The matrix also was used to summarize available plot data. The same cell in figure 3, for example, contains 307 timber inventory plots and 6 CVS plots.

Results from landscape departure analysis identify trends in patterns of forest structure and patch size in the Gotchen LSR. Initial results indicate that both the average patch size and the total area of the understory reinitiation structural stage have increased significantly since the 1930s, in contrast with the average patch size and area of young forest multistory, which have decreased. The total area of old-forest multistory structures has not decreased significantly, and patches are larger and more spatially clumped in comparison with ESR4 conditions.

These results point to stand types in the Gotchen LSR where silvicultural treatments might help to maintain or develop late-successional forest and reduce the risk that unplanned disturbances could adversely affect associated species. Silvicultural treatments are applied at the stand rather than the landscape scale; however, and stand-level data are needed to evaluate potential treatment effects on landscape-level processes and management objectives. For example, our photointerpretation rules resulted in mixed cover types where at the midscale a given species may represent 20 to 80 percent of the total crown cover (Eyre 1980). The relative proportion of these species makes a difference, however, in evaluating the financial effects of proposed treatments at the stand level because Douglas-fir forest products generally have a higher value than grand fir (WWPA 2000). In financial evaluations of alternative treatments, we therefore use stand exam data to reflect the potential influence of variation in species proportions on the characteristics and value of wood removed.

Assessing the characteristics of potential forest products derived from different treatments and estimating the value of these products under various market conditions requires tree-level data. This requires a "stepping down" from the mid to the fine scale, or individual tree level. A process for identifying a stand type, choosing a patch from that stand type, selecting tree-level data, designing and applying silvicultural prescriptions in FVS, and evaluating the financial implications of the prescriptions is detailed below, and an example illustrates the process. Models used to select a plot, to apply a prescription, and to estimate resultant wood volumes and values are still being refined, and the example should not be used for planning or for investment purposes.

Increased contagion of forest structures in the Gotchen LSR dominated by multilayered canopies and shade-tolerant cover types increases landscape susceptibility to budworm defoliation and to fire hazard (Hessburg et al. 1999b, 2000c). These results suggest that management to maintain current vegetation patterns in the Gotchen LSR increases the likelihood of such unplanned disturbances. Landscape management prescriptions could, alternatively, alter the intensity and timing of disturbances in support of LSR objectives and modify potential risk to existing owl habitat. To reduce contagion of budworm habitat, for example, treatments could break up the continuity of grand fir and Douglas-fir understory reinitiation structures located in the warm-dry Douglas-fir/grand fir potential vegetation type. The area of this stand type covers nearly 50 percent of the Gotchen LSR (figs. 2 and 3). Altering the spatial patterns of structural classes may do little to decrease contagion of budworm habitat, however, without also creating conditions suitable for regenerating ponderosa pine rather than shade-tolerant grand fir. Maintaining Douglas-fir also may be important for spotted-owl habitat (Everett et al. 1991).

A landscape prescription could, for example, aim to increase the total area and patch size of the young-forest multistory structural stage while simultaneously reducing continuity of Douglas-fir/grand fir understory reinitiation patches. With this in mind, an understory reinitiation patch adjacent to a young-forest multistory patch was selected for the following example.

Plot data from the most recent stand exam (1981) for the selected patch was migrated from an inventory database into FVS and projected forward to 2001 (fig. 4). The FVS tree mortality function was enabled but not the western spruce budworm or western root disease models (Sheehan et al. 1989, Stage et al. 1990, respectively). For illustrative purposes, one prescription of variable intensity was applied in FVS. Only grand fir was removed; other species (Douglas-fir and ponderosa pine) were retained for contribution to future owl habitat. The prescription intent was to reduce budworm host species and crown fire potential and to recruit ponderosa pine. Removals were proportional from all diameter size classes between 5 and 40 inches d.b.h. The treatment differed only in intensity of grand fir removed (33, 50, and 75 percent) (fig. 5). The least intensive treatment, which did not regenerate ponderosa pine, retained a crown closure of 47 percent. In contrast, the most intensive treatment provided conditions suitable for pine regeneration but reduced canopy closure to below 40 percent, which is considered a minimum threshold for owl habitat. This extreme example illustrates the potential conflict in objectives for the same site and underscores the need to consider a range of treatments over both space and time. In FVS, it is possible to evaluate potential effects associated with variable-intensity

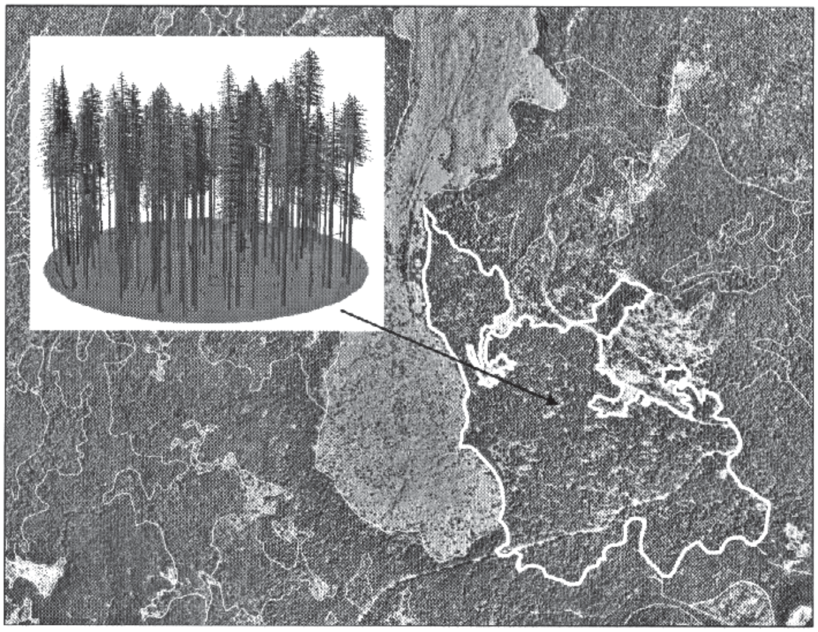

Figure 4—Plot data from outlined patch projected by using the forest vegetation simulator model to characterize potential stand conditions.

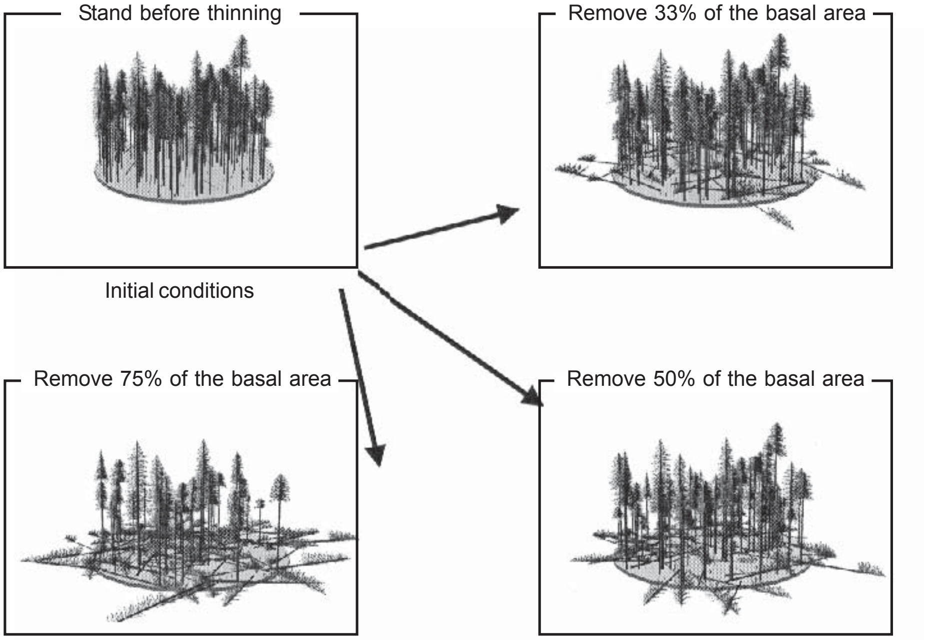

Figure 5—Grand fir removal (percentage of basal area) under three treatment intensities applied to the patch outlined in figure 4 (above).

management based on changes in diameter limits, basal area targets, and total stand density, which we will explore in future analyses. Lists of trees removed in the FVS simulation of each alternative were entered into FEEMA, and volume in hundred cubic feet per acre (ccf) was calculated for each treatment.

The FEEMA analyses included several assumptions. For example, grand fir was removed from a location with a 10-percent slope suitable for ground-based logging systems. Two harvesting options were examined: mechanized and manual felling. The former assumed a drive-to-tree feller-buncher for trees below 20 inches d.b.h. and manual felling of trees over 20 inches d.b.h., whereas the latter assumed manual felling for all trees. Both harvesting options used a grapple skidder. Estimates of manufacturing and hauling costs plus any reforestation fees were made with assistance from local Mount Adams Ranger District and mill personnel.

Two market conditions, high and low, were used in the analysis. The high market condition used lumber prices from the third quarter of 1999, and the low market used lumber prices from the fourth quarter of 1998. Both market options used current log purchase prices. We assumed that all logs were sound and free of defect, which might be questionable in older grand fir. This assumption will be explored in future analyses. All other prices and costs were the same for each of the four possible combinations of harvesting options and market conditions. Additional costs included hauling at $40 per ccf, road maintenance at $5 per ccf, contractual requirements at $15 per acre, and required reforestation at $350 per acre. Logs with small-end diameters (SEDs) between 4 and 20 inches were allocated to a random-length dimension mill, but logs in this range also could be sold as logs when the net revenue was higher. Logs larger than 20 inches SED were sold as logs. Chip logs could be between 3 and 6 inches SED.

The FEEMA software package is a tool for comparing possible financial returns from different silvicultural treatments. By allowing the separation of the various cost and revenue components, and assigning them on a tree-by-tree basis, FEEMA enables a user to develop an understanding of how trees of different size and species, removed under different harvesting equipment configurations and contractual requirements may affect the financial outcome of a management action. We used FEEMA to examine two aspects of the treatments. The net value per cubic foot of log at the stump is displayed in figure 6, and the net value per acre is shown in figure 7. These figures illustrate the relative importance of economic conditions, the silvicultural prescription, and the harvesting method in determining net return.

The results presented in figure 6 demonstrate that thinning intensity has only a small influence on the dollar value per ccf of timber when compared to harvesting method or economic condition. This difference is small because all the trees in this example are the same species, and there is only a small change in the selling price of different size logs. If multiple species were removed or there was a substantial premium for logs with specific characteristics, this result could differ considerably.

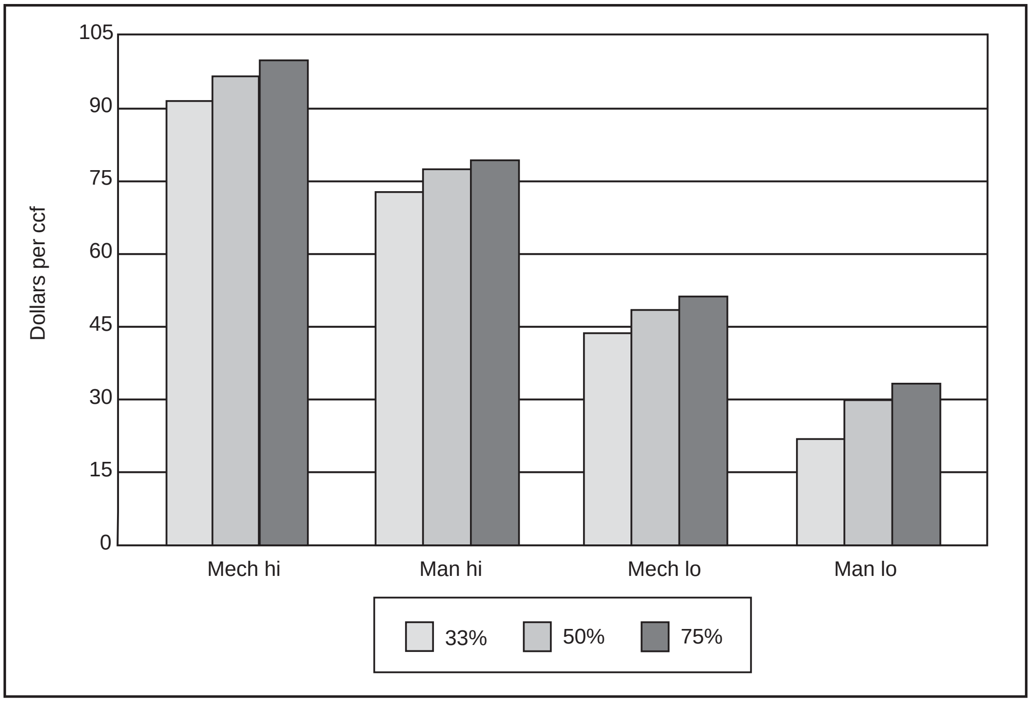

Figure 6—Net value per hundred cubic feet of log volume (ccf) at the stump based on 33, 50, and 75 percent removal of grand fir basal area. Mech = mechanized felling, man = manual felling, hi = high market (1999), lo = low market (1998).

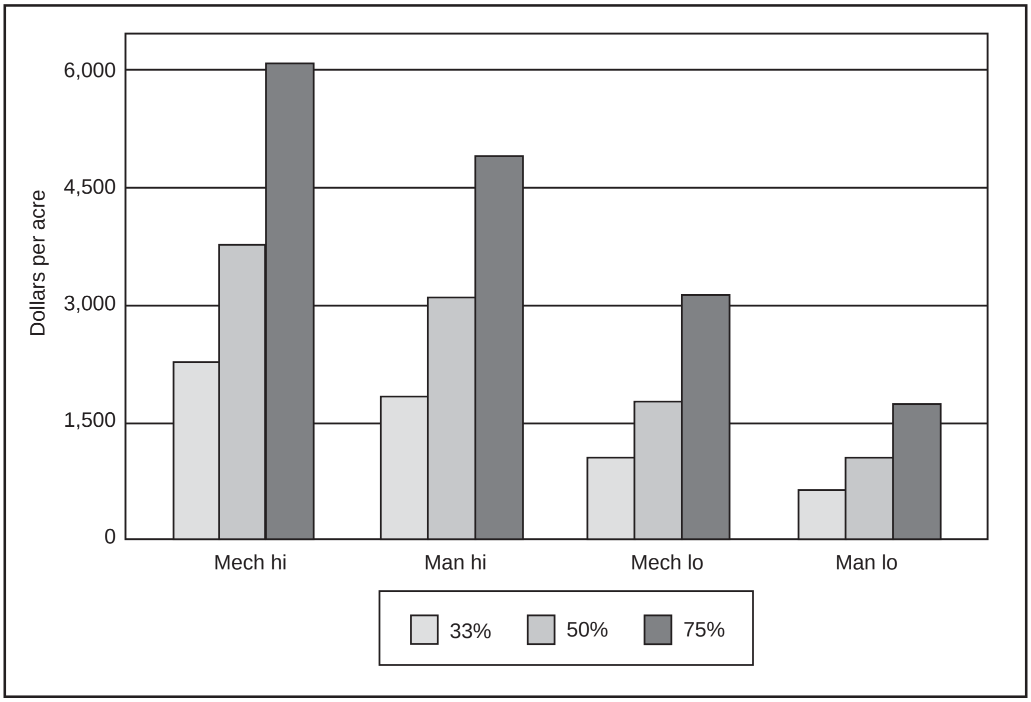

Figure 7—Net value per acre based on 33, 50, and 75 percent removal of grand fir basal area. Mech = mechanized felling, man = manual felling, hi = high market (1999), lo = low market (1998).

Market condition had the largest influence on net value at the stump. There is a 50- to 65-percent difference in the net return at the stump between the high and low market conditions. Sale planners or administrators cannot directly influence this. They can, however, provide sufficiently long contracting periods to allow for highs and lows in markets. This could make marginal sales more attractive by reducing the risk that poor market conditions might prevail over the duration of the contract.

Sale planners do have some discretion over the specification of harvesting equipment, and this analysis clearly shows that in some cases, this choice could make the difference between a positive or negative return to the purchaser. The decrease in net return at the stump between the mechanized felling and manual felling options is about 20 percent for the low market condition and about 40 percent for the high market condition. There are reasons why sale planners might chose to designate manual felling over mechanical felling, such as controlling soil disturbance, reducing damage to residual trees, or enhancing the ability to implement a prescription. There also may be situations where the impacts from mechanical harvesting are limited, and in these situations, the FEEMA analysis suggests that allowing mechanical harvesting might improve bidder interest in a timber sale or service contract.

When results are analyzed on an area basis, the intensity of the thinning becomes the dominant factor in determining the net return from the set of treatments (fig. 7). The 75-percent crown removal treatment returns generally between 1.5 and two times more per acre than the 33-percent crown removal treatment depending on the harvesting method and market condition. The differences in net return per acre owing to thinning intensity represent both the increased revenue from the sale of more timber volume and the reduced operating costs associated with removing more trees per unit area. Costs decline because harvesting is more efficient when operators do not have to move and set up equipment as frequently to harvest a given volume or travel as far between trees during felling and skidding operations.

The relations between market condition, harvesting method, and net return are identical to those for net value at the stump. These relations do not change because although in one case calculations are made on a volume basis and in the other they are made on an area basis, the proportional change in revenue remains the same. The analysis suggests that within the cost and revenue parameters used here, the amount of wood removed is the most important factor in determining net revenue, market conditions are the next, and the choice of harvesting equipment is the least important.

This order of importance could change if different cost and revenue parameters were selected or if different harvest prescriptions were used. Using FEEMA makes it relatively easy to explore questions about the source of variation in net revenue. FEEMA also has other analytical features that could be useful if financial viability were a key concern.

Conclusion

Landscape prescriptions require information on the relations among stands and on how stand-level treatments may or may not contribute to LSR objectives. Our results to date provide a basis for identifying vegetation patterns that may support management objectives in the Gotchen LSR and can assist land managers both in selecting treatment areas and in designing silvicultural treatments. Prescriptions developed for future analyses will include a combination of treatments to maintain or restore compositional and structural characteristics that provide late-successional habitat and reduce fire and budworm hazards in the LSR. Future analyses will clarify how these different treatment combinations contribute to LSR objectives and their financial implications. The question remains whether the LSR is the appropriate scale at which to study or manage owl habitat east of the Cascade Range. Results from this study will help address this important question.

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Appendix

Appendix 1—Classification rules for forest structural classes in the Gotchen Reserve[a]

No.	Structural class (code)	Classification rule
1	Stand initiation (si)	LgT_cc[b] < 30 percent (i.e., = 0, 10, or 20 percent) and SS[c]_cc > 10 percent and {[PT_cc + SmT_cc + MedT_cc < 20 percent] or [PT_cc + SmT_cc + MedT_cc > 60 percent and PT_cc + SmT_cc + MedT_cc > 20 percent and SmT_cc + MedT_cc < 10 percent]}
2	Stem exclusion open canopy (seoc)	LgT_cc < 30 percent (i.e., = 0, 10, or 20 percent) and SS_cc < 10 percent and PT_cc + SmT_cc + MedT_cc < 70 percent
3	Stem exclusion closed canopy (secc)	LgT_cc < 30 percent (i.e., = 0, 10, or 20 percent) and SS_cc < 10 percent and PT_cc + SmT_cc + MedT_cc > 70 percent
4	Understory reinitiation (ur)	LgT_cc < 30 percent (i.e., = 0, 10, or 20 percent) and SS_cc > 10 percent and PT_cc + SmT_cc + MedT_cc > 60 percent
5	Young-forest multistory (yfms)	LgT_cc < 30 percent (i.e., = 0, 10, or 20 percent) and SS_cc > 10 percent and PT_cc + SmT_cc + MedT_cc > 60 percent and SmT_cc > 10 percent or MedT_cc > 10 percent
6	Old-forest multistory (ofms)	LgT_cc > 30 percent and SS_cc + PT_cc + SmT_cc + MedT_cc > 20 percent
7	Old-forest single story (ofss)	LgT_cc > 30 percent and SS_cc + PT_cc + SmT_cc + MedT_cc < 20 percent

[a] From Hessburg et al. 1999b.

[b] cc = crown cover; crown cover was interpreted in 10-percent increments, and class percentages were expressed as midpoints; e.g., 10 percent = 5 to 14 percent; 20 percent = 15 to 24 percent.

[c] Tree sizes were estimated as SS-seedlings and saplings (< 12.7 cm d.b.h.), PT-poles (12.7 to 22.6 cm d.b.h.), SmT-small trees (22.7 to 40.4 cm d.b.h.), MedT-medium trees (40.5 to 63.5 cm d.b.h.), and LgT-large trees (> 63.5 cm d.b.h.).

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