Tradeoffs Between Fire and Habitat Management in a Forest Reserve[1]

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Abstract

Silvicultural treatments to manage fire behavior affect both forest values that can be priced (market) and those that cannot (non-market). When the purpose of the treatments is to benefit a non-market value, evaluating their net effect is complicated by difficulties in assessing their total cost. Production possibility (PP) curves illustrate the relative cost, or tradeoffs, of managing for a non-market value in terms of market or other non-market values.

We combined simulation and optimization models to schedule treatments that reduce fire threat (FT) and maintain late successional forest habitat (LSF structure) for the northern spotted owl over thirty years in a 6070 ha forest reserve. We evaluated the tradeoffs between reducing FT and maintaining LSF structure by constructing a set of PP curves. Results suggest that at low and moderate levels of LSF structure in the reserve, treating non-LSF units is as effective in reducing fire threat as is treating LSF units. In this range, the treatments impose a low cost on owl habitat. In contrast, at high levels of LSF habitat structure, treating some LSF units could reduce fire threat in the reserve. In this range, treatments come at a cost to owl habitat.

Treatment effects in the reserve, whether ecological or financial, need to be evaluated at scales relevant to fire and owls. Hence, we evaluated net present value (NPV) for the collection of treatment units in the reserve over thirty years rather than for each unit in each decade. Results indicate that the lowest cost to the non-market values of LSF structure and FT reduction was achieved by a mixture of treatments -- some that earned money and some that lost money in an individual unit but that collectively broke even (NPV≥0). In contrast, if breaking even was required within each decade the cost was similar to requiring that treatments earn \$0.5 million NPV over thirty years. This implies that constraining the time period within which the financial effect of the treatments was evaluated imposed a cost on the non-market values in the reserve.

Introduction

Background

A network of forest reserves exists in the Pacific Northwestern United States (PNW). The main objective for the reserves is to provide habitat for species associated with structurally complex, late successional forest (LSF). One such species is the northern spotted owl (*Strix occidentalis caurina*). The Northwest Forest Plan (Plan), which

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[1] An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April 2004, Córdoba, Spain.

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established the reserves, permits silvicultural treatments within them to avoid potentially negative impacts on habitat (LSF structure) associated with extensive natural disturbances like wildfire (USDA/USDI 1994). The Plan distinguishes between treatments permitted in reserves lying to the west or to the east of the Cascade Range (Cascades) due to regional differences in climate, vegetation, and management history (USDA/USDI 1994). The eastern region (eastside) is characterized by mixed-severity fire regimes with shorter average fire return intervals than the western region (Agee 1993). Consequently, more silvicultural flexibility is permitted in eastside reserves.

Issue

Silvicultural treatments within reserves are contentious, in part because of limited information on the effectiveness of treatments in reducing the likelihood of large-scale disturbances, their financial cost, and their effects on the primary reserve objective of maintaining LSF structure.

Objectives

Our objectives were threefold: 1) quantify the relationship between two non-market values: LSF structure and fire threat (FT) in an eastside reserve; 2) schedule silvicultural treatments over thirty years to maintain LSF structure while maximizing FT reduction in the reserve; and 3) evaluate the effects of different financial constraint levels on FT reduction and on treatment options to maintain LSF structure in the reserve.

Methods

Characterize Current Vegetation Structure

We selected an eastside reserve in Washington State for this analysis (*fig. 1*). On the eastern slopes of the Cascades, annual precipitation decreases on a west-east gradient. In the 6070 hectare (ha) reserve this gradient is modified somewhat by Mount Adams (3700 meters (m)), located immediately to the north. Changes in precipitation and elevation within the reserve influence the spatial patterns of variables like vegetation and fire, and their interaction.

We began our analysis by characterizing current vegetation structure in the reserve using 1995 aerial photos (1:12,000 scale). Patches of vegetation (159 total) sharing similar structure and composition were photo-interpreted using methods from Hessburg and others (1999) and entered into an ArcView® GIS database. A summary matrix was constructed from two patch attributes, structure class and potential vegetation, to stratify all patches into 15 stand types (details in Hummel and others 2001). In combination, these two attributes provide information on the current forest structure in any given patch and the conditions influencing its potential rate of change. Each stand type was assigned a root disease severity rating using methods from Goheen (1997).

Figure 1--Location of the study reserve (black star) in the northwestern United States. California (CA) is provided for reference.

We next summarized available vegetation data for each stand type and discarded data collected before 1999. Using a randomized design with probability proportional to size, we selected patches for field sampling in 2000 and 2001. The range of stand types was sampled. All data were collected using the USDA Forest Service Region 6 stand exam protocol. The number of exams done within each patch depended on the patch size. Exam data were used to create "tree lists" for that patch following standard procedures for the Forest Vegetation Simulator (FVS) (Dixon 2003). Using the set of existing FVS tree lists within each stand type, any unsampled patches were randomly assigned a FVS tree list within the same stand type.

We divided some photo-interpreted patches, based on species composition or special features, to refine our GIS coverage. A unit is the smallest area to which a treatment can be applied, and is the basis for our analysis of current and projected vegetation structure. Units in the reserve averaged 18 ha and ranged in size from 0.8 ha to 464 ha. All units were assigned the FVS tree list associated with their original patch (details in Hummel and others 2002).

Develop Structural Definitions for Fire Threat (FT) and Late Successional Forest (LSF) Habitat

We developed structure-based definitions for LSF and for a spatially explicit FT index. 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 and to owl habitat. In addition, it provides a common denominator for the non-market values of LSF and FT.

For LSF structure, we relied on published data and knowledge of local conditions (Thomas and others 1990, Buchanan and others 1995, Mendez-Treneman 2002). The LSF structure definition is based on the basal area of trees in specific diameter classes (*table 1)*. We assumed that providing structural conditions consistent with published studies of eastside owl habitat would enable the reserve to support reproductively successful owl pairs.

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

For FT we used three variables: flame length, crown fire initiation, and crown fire spread (Scott and Reinhardt 2001). The FVS tree list was evaluated with the Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003) to estimate these three variables for each unit. A unit's FT index was a weighted combination of the within-unit variables and those in adjacent-units (details in Hummel and others 2002, Calkin and others in review). A FT index level (low, moderate, or high) was developed for each unit. We included information on neighboring units in our FT index so that treating one unit could influence FT in adjacent units and vice versa. A landscape FT was computed from the proportion of the reserve in each of the low, moderate, and high FT categories for every decade. We chose a 30-year analysis period by considering fire return intervals for mixed-conifer forests in the region (Agee 1993).

Simulate Vegetation Response to Silvicultural Treatments

We used the East Cascades FVS variant (Johnson 1990), the Western Root Disease Model (Frankel 1998), and FFE-FVS (Reinhardt and Crookston 2003) to evaluate LSF structure and to assign a FT level in each unit. FVS keywords (Van Dyck 2000) were used to bring all tree lists to a common date, modify the default large tree diameter growth equation based on calibration statistics from local samples, change default values for down wood and fuel moisture based on field samples and site visits (e.g. Hummel and Agee 2003), classify the unit according to our LSF definition, set wind speed values based on local weather station data, and simulate tree regeneration (details in Calkin and others in review).

Variable-intensity silvicultural treatments were applied in FVS to all units and forest development simulated over three, 10-year cycles. The treatments differ in the type of thinning, species removed, maximum diameter limit, residual basal area target, and residual fuel loads (*table 2*). Passive management in the reserve was simulated by applying the "no prescription" (noRx) treatment to all units. Active treatments that cut trees were applied according to a rule set. The rules were chosen by consulting applicable laws, Plan standards and guidelines, and managers of the reserve (details in Calkin and others in review). For example, no active treatment was applied in any unit which met structural criteria as spotted owl nesting habitat.

Vegetation structure in each unit in each cycle associated with each treatment was evaluated according to the definitions established for FT and LSF using FVS commands. We used results from the noRx simulation to identify baseline values for the reserve. Thus, the maximum projected area of LSF structure with passive management (6982 ha) became the maximum area of LSF structure to be maintained over thirty years.

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 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*)

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).

Develop Production Curves by Varying Silvicultural Treatments and Area Treated

Production possibility (PP) curves illustrate the relative cost, or tradeoffs, of managing for a non-market value in terms of market or non-market values (Montgomery 2003). We developed a simulated annealing (SA) algorithm (Kirkpatrick 1983) to construct a set of PP curves for the reserve. The SA algorithm was written to maximize the reduction of landscape FT subject to constraints on the total area of LSF structure maintained over thirty years and the amount of area that could be treated in any cycle. 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 6678, 6780, and 6880 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 (details in Calkin and others in review).

Identify Marginal Cost of Silvicultural Treatments

We entered price assumptions, harvest costs, fuel treatment, and wood products into FEEMA to calculate net revenues 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. The amount of defect by log size class was estimated by using previous timber sale records for the area and recommendations from personnel responsible for scaling and cruising. Wood product prices representing a stable high market (fourth quarter 1999) and a stable low market (fourth quarter 2001) in the PNW were averaged to reflect a stable market. Product prices and all harvest and operational costs were assumed to be constant over time. Future costs and revenues were discounted by 4 percent.

We identified a range within which silvicultural treatments could achieve relatively high FT reduction at relatively low cost to LSF structure by using the PP curves. 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 the area of LSF structure (6880 ha), the maximum treated area (≤10% of the reserve), and NPV were set as constraints. The NPV constraint levels were USD $0, $0.5 million, $1 million, and $1.5 million in addition to an unconstrained baseline. The three cases in excess of $0 are also referred to as +NPV.

Results

Tradeoffs Between LSF and FT Reduction (FTR)

Figure 2 illustrates the tradeoffs between LSF structure and reduction of the landscape FT index (FTR) for different treatments and area treated. Point (a) illustrates the strict area constraint and maximum amount of LSF structure projected over thirty years. Curve (b), drawn freehand for illustration, is the case when only the diameter limit treatment (DiameterRx) was applied. The outermost curve (e), also drawn freehand, is the unconstrained case. The other curves represent mixtures of silvicultural treatments and area treated.

The relatively flat portion of the curves implies that, for low and moderate levels of LSF structure in the reserve, treating non-LSF units is as effective in reducing fire threat as is treating LSF units. In this range, the treatments impose a low opportunity cost in terms of owl habitat. In contrast, the sloping portion of the curves indicates that, at high levels of LSF habitat structure, treating some LSF units could reduce fire threat in the reserve. In this range, treatments come at a cost to owl habitat.

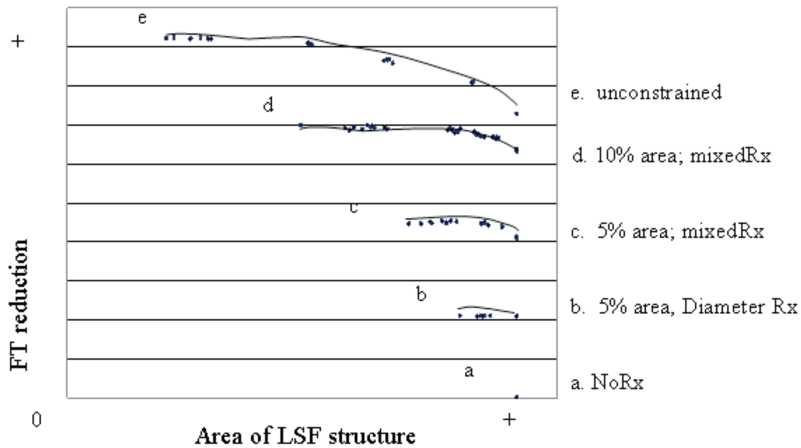

Figure 2--Tradeoffs between late successional forest (LSF) structure and fire threat (FT) reduction) for different silvicultural treatments (Rx) and constraints on area treated (5% or 10% of the reserve). For illustration, curves b, c, d, and e were drawn freehand rather than fitted.

Treatment Options

Results for passive management indicate that landscape FT levels increased over thirty years. Several units changed from low or moderate FT to a high FT level in the first two decades and remained high in the third. In contrast, the area projected to be in LSF structure remained fairly constant over the same analysis period. This baseline analysis suggests an increasing likelihood of large-scale disturbance to LSF structure in the reserve over time.

Results for active management indicate that a mix of silvicultural treatments, rather than a single treatment, was better at achieving landscape objectives for maintaining LSF structure and FT reduction. Application of the diameter limit treatment did not result in a reduction of FT for many units.

Marginal Costs of Silvicultural Treatments on LSF and FTR

Over our 30-year analysis period, a constraint to break even (NPV≥0) did not bind the simulated annealing algorithm. This means that with or without a financial requirement to break even, treatments accomplished about the same level of FT reduction and LSF structure. However, 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. Financially unconstrained solutions always resulted in large negative NPV solutions.

Requirements for the collection of treatments to earn money (+NPV) negatively affected FT reduction over the 30-year period. Extreme constraints carried high marginal costs. This is because silvicultural treatments that consistently lost money were not applied despite reducing fire threat at low cost to LSF structure. Some treatments had negative net present values on all units in all decades. A requirement to make money, therefore, imposed a cost on non-market values in the reserve.

Finally, if breaking even was required within each decade, the cost was similar to requiring that treatments earn \$0.5 million NPV over all three decades. This implies that constraining the time period within which the financial effect of the treatments is evaluated came at a cost to the non-market values in the reserve. Results are sensitive to the non-market values considered and to the time period over which they were evaluated.

Discussion

The ecological and financial implications of silvicultural treatments need to be evaluated at geographic and temporal scales relevant to their objectives. In this analysis, with objectives related to wildfire and owl habitat, we considered results for the collection of treatment units in the reserve over thirty years rather than unit by unit. Our results suggest that variable-intensity silvicultural treatments can be applied that reduce FT at low opportunity cost to existing or projected LSF structure within the reserve.

The USDA Forest Service is not required by law to make money. Prudence dictates, however, that public forest management objectives be achieved at the lowest cost. When the objectives include non-market values, the total costs will include impacts not measurable in dollars. One way to evaluate these impacts is by identifying production relations between non-market values and then estimating the relative cost of managing one in terms of the other. For example, given a NPV$\geq$0 strict area constraint, our results indicate that the marginal cost of an 8 percent improvement in FT reduction is a 1.5 percent reduction in LSF structure.

Although PP methods can increase understanding of potential tradeoffs between non-market values, two or three dimensions are likely insufficient to capture biologically and socially important variables. In this analysis, for example, uncertainty over the relation of forest structure to owl persistence will affect perceptions of the risk to owls from different silvicultural treatments. This, in turn, will introduce other constraints that are outside the scope of our analysis. Economic efficiency is not the only factor considered by managers of public lands, but economic methods can be used to provide information on tradeoffs associated with different management options.

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