Landscape Silviculture for Late-Successional Reserve Management[1]

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Abstract

The effects of different combinations of multiple, variable-intensity silvicultural treatments on fire and habitat management objectives were evaluated for a ±6,000 ha forest reserve using simulation models and optimization techniques. Our methods help identify areas within the reserve where opportunities exist to minimize conflict between the dual landscape objectives. Results suggest that most of the trees removed by silvicultural treatments designed to support fire and habitat objectives, while generating enough revenue to break-even, would be medium-sized (17-40 cm), shade-tolerant conifers. The study produced information that was used by a planning team on the Gifford Pinchot National Forest to develop stand-level treatments based on mid-scale landscape patterns. New contracting authorities give the Forest Service ways to offer sales that support landscape management objectives in the reserve, but the contracts are time-consuming to prepare and award. Implementation of a stewardship contract associated with the study reserve is scheduled to begin in summer 2006.

Introduction

The Northwest Forest Plan (Plan) designated late-successional forest reserves on some federal lands in Oregon, Washington, and California. One goal of the reserve network is to sustain habitat for the northern spotted owl (*Strix occidentalis caurina*) and other species associated with older, late seral forests (USDA and USDI 1994). Plan guidelines require land managers to protect these reserves, or LSR, from large-scale natural and human disturbances. An ongoing challenge for managers of LSR in drier Plan provinces is to conserve and develop older forests in ways that support their resilience in fire-adapted ecosystems. In such places, LSR managers are concerned about effects to late seral forest habitat structures associated both with severe wildfires and with silvicultural treatments done to reduce fire severity. The problem of potentially conflicting effects from forest management is not confined to LSR, however. Throughout fire-adapted forest ecosystems of the western US, federal land managers seek ways to promote forest structures and processes that are consistent with pre-fire exclusion conditions, while preserving some of the attributes of existing conditions that people have come to value.

Our interest lies in developing methods to quantify tradeoffs among various forest management objectives. A need for analytical methods of this type occurs everywhere that multiple resource objectives exist but is acute in the West, because of extensive areas of public land combined with an increasing human population.

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Many people are interested in land management issues. At times, their preferences and the best ways to provide them appear to be in conflict.

In this paper, our objective is to describe a method for identifying silvicultural solutions to potentially conflicting landscape management objectives. We summarize results from a study in which we investigated how treatments to moderate fire behavior could impact late seral forest structure in one LSR, if treatment expenses might be offset by revenue generated from harvest activities, and the dimensions of the trees removed. We use the term "landscape silviculture" for treatments applied to a stand but evaluated collectively according to objectives for an entire reserve.

Site Description

The Gotchen LSR lies on the eastern flank of the Cascade Range in Washington State, covering about 6,070 ha of the Mount Adams Ranger District on the Gifford Pinchot National Forest. Like many other reserves in the drier provinces of the Plan area, the Gotchen LSR includes a mix of older, mixed-conifer forests and plantations. Tree species include Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), and lodgepole pine (*Pinus contorta*). Six documented spotted owl nest sites exist (Mendez-Treneman 2002). Defoliation of true firs (*Abies*) associated with an outbreak of western spruce budworm is contributing to increasing fuel loads and to declining crown cover, which affects owl habitat quality (Hummel and Agee 2003). Managers responsible for the Gotchen LSR seek ways to moderate ongoing risks to owl habitat associated with potential stand-replacement severity fire, while retaining older forest structures within the reserve landscape (Hummel and Holmson 2003).

Methods and Analysis

Characterize Landscape Conditions

At the outset of the Gotchen LSR study, we considered it important to use a simulation model that could recognize the contribution of individual trees to forest structure at both within-stand and among-stand (landscape) scales. We needed a model that could track residual stand structure and forest dynamics following a silvicultural treatment, and account for any trees cut during the treatment both by size and species. In addition, because wildfire can affect multiple stands, we wanted the model to have spatial database capabilities, so that the influence of conditions in neighboring stands on fire behavior and effects within a stand (and vice-versa) could be simulated. We ultimately selected the Forest Vegetation Simulator East Cascades variant (FVS) (Stage 1973, Johnson 1990, Crookston and Havis 2002).

We began by using aerial resource photos to identify vegetation patches in the Gotchen LSR, and then spatially described them in a geographic information system (GIS) database (*fig. 1*). The patches were stratified into a summary matrix of stand types based on structure class and potential vegetation type (details in Hummel et al. 2001). By selecting patches within stand types using probability proportional to size, field samples made in 2000 and 2001 covered the range of existing conditions. The data were used to create "tree lists" for sampled patches following FVS procedures (Dixon 2003). We randomly assigned a FVS tree list to any unsampled patches within the same stand type, our assumption being that within-stratum variation in forest structure is lower than among-strata variation.

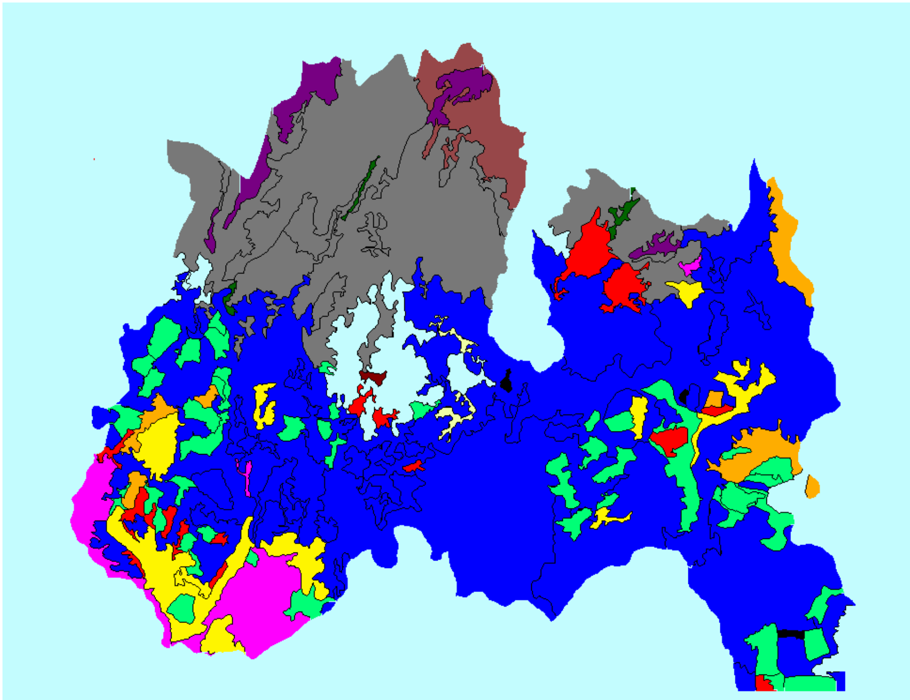

Figure 1–Landscape patches in the Gotchen LSR identified by using aerial photographs. Each colored patch is a different combination of forest structural stage and vegetation cover type (Source: Hummel et al. 2001).

We considered it vital that vegetation patterns be able to change with time in our analysis and not be constrained by existing landscape geometry. Some of the large patches in the southern part of the Gotchen LSR, for example, result from previous logging and fire suppression activities, and tend to be bigger than regional studies of disturbance ecology would suggest for areas like this one with mixed-severity fire regimes. We therefore introduced the ability for new patterns to emerge by sub-stratifying the original patches into smaller "projection units." These units represent the smallest area to which a treatment could be applied. Each unit received the FVS tree list associated with its original patch, but individual unit growth trajectories could differ based on stochastic variation within the model, and on the treatment schedules ultimately selected for each one (details in Hummel et al. 2002, Calkin et al. 2005).

Use Forest Structure to Describe Fire and Habitat Objectives

Once we had a database representing existing forest vegetation, we turned our attention to how its structural dynamics related to fire and to owl habitat. We focus on structure, or the arrangement and variety of living and dead forest vegetation, because it can be measured and it is physically and biologically relevant to fire behavior and to owl habitat. We selected a 30-year analysis period by considering both fire return intervals for mixed-conifer forests in the region and model capabilities. For fire threat (FT), we used three variables: flame length, crown fire initiation, and crown fire spread, which we estimated for each unit using the Fire and Fuels Extension to FVS (FVS-FFE) (Reinhardt and Crookston 2003). A unit's FT index (low, moderate, or high) was a weighted combination of these variables within a unit and its adjacent units (details in Calkin et al. 2005):

$$Threat10i=FLi+w1*(Torchi+Crowni)+(w2*\sum j[Edgej*\{Torchj+Crownj\}] / \sum jEdgej)$$

Where,

i is the reference unit for which fire threat is being calculated,

j references adjacent units to unit i,

FL_i = 1 if flame length for reference unit i < .92m,

= 2 if flame length is between .92 and 1.22m,

= 3 if flame length is between 1.23 and 1.51m,

= 4 if flame length is between 1.52 and 1.82m,

= 5 if flame length is ≥ 1.83m,

Torch = 1 if torching potential wind speed < 95% local wind speed,

= 0 else,

Crown = 1 if crowning potential wind speed < 95% local wind speed and Torch = 1,

= 0 else,

$Edge_j$ is the amount of perimeter accounted for by adjacent unit j, and

w_1 and w_2 are relative weighting variables.

The fire threat index is on a continuous scale ranging from 1 to 10. However, Calkin et al. (2005) collapsed it into a three point scale to make it easier to express results consistent with area in reduced threat categories after treatment:

Threat

= 1 if Threat10*i* < 3 (low threat, control likely, fair survival of residual trees),

= 2 if Threat10*i* = 3-5.99 (moderate threat, control problematical, some residuals survive),

= 3 if Threat10*i* ≥ 6, (high threat, control unlikely, high mortality likely).

A landscape FT was computed from the proportion of the reserve in each of the low, moderate, and high FT categories for each decade (details in Calkin et al. 2005).

For late seral forest (LSF) structure, we developed a definition using the basal area of trees in specific diameter classes that incorporated eastside owl habitat requirements (Hummel and Calkin 2005) (*table 1*). By using FVS, the Western Root Disease Model (Frankel 1998), and FFE-FVS, we evaluated LSF structure and assigned a FT index to each unit.

Model Forest Structure with and without Treatment

We first projected trends in LSF structure and in high FT (*fig. 2*) in the Gotchen LSR over three decades by simulating all units without any treatment (NoRx).

For comparison with the NoRx baseline, we also applied multiple, variable-intensity silvicultural treatments to each unit and simulated forest development over

Table 1--*Structural definition of late successional forest (LSF).*

Basal area (BA) at least 55.2 m^2/ha
BA of trees greater than 61.0 cm dbh $\geq$ 8.3 m^2/ha
BA of trees greater than 35.6 cm dbh $\geq$ 33.1 m^2/ha
BA of trees less than 35.6 cm dbh $\geq$ 8.3 m^2/ha

Source: Hummel and Calkin 2005.

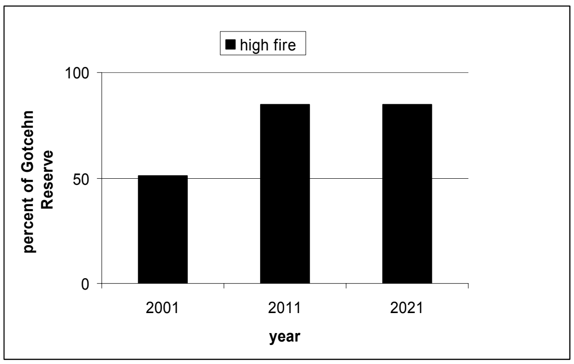

Figure 2–Percent of Gotchen Late-Successional Reserve (LSR) projected to be in high fire threat (high fire) in each of three decades without any treatment (NoRx). (Source: Hummel and Calkin 2005)

the same analysis period. Vegetation structure in each unit in each decade associated with each treatment was evaluated according to our FT and LSF structure definitions. The treatments differed in the type of thinning, species removed, maximum diameter limit, residual basal area target, and residual fuel loads) (*table 2*) (details in Hummel and Calkin 2005). All FVS simulation results were saved and linked to the GIS database. The list of trees cut by FVS following any active treatment was saved in a format compatible with the Financial Evaluation of Ecosystem Management Activities (FEEMA) model (Fight and Chmelik 1998), with which we also kept track of treatment costs, i.e., reforestation and fuels treatments.

We entered harvest costs, fuel treatment costs, and wood product prices into the FEEMA model to calculate net revenue per unit per treatment per decade. Harvest costs, including hauling, road maintenance, contractual requirements, reforestation, slashing, and piling and burning were obtained from reserve managers. We estimated defect by log size class by using previous timber sale records for the area and recommendations from Pacific Northwest (PNW) personnel responsible for scaling and cruising. Product prices represent a stable market in the PNW. We assumed that all harvest and operational costs remain constant over time, and discounted future costs and revenues by four percent.

We used results from the NoRx baseline simulation to identify the total area of LSF structure to be maintained over 30 years, subject to reducing FT in the reserve landscape. This objective was then written in the form of an algorithm. By using a simulation model, we could apply each treatment to each unit subject to a rule set and then let the algorithm select the one that, together with conditions in neighboring units, best met the dual landscape objectives over time (details in Calkin et al. 2005). Because we kept track of treatment costs and revenues on a per unit basis, we could evaluate the net revenues (negative, break-even, positive) earned collectively by any set of treatments. This feature became invaluable when we specified financial requirements to be met by landscape silviculture treatments.

Table 2--*Silvicultural treatments.*

Treatment (Rx)	Rx Objective	Silvicultural treatment applied in FVS	Citation for Rx targets
No Rx	Minimize human disturbance	No activity scheduled	
Reduce Rx	Reduce crown fire potential in historically low fire-severity forest ecosystems	40% canopy cover Thin from below to 50.8 cm dbh Preferentially remove ABGR Pile and burn Plant PSME, PIPO, LAOC	Agee 1996 Agee et al. 2000 Graham et al. 1999
Restore Rx	Reduce density of shade-tolerant true fir trees (Abies) that have established since the 1920s	Thin from below to 38.1 cm dbh Keep at least 23 m2/ha basal area Retain PSME, PIPO, LAOC, PIEN Pile and burn	Hummel et al. 2002
Protect Rx	Protect large trees (>53.3 cm dbh) and retain sufficient basal area to meet LSF definition	If more than 55.2 m2/ha in unit then thin trees 0-35.6cm dbh to 8.3 m2/ha Pile and burn	Johnson and O'Neil 2001 Mendez-Treneman 2002
Diameter Rx	Reduce density of shade-tolerant understory true fir trees (Abies)	Thin from below to 25.4 cm dbh Keep at least 23 m2/ha basal area Retain PSME, PIPO, LAOC, PIEN Pile and burn	
Accel Rx	Accelerate the development of LSF structure	Thin to 247 trees/ha Keep PSME, PIPO, LAOC Plant 247 PSME/ha	

ABGR = grand fir (*Abies grandis*)
PSME = Douglas-fir (*Pseudotsuga menziesii*)
PICO = lodgepole pine (*Pinus contorta*)
LAOC = western larch (*Larix occidentalis*)
PIPO = ponderosa pine (*Pinus ponderosa*)
PIEN=Englemann spruce (*Picea englemannii*)
Source: Hummel and Calkin 2005.

Develop Production Curves by Varying Silvicultural Treatments and Area Treated

Using the GIS data layers linked with the FVS treatment results and costs, Calkin et al. (2005) constructed a set of production possibility (PP) curves for the Gotchen LSR by using a simulated annealing (SA) algorithm. The SA algorithm was written to maximize reducing landscape FT subject to constraints on the total area of LSF structure maintained and on the amount of area that could be treated in any decade. Each point on the PP curves represents the results of different combinations of silvicultural treatments in terms of FT reduction and LSF structure, while each curve represents the relative tradeoffs between FT reduction and LSF structure subject to a given area constraint. The LSF constraint was varied, from allowing any unit that qualified as LSF to be treated (unconstrained), to allowing no unit that qualified as LSF to be treated (strict). Intermediate constraints included 6,678, 6,780, and 6,880 ha of LSF structure maintained over the 30-year analysis period. The effectiveness of treatments was assessed by identifying if existing FT levels were reduced for treated units and their overall effect on landscape FT. The silvicultural treatment scheduling problem is defined in Calkin et al. 2005:

Maximize $\Sigma_t \Sigma_i (\text{Threat}_{i,t} (\text{no treatment}) - \text{Threat}_{i,t} (j, \text{adj}_i(j)))^* \text{Area}_i$
$- B_1^* \text{ LSF Penalty} - B_2{}^*\text{Total Area Penalty}$

If $\Sigma_t \Sigma_i \text{ Area}_i * \text{LSF}_{i,t} < X$

$\text{LSF Penalty} = X - \Sigma_t \Sigma_i \text{ Area}_i * \text{LSF}_{i,t}$

Else LSF Penalty = 0

If $\Sigma_i \text{ Area}_i * \text{Period}_{i,t} > Y$ for t = 1,2,3

$\text{Area Penalty}_t = \Sigma_i \text{Area}_i * \text{Period}_{i,t} - Y$,

Else Area Penalty = 0

$\text{Total Area Penalty} = \Sigma_t \text{Area Penalty}_t$

Where,

i indexes the individual projection units,

j indexes the set of treatment alternatives including no treatment,

t indexes the planning horizon periods 1 to 3 (three decade planning horizon),

$\text{Threat}_{i,t}$ is the fire threat class of unit i in period t,

$\text{adj}_i(j)$ is the set of treatment selected for adjacent units that affect the threat index for unit i,

LSF Penalty is the penalty for violating the minimum area required to meet the LSF definition, Total Area Penalty is the aggregate penalty for violating the maximum area treated in each period;

B_1 is the weighting factor for the LSF penalty

B_2 is the weighting factor for the area penalty

Area Penalty_t is the periodic penalty for violating the maximum area treated,

Area_i is the size of unit i in hectares,

$\text{LSF}_{i,t} = 1$ if Unit i meets the LSF definition in period t, otherwise= 0,

$\text{Period}_{i,t} = 1$ if Unit i is scheduled for an active treatment in period t, otherwise=0, X is the minimum amount of LSF structure required, aggregated for all three periods, and

Y is the maximum amount of area that could be treated in a single period.

Identify Marginal Costs of Silvicultural Treatments

The PP curves helped identify a range within which silvicultural treatments could achieve relatively high FT reduction at relatively low cost to LSF structure. We then examined how FT reduction levels within this range would be affected by different financial requirements for the treatments. To develop a three- dimensional production function in terms of net present value (NPV), LSF structure, and FT, we held LSF structure and treated area constant. The objective function was to reduce landscape FT, while setting as constraints the area of LSF structure (6,880 ha), the maximum treated area (≤10% of the reserve), and NPV. The NPV constraint levels were USD $0 (break-even), $0.5 million, $1 million, and $1.5 million in addition to an unconstrained baseline. We also refer to the three cases in excess of $0 as positive financial constraints or +NPV (details in Hummel and Calkin 2005).

Results

Costs of Landscape Silviculture Treatments

The levels of FT reduction and LSF structure in the reserve decreased with increasing financial requirements (*fig. 3*). A positive financial constraint imposed costs on landscape objectives because the net revenue from silvicultural treatments at a unit scale could be either positive or negative, depending on the existing stand conditions and the treatment applied. Treatments that lost money at the scale of an individual unit were rarely selected by the algorithm when a high NPV constraint was imposed even though they reduced landscape FT at low cost to LSF structure (details in Hummel and Calkin 2005).

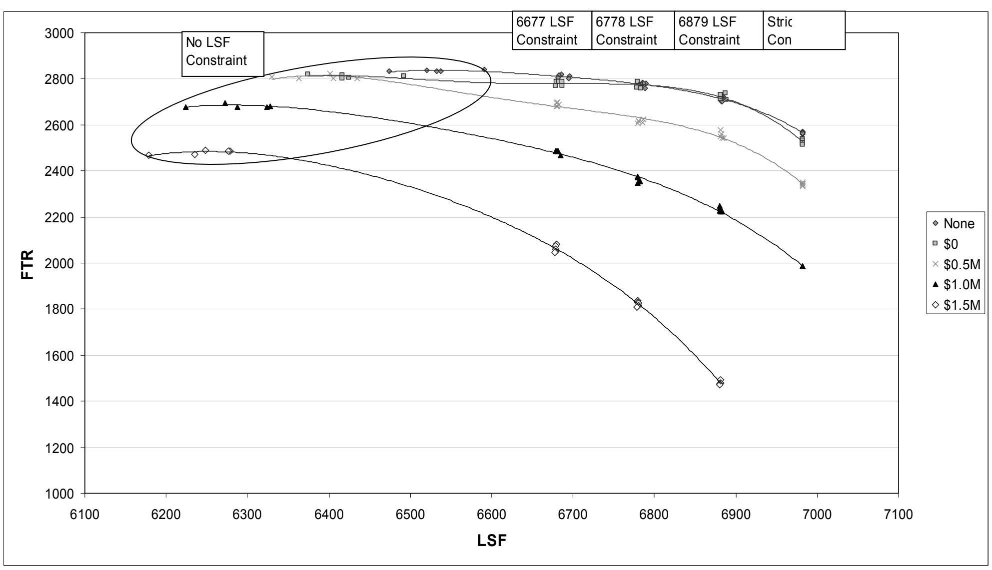

Figure 3–Fire threat reduction (FTR) (weighted index values) vs. late-seral forest (LSF) structure (hectares) for a range of net present value (NPV) requirements over 30 years in the Gotchen LSR. The ellipse highlights the unconstrained option (Source: Hummel and Calkin 2005).

With or without a financial requirement to break-even, treatments accomplished about the same level of FT reduction and LSF structure over the 30-year analysis period (*fig. 3*). Although the treatment results were similar, the net revenues were not. For similar levels of FT reduction and LSF structure, net revenues for various mixtures of treatments ranged from -$1,000,000 to $3,000 over thirty years (details in Hummel and Calkin 2005).

Characteristics of Trees Removed in the Break-Even Case

The mixture of treatments that met landscape objectives for fire and habitat management, and also generated enough revenue to break-even, included wood volume from trees <17.8-55.9 cm. The largest component came from the 18-40.6 cm size class (*fig.4*). In each decade, the main species harvested in this diameter class was grand fir (*fig.5*).

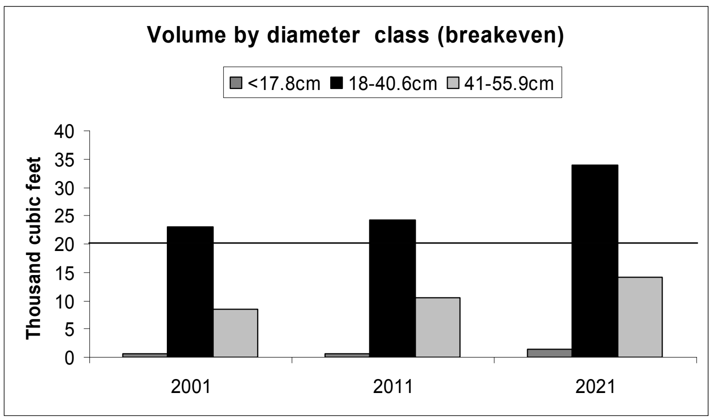

Figure 4–Volume of wood removed by diameter class in simulated treatments that broke even over 30 years in the Gotchen LSR landscape and met fire and habitat management objectives**.**

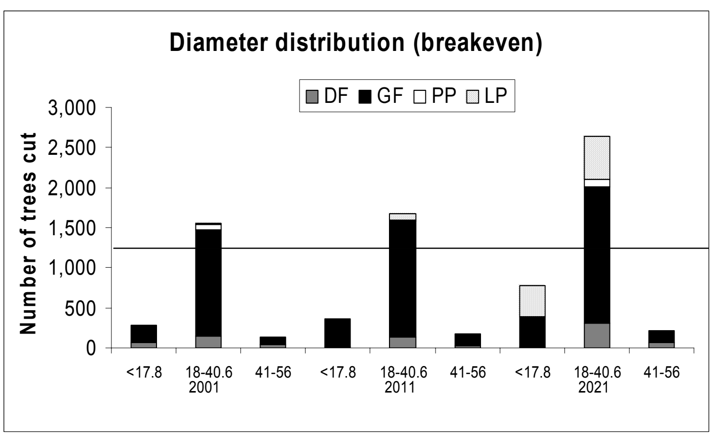

Figure 5–Number of trees cut by diameter in simulated treatments that broke even financially over 30 years in the Gotchen LSR landscape and met fire and habitat management objectives (DF=Douglas-fir, GF= grand fir, PP=ponderosa pine, and LP=lodgepole pine).

Discussion

The predominance of medium-sized, shade-tolerant conifers in the break-even case contributes to contemporary discussions about conserving and developing older forests in ways that support their resilience in fire-adapted ecosystems of the West. Such trees are unlikely to be legacies remaining from pre-settlement, pre-fire exclusion days. For example, a 38.1 cm grand fir tree in the Gotchen LSR is, on average, about 80 years old (Hummel et al. 2002). This means that a focus on removing medium-sized, shade tolerant trees to support fire and habitat management objectives in the reserve would be consistent with reducing the number of trees that have established since federal fire exclusion policies began in the early 1900s. While this result may seem intuitive with respect to fire, by using simulation and optimization techniques, we gain additional information about tradeoffs with other landscape objectives. Namely, an emphasis on removing medium-sized trees may not directly conflict with owl habitat objectives for late-seral forest at the among-stand scale. This is informative, given that questions exist about the compatibility of fire and habitat objectives in the drier provinces of the Plan area (e.g. Spies et al. 2006). While results from the Gotchen LSR case study are applicable only in the study reserve, the method we used--linking landscape dynamics and patterns of forest structure to stand level silvicultural treatments by considering the treatments collectively rather than on a stand-by-stand basis--could be used anywhere that multiple management objectives share a common basis in forest structure (e.g. wildfire and home sites, recreation opportunities, and wildlife habitat).

Medium-sized grand fir trees are merchantable in the mills located in the geographic area of the Gotchen LSR and should be readily accepted in local markets (Barbour et al. 2001). Available data (1991 to 2001) for lumber from grand fir indicates that true firs (hem-fir lumber) has consistently been priced about 12 to 20 percent (average 13.5 percent) lower than Douglas-fir in coastal markets and about 65 percent below ponderosa pine in interior markets (Warren 2004).

Possibly a more important question than whether the harvested wood is merchantable is whether stewardship contracts, such as the one associated with the Gotchen LSR planning area (Stray Cat), will find bidders. The issue is not solely one of merchantability but also one of risk, including how it is calculated, what it costs, and who bears it. Stewardship contracts are for services (such as fuel reduction and pre-commercial thinning) in which some of the implementation costs can be offset by the value of the resources that are removed. Revenues from stewardship contracts might not be returned to the US Treasury. Because of concerns about decay in true fir trees (Aho 1977), potential bidders on Stray Cat preferred a scaled sale, whereas the Forest Service tends to prefer lump sum sales.

Other challenges related to designing and awarding stewardship contracts relate to the length of contractual obligations for services. Obligations that impose contractual burdens into the future (like controlling invasive herbaceous plants) carry uncertainty for bidders. Such an obligation can seem very risky to bidders, particularly when experience is limited with which to evaluate probable costs. For the Forest Service, such obligations carry a different challenge. While collections processes exist for contractual requirements, like reforestation and fuels treatments, similar processes are not yet in place for other, newer requirements related to landscape restoration activities and community needs. In addition, budget reductions and reduced agency personnel limit the marking of individual trees within sale units. Designation by description (DxD) is often used instead. Bidders on stewardship contracts can also be concerned about the costs associated with deciding which trees to remove during sale volume determination and logging activities. From a different perspective, interest groups express concern whether residual forest conditions will be consistent with the intended prescription. Stray Cat, which includes DxD units, is lump sum and due to be implemented, beginning in 2006. Almost two years elapsed between the signed project decision and the award of a stewardship contract.

Summary

When the Gotchen LSR study began, forest growth models were relatively limited in their ability to link a landscape shape file with the multiple stands and the trees comprising it. FVS was no exception (e.g. Hummel et al. 2001). In the years since then, model developers have devoted considerable time to link stand attributes with landscape models (e.g. FARSITE [Finney 1998], LMS [McCarter 1997], and FVS). Continued progress in this area will help to automate and standardize the approach we took in this study, namely, to link a landscape to its stands and then to individual trees. Our intent in taking this approach was to expand silvicultural decision-making beyond a unit-by-unit approach, and instead to consider adjacent units and landscape objectives explicitly in such decisions. In landscape silviculture (as we define it), post-treatment conditions in a given unit can only be evaluated within the context of objectives for an LSR, because what appears to support landscape objectives in isolation may change when considered in total. Indeed, study results suggest that the potential for conflict or compatibility among landscape objectives for fire and habitat management is scale-dependent. There are questions raised or unanswered by the Gotchen LSR study that seem important, if additional progress is to be made on designing and evaluating silvicultural treatments to accomplish multiple landscape objectives. With respect to wildfire in particular, these include understanding what mean size and shape of treated units is most effective in reducing severity, and whether the spatial pattern of treatments matters more than the total biomass removed, or vice versa.

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