Historical disturbance regimes as a reference for forest policy in a multiowner province: a simulation experiment

Jonathan R. Thompson, K. Norman Johnson, Marie Lennette, Thomas A. Spies, and Pete Bettinger

Abstract: Using a landscape simulation model, we examined ecological and economic implications of forest policies designed to emulate the historical fire regime across the 2×10^6 ha Oregon Coast Range. Simulated policies included two variants of the current policy and three policies reflecting aspects of the historical fire regime. Policy development was guided by the management intentions of four owner groups: forest industry, nonindustrial private, state, and federal. Fire severity was emulated with green-tree retention standards; fire frequency was emulated with annual harvestable area restrictions; and fire extent was emulated with harvest-unit size regulations. Simulated disturbance-based policies produced age-class distributions closer to the estimated historical range than those created by the current policy. Within 100 years, proportions of younger forests were within the historical range, while older forests moved closer to, but remained below, historical conditions. In the near term, disturbance-based policies produced annual harvest volumes 20%–60% lower than those produced by the current policy. However, relative costs of disturbance-based policies diminished over time. Our results suggest that if expediting a return to historical age-class distributions at a provincial-scale was a goal, then public lands would be needed to provide large patches of old forest. In addition, this experiment illustrated that distributing costs and benefits of conservation policies equitably across multiple private landowners is a significant challenge.

Résumé : À l'aide d'un modèle de simulation du paysage, les auteurs ont examiné quelques unes des conséquences écologiques et économiques des politiques forestières qui visent à simuler le régime historique des feux dans la chaîne côtière de l'Oregon, un territoire d'une superficie de 2×10^6 ha. Les politiques simulées incluaient deux variantes de la politique actuelle et trois autres reflétant le régime historique des perturbations. Le développement de ces dernières a été guidé par les objectifs d'aménagement de quatre groupes de propriétaires : l'industrie forestière, les propriétaires privés non industriels, l'État et le gouvernement fédéral. La sévérité des feux a été simulée par des normes de rétention de tiges résiduelles; la fréquence des feux a été simulée par des restrictions quant à la superficie récoltable annuellement et la dimension des feux a été simulée à l'aide de normes quant à la taille des blocs de récolte. Les politiques basées sur les perturbations ont produit des distributions de classes d'âge plus proches du domaine historique estimé que celles qui ont été obtenues avec les politiques actuelles. Dans une période de 100 ans, la proportion des forêts jeunes se situait dans leur domaine historique alors que celle des forêts plus âgées s'en rapprochait mais demeurait en dessous de leur niveau historique. Dans un avenir proche, les politiques basées sur les perturbations ont produit des volumes de récolte 20 à 60 % plus faibles que la politique actuelle. Cependant, le coût relatif des politiques basées sur les perturbations diminue avec le temps. Les résultats indiquent que les forêts publiques devraient fournir de grandes superficies de forêts anciennes si on voulait rapidement revenir aux distributions historiques de classes d'âge. De plus, cette expérience montre que la distribution équitable des coûts et des bénéfices des politiques de conservation parmi les multiples propriétaires privés représente un défi important.

[Traduit par la Rédaction]

Received 21 March 2005. Accepted 17 October 2005. Published on the NRC Research Press Web site at http://cjfr.nrc.ca on 8 February 2006.

J.R. Thompson,[1,2] K.N. Johnson, and M. Lennette.[3] Department of Forest Resources, 280 Peavy Hall, Oregon State University, Corvallis, OR 97331, USA.
T.A. Spies. USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way Corvallis, OR 97331, USA.
P. Bettinger. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602, USA.

[1]Corresponding author (e-mail: jonathan.thompson@oregonstate.edu).
[2]Present address: Department of Forest Science, 321 Richardson Hall, Oregon State University, Corvallis, OR 97331, USA.
[3]Present address: Forest Planning and Economics Group, Mason, Bruce, and Girard, Inc., 707 SW Washington Street, Suite 1300, Portland, OR 97205, USA.

 doi:10.1139/X05-247

Introduction

Natural disturbances have been fundamental to the evolutionary history of forest ecosystems such that the continuation of disturbance is essential to maintaining native diversity (Attwill 1994). Some argue that by emulating historical disturbance processes, such as wind or fire, forest management can produce forest composition and structure that is similar to the conditions that supported native biota (Hunter 1993; Swanson et al. 1993; Cissel et al. 1994; Landres et al. 1999; Kuuluvainen 2002). This is considered a coarse-filter approach to forest conservation and ecosystem management (The Nature Conservancy 1988; Hunter 1990; Armstrong et al. 2003). It relies on the assumption that native forest species evolved within a bounded range of landscape conditions, within which there were constant fluctuations driven by disturbance processes (Holling 1973; Swanson et al. 1993; Reeves et al. 1995; Landres et al. 1999). Although many differences between "natural" disturbance and timber harvests cannot be overcome, disturbance-based forest management can be used to find a point on a gradient of conditions that is closer to the outcome expected from a natural disturbance that might result from traditional timber management or current forest policies. Many forest scientists have met experimental conservation goals, through simulations and field experiments, by approximating the spatial distribution (Franklin and Forman 1987; Andison and Marshall 1999), frequencies (Cissel et al. 1999), and residual structure (McComb et al. 1993; Stuart-Smith 2002) of historical fire regimes.

As interest in disturbance-based management grows, there is impetus to incorporate it into forest policy (Bunnell 1998; Andison and Marshall 1999; Armstrong et al. 2003). Few examples of policies explicitly based on natural disturbance regimes exist in North America. Noteworthy exceptions include the *British Columbia Biodiversity Guidebook* (British Columbia Ministry of Forests 1995) and the *Ontario Forest Management Guide to Natural Disturbance Pattern Emulation* (OMNR 2001). In both cases, forest management guidelines were set explicitly with historical disturbance regimes as a reference. In contrast to Canada, policy-makers in the United States have been less aggressive in incorporating this approach, but notably, in 2000, new regulations for the National Forest Management Act were adopted (though not generally implemented) and for the first time included a reference to using historical disturbance regimes to assist evaluations of ecosystem sustainability (36 CFR 219.20). Implementing disturbance-based policies in the United States has unique challenges as compared with Canada: whereas most Canadian forests are centrally owned, US forest practices are governed by a variety of policy structures based on diverse land tenure.

The primary objective of this study was to better understand some of the economic costs and ecological benefits of disturbance-based policies applied over a large multiowner provinc: the Oregon Coast Range. Throughout western Oregon, logging has replaced fire as the prevailing forest disturbance agent (Cohen et al. 2002). This has resulted in dramatic changes in forest structure (Wallin et al. 1996; Spies 1998; Stanfield et al. 2002; Wimberly and Ohmann 2004; Nonaka and Spies 2005) and has reduced the quantity and quality of habitat for many native species (FEMAT 1993). Consequently, there have been calls from scientists (Reeves et al. 1995), natural resource advisory groups (IMST 1999), and policy-makers (Lorensen 2003) to modify Oregon's forest policies to incorporate disturbance-based management. Within the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests of western Oregon, several silvicultural and simulation experiments have shown promise for reaching conservation goals using this approach (e.g., McComb et al. 1993; Hansen et al. 1995; Cissel et al. 1999). However, these experiments were restricted to management over limited spatial scales and occurred on a single ownership.

In a related study, Nonaka and Spies (2005) found that neither a continuation of the current policy nor a sudden return of the historical wildfire regime would move the landscape toward the historical range of variability in the next century. Therefore, if the eventual goal is a change in regional forest structure and composition toward historical conditions, a proactive set of disturbance-based policies might be required. The effects of such an approach need to be examined over multiple landowners and at large spatial scales. This study is one of the first to do that.

The recent development of a landscape policy simulator, parameterized for the region (Bettinger et al. 2005), provided an opportunity to examine some likely effects of disturbance-based forest policies. In addition, the published results of a stochastic fire simulator (Wimberly 2002), built for the Coast Range's historical disturbance regime, presented a useful gauge of the policies' efficacy. Our specific objectives were as follows: (1) develop and simulate the effects of several forest policies that used the historical fire severity, frequency, and extent, to inform retention levels, harvest rates, and harvest size distributions; (2) compare the simulated landscapes in terms of landscape composition and structure to the range of estimated historical conditions; and (3) compare the simulated landscapes in terms of forest composition and economic indicators to projected conditions under the current policy structure.

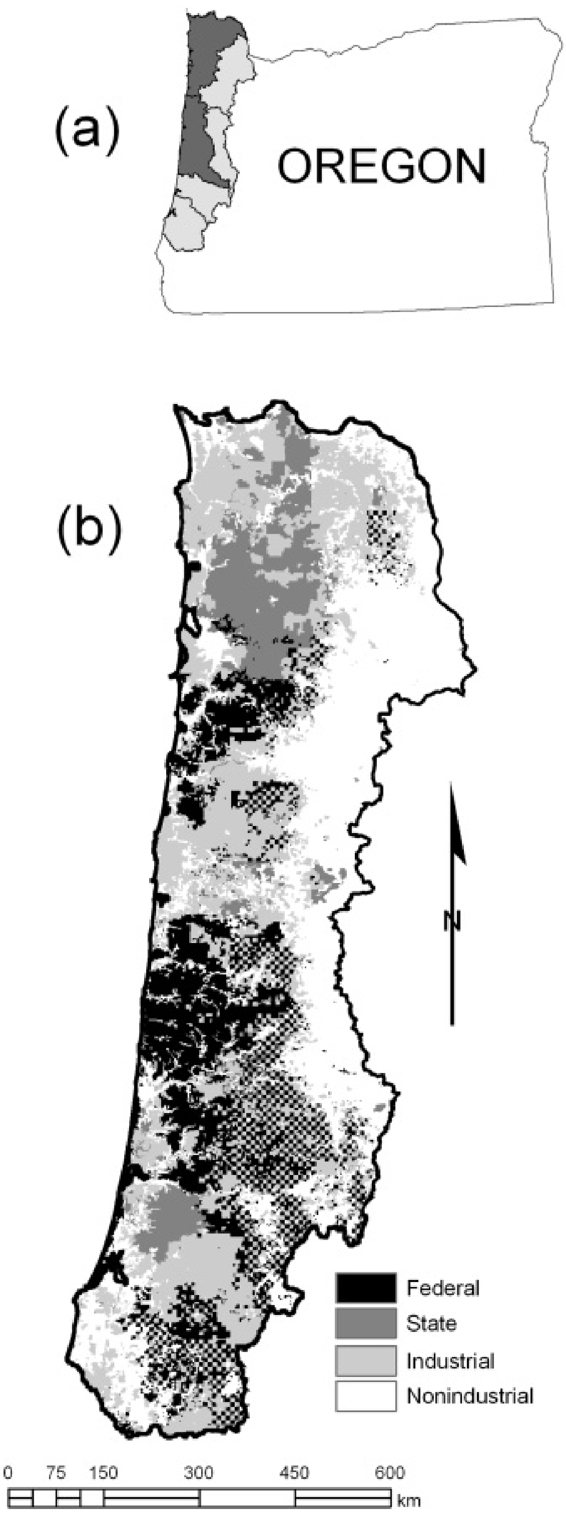
Materials and methods

Study area

Our study area was the Oregon Coast Range physiographic province. It contains approximately 2×10^6 ha of some of the most productive forests in the world (Spies et al. 2002*a*). It is bordered to the north by the Columbia River, to the south by the Klamath Mountains, to the west by the Pacific Ocean, and to the east by the Willamette Valley (Fig. 1*a*). Low but steep mountains with high stream densities characterize the region. The majority of the province is forested and lies predominantly within the Western Hemlock vegetation zone (Franklin and Dyrness 1988). The forest overstory is dominated by Douglas-fir, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and red alder (*Alnus rubra* Bong.).

Two climate zones are recognized. The coastal zone in the northwest is cool with high precipitation; the interior zone, along the Willamette Valley margin and bordering the Klamath Mountains, is relatively warmer with less precipitation (Impara 1997; Wimberly 2002).

Fig. 1. The Oregon Coast Range study area and ownership mosaic. (*a*) The study area with megasheds delineated. The light grey megasheds represent the interior climate zone (from north to south: Northeast, Mideast, South, Umpqua); dark grey megasheds represent the coastal climate zone (North, Midwest). (*b*) The ownership mosaic of the Oregon Coast Range.



Wind and landslides significantly influence stand-level forest structure in portions of the Coast Range (Wimberly and Spies 2001). Historically, however, wildfire was the primary disturbance agent controlling landscape-level forest structure and composition (Agee 1993; Impara 1997). The fire regime was characterized by large mixed- to high-severity fires on relatively long return intervals (Impara 1997). Analysis of macroscopic charcoal sediments, taken from a lake core in the central Coast Range, shows the return interval was relatively stable throughout the 1000 years prior to European settlement (Long et al. 1998). Dendroecological studies revealed fires in the interior climate zone were smaller, more frequent, and less intense than those in the coastal zone (Impara 1997). Throughout both climate zones, surviving "legacy" trees created variable tree sizes and canopy layering; trees killed in fires provided abundant large snags and down wood (Spies et al. 1988; Hansen et al. 1991). Long fire-return intervals produced a landscape typically occupied by greater than 40% old forests (>200 years) in variably sized patches often greater than 10 000 ha (Wimberly et al. 2000).

Since European settlement began in the late 19th century, the Coast Range has undergone significant changes in forest composition and structure. The modern landscape is a mosaic of ownerships and forest structural classes displaying a mix of different management objectives (Spies et al. 2002*b*). Industrial forestlands constitute the majority of the forested area (~40%), followed by nonindustrial private (NIP) forests and federally managed lands (each approximately 23%), and state forests (~14%) (Fig. 1*b*). Ownership explains a significant portion of the variability in forest structure; private industrial lands are associated with simplified young forests, federally managed lands with mature forest cover, and NIP lands with a wide diversity of cover classes (Stanfield et al. 2002). Regional timber harvest is primarily regulated by market forces, the Oregon Forest Practices Act (OFPA) for private lands, state forest management plans, and federal land management policy (primarily the Northwest Forest Plan).

Virtually all private lands have been harvested at least once since European settlement (Ohmann and Gregory 2002), and most of the harvest volume has come from clear-cutting (Lettman and Campbell 1997). Old forests (>200 years), which were historically the most abundant age-class (Wimberly et al. 2000; Wimberly 2002), now represent less than 5% of the landscape structure (Ohmann and Gregory 2002). Over the past decade, since the adoption of the Northwest Forest Plan on federal lands (NWFP EIS 1994), the vast majority of timber harvests have occurred on private lands.

Policies governing the modern disturbance regime (clear-cutting) promote a landscape that differs from the historical range of conditions in five primary ways:

(1) The legacy of fire severity, as measured by quantity of dead wood and residual trees left after a fire, has shifted from high to low. The OFPA requires only 5 small trees and 1.5 m^3 of down wood retained per hectare, whereas wildfires left much larger quantities of residual structure (Spies et al. 1988).

(2) The frequency of disturbance has shifted from long to short. Historical fire-return intervals are estimated at 100–300 years (Teensma et al. 1991; Ripple 1994; Impara

1997); in comparison, recent harvest rotations on private land have typically ranged from 40 to 100 years (Cohen et al. 2002), though there is no explicit policy governing the frequency of harvest.

(3) The spatial extent of disturbance events has shifted from large to small. Although historically most fires were small (<100 ha), the majority of the area burned in relatively few large fires, often larger than 10 000 ha (Teensma et al. 1991; Wimberly 2002). This contrasts with clearcutting restrictions in the OFPA that limit timber harvests to 48 ha.

(4) Early seral forests have shifted from a complex to a simple structure. Due to economic incentives and regulations governing reforestation on private land, most early seral forests created over the last 30 years lack a diversity of shrubs and hardwoods.

(5) The shapes and configuration of forest patches have shifted from large and complex to small and simple (Nonaka and Spies 2005). Differences in policies and objectives between ownership classes have resulted in high but predictable contrasts at ownership boundaries; this contrasts sharply with the historical landscape, which contained high variation in patch juxtaposition (Nonaka and Spies 2005).

We examined the implications of reversing the first three of these trends.

Overview of the models

Policy simulator

We used the Landscape Management Policy Simulator (LAMPS) (Bettinger and Lennette 2004; Bettinger et al. 2005) to project the effects of several forest policies. This simulation model is the analytical centerpiece of the Coastal Landscape Analysis and Modeling Study (CLAMS), an interdisciplinary effort to analyze the combined ecological, economic, and social consequences of forest policies in the Coast Range (Spies et al. 2002*b*). LAMPS tracks ownership, vegetation patterns, economic indicators, and biophysical characteristics of parcels of land in relation to their context within the surrounding landscape. A gradient, nearest-neighbor classification of satellite imagery and plot data was used to represent the initial vegetation conditions (Ohmann and Gregory 2002). Embedded in the model was a projection of the expected conversion of forests to nonforest due to urban and rural development (Kline et al. 2001). Topography, climatic influences, and stream networks are explicitly recognized and influence the timing and arrangement of regeneration, succession, stochastic forest gaps, and management activities (Bettinger et al. 2005). LAMPS has the capacity to simulate landscape changes resulting from different policy structures over a 100-year planning period (Bettinger and Lennette 2004; Bettinger et al. 2005).

LAMPS simulations attempt to represent future landscape conditions and timber outputs under plausible management assumptions. To build credibility and realism, LAMPS explicitly recognizes land ownership groups and simulates different management objectives. CLAMS scientists and cooperating agencies conducted surveys of management intentions and engaged in discussions with land managers to provide insight into the factors controlling current and future management behavior, which were then built into the simulations. The primary utility of LAMPS is to simulate a range of forest policy options to help land managers "think through" the potential landscape-scale effects across all ownerships (Spies et al. 2002*b*; Bettinger et al. 2005).

Within LAMPS, forest dynamics are modeled at a variety of spatial scales integrated into a larger hierarchical structure. Homogenous response units, called basic simulation units (BSUs), are used to track forest structure and model gap disturbances. They are the smallest spatial unit recognized in LAMPS, averaging about 0.30 ha. LAMPS tracks forest structural conditions and models small gap disturbances at a small spatial scale (0.06–1.94 ha), schedules management activities at a medium scale (10–46 ha), and imposes some constraints on activities at much larger scales (2000 – 800 000 ha) (Bettinger et al. 2005). The ownership group being simulated dictates which levels of this hierarchy are applied. Because of computer memory limitations and the number of BSUs recognized, LAMPS programmers needed to model the Coast Range in six separate pieces. These parts, called megasheds, are divided along fourth-field watershed boundaries (Fig. 1*a*). The spatial hierarchical structure is described in detail in Bettinger et al. (2005).

LAMPS uses BSUs to project the structural characteristics of forests over time as they grow and undergo natural and human disturbance (Bettinger et al. 2005). Two existing stand simulation models, calibrated for the Coast Range, were used: ORGANON (Hann et al. 1997) and ZELIG.PNW (Busing and Garman 2002; Garman et al. 2003).

Additional details regarding the LAMPS model, including its treatment of growth and yield, recognition of multiple succesional pathways after regeneration harvest, spatial scheduling of harvests, stochastic gap-level disturbance, transition probabilities, and the organization of spatial databases, can be found in Spies et al. (2002*c*), Bettinger and Johnson (2003), Bettinger and Lennette (2004), and Bettinger et al. (2005).

Landscape fire model

Data used to inform the disturbance-based policies and to gauge their capability to emulate natural disturbance came from the Landscape Age-class Demographic Simulator (LADS) (Wimberly et al. 2000; Wimberly 2001, 2002). LADS was originally developed to assess historical amounts of old forest in the Coast Range (Wimberly et al. 2000); it has subsequently been improved to better represent the shape and severity of the Coast Range's historical fire regime (Wimberly 2002). LADS is a probabilistic simulation model that uses a cellular automata approach to approximate fire spread. Wimberly (2002) used probability distributions of fire size and frequency that were derived from historical documents (Teensma et al. 1991; Ripple 1994; Ripple et al. 2000), a macroscopic charcoal analysis from a lake core (Long et al. 1998), and a dendroecological study (Impara 1997) to calibrate LADS to the pre-European fire regime.

The historical range variability (HRV) of forest conditions was developed by running LADS for 50 000 years and calculating landscape summaries at 200-year intervals (Wimberly 2002). The HRV refers to the bounded range of variability in the composition, structure, and dynamics of ecosystems before the pulse of changes associated with Euro-American settlement (Swanson et al. 1993). Once HRV was explicitly defined, it was used as a range of reference conditions from which disturbance-based strategies were developed and assessed.

The simulations

Five policy alternatives were simulated in LAMPS. Two simulations modeled anticipated forest management under the current policy structure; they are distinct in the manner that they simulate the actions of industrial owners. Three simulations were parameterized to incrementally introduce a disturbance-based forest policy structure to private lands in the study area. For the purposes of this study, two megasheds in the northwest portion of the study area were treated as the coastal climate zone and four megasheds in the south and east were treated as the interior climate zone (Fig. 1*a*). Although stochastic windfall disturbances were included, the potential for future wildfire was not considered; as such, timber harvests were the only stand-replacing disturbance simulated.

Base policies (Base25 and Base25/33)

The simulations that were designed to emulate the expected management activities over the next century, given the current policy structure, are referred to here as the "base policies". As we have discussed previously, LAMPS has the capacity to simulate the likely behavior of multiple ownership groups. We briefly outline here the major elements of the simulations.

Federal

The scheduling process on federal lands (USDA Forest Service and Bureau of Land Management) was based on the Northwest Forest Plan (NWFP EIS 1994). In late-successional and riparian reserves (approximately 80% of the federal land), thinning in plantations to increase structural diversity and accelerate development of late-successional conditions is the primary harvest activity. After one or two thinnings, the stands are left to develop without further entry. In the remaining 20% of federal lands, categorized as matrix lands, timber harvest occurred through a combination of commercial thinning and patch cuts. To simulate the planned level of activity in the matrix, CLAMS scientists obtained volume targets from the federal agencies to determine the harvest level. They then simulated the allocation of the matrix harvest across the landscape, assuming patch-cut harvests would occur in mature forest (approximately 80–120 years) and commercial thinning would occur in young stands (approximately 30–80 years), as their conditions warranted. Patch cuts averaged less than 6 ha and were selected randomly from the mature forest. Overall, the federal forests constituted less than 2% of the total area harvested within the study area during the simulation period.

State

Management actions on state lands were based on the Oregon Department of Forestry's published forest plans (2001). LAMPS achieved the state's structural goals by managing for four attributes: (1) the desired proportion of structural stages (regeneration, young, mature, multilayered, old), (2) the desired patch-size distribution of each structural stage, (3) two layers of special management zones near streams, with increasingly protective strategies applied closer to the stream, and (4) special habitat anchors designated for mature and old forest. These structural goals guided and controlled the harvest location and level and the relative proportion of thinning and regeneration harvest. A minimum clear-cut harvest age was set at 45 years, and a 5-year green-up period was required; actual rotation ages to meet the structural goals approached 120 years. Regeneration harvests occurring in matrix lands averaged less than 6 ha and retained 12 medium-sized trees/ha, except for the midslope riparian zone in which 35 trees/ha were retained during clear-cutting. Regeneration harvest on state lands constituted less than 3% of total harvest area within the study area.

NIP

Several economic, environmental, and social forces influence the behavior of NIP forest owners (Kline et al. 2000). Therefore, to simulate the actions of this diverse group, LAMPS used a probabilistic approach to model harvest decisions that combined historical information and owner surveys with economic analysis. NIP harvest information from inventory plots taken in the early 1990s was used to estimate the probability of commercial thinning and regeneration harvest (clear-cutting) as a function of age (Lettman and Campbell 1997). We used these probabilities to distribute the harvest among different ages. Used directly, though, this resulted in a substantial increase in inventory and rotation age over time. This did not seem reasonable, especially since the premium for large trees that was once associated with longer rotation ages has largely disappeared. Therefore, we augmented these probabilities with volume targets, resulting in relatively stable rotation age (approximately 60 years) and much less buildup in inventory. Clearcut size distributions were modeled after the actual distribution of NIP harvests in recent years (as adapted from Cohen et al. (2002)). Other restrictions were consistent with the OFPA, including a 5-year green-up period, a maximum clearcut size of 48.5 ha, retention of 5 small trees/ha, and retention of riparian buffers.

Forest industry

Behavior of the forest industry in large-scale studies, such as this analysis, is often modeled under the assumption that these firms will choose forest management practices that maximize the net present value (NPV) of their forest assets (Adams et al. 2002). Alternatively, they can be assumed to focus on providing the highest constant supply of wood to mills while using investment-efficient management regimes (Sessions et al. 1990). In western Oregon, it is likely that industrial owner actions will reflect a blend of the two goals (Adams et al. 2002).

Generally, landowners are assumed to react to policy change in ways that allow them to achieve as high a level of their goal (maximum NPV or maximum sustainable harvest level) as possible (Adams et al. 2002). In the Coast Range, industrial harvest in the last 30 years has shown considerable stability at the regional level, although less stability at the subregional level. This trend may continue or there may be a short-term increase in harvest reflective of individual firms maximizing their NPV (Adams et al. 2002). Both hypotheses about industrial behavior are represented below through different simulations. (1) The Base25 simulation set a constant upper limit on hectares clear-cut per 10-year period at ap-

Table 1. Descriptions of the five policy simulations.

Policy	Goal	Industry	Nonindustrial
Base25	Simulate the current policy structure	Oregon Forest Practices Act, maximize NPV; never clear-cut more than 24% of ownership in a period	Oregon Forest Practices Act, historical tendencies
Base25/33	Simulate the current policy structure	Oregon Forest Practices Act, maximize NPV; cannot clear-cut more than 24% of ownership in the first period, and not more that 33% after that	Oregon Forest Practices Act, historical tendencies
Sim(S)	Same as Base25/33, except emulate fire severity by increasing the number of tree retained in clumps and individual leave trees	Same as Base25/33, except retain 40% of BSUs and 12 trees/ha in the interior zone and 10% of BSUs and 12 trees/ha in the interior zone	Same as Base25/33, except retain 40% of BSUs and 12 trees/ha in the interior zone and 10% of BSUs and 12 trees/ha in the interior zone
Sim(S+F)	Same as Sim(S), except emulate fire frequency by limiting the number of hectares harvested to what would be expected given the average natural fire rotation	Same as Sim(S), except area harvest limited to the natural fire rotation (100 years in the interior zone and 200 years in the coastal zone)	Same as Sim(S), except area harvest limited to the natural fire rotation (100 years in the interior zone and 200 years in the coastal zone)
Sim(S+F+E)	Same as Sim(S+F), except emulate fire extent by increasing the harvest block size closer to the average fire size	Same as Sim(S+F+E), except clearcut size increased to 250 ha	Same as Sim(S+F)

Note: At the federal level, the Northwest Forest Plan applies, while state forest plans apply at the state level. BSU, basic simulation unit (see text for definition); NPV, net present value.

proximately one-quarter of the industrial land. This approach resulted in a fairly stable harvest starting at historical levels and slightly increasing harvest over time. (2) The Base25/33 simulation set an upper limit of approximately one-quarter of the industrial land for the first 10-year period to allow a transitional stage and then one-third of the area after that. This approach resulted in an accelerated harvest for two decades to decrease the surplus inventory (trees above 40 years old) and then an oscillating harvest volume for the duration of the simulation. Both approaches resulted in an average rotation age of approximately 40 years, but the Base25/33 simulations reached that age sooner.

To implement either scenario, regeneration harvest blocks (clearcuts) were constructed from smaller parcels, with the most valuable parcels selected in each period as seeds, and harvest blocks were then built around them; only positively valued parcels were added to a harvest unit (as detailed in Bettinger and Johnson (2003)). No stand younger than 25 years was eligible for harvest. The target clearcut size distribution was modeled after the actual pattern of harvests seen on industrial lands (as adapted from Cohen et al. 2002) and OFPA regulations were followed. Average clearcut size diminished over time as it became more difficult to find adjacent parcels that met the qualifications for clear-cut harvest.

Disturbance-based simulations

The disturbance-based scenarios described next were used to incrementally introduce constraints on harvest scheduling that could move forest structure and composition toward the HRV. The parameters used to emulate wildfire — green-tree retention, controls on the rate of harvest, and harvest size restrictions — have been advocated elsewhere as likely components of a disturbance-based policy structure (e.g., The Nature Conservancy 1988; Hunter 1993; Cissel et al. 1999; Lindenmayer and Franklin 2002; Armstrong et al. 2003; Wimberly et al. 2004). Although it would have been interesting to explore every permutation of these policy mechanisms, because of time and space constraints we used an incremental approach that highlighted only three disturbance-based policy scenarios. Throughout these simulations we retained the parameters from the base simulations to manage federal and state lands and focused disturbance-based strategies on private lands, where most timber harvests occur (Table 1).

When developing the disturbance-based policies, we maintained all the parameter settings of the Base25/33 except for those used to emulate the disturbance regime (Table 1). Ideally, we would have used both the Base25 and Base25/33 throughout the analysis. However, we felt the need to choose one because of the computational burden of carrying two hypotheses through the analysis. We chose to use Base25/33 after comparison with Base25 for two reasons: (1) Economic analysis and conversations with forest industry analysts suggest the recent loss of the price premium for larger logs combined with global competition for available capital and markets has shifted rotation ages downward. With the Base25 simulation, it took many decades to work through the older timber and move to the likely target rotation age of 35–45 years — this did not seem realistic. The Base 25/33 simulation achieved the target rotation age sooner. (2) The Coast Range recently experienced a major shift between industrial forest owners that affected thousands of hectares. Ownership was transferred from a firm that retained older timber to one that will likely quickly liquidate inventory older than its target rotation age. We believe that the actual schedule will fall between the hypotheses of constant flow and accelerated harvest of surplus inventory.

Emulating wildfire severity (Sim(S))

Retaining large quantities of trees on-site after a harvest is a frequently cited approach to emulating the heterogeneity of wildfire severity (Hunter 1993; McComb et al. 1993; Bergeron et al. 1999; Cissel et al. 1999). Therefore, the first disturbance-based simulation, termed Sim(S), increased the retention standards on private lands during clear-cut harvest while maintaining the other parameters set in the Base25/33 simulation. After LAMPS scheduled a management unit for clear-cutting in the interior climate zone, 40% of the unit's area was left in randomly selected uncut patches; in addition, 12 randomly selected trees/ha with DBH >60 cm were also retained. In the coastal climate zone, 10% of the area was left in uncut patches and 12 trees/ha with DBH >60 cm were retained. The difference in fire severity between the two climate zones is consistent with dendrochonological studies in the region (Impara 1997).

A behavioral assumption was made during the development of Sim(S). We assumed that if private landowners were required to retain a significant portion of the trees, they would react by seeking to make up that volume elsewhere on the landscape. Therefore, the per-period harvest volumes reported in the Base25/33 simulation were set as targets in Sim(S). Period by period, LAMPS attempts to match these targets; however; they were rarely met because of other constraints such as ownership boundaries, minimum rotation ages, and adjacency standards.

Emulating wildfire severity and frequency (Sim(S+F))

To emulate the severity and frequency of historical wildfires we developed Sim(S+F), which used the natural fire rotation (NFR) to control the area cut per period. The NFR is equal to the mean number of years required to burn an area equal in size to the area of interest (Heinselman 1973). NFR, for stand-initiating fires in the Coast Range, is thought to be approximately 100 years in the interior climate zone and approximately 200 years in the coastal climate zone (Wimberly 2002). Although the average fire frequency has been used as a proxy for disturbance-based management in other experiments (e.g., Cissel et al. 1999), it has also received criticism for neglecting the variable nature of natural fire regimes (Armstrong et al. 1999). However, a policy that imposed dramatic shifts in the allowable harvest area through time is particularly impractical. Therefore, we used the NFR evenly distributed over the planning horizon.

There are several ways to incorporate the average NFR into an allowable harvest target. Doing so in a multiowner province such as the Coast Range requires some consideration of equitability between ownerships and subregions. We used the natural fire rotation for all land within a climate zone and then applied the area disturbed per period to only private land. We also maintained the same proportions of the area harvested between ownership classes that were established in the Base25/33 simulation. This method distributed harvests evenly across megasheds within a climate zone. It also utilized the federal forests to provide forest structure older than the fire rotation, thereby reserving all scheduled disturbances for private landowners and reducing economic impact on those landowners.

The following example illustrates the procedures we used to calculate the allowable per-period harvest in each megashed: (1) The Midwest megashed (~530 000 ha) is in the coastal climate zone with an NFR of 200 years; this assumes, on average, 0.5% of the megashed would burn annually, or 5% in every 10-year period. Thus, the per-period allowable harvest in the Midwest was set to 26 500 ha. (2) During the Base25/33 simulation, 87% of the clear-cut harvest was on industrial land, 12% was on NIP land, and 1% was split between state and federal lands. We maintained these proportions by setting per-period allowable harvest targets at 23 055 ha for industry and 3180 ha for NIP (public lands were left unchanged). (3) These targets were then used to set the per-period gross harvestable hectares; the harvest was reduced further when 10% of the BSUs along with 12 trees/ha were retained within each harvest unit to emulate fire severity (as described in Sim(S)). This procedure was completed separately for all six megasheds.

Emulating wildfire severity, frequency, and extent (Sim(S+F+E))

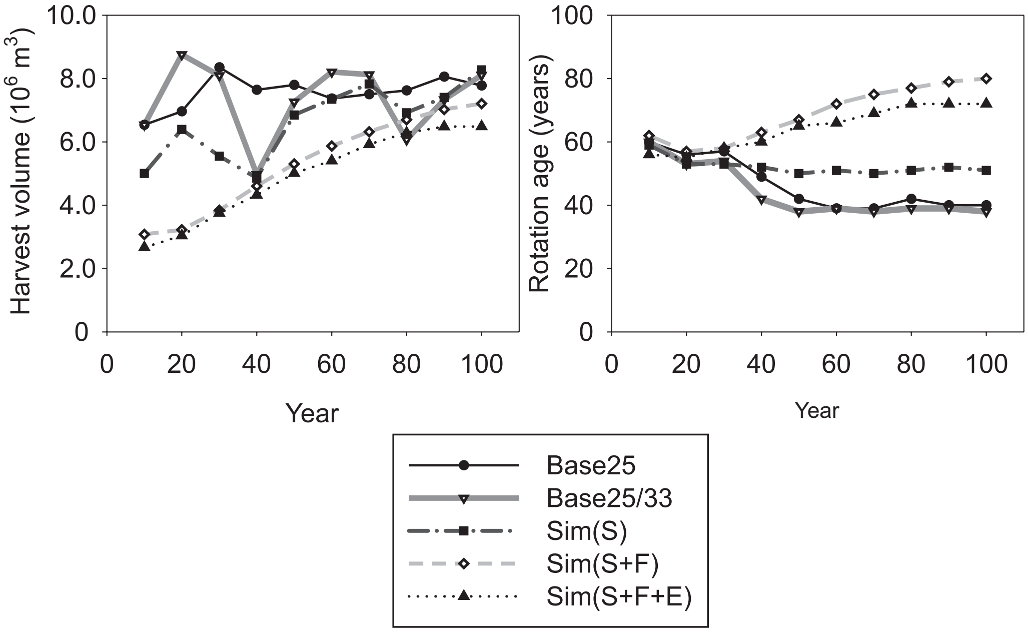
Spatial extent is another attribute of wildfire that can be emulated through forest management (Franklin and Foreman 1987; Hunter 1993; Bunnell 1998; OMNR 2001). Because historical wildfires in the Coast Range were very large, we set the size of all industrial clearcuts to 250 ha. Although this represented a 10-fold increase over the average clearcut size in the base policy simulations, it still did not approach the average size of historical wildfires in the Coast Range (estimated at 2220 ha in the interior climate zone and 7300 ha in the coastal (Wimberly 2002)). However, several logistical issues, such as ownership boundaries, adjacency constraints, and model limitations, in addition to behavioral assumptions, led us to set the clearcut size to 250 ha. This scenario is termed Sim(S+F+E).

All parameters developed for Sim(S+F), except those related to industrial clear-cut units, were held constant in Sim(S+F+E). Nonindustrial harvest size remained unchanged; this reflected NIP landowner's smaller average property size and was consistent with their tendency to harvest smaller units (Cohen et al. 2002; Stanfield et al. 2002). It also maintained a diversity of harvest sizes across the landscape that we felt better emulated the historical heterogeneity of patch sizes. To facilitate an increased industrial clearcut size, changes were made to the parameters controlling the LAMPS harvest scheduling process. The minimum harvest age was reduced from 25 to 20 years. And although LAMPS continues to prioritize the addition of parcels to a harvest unit based on their value, we removed the constraint that required all parcels to be positively valued.

Policy analysis

To help understand the economic effects, we report volume harvested per period, rotation age, and two income measures. To portray the differences between simulations in the near term, we report the projected average net revenue from

Fig. 2. Industrial harvest volumes and rotation ages throughout the 100-year LAMPS policy simulations.



timber harvest for the first 20 years of the simulations. Stumpage rates were set at a 1:1 ratio with harvest volumes and were based on our recent experience in the Coast Range. To portray the aggregate effect on wealth, we report the NPV at two interest rates: 4% and 8%. Four percent might be seen as a low-end, long-term rate that might be used by a private owner (similar to the rate used for analysis by federal forests), and 8% might be seen as a high-end, long-term rate used by the forest industry (Davis et al. 2001).

To portray the ecological effects, we describe the forest condition in terms of dominant age-classes (0–30 years (early seral), 30–80 years (young), 80–200 years (mature), and >200 years (old)) at 50-year time steps. In Coast Range forests, structural development is closely associated with age (Spies and Franklin 1991); therefore, we used age-class as a surrogate for structural class. Age-class was defined as the average age of dominant and codominant trees within each 25 m pixel (Ohmann and Gregory 2002). These structural classes had been defined previously to measure the HRV with the LADS fire model (Wimberly 2002). To allow direct comparison with the LADS output, the LAMPS pixel size was increased to 300 m using a “majority filter” in a GIS.

Results

Rotation ages

Industry

Through the first two periods, industrial rotation ages were similar between simulations. However, by period 3, the different policy structures caused the rotation ages to diverge (Fig. 2). The base policies achieved equilibrium at 38–40 years, although the Base25/33 simulation arrived there two decades earlier. Sim(S) required an abundance of live trees left after harvest; these were eventually cut on the next rotation, which resulted in the most consistent rotation ages: 50–53 years for all but the first period. The constraints on the allowable harvest area in Sim(S+F) and Sim(S+F+E) meant stands were older by the time they were scheduled for harvest. As a result, rotation ages increased throughout the simulation.

NIP

Under the base policy, rotation ages dropped slowly to 60 years and stabilized at that point (Fig. 3). The green trees retained in Sim(S) were cut on a second rotation; this resulted in stable rotation ages through all periods at 67–69 years. The constraints on the allowable harvest area in Sim(S+F) resulted in steadily increased rotations throughout the simulation from 68 to 96 years.

Harvested volume and value

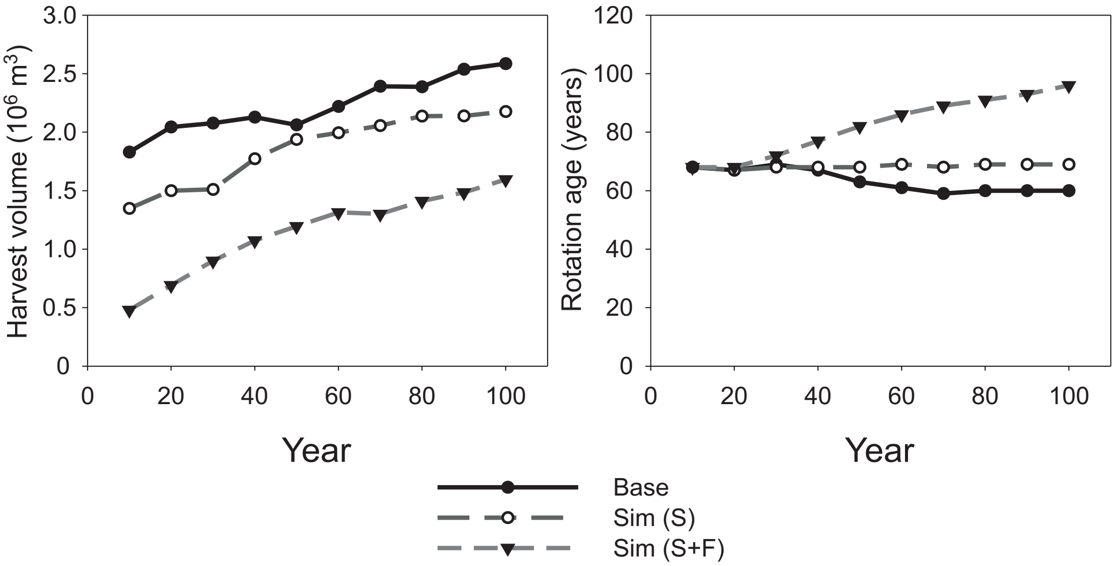
Industry

Over the duration of the simulations, the Base25 simulation harvested the most volume, while Sim(S+F+E) harvested the least (Table 2). Under all policies, hardwoods constituted roughly 20% of harvest volume in the early periods but then diminished as planted conifers came of age. The Base25/33 simulation resulted in more period-to-period variability in terms of harvest volume (Fig. 2) than did the Base25 simulation. Sim(S) used volume targets derived from the Base25/33 simulation and therefore displayed similar variability.

The different policy structures had their greatest impact on harvest volume in the early periods. For example, in period 1, Sim(S+F+E) harvested approximately 40% of the volume cut in the Base25/33 simulation, but in period 10, it harvested 80%. This was primarily the effect of older rotation ages (i.e., higher volume stands) in the later periods and the harvest of legacy trees and patches left in the previous rotation. Thinning constituted a small percentage of the industrial harvest volume in all simulations.

The disturbance-based policies reduce the volume and net revenue on industry land over the next 20 years by 25%–60% (~US$120–300 million/year; all dollar values presented are in US dollars), with the impact increasing as more elements of the disturbance regime are added (Table 3). In

Fig. 3. Nonindustrial harvest volumes and rotation ages throughout the 100-year LAMPS policy simulations.



terms of NPV, similar reductions are associated with an 8% interest rate, since it greatly values revenue in the near term. At a 4% interest rate, though, the NPV losses are somewhat less because of the recovery of harvest in the later periods. This analysis also showed why the Base25/33 simulation might be valued by industry over the Base25 simulation: the difference in revenue in the short term was more than $50 million annually.

NIP

About one-third of NIP forest area was converted to other land uses over the planning horizon (Kline et al. 2001); this accounted for much of the declining NIP harvest. Under the base policies, the volume harvested on NIP land was approximately 30% of industrial lands (Table 4). Like industry, harvest volume initially had a significant hardwood component, but this diminished through time. Disturbance-based policies reduced the volume by between 15% and 50% compared with the base policy (Fig. 3). Disturbance-based policies resulted in steadily increasing rotation ages throughout the simulations (Fig. 3). Through the first 20 years, the reduced revenue due to disturbance-based policies ranged from approximately $30 to $70 million annually (Table 3). Unlike industrial lands, the differences in harvest volume between policy alternatives were relatively constant throughout the 100-year simulation. Like industry, the value of the policies was most significantly reduced when emulating the frequency of historical fires. NIP suffered a greater proportional loss compared with that lost by industrial lands. This was surprising at first glance, because NIP lands are concentrated in the interior climate zone, which had the shorter NFR (100 years). However, they are also concentrated in megasheds that contain little public land, therefore, they do not benefit from the lack of public harvest in the way industrial lands do.

Forest inventory

The five policy structures produced distinct inventories by the end of the 100-year simulations (Figs. 4 and 5). However, throughout all simulations the majority of federal forests began in the young forest class and moved to the mature class. This was the effect of the aging federal forest and not a result of the disturbance-based policies. Nevertheless, these simulations revealed that less than 10% of Coast Range forests would be in an old-forest condition in 100 years, irrespective of the policy structure.

Under the base policy, early seral (0–30 years) quickly became the dominant age-class on industrial lands; this was primarily driven by the 40-year rotation age (Fig. 4). Trends on NIP lands were similar to those on industrial lands, but NIP owners maintained a higher proportion of their land in the young (30–80 years) forest class (Fig. 4). All of the simulations resulted in an overall decline of young forests associated with the aging federal forests, but the base policies resulted in the most precipitous decline because they also incurred the shift from young to early seral on industrial land. Sim(S) resulted in a near-steady proportion of early seral forest on private lands. In contrast, the reduced harvest level prescribed in Sim(S+F) and Sim(S+F+E) caused more than half of the early forests across all ownerships to grow into the young age-class. Although mature forest abundance increased in all simulations, industrial forests contributed significantly under Sim(S+F) and Sim(S+F+E) and very little in the base and Sim(S).

The future landscape, as simulated here, falls into one of two potential scenarios: (1) Under the base policies and Sim(S), early seral continued to be most abundant and well above the HRV; meanwhile, the proportion of young forests declined to a level within the HRV and the amount of mature forests increased beyond the HRV (Fig. 5). (2) Under Sim(S+F) and Sim(S+F+E), the proportion of early and young forest declined and then stabilized within the HRV; mature forest abundance increased sharply beyond the HRV. A small increase in the proportion of old forests was observed during the later periods under all four policy structures (Fig. 5).

Discussion

Meeting ecological goals across ownerships

There is growing recognition that conventional strategies for resource protection, both within the OFPA and US forest

Table 2. Industrial clear-cut (CC) harvest volume (vol.) and area (volume expressed in 10^6 m^3 and area in 10^3 ha).

	Base25			Base24/33			Sim(S)			Sim(S+F)			Sim(S+F+E)		
Period	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC
1	6.5	236	235	6.5	236	235	5.0	260	194	3.1	141	101	2.7	132	96
2	7.0	238	238	8.8	323	323	6.4	331	252	3.2	140	100	3.0	142	101
3	8.4	237	236	8.1	240	240	5.5	224	170	3.8	139	99	3.7	142	100
4	7.6	218	214	5.0	167	161	4.9	198	140	4.6	139	98	4.3	141	99
5	7.8	227	220	7.3	249	239	6.8	262	187	5.3	138	96	5.0	137	96
6	7.4	227	218	8.2	261	252	7.3	248	180	5.9	137	96	5.4	140	97
7	7.5	223	216	8.1	252	243	7.8	252	182	6.3	137	95	5.9	138	95
8	7.6	214	206	6.1	193	186	6.9	225	159	6.7	136	94	6.3	139	96
9	8.1	221	214	7.3	224	216	7.4	226	162	7.0	136	94	6.5	138	95
10	7.8	222	213	8.1	257	247	8.3	251	181	7.2	136	93	6.5	136	93
Total	75.6	2263	2210	73.5	2402	2343	66.4	2475	1807	53.2	1380	965	49.3	1387	968

Note: Gross clear-cut (CC) acres refers to the total perimeter of the harvest units, while net clear-cut refers to the area actually harvested after the retention standards have been subtracted.

policy generally, focus too heavily on site-specific concerns and consequently do not offer sufficient recognition to ecological processes at landscape scales (Franklin 1993; IMST 1999; Spies and Johnson 2003). Though there is impetus for change, landowner actions are typically not considered with respect to adjacent ownerships (Sample 1994; Thompson et al. 2004). Within the OFPA, provisions to protect water quality, wildlife, and soil are all addressed at the scale of a timber harvest unit and are applied uniformly across a region. The OFPA offers few provisions for dealing with the cumulative effects of habitat alteration or resource degradation. Emulating historical disturbance regimes through forest management is a frequently cited way to address this issue (e.g., Lindenmayer and Franklin 2002).

In general, the simulations of current (base) policies developed for this study were consistent with other LAMPS simulations of the current policy structure (Spies et al. 2002*b*; Bettinger et al. 2005). The primary conclusion of this and other studies was that forest structure will continue to diverge in the Coast Range between public and private lands (Spies et al. 2002*b*; Nonaka and Spies 2005). In these simulations, private lands were increasingly dominated by dense, simplified early seral and young patches. Simulation of current policies also showed a maturation of federal forests over the projection period (100 years), the effect of federal lands policy. The federal inventory shifted from a near-even split of young and mature forests to nearly all forests in the mature class. Interestingly, this resulted in the proportion of mature forests in the Coast Range moving above the HRV. However, a continuation of these simulations beyond the planning horizon would have resulted in the mature forest aging into the old forest class, which remained well below the HRV throughout the simulation. In sum, the lack of harvest of federal lands did more to move the forest composition of the Coast Range toward the HRV than did any provisions in the disturbance-based policies.

Our findings demonstrate the importance of considering the effects of management and policy decisions across large areas and across all ownerships. Choosing the appropriate scale of analysis for spatial assessments of ecological and socioeconomic change is critical to interpretation (Spies and Johnson 2003). For example, consider a disturbance-based approach to forest management applied only to federal forests in the Coast Range. It would likely include provisions for increased retention, long rotations, and large harvest blocks (for an example from the western Cascades, see Cissel et al. (1999)). Meanwhile, the surrounding private lands, unaffected by the change in policy, would continue to be harvested on short rotations, consistent with their management objectives. The likely outcome of this approach over the long term would be increased similarity to the HRV at a federal forest scale in conjunction with decreased similarity to HRV at a regional scale.

However, even the similarity to historical conditions on the federal forests is subject to scale effects. When measuring the HRV of old forests in the Coast Range, Wimberly et al. (2000) found that the federal forest scale was too small to define a meaningful estimate of the HRV. In other words, variability was too large to create bounds around the historical range of conditions. They determined that, with regard to old forests in the Coast Range, the entire province was the

Table 3. Average annual revenue over the first 20 years of the simulated policy structures and net present value (NPV) over the 100-year planning horizon at two rates of discount (% of Base25/33 in parentheses) for industrial and nonindustrial private (NIP) forests; all values are in millions of US dollars.

	Average annual revenue (first 20 years)		Total NPV, 4% discount		Total NPV, 8% discount	
Policy structure	Industry	NIP	Industry	NIP	Industry	NIP
Base25/33	476 (100%)	117 (100%)	12 013 (100%)	3169 (100%)	5830 (100%)	1505 (100%)
Base25	423 (89%)	117 (100%)	11 924 (99%)	3169 (100%)	5632 (97%)	1505 (100%)
Sim(S)	353 (74%)	87 (74%)	9 520 (79%)	2489 (78%)	4411 (76%)	1144 (76%)
Sim(S+F)	204 (43%)	46 (39%)	6 615 (55%)	1513 (48%)	2843 (49%)	637 (42%)
Sim(S+F+E)	183 (38%)	46 (39%)	6 091 (51%)	1513 (48%)	2569 (41%)	637 (42%)

Table 4. Nonindustrial clear-cut (CC) harvest volume (vol.) and area (volume expressed in 10^6 m^3 and area in 10^3 ha).

	Base			Sim(S)			Sim(S+F)		
NIP Period	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC
1	1.83	66 885	66 843	1.35	75 488	50 996	0.48	32 913	18 278
2	2.04	69 625	69 781	1.50	76 751	53 081	0.69	38 537	23 285
3	2.08	60 498	60 482	1.51	65 737	46 194	0.90	40 910	25 668
4	2.13	57 104	55 353	1.77	67 939	46 847	1.07	40 911	26 114
5	2.06	50 380	48 503	1.94	65 955	44 902	1.19	40 107	25 562
6	2.22	48 202	46 632	1.99	61 918	42 281	1.31	39 140	24 890
7	2.39	47 656	46 046	2.06	59 473	40 331	1.30	36 329	22 766
8	2.39	44 956	43 265	2.14	59 135	39 774	1.41	36 221	22 627
9	2.54	44 484	42 932	2.14	56 050	37 799	1.48	36 201	22 780
10	2.59	44 756	43 079	2.18	55 088	37 057	1.59	36 106	23 072
Total	22.26	534 545	522 917	18.57	643 534	439 264	11.44	377 376	235 043

Note: Gross clear-cut (CC) acres refers to the total perimeter of the harvest units, while net clear-cut refers to the area actually harvested after the retention standards have been subtracted.

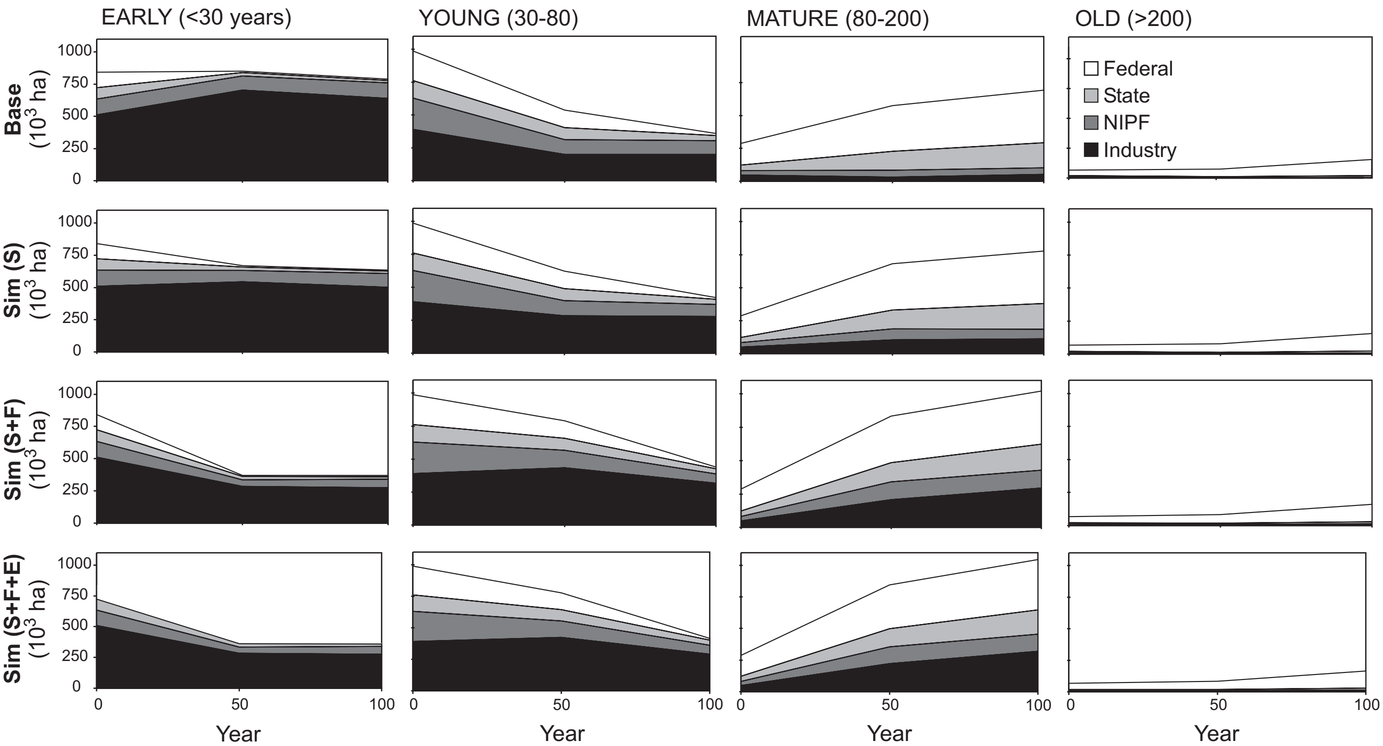
appropriate scale at which to define the HRV. Therefore, in this example, applying a disturbance-based approach to only the federal forests may push the Coast Range further from its historical condition than would maintaining the current policy structure. In contrast, applying a disturbance-based approach to private lands, as was done here, moved the Coast Range closer to historical conditions than would the current policy. By focusing policy changes on those forests currently slated for harvest, the federal forests can be used to provide large patches of old forest that were characteristic of provincial historical conditions and are unlikely to be found within the private ownerships. We conclude that a regional perspective on a disturbance-based approach to managing federal forests in the Coast Range would include little or no regeneration harvesting.

The costs of disturbance-based policies

Most of the private land under consideration in these simulations is managed for timber production as one of their primary goals (Lettman and Campbell 1997), and our analysis suggests that timber harvest has considerable value — over $500 million/year. Therefore, when assessing potential changes in forest policy, landowners' judgments will hinge to a significant degree on the economic losses associated with new policies. Further, it is clear from these simulations that a disturbance-based policy structure in the Coast Range comes at a significant loss in revenue to landowners — approximately $100–$300 million/year — depending on the attributes of disturbance being emulated. The magnitude of these costs is reflective of the degree of departure between the modern and historical disturbance regimes. Given this, it is likely that a disturbance-based approach, as simulated here, would be highly unpopular with those who value their forests primarily as a source of timber revenue.

Although these costs may seem high, they were lower than they might have been when compared with other methods of calculating allowable harvest from fire frequency (Armstrong et al. 1999). We used the natural fire rotation for all land within a climate zone and then applied the area disturbed per period to only private land. In effect, the private lands were able to benefit from the lack of harvest on the public lands. Implicit in this approach is a lack of recognition of any other disturbance events, including additional harvest on public lands or wildfires within the planning horizon. In other words, the harvests scheduled in our simulation were intended to be completely compensatory to suppressed fire and other stand-initiating disturbances within the Coast Range. Given the timeframe of our simulations, this simplifying assumption is likely false. However, the rate of exogenous disturbances is unknown; therefore, this method was chosen to illustrate one manner of emulating disturbance frequency that could reduce costs to private landowners. If federal forests were allocated their proportion of the expected disturbance under the NFR, the average rotation age on private lands would increase to 100 years in the interior climate zone and 200 years in the coastal climate zone. Similarly, if

Fig. 4. Forest inventory by ownership group and age-class throughout the 100-year LAMPS policy simulations.



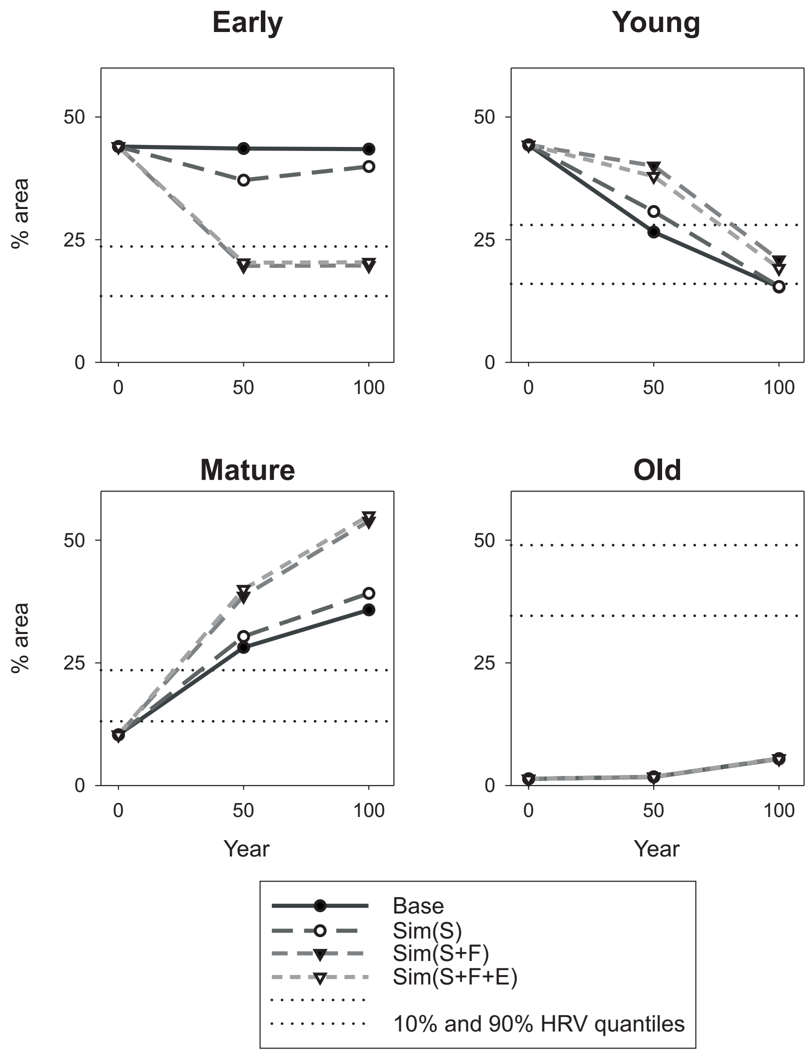
an estimate of the area burned or cut over the next century on federal land could be established, this amount could be subtracted from the allowable harvest area; this would increase the costs of the policy.

Implementing a policy structure similar to Sim(S+F) or Sim(S+F+E) would require the state to allot an allowable harvest area over multiple private ownerships. We allocated harvests at the megashed scale (collections of large watersheds) to ensure harvesting was spread across every region of the Coast Range. We also chose to maintain the current ratio of area harvested between NIP and industrial land within a megashed. Our intention was to distribute the impact of policies evenly within a subregion. Because the amount of harvest was rationed based on the expected area burned given the total hectares within a megashed, those megasheds with large percentages of public land allocated more harvest area to private land. In other words, private owners who shared their megashed with abundant public land had proportionately more harvestable area than private owners in megasheds with little public land. This, like most methods of allocating allowable harvests, could raise substantial equity concerns with regard to the way forest policies are implemented on a multiowner province. Policy-makers would likely face several trade-offs and potential legal hurdles to coordinate harvest levels across multiple private landowners (Thompson et al. 2004).

In Sim(S+F+E), emulating the extent of disturbance events was represented through a constraint that required all industrial harvests be 250 ha. This represented a 10-fold increase above the average clearcut size in the base policies; however, it did not approach the average historical fire size. The larger 250 ha harvest units resulted in an additional 8% reduction in total harvest volume. This was due to the loss of flexibility in choosing harvest units. Although LAMPS continued to prioritize on value, it was forced to harvest stands of multiple ages that were the legacy of previous harvests. Often this resulted in harvesting trees that were not economically mature. The costs of Sim(S+F+E) would likely be reduced in a "real world" setting because we have not accounted for any savings associated with the economics of scale or other more flexible options of aggregating harvests.

Our estimates of lost revenue should be seen as the maximum cost of the disturbance-based policies devised for this study, for three reasons: (1) Although we believe these are plausible harvest volumes, we may have over estimated the rate of harvest on private land during the base policies. As we noted, our projection assumed an increase above what NIP has harvested historically. It is possible that the harvest level projected by Sim(S) will be closer to the actual level, since this resulted in rotation ages consistent with what has been witnessed over the past several decades. On industry lands, in both base policies, we assumed rotation ages would drop to 40 years in the first few decades. Here, the initial pulse of harvest that we simulated to achieve a 40-year rotation represents a higher harvest rate than has been witnessed historically. If the base harvest volumes turn out to be too high, then the relative costs of the disturbance-based policies will be smaller than we have portrayed. (2) The forest industry and NIP owners might react to constrained clear-cut rates by significantly increasing their partial cutting. We did not model this potential reaction. It is likely that policy-makers would need to explicitly define what constitutes a thinning versus a clearcut with increased retention levels if this type of policy were developed. But it is probable that private landowners would increase partial cutting to the extent that is lawful to recover revenue lost from clear-cutting restric-

Fig. 5. Relative area in each age-class throughout the 100-year LAMPS simulations. Dotted lines represent the estimated historical range of variability (HRV) established from the Landscape Age-class Demographic Simulator (Wimberly 2002).



tions. (3) In scenarios where regional harvest volume was reduced significantly, it is likely that prices would increase in response, as was the case when the federal forests dramatically reduced their harvest in the mid 1990s (Wear and Murray 2004). The potential increase in stumpage prices would offset some of the costs associated with the disturbance-based policies.

The magnitude of lost revenue is sensitive to the assumed stumpage prices, which were based on recent experiences in the Coast Range. They provide one example of the real cost differences between policies. But real differences between policy scenarios are likely less reliable than relative differences. The real values are useful, however, to help understand the economic magnitude of timber harvests and the magnitude of landowner resistance to the potential changes in forest policy.

The costs described in this experiment are unique to the ownership pattern within the Oregon Coast Range, its historical disturbance regime, and the manner in which we chose to emulate it. Thus, this approach gives a quantitative “first approximation” of the cost of disturbance emulation in a coastal temperate forest with relatively long fire-return intervals. If this methodology were applied to a region characterized by shorter fire-return intervals and (or) higher severity fires, the costs could be substantially reduced. This may help explain why disturbance-based forestry has been more widely embraced in the boreal forests of Canada and Fennoscandia (e.g., British Columbia Ministry of Forests 1995; OMNR 2001; Kuuluvainen 2002).

Narrowing the gap between historical and modern disturbances

In this study, three attributes of the region’s historical fire regime were incorporated into forest policy: the live-tree legacy, the average rate of fires, and the spatial extent of individual fires. Several other attributes could potentially be incorporated into forest policy that may narrow the gap between historical and modern regimes. For example, postfire landscapes contained large quantities of down and standing dead wood that persisted for centuries (Spies et al. 1988). Although it was not included here, a disturbance-based policy structure could easily accommodate a dead-wood requirement. Another major deviation between historical and modern forest structure relates to regeneration. Natural regeneration after variable-intensity fires typical of the Coast Range is unpredictable and produces complex forest structure at both the stand and landscape levels (Franklin and Dyrness 1988; Wimberly and Spies 2001); in contrast, current policy requires high-density plantations that are "free to grow" within 5 years of harvest. To reduce the discrepancy, variable-density planting, or some level of natural regeneration, could potentially be incorporated into forest policy. The spatial distribution and pattern of mortality is another point of divergence that may be alleviated through management. From a managerial perspective, it would be possible to configure harvest units across a landscape in a manner more consistent with an expected pattern of wildfire.

No amount of effort and creativity will ever devise a way for timber harvest to exactly mimic the natural disturbance regime. They are fundamentally different processes. The most obvious distinction is the removal of trees that, when remaining after a disturbance, provide food and habitat, affect microclimate, and influence subsequent disturbances. In the case of fire, the comparison is between a mechanized and a chemical process; this results in untold differences in the ecology of the soil and hydrologic functions. In temperate ecosystems, such as the Coast Range, disturbance-based management means emulating a complex system of many small and a few large fires on long fire-return intervals. This may lead to smoothing the rate of disturbance to accommodate something akin to even flow (Armstrong et al. 2003). The resulting difference between the two disturbance regimes has been described as a "press versus a pulse" and has been shown to affect community composition in different ways (Bender et al. 1984). Therefore, simply using the average rate of disturbance, spread out over time, will not necessarily have the desired ecological effects. For these reasons, if the disturbance-based approach is used for conservation, it may be prudent to count it as one among several conservation strategies including a reserve system and other coarse- and fine-filter strategies.

Limitations and scope

The consequences of changing forest policy must be considered over large spatial and temporal extents, larger than could reasonably be explored through field experiments. Hence, landscape simulation models are valuable exploratory tools during policy development and are frequently used to compare management strategies over large areas and long time frames (e.g., Wallin et al. 1996; Johnson et al. 1998; McCarter et al. 1998; Cissel et al. 1999; Hemstrom et al. 2001; Spies et al. 2002*b*; Swanson et al. 2003). However, like all models, LAMPS is a simplification of reality and the realities of human and forest dynamics are immeasurably complex. The architects and programmers of LAMPS incorporated human population growth estimates, stochastic gap-level disturbances, management intentions for specific ownerships, peer-reviewed tree-growth models, and several other components into their simulator. Still, the trends and generalities produced by LAMPS should not be seen as predictions about the future; rather they should be viewed as a projection of the implications of a specific set of policies, physical and economic relationships, and assumptions about how landowners attempt to achieve their goals.

In many ways, using a fixed set of policies that result in predictable harvest behavior is incongruous with emulating a stochastic and highly variable disturbance regime. On the other hand, a more authentic approach to disturbance emulation, such as creating forest policies that vary unpredictably over time and space, would certainly be socially unattainable. In the simulations we have presented here, we have simply adjusted conventional policy mechanisms in ways that may move the landscape toward the range of conditions that existed under the historical fire regime. The disturbance events themselves, their timing, and their spatial distributions bear little resemblance to what an uninhibited fire regime might yield over the same time frame.

A number of factors, such as future climate change and wildfires, were not included in this analysis. With regard to future changes in climate, the Coast Range is a comparably stable region to simulate a century of vegetation growth. However, much uncertainty remains and projections must be framed within the context of what is known and unknown. Average temperature is expected to rise moderately during the next century throughout the Pacific Northwest (Bachelet et al. 2001). Many models predict that this will be buffered by increased winter precipitation (Hamlet 2004); however, the timing of this is confounded by a drought that is occurring on a continental scale (Nielson 2004). The Coast Range, like most forested regions, will experience changes in disturbance regimes that will impact the composition and configuration of vegetation (Dale et al. 2001; Nielson 2004). Summer droughts, higher temperatures, and increased biomass production may result in more frequent fires and hinder fire suppression. This could shorten fire-return intervals and increase the severity of the disturbances, which would shift the disturbance regimes modeled here. On the other hand, increased precipitation may offset higher temperatures to the degree that the fire-return interval lengthens. Given these uncertainties, the LAMPS simulations should be viewed with caution and an eye to the unknown. Future analysis will examine in more detail how different climate change scenarios might play out in Oregon's Coast Range.

Wildfires have consumed very little acreage over the last 50 years in the Oregon Coast Range, but we can expect that they will occur at some level and modify these projected structures. When they occur on private forests, they would only slightly alter what we have shown. When they occur on federal land, though, they will reduce the proportion of mature and old forests while increasing the proportion of early and young forests and thus reduce the amount of permitted harvest on private lands. Thus, the levels of mature and old forest shown here should be seen as upper limits on what might occur.

Summary and conclusions

Emulating regional disturbance regimes through forest policy is a frequently cited way to implement coarse-filter conservation. We explored this hypothesis in a coastal temperate forest province containing multiple ownerships and management objectives. The LAMPS model was used to simulate a range of policy alternatives over the next century. To emulate the mixed severity of wildfires, we used green-tree retention, both in clumps and individual trees — retention levels were higher in the drier interior climate zone than they were in the wetter coastal climate zone. We also incorporated the natural fire rotation of each climate zone into annual harvest targets to match the frequency of fire. Finally, the clearcut size limit was increased to emulate the historical fire size.

These changes represented major departures from the current policies governing timber harvest in the region. Still, the ownership mosaic, the different policies that govern that mosaic, and the legacy of timber harvest will prevent disturbance-based policies from completely returning the landscape to the historical range of variability. That notwithstanding, these policies did result in an age-class distribution closer to historical conditions than those created by the current policy structure.

We attempted to incorporate disturbance-based policies in ways that minimized the cost to private landowners. In this context, our simulations suggested that policies attempting to reproduce historical conditions would require federal forests to provide large patches of old forest that were common on the historical landscape. The large patches of old forest were a defining feature in the historical landscape; therefore, ensuring their presence is a necessary part of any coarse-filter strategy. The approach, as applied in the simulations, used federal lands to provide them, and this dampened the economic impact to private landowners as compared to a region with no public lands. Despite this benefit, the policies resulted in significant costs to private landowners, as much as a 60% reduction in annual volume and revenue to private landowners.

Should we therefore assume that a coarse-filter approach is not a practical way to reach society's conservation goals? Are we better off continuing with the fine-filter, species-by-species approach to conservation? Certainly, this analysis cannot fully answer that question. However, we can say that it was the degree of departure from historical conditions that resulted in the costs of our approach. In the long term, the disturbance-based policies allowed significant timber harvest while also meeting many landscape-level conservation goals. The near-term costs are, in one sense, paying for the alteration of the landscape over the last century.

In a related context, a disturbance-based approach may have some economic advantages over a fine-filter approach, whose entire commodity base may hinge on the status of a single species. The listing of the Northern spotted owl (*Strix occidentalis*) under the federal Endangered Species Act provided a poignant example of the potential economic impact of conserving habitat for one threatened species. Increasingly, alterations to the historical Coast Range landscape are resulting in endangered species listings, such as the marbled murrelet (*Brachyramphus marmoratus*) and coho salmon (*Oncorhynchus kisutch*). Thus, the costs presented here may not necessarily be unique to a coarse-filter approach: they may be the costs of meeting conservation goals generally.

Acknowledgements

This project was funded through the Coastal Landscape Analysis and Modeling Study (CLAMS), a multidisciplinary research effort sponsored cooperatively through Oregon State University's College of Forestry, the USDA Forest Service Pacific Northwest Research Station, the Oregon Department of Forestry, and the National Commission on Science for Sustainable Forestry. We are grateful to Keith Olsen for GIS help and Amanda Robillard, Mischa Hey, John Cissel, Fred Swanson, and an anonymous reviewer for helpful reviews of this manuscript.

References

Adams, D.M., Schillinger, R.R., Latta, G., and Van Nalts, A. 2002. Timber harvest projections for private land in western Oregon. Research Contribution 37. Forest Research Laboratory, Oregon State University, Corvallis, Ore.

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.

Andison, D.W., and Marshall, P.L. 1999. Simulating the impact of landscape-level biodiversity guidelines: a case study. For. Chron. **74**: 655–665.

Armstrong, G.W., Cumming, S.G., and Adamowicz, W.L. 1999. Timber supply implications of natural disturbance management. For. Chron. **75**: 497–504.

Armstrong, G.W., Adamowicz, W.L., Beck, J.A., Cumming, S.G., and Schmiegelow, F.K.A. 2003. Coarse filter ecosystem management in a nonequilibrating forest. For. Sci. **49**: 209–223.

Attwill, P.M. 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. For. Ecol. Manage. **63**: 247–300.

Bender, E.A., Case, T.J., and Gilpin, M.E. 1984. Perturbation experiments in community ecology: theory and practice. Ecology, **65**: 1–13.

Bachelet, D., Neilson, R.P., Lenihan, J.M., and Drapek, R.J. 2001. Climate change effects on vegetation distribution and carbon budget in the United States. Ecosystems, **4**: 164–185.

Bergeron, Y., Harvey, B., Leduc, A., and Gauthier, S. 1999. Forest management guidelines based on natural disturbance dynamics: stand and forest level considerations. For. Chron. **75**: 49–54.

Bettinger, P., and Johnson, K.N. 2003. Spatial scheduling of forest management activities using a dynamic deterministic harvest block aggregation process. J. For. Plan. **9**: 25–34.

Bettinger, P., and Lennette, M. 2004. Landscape Management Policy Simulator, version 1.1 user's manual. Research Contribution 43. Forest Research Laboratory, Oregon State University, Corvallis, Ore.

Bettinger, P., Lennette, M., Johnson, K.N., and Spies, T.A. 2005. A hierarchical spatial framework for forest landscape planning. Ecol. Model. **182**: 25–48.

British Columbia Ministry of Forests. 1995. Forest practices code of British Columbia: biodiversity guidebook. Victoria, B.C.

Bunnell, F.L. 1998. Setting goals for biodiversity in managed forests. *In* Policies and practices for biodiversity in managed forests. *Edited by* F.L. Bunnell and J.F. Johnson. University of British Columbia Press, Vancouver, B.C. pp. 117–153.

Busing, R.T., and Garman, S.L. 2002. Promoting old-growth characteristics and long-term wood production in Douglas-fir forests. For. Ecol. Manage. **160**: 161–175.

Cissel, J.H., Swanson, F.J., McKee, W.A., and Burditt, A.L. 1994. Using the past to plan the future in the Pacific Northwest. J. For. **30**: 31–46.

Cissel, J.H., Swanson, F.J., and Weisberg, P.J. 1999. Landscape management using historical fire regimes: Blue River Oregon. Ecol. Appl. **9**: 1217–1231.

Cohen, W.B., Spies, T.A., Alig, R.J., Oetter, D.R., Maiersperger, T.K., and Fiorella, M. 2002. Characterizing 23 years (1972–

1995) of stand replacement disturbance in western Oregon forests in Landsat Imagery. Ecosystems, **5**: 122–137.

Dale, V.H., Joyce, L.A., McNulty, S., Nielson, R.P., Ayres, M.P., Flannigan, M.D. et al. 2001. Climate change and forest disturbance. Bioscience, **59**: 723–734.

Davis, L.S., Johnson, K.N., Bettinger, P.S., and Howard, T.E. 2001. Forest management: to sustain ecological, economic, and social values. 4th ed. McGraw Hill Press, New York.

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest Ecosystem Management: an ecological, economic and social assessment. USDA Forest Service; US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service; USDI Bureau of Land Management, Fish and Wildlife Service, National Park Service, Environmental Protection Agency, Portland, Ore.

Franklin, J.F. 1993. Preserving biodiversity: species, ecosystems, or landscapes? Ecol. Appl. **3**: 202–205.

Franklin, J.F., and Dyrness, C.T. 1988. Natural vegetation of Oregon and Washington. Oregon State University Press, Corvallis, Ore.

Franklin, J.F., and Forman, R.T. 1987. Creating landscape pattern by forest cutting. Landsc. Ecol. **1**: 5–18.

Garman, S.L., Cissel, J.H., and Mayo, J.H. 2003. Accelerating development of late-successional conditions in young managed Douglas-fir stands: a simulation study. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-557.

Hamlet, A. 2004. Summary of expected changes associated with climate change in Oregon. Document prepared for the Oregon Water Resources Group, Oregon State University, Corvallis Ore.

Hann, D.W., Hester, A.S., and Olsen, C.L. 1997. ORGANON user's manual, version 6.0. Department of Forest Resources, Oregon State University, Corvallis, Ore.

Hansen, A.J., Spies, T.A., Swanson, F.J., and Ohmann, J.L. 1991. Conserving biodiversity in managed forests: lessons from natural forests. Bioscience, **41**: 382–392.

Hansen, A.J., Garmen, S.L., Weigand, J.F., Urban, D.L., McComb, W.C., and Raphael, M.G. 1995. Alternative silvicultural regimes in the Pacific Northwest: simulations of ecological and economic effects. Ecol. Appl. **5**: 535–554.

Heinselman, M.L. 1973. Fire in the virgin forest of the Boundary Waters Canoe Area, Minnesota. Quat. Res. **3**: 329–382.

Hemstrom, M.A., Korol, J.J., and Hann, W.J. 2001. Trends in terrestrial plant communities and landscape health indicate the effects of alternative management strategies in the interior Columbia River basin. For. Ecol. Manage. **153**: 105–126.

Holling, C.S. 1973. Resilience and stability in ecological systems. Annu. Rev. Ecol. Syst. **4**: 1–23.

Hunter, M.L. 1990 Wildlife, forests, and forestry. Prentice Hall, Englewood Cliffs, N.J.

Hunter, M.L. 1993. Natural fire regimes as spatial models for managing boreal forests. Biol. Conserv. **65**: 115–120.

Impara, P.C. 1997. Spatial and temporal patterns of fire in the forests of the central Oregon Coast Range. Ph.D. thesis, Oregon State University, Corvallis, Ore.

IMST (Independent Multidisciplinary Science Team). 1999. Recovery of wild salmonids in western Oregon forests: Oregon Forest Practices Act rules and the measures in the Oregon Plan for Salmon and Watersheds. Technical Report 1999-1 to the Oregon Plan for Salmon and Watersheds, Governor's Natural Resources Office, Salem, Ore.

Johnson, K.N., Sessions, J., Franklin, J., and Gabriel, J. 1998. Integrating wildfire into strategic planning for Sierra Nevada Forests. J. For. **96**: 42–49.

Kline, J.D., Alig, R.J., and Johnson, R.L. 2000. Fostering the protection of nontimber resources among forest owners with heterogeneous objectives. For. Sci. **46**: 302–311.

Kline, J.D., Moses, A., and Alig, R.J. 2001. Integrating urbanization into landscape-level ecological assessments. Ecosystems, **4**: 3–18.

Kuuluvainen, T. 2002. Natural variability of forests as a reference for restoring and managing biological diversity in boreal Fennoscandia. Silva Fenn. **36**: 98–125.

Landres, P.B., Morgan, P., and Swanson, F.J. 1999. Overview of the use of the natural variability concepts in managing ecological systems. Ecol. Appl. **9**: 1179–1188.

Lettman, G.J., and Cambell, D. 1997. Timber harvesting practices on private forest land in western Oregon. A report from the Oregon Department of Forestry, Salem, Ore.

Long, C.J., Whitlock, C., Bartlein, P.J., and Millspaugh, S.H. 1998. A 9000-year fire history from the Oregon Coast Range based on a high-resolution charcoal study. Can. J. For. Res. **28**: 774–787.

Lorensen, T. 2003. Forest practices "protection" on forestlands in the context of dynamic ecosystems. White paper. Oregon Department of Forestry, Salem, Ore.

Lindenmayer, D.B., and Franklin, J.F. 2002. Conserving forest biodiversity: a comprehensive multiscaled approach. Island Press, Washington, D.C.

McCarter, J.B., Wilson, J.S., Baker, P.J., Moffett, J.L., and Oliver, C.D. 1998. Landscape management through integration of existing tools and emerging technologies. J. For. **96**: 17–23.

McComb, W.C., Spies, T.A., and Emmingham, W.H. 1993. Douglas-fir forests: managing for timber and mature-forest habitat. J. For. **91**: 31–42.

Neilson, R.P. 2004. Impact of climate change on Pacific Northwest terrestrial ecosystems. *In* Proceedings, Impacts of Climate Change on the Pacific Northwest, Corvallis, Ore., 15 June 2004. Oregon State University, Corvallis, Ore. Available from http://inr.oregonstate.edu/presentations.html. [Abstr.]

Nonaka, E., and Spies, T.A. 2005. Historical range of variability in landscape structure: a simulation study in Oregon, USA. Ecol. Appl. **15**: 1727–1746.

NWFP EIS (Northwest Forest Plan, Environmental Impact Statement). 1994. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. USDA Forest Service and US Bureau of Land Management, Portland, Ore.

OMNR. 2001. Forest management guide for natural disturbance pattern emulation, version 3.1. Ontario Ministry of Natural Resources, Toronto, Ont.

Ohmann, J.L., and Gregory, M.J. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in coastal Oregon, U.S.A. Can. J. For. Res. **32**: 725–741.

Oregon Department of Forestry. 2001. Northwest Oregon State Forests Management Plan. Oregon Department of Forestry, Salem, Ore.

Reeves, G.H., Benda, L.E., Burnett, K.M., Bisson, P.A., and Sedell, J.R. 1995. A disturbance based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. Am. Fish. Soc. Symp. **17**: 334–349.

Ripple, W.J. 1994. Historic spatial patterns of old forests in western Oregon. J. For. **92**: 45–49.

Ripple, W.J., Hershey, K.T., and Anthony, R.G. 2000. Historical forest patterns of Oregon's central Coast Range. Biol. Conserv. **93**: 127–133.

Sample, V.A. 1994. Building partnerships for ecosystem management on mixed ownership landscapes. J. For. **92**: 41–44.

Sessions, J., Johnson, K.N., Beuter, J., Greber, G., and Letmann, G. 1990. Timber for Oregon's tomorrow: the 1989 update. Forest Research Laboratory, Oregon State University, Corvallis Ore.

Spies, T.A. 1998. Forest structure: a key to the ecosystem. Northwest Sci. **72**: 34–39.

Spies, T.A., and Franklin, J.F. 1991. The structure of natural young, mature, and old-growth Douglas-fir forests in Washington and Oregon. *In* Wildlife and vegetation of unmanaged Douglas-fir forests. *Technical coordinators* L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff. USDA. For. Serv. Gen. Tech. Rep. PNW-GTR-285. pp. 91–109.

Spies, T.A., and Johnson, K.N. 2003. The importance of scale in assessing the compatibility of forest commodities and biodiversity. *In* Compatible forest management. *Edited by* R.A. Monserud, R.W. Haynes, and A.C. Johnson. Kluwer Academic Publishers, Dordrecht, Netherlands. pp. 211–235.

Spies, T.A., Franklin, J.F., and Thomas, T.B. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. Ecology, **69**: 1689–1702.

Spies, T.A., Hibbs, D.A., Ohmann, J.L., Reeves, G.H., Pabst, R., Swanson, F.J. et al. 2002*a*. The ecological basis for forest ecosystem management in the Oregon Coast Range. *In* Forest and stream management in the Oregon Coast Range. *Edited by* S.D. Hobbs, J.P. Hayes, R.L. Johnson, G.H. Reeves, T.A. Spies, J.C. Tappeiner II, and G.E. Wells. Oregon State University Press, Corvallis, Ore. pp. 31–67.

Spies, T.A., Reeves, G.H., Burnett, K.M., McComb, W.C., Johnson, K.N., Grant, G. et al. 2002*b*. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. *In* Integrating landscape ecology into natural resource management. *Edited by* J. Lui and W. Taylor. Cambridge University Press. Cambridge, UK. pp. 179–207.

Stanfield, B.J., Bliss, J.C., and Spies, T.A. 2002. Landownership and landscape structure: a spatial analysis of sixty-six Oregon Coast Range watersheds. Landsc. Ecol. **17**: 685–697.

Stuart-Smith, K. 2002. Songbird communities in burned and logged stands with variable tree retention in the Canadian Rocky Mountains. Ph.D. thesis, Oregon State University, Corvallis, Ore.

Swanson, F.J., Jones, J.A., Wallin, D.O., and Cissel, J.H. 1993. Natural variability — implications for ecosystem management. *In* Eastside forest ecosystem health assessment. *Edited by* M.E. Jensen and P.S. Bourgeron. Vol. II. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-318. pp. 89–103.

Swanson, F.J, Cissel, J.H., and Reger, A. 2003. Landscape management: diversity of approaches and points of comparison. *In* Compatible forest management. *Edited by* R.A. Monserud, R.W. Haynes, and A.C. Johnson. Kluwer Academic Publishers, Dordrecht, Netherlands. pp. 237–265.

Teensma, P.D.A., Rienstra, J.T., and Yeiter, M.A. 1991. Preliminary reconstruction and analysis of change in forest stand age classes of the Oregon Coast Range from 1850 to 1940. USDI Bur. Land Manage. Tech. Note T/N OR-9.

The Nature Conservancy. 1988. Natural Heritage Program operations manual. The Nature Conservancy, Arlington, Va.

Thompson, J.R., Anderson, M.A., and Johnson, K.N. 2004. Ecosystem management across ownerships: the potential for collision with Antitrust Laws. Conserv. Biol. **18**: 1475–1481.

Wallin, D.O., Swanson, F.J., Marks, B., Cissel, J.H., and Kertis, J. 1996. Comparison of managed and pre-settlement landscape dynamics in forests of the Pacific Northwest, USA. For. Ecol. Manage. **85**: 291–309.

Wear, D.N., and Murray, B.C. 2004. Federal timber restrictions, interregional spillovers, and the impact on U.S. softwood markets. J. Environ. Econ. Manage. **47**: 307–330.

Wimberly, M.C. 2001. User's guide to the Landscape Age-class Dynamics Simulator, version 3.1. Warnell School of Forest Resources, University of Georgia, Athens, Ga.

Wimberly, M.C. 2002. Spatial simulation of historical landscape patterns in coastal forests of the Pacific Northwest. Can. J. For. Res. **32**: 1316–1328.

Wimberly, M.C., and Ohmann, J.L. 2004. A multiscaled assessment of human and environmental constraints on forest land cover change. Landsc. Ecol. **19**: 631–646.

Wimberly, M.C., and Spies, T.A. 2001. Influences of environment and disturbance on forest patterns in coastal Oregon watersheds. Ecology, **82**: 1443–1459.

Wimberly, M.C., Spies, T.A., Long, C.J., and Whitlock, C. 2000. Simulating the historical variability in the amount of old forest in the Oregon Coast Range. Conserv. Biol. **14**: 167–180.

Wimberly, M.C., Spies, T.A., and Nonaka, E. 2004. Using natural fire regime-based criteria to evaluate forest management in the Oregon Coast Range. *In* Emulating natural forest landscape disturbances: concepts and applications. *Edited by* A.H. Perera, L.J. Buse, and M.G. Weber. Columbia University Press, New York.