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SIMULATING FOREST STRUCTURE, TIMBER PRODUCTION, AND SOCIOECONOMIC EFFECTS IN A MULTI-OWNER PROVINCE

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Abstract. Protecting biodiversity has become a major goal in managing coastal forests in the Pacific Northwest—an area in which human activities have had a significant influence on landscape change. A complex pattern of public and private forest ownership, combined with new regulations for each owner group, raises questions about how well and how efficiently these policies achieve their biodiversity goals. To develop a deeper understanding of the aggregate effect of forest policies, we simulated forest structures, timber production, and socioeconomic conditions over time for the mixture of private and public lands in the 2.3-million-ha Coast Range Physiographic Province of Oregon. To make these projections, we recognized both vegetative complexity at the stand level and spatial complexity at the landscape level. We focused on the two major factors influencing landscape change in the forests of the Coast Range: (1) land use, especially development for houses and cities, and (2) forest management, especially clearcutting. Our simulations of current policy suggest major changes in land use on the margins of the Coast Range, a divergence in forest structure among the different owners, an increase in old-growth forests, and a continuing loss of the structural elements associated with diverse young forests. Our simulations also suggest that current harvest levels can be approximately maintained, with the harvest coming almost entirely from private lands. A policy alternative that retained live trees for wildlife would increase remnant structures but at a cost to landowners (5–7% reduction in timber production). Another alternative that precluded thinning of plantations on federal land would significantly reduce the area of very large diameter (>75 cm dbh) conifer forests 100 years into the future

Key words: biodiversity policy; land-owner behavior; landscape simulation; land-use change; Oregon Coast Range; timber harvest.

Introduction

Forest policy makers and managers struggle to meet society's new demands for a wider variety of social, ecological, and economic services and goods than in the past. An essential element in this effort is the ability to anticipate the effects of forest management policies at broad scales and across multiple ownerships. Despite recent interest in assessing the ecological and socioeconomic effects of forestry at multiple scales (Jensen and Bourgeron 2001), the science and assessment tools available to policy makers and managers are often inadequate for the relatively broad nature of contemporary forest resource issues.

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In this paper, we describe a landscape simulation of the forests of the Coast Range Physiographic Province of Oregon. Our overall effort—the Coastal Landscape Analysis and Modeling Study (CLAMS)—attempts to describe the ecological and socioeconomic consequences of recently enacted forest policies for this 2.3-million-ha multi-ownership region (Spies et al. 2007). Here, we cover our simulation of forest structure, timber production, and socioeconomic effects under these forest policies along with some alternatives to the policies that attempt to increase conservation of biodiversity.

Previous Approaches

In Oregon, federal and state policy makers have long expressed an interest in the sustainability of the state's forest resources. Historically, sustainability assessments centered on the sustained yield of timber products. Analyses dealt with the myriad of private ownerships that provide much of the timber harvest and many of the policy problems in Oregon, and some also dealt with federal and state forests that have their own harvest and policy controversy (Beuter et al. 1976, Johnson et al. 1991, Adams et al. 2002, Haynes et al. 2003). All of these studies took a similar approach: they divided the forest across a large area (multi-county or region) into age or structural categories and tallied the area in each category. They recognized the vegetative complexity of these age or structural categories by utilizing forest inventory plot data representative of the different inventory groups. Some studies used stand variables from these plots (basal area, volume, and so on), but more recent models used tree lists (number, size, and health of the live and dead trees in the stand), which can be employed in individual tree models to develop alternative stand-level prescriptions. These studies have been effective in finding harvest levels that could be sustained over a number of decades and also in estimating regional prices and quantities of timber that would be offered from private lands. In addition, they have been combined with optimization models to find economically efficient solutions to policy problems.

The approach generally taken in these studies assumes that each inventory category or "stand" (all lands across the study area with the same characteristics) can be analyzed without considering portions of other spatially intermingled inventory categories. Thus, the approach assumes that management decisions and sustainability assessments can be made by examining inventory categories and aggregating their characteristics and outputs, without considering the detailed spatial context in which they occur. We call these approaches "nonspatial forest policy models." They have found recent important policy use in assessing the national (United States) relationship between future supply and demand for timber products (Haynes 2003) and in helping define the potential national effects of climate change on forest production and use (McCarl et al. 2000).

More recently, policy makers have broadened their interests in forest sustainability to include the sustainability of ecosystems and habitats. This interest can be seen locally in the Northwest Forest Plan for federal forests, which attempts to sustain species and ecosystems in the region of the Northern Spotted Owl. Also, the State of Oregon's Plan for Salmon and Watersheds calls for maintenance and restoration of salmon habitat across all land types and ownerships, with forests as a key component, and state regulations controlling use of private forests on the Pacific Coast increasingly focus on protection of aquatic systems. Finally, the federal recognition of Threatened and Endangered species creates new concerns and management considerations across all land ownerships.

It can be difficult to address these issues with the nonspatial models typically used in previous assessments because those models focus on vegetative complexity at the stand level and generally lack the spatial definition important to ecosystem and habitat modeling. Recently, a few spatially explicit policy-analysis models have been applied to multi-ownership watersheds in different parts of the United States ranging in size from 100 000 to 1 000 000 ha (Wear et al. 1996, Pearson et al. 1999, Hulse et al. 2004, Schumaker et al. 2004). These efforts simulated land-cover dynamics by applying models of land cover change to cover maps developed from Landsat imagery. Landscape change for the 50- to 100-year periods was generally driven by conditional transition probabilities, with the transition equations coming from historical information, hypothetical regulatory schemes, or stakeholder assumptions about future development. Landscape dynamics were evaluated in terms of the proportion of the landscape in different land cover categories, mean patch size, and other spatial metrics. In addition, Pearson et al. (1999) and Schumaker et al. (2004) estimated the ecological effects of land cover change by projecting changes in the abundance and spatial distribution of habitats for a suite of species.

These spatially explicit approaches to simulating conditions on large, multi-owner landscapes recognize and retain the spatial complexity of the landscape in their policy analysis. In this way, they improve assessment of the biodiversity effects of alternative land use and land cover policies. However, these studies generally lack the vegetative complexity recognized in nonspatial models. Specifically, they lack detailed attributes of stands, such as species and size of trees over time and number of snags, which can be important for policy decisions. As a result, these studies did not project commercial harvest volume and value or the effects of stand-level silvicultural practices on biodiversity.

One study (Johnson et al. 1998) comes close to integrating the two approaches in its portrayal of alternative forest management scenarios for the Central Sierra Nevada Mountains of California. That analysis retained both spatial complexity of the landscape and the vegetative complexity of individual stands, but it was unable to reconcile these two different portrayals of the forest.

Other recent work also attempts to integrate stand and landscape approaches. In particular, the Forest Landscape Disturbance and Succession Model (LANDIS; Mladenoff 2004) has received wide use. LANDIS is a raster model that operates on landscapes mapped as cells containing information on tree-species and age classes. Spatial processes, such as seed dispersal, and disturbances such as fire, wind, and timber harvest can occur. LANDIS integrates spatial complexity with characteristics of individual stands and can recognize multiple owners across large areas.

In this study, we integrate the two prevailing approaches to recognizing the complexity of forest structure (stand vegetative complexity and spatial landscape complexity) to assess forestry management trends and policy in the Coast Range. The resulting data-richness of this approach has both advantages and

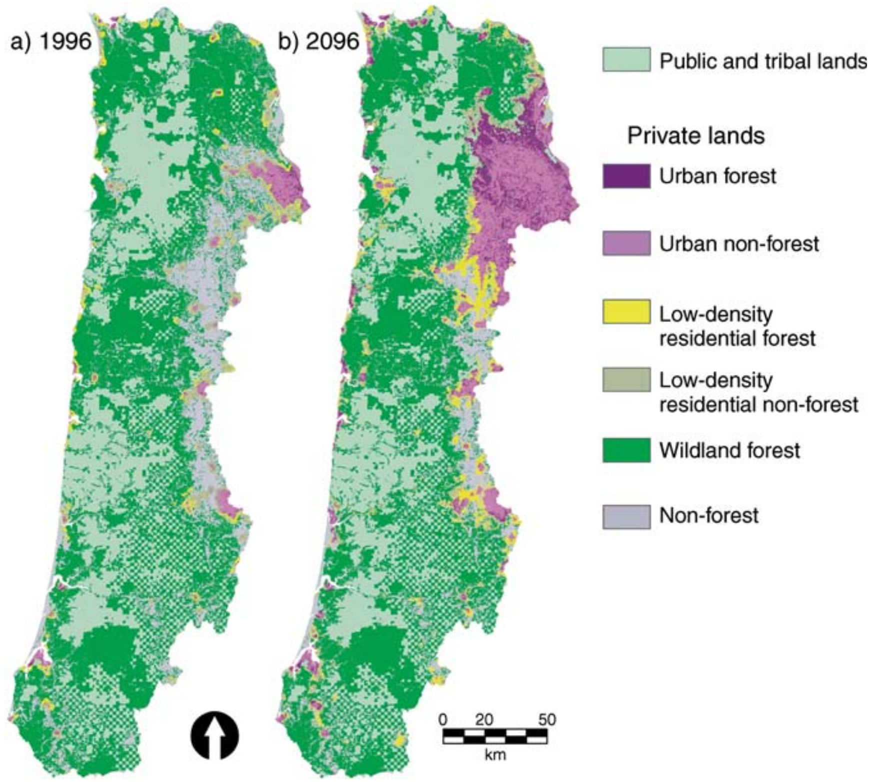

FIG. 1. (a) Land development in the Coast Range Physiographic Province of Oregon, USA, in 1996 and (b) projected development in 2096.

disadvantages. Maintaining both vegetative and spatial complexity increases our ability to portray policy effects with credibility and accuracy. Maintaining that complexity, though, greatly increases the amount of data that must be handled and processed, limiting the kinds of analytical approaches that can be taken. The region of interest may need to be broken into subregions for analysis, as done here, and optimization approaches can be difficult to implement.

We have three major objectives in the simulations reported here: (1) to assess how the forest land base might change in the future because of rural and urban development; (2) to assess how recently enacted forest policies, designed to maintain or restore forest biodiversity, affect forest structures, timber harvest levels, and associated timber-related income and employment at the province scale; and (3) to evaluate the implications of alternatives to current forest policies that attempt to enhance conservation of biodiversity.

Study Area

Economic and social context

As described in the introductory article (Spies et al. 2007), the CLAMS region is characterized by a forested center with urban and rural residential development around its edges (Fig. 1a). Most of the private forestland is utilized extensively for wood production.

Traditionally, the economies of the northern and western margins (Coast and Columbia River) were dominated by the fishing and lumber industries, along with dairies in some coastal areas like Tillamook. In the last 30 years, that traditional focus has given way to construction, real estate, and wholesale and retail trade as timbering and fishing receded, tourism gained in importance, and people sought the area for second homes and retirement (Johnson and Stankey 2002). The eastern margin, on the other hand, lies along the Willamette Valley, where two-thirds of Oregon's population lives and three-quarters of its wealth and economic activity are located.

Timber production and processing, though less significant than in the 1970s and 1980s, is still an important contributor to the economic and social well-being of people living within the CLAMS area. In addition, the logging history is an important part of the cultural identity of many people living within the CLAMS area.

Forests and forest policies

For purposes of this analysis, we have grouped the 2.3 million ha of forest in the Coast Range into four major ownership groups (federal, state and other public, forest industry, nonindustrial private). Federal forests are composed of USDA Forest Service lands (10% of forest

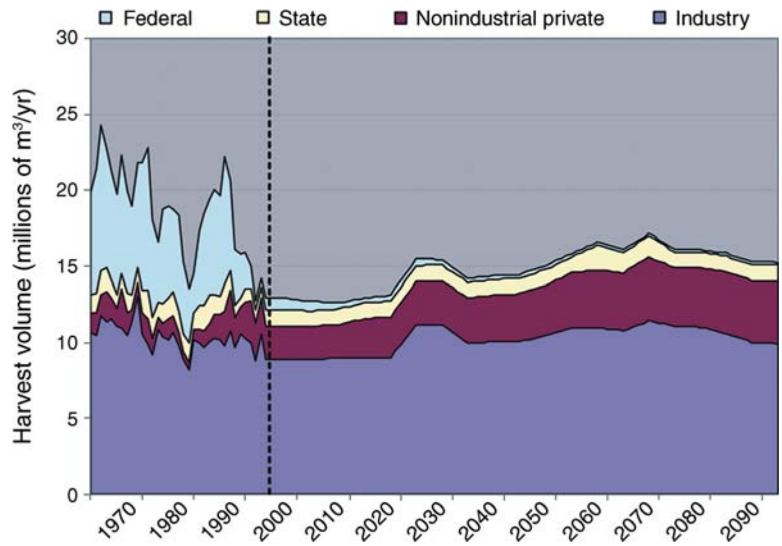

Fig. 2. Historical harvest (1962–1996 portrayed as a five-year moving average) and projected future harvest volume under current policy (1996–2096) by owner group in the Coast Range. Historical harvest data are from ⟨www.odf.state.or.us/divisions/resource_policy/resource_planning/Annual_Reports⟩.

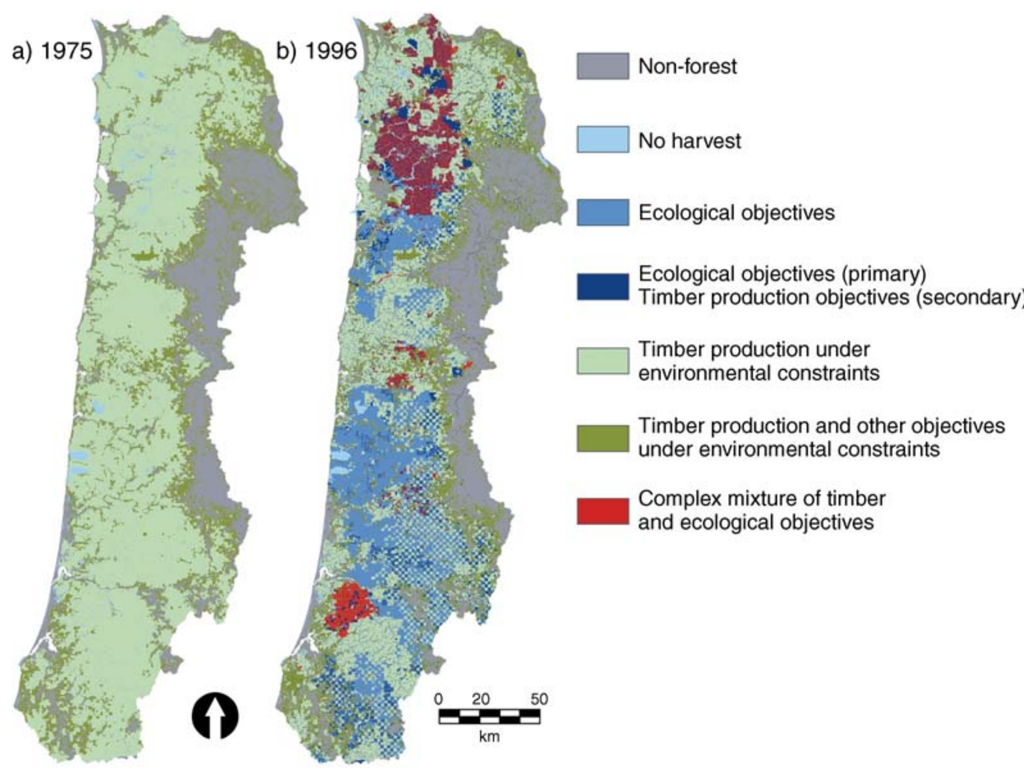

Fig. 3. Management emphases of different ownership groups in the Coast Range over time. (a) In 1975, federal, state, and forest industry owners emphasized timber production under environmental constraints; nonindustrial private owners emphasized timber production and other objectives under environmental constraints. (b) In 1996, federal owners emphasized no harvest, ecological objectives, and ecological objectives (primary)/timber production (secondary); state owners emphasized a complex mixture of timber and ecological objectives; the forest industry emphasized timber production under environmental constraints; nonindustrial private owners emphasized timber production and other objectives under environmental constraints.

area) and USDI Bureau of Land Management lands (15%), while state and other public forests are composed of State of Oregon lands (12%), and county, municipal lands, and Indian lands (1%). Private forests are divided into lands of the forest industry (owners whose primary income comes from timber harvest), which cover 42% of the forest area, and those of nonindustrial private landowners (other private forests), which make up 20% of forest area. (See Fig. 1 in Spies et al. [2007] for the spatial distribution of the ownerships across the Coast Range.)

Large-scale commercial timber harvest started on industrial forests in the northern part of the Coast Range in the late 1800s and then spread south over the next 50 years. By the 1980s, much of the original forest on private land had been cut and regenerated, and industrial harvests contracted and stabilized at levels that continue today, fueled by timber from second-growth forests. Harvest from federal lands started more slowly, but by the 1960s, those lands contributed over one-third of the total harvest in the Coast Range (Fig. 2). Federal, state, and forest industry managers were all committed to a similar approach—converting natural stands (mostly conifers and some hardwoods) into conifer plantations managed at a high intensity for timber production (Fig. 3a). Federal and state managers proposed using slightly longer rotations than those in industry, but the general management schemes were similar.

Federal harvests went through a series of market-driven ups-and-downs over time (Fig. 2). In the early 1990s, timber sales from federal forests largely halted due to lawsuits that successfully challenged federal conservation strategies for protecting the Northern Spotted Owl (*Strix occidentalis caurina*). After almost five years of turmoil, federal policy makers adopted the Northwest Forest Plan (U.S. Department of Agriculture and U.S. Department of Interior 1994). This plan strongly committed the federal forests to management for ecological objectives, especially maintenance and restoration of late-successional forests and aquatic ecosystems (see the management emphases that highlight ecological objectives in Fig. 3b).

In the late 1990s, management of state forests also shifted toward strategies more favorable to maintenance and restoration of late-successional forest and aquatic ecosystems. State planners were especially concerned about the northern state forests, (see Fig. 1 in Spies et al. 2007), which provide the only public lands in a landscape heavily dominated by industrial ownerships. In its most recent plans, the state committed to "structure-based" management, which attempts to combine restoration of mid- to late-successional forest and enhanced riparian protection with timber production (Bordelon et al. 2000) (see the management emphasis that describes a mixture of timber and ecological objectives in Fig. 3b).

Private landowners in Oregon have considerable freedom in deciding when to harvest. Over the last 30 years, however, state forest practices rules have gradually evolved, with special emphasis on reforestation after harvest and protection of riparian systems during harvest (Hairston-Strang and Adams 1997, Rose and Coate 2000). Reforestation requirements have been tightened to increase the certainty that conifer reproduction will occur after conifer harvest. Riparian rules control placement of roads near streams through a set of "best management practices" and limit removal of conifers and hardwoods near perennial streams through the use of riparian buffers that must retain specified amounts of conifers. Also, clearcut patches have been limited to 45 ha in size, with the requirement lasting for five years after harvest (i.e., after five years have elapsed, another clearcut patch can be placed adjacent to the clearcut patch in question).

Currently, the Coast Range provides nearly half of Oregon's annual timber harvest: approximately 14 million cubic meters out of a total annual harvest of about 29 million cubic meters. This harvest comes almost entirely from private lands, with the forest industry the dominant provider. Much of this timber is processed along the eastern fringe close to the Willamette Valley, although some processing plants still exist in the interior coastal region.

Methods

Our simulation of the aggregate effects of forest policies for the different ownerships in the Coast Range has three major components. First, we estimate the availability of land for forest management over the relatively long time period of our simulations (100 years). Second, we recognize legal requirements and policies that direct and constrain forest management, i.e., the public policy framework within which forest management will occur. Third, we simulate the actions likely to be taken by forest managers of the different ownership groups, given their goals, within the context of the expected land use pattern and public policy framework.

We simulate management actions with the Landscape Management Policy Simulator (LAMPS; Bettinger et al. 2004), a spatially-explicit, dynamic simulation model that examines forest development across long time frames with both deterministic and stochastic processes, while recognizing the juxtaposition of land resources (ownership boundaries, streams, watersheds) across the landscape. LAMPS emphasizes the projection of forest conditions and timber harvest over time as a result of stand growth and the actions taken by the different landowners to achieve their disparate objectives.

We model landscape responses to events in LAMPS at their smallest appropriate spatial scale, and integrate them within a larger hierarchical structure (Bettinger et al. 2004). We track forest structural conditions and model natural disturbances at a small spatial scale (basic

TABLE 1. Levels of the spatial data structure in CLAMS utilized by each owner group (from highest to lowest level, from most aggregated to most disaggregated).

	Owner group			
Spatial data level	Forest industry	NIPF	State	Federal
Fifth-field watershed			X	X
Ownership	X	X	X	X
Land allocation	X	X	X	X
Harvest block	X	X		
Management unit	X	X	X	X
Basic simulation unit	X	X	X	X

Note: Key to abbreviations: CLAMS, Coastal Landscape Analysis and Modeling Study; NIPF, nonindustrial private forests.

simulation unit; 0.06–1.94 ha), schedule management activities at a medium scale (management unit or harvest block; 10–46 ha), and constrain activities based on certain metrics measured at much larger scales (land allocation, ownership, or fifth-field watershed; 2000–800 000 ha). Use of members of the hierarchy is a function of the owner group being simulated (Table 1).

In addition, we recognize vegetative complexity at the stand level in LAMPS, which has been the focus of previous economic analyses. Tree lists (number, size, and health of the live and dead trees in the stand) representing stand characteristics are utilized in individual tree models such as ORGANON (Hann et al. 1997) and ZELIG (Busing and Garman 2002, Garman et al. 2003) to develop alternative stand-level prescriptions. Through this process, we estimate growth and harvest associated with different forest management prescriptions (see Bettinger et al. 2004 for more detail).

We estimate initial vegetation conditions from a model that integrates satellite imagery and inventory plot data (Ohmann and Gregory 2002) by using a "most similar neighbor" approach. This method assigns an inventory plot to each pixel, overcoming the previous problems caused by inconsistent estimates from satellite and plot data.

Projected land use change

We utilize the work of Kline et al. (2003) to estimate projected land use change from estimates of changes in building densities, with building density changes calculated as a function of existing building densities, projected population growth, a gravity index of commuting opportunities to existing cities in western Oregon, slope, elevation, and land use zoning. Projected building densities over time are then converted into wildland forest, rural residential, and urban land-use classes using a decision rule that identifies building density thresholds. Previous work suggests that intensive management diminishes as housing density increases (Kline et al. 2004). We assume that forests will no longer be available for commercial timber production once they shift to the rural residential class, but can still provide forest cover. We further assume that both commercial timber and habitat potential are lost once forests shift to the urban class.

The public forest policy framework

We express the effects of laws, regulations, and policies on forest management largely through the area to which they apply and the actions that are permitted and encouraged on that area (Table 2). Integrating the public policy framework with landowner goals, we can portray general management emphases for the forests of the Coast Range (Fig. 3b).

Modeling landowner behavior

Forest management, especially clearcutting and road building, has been the major driver of landscape change in the last 50 years in the Coast Range, and we assume that it will be the major driver in the future. Given the federal and state plans for coastal forests, most forest management activities will occur on private land. We focus on the silvicultural aspects of forest management in this analysis; we do not simulate road construction.

Projecting likely landowner behavior can be a challenge, given the susceptibility of public landowners to political processes and the freedom that private landowners have in their harvest decisions. We used multiple sources of information to develop a set of assumptions about landowner behavior; these sources varied by landowner. To project likely actions on federal and state forests, we used published forest plans, modified by discussions with managers on implementation experience. To project likely actions on private lands, we used a mix of historical information, group surveys, and interviews. In addition, we compared our private landowner simulations with those of other Coast Range studies.

We describe our approach to modeling forest industry behavior in LAMPS in the most detail, among the four landowner groups, since the industry is the most significant agent of landscape change among those groups. Then we briefly describe our approach to modeling the other three landowners. Statements of the mathematical models underlying our approach to the forest industry and state can be found in Bettinger et al. (2004).

Industrial forests

We focus the discussion here on three key variables for our analysis: (1) target rotation age, (2) short-term harvest rate, and (3) stand selection/patch size.

Long-term target rotation age is a key variable in future landscape condition. The forest industry historically has shown the inclination to harvest a similar number of hectares per year utilizing a rotation age of approximately 50 years (Greber et al. 1990). Surveys of the industry from the late 1990s also indicated a rotation age of approximately 50 years (G. Lettman, *personal communication*). Economic planning models suggest a

TABLE 2. Division of the forests of each ownership group in the Coast Range of Oregon among different land allocations under current policy, along with a description of permitted activities (PA) within each allocation.

Forest division, by owner	Land allocation (%)	Permitted actions (PA)
Federal†		
Late-successional reserves (LSR)	61	Thinning of plantations to increase structural diversity and accelerate development of late-successional forest
Riparian reserves (RR)‡	21‡	Thinning of plantations to increase structural diversity and accelerate development of late-successional forest
Upslope forest§	15	Thinning; clearcutting with retention of a significant portion of the stand
State‖		
Habitat anchors (HA)	10	Thinning to increase structural diversity and accelerate development of late-successional forest
Riparian management area (RMA)	7	Thinning to increase structural diversity and accelerate development of late-successional forest
Midslope riparian management area	19	Thinning to increase structural diversity; clearcutting with retention of a significant portion of the stand (rotation age 100–120 yr)
Upslope forest§	60	Thinning to increase structural diversity; clearcutting with retention of a portion of the stand (rotation age 100–120 yr)
Private forests¶		
Riparian management area (RMA)	5–7	Thinning down to a specified basal area of conifers
Upslope forest§	93–95	Thinning and clearcutting with retention of a small portion of the stand (rotation age of 40–50 yr on forest industry lands; 50–70 yr on nonindustrial private)

† Federal forests also have 3% of land allocated to Wilderness, in which harvest is not permitted.
‡ Outside of LSRs.
§ Forest available for timber production and other objectives.
‖ State forests also have 4% of land allocated to reserved status, in which harvest is not permitted.
¶ Outside of urban and rural residential areas.

rotation age between 40 and 55 years (Adams et al. 2002), while recent discussions with members of the industry suggest they now consider the optimal rotation age to be 40–45 years. Considering all this information, we use a target age of 40–50 years to guide our simulations.

A number of pathways exist to the long-term rotation age as landowners have substantial freedom in deciding the rate of harvest of their inventory. The industry has tended to harvest at a fairly even rate in the last 30 years (Fig. 2), but recent changes in ownership to potentially more aggressive owners and global economic pressures suggest an alternative hypothesis—that the industry will increase their harvest temporarily over the next 20 years (Adams et al. 2002). Here, we model industry's harvest as fairly constant, consistent with the recent past. For an application of the alternative hypothesis of accelerated short-term harvest, see Thompson et al. (2006).

Any spatial model of forest harvest must represent the size and distribution of harvest patches. We focus on clearcut patches in the discussion here because they are the most common type of harvest on industry lands. Planning models, past history, and discussions with members of the industry suggested that forest industry owners tend to harvest their most valuable (often the oldest) stands first. Thus, we search for their most valuable management units to seed a patch for harvest and then add adjacent units until we achieve a specific patch size (Bettinger and Johnson 2003). These clusters of management units are not permanently defined, rather they are built dynamically based on the specified priorities (such as highest-valued stands). Thus, their shape may change over time. As mentioned above, patch size is limited to 45 ha within one 5-year period under state forest practice rules. Rather than assume that all harvests would be the maximum size, we utilize historical distribution of patch sizes from the most recent 5-year period based on their characterization by Cohen et al. (2002).

Nonindustrial forests

Given the large number of nonindustrial private landowners in western Oregon and their diverse objectives, a number of factors (e.g., age of trees, age of landowner, economic needs of landowner) may be important in management decisions. We utilize a Monte Carlo approach to simulate management, based on an analysis of nonindustrial private management behavior (Lettman and Campbell 1997) which estimated propensity to harvest as a function of stand age. If a management unit is scheduled for clearcutting, we create a harvest block from neighboring management units using the blocking process described above and the historical distribution of patch size for nonindustrial lands from Cohen et al. (2002).

State forests

In general, managers of state forests attempt to achieve a distribution of structural conditions over time across the landscape, in habitat patches of different sizes, while producing a high level of timber volume (Bordelon et al. 2000). They also recognize special strategies for areas of high importance for wildlife, especially the Northern Spotted Owl, and along streams. To meet these goals, we use a complicated simulation process to schedule management activities (see Bettinger et al. 2004 for details). The state strategy continues to evolve and our simulations should be viewed as only an approximate rendering of the approach on these lands.

Federal forests

Under the Northwest Forest Plan, over 80% of the federal forests in the Coast Range are in reserves of one sort or another (Table 2). On those lands, forest management activities, beyond fire suppression, are limited to thinning plantations to increase diversity and potentially accelerate the development of old-growth forest structure. To simulate plantation thinning, we apply a variety of thinning regimes, based on landscape location and forest condition. The remaining 15% of the federal forests is in a matrix allocation with timber production as one of the goals—a controversial part of the plan. On those lands, we simulate both thinning and regeneration harvest (small patch cuts).

Economic effects

We estimate the direct economic value of the forest in two ways: (1) the return to landowners from timber harvest, and (2) the public "willingness-to-pay" to devote more forest land to achieving old growth conditions in the Coast Range. We utilize local price and cost information to estimate the net return to landowners from timber harvest and also to set harvest priorities for the forest industry. Costs were recognized for logging, hauling, and reforestation.

We utilize a nonmarket valuation study (Garber-Yonts et al. 2004) to estimate the value people place on additional amounts of old-growth forests. That study employed a choice experiment framework to estimate Oregonians' willingness-to-pay for changes in levels of biodiversity protection under different conservation programs in the Coast Range. In the study, the researchers gave respondents a number of choice sets in which the respondents were asked to indicate their first choice of three alternatives: a status quo alternative and two alternative conservation plans that varied in the levels of four biodiversity programs and "bid levels" described as annual household cost.

We estimate the direct employment effects of timber harvest from recent estimates of total employment in the forest industry in Oregon and associated harvest levels: approximately 45 000 people have been employed recently in the forest industry of Oregon to process approximately four billion board feet of timber (Warren 2005). That relationship gives an employment multiplier of approximately 11 jobs per million board feet harvested, consistent with other recent estimates (Bormann et al. 2006). We did not estimate the employment from forestry services (such as reforestation) or that generated by forest industry workers spending their incomes.

Recognizing the random nature of activities and effects

Although we gained much information on likely landowner behavior, we also recognize random components to human actions. With our spatial approach, we need to relate decisions to individual pieces of land (stands). Often we had information about what might be done on the average, such as the percentage of a particular class that would be thinned on nonindustrial land or the percentage of conifer stands near streams that would regrow as conifer, hardwood, or mixed after clearcutting. We turn these proportions into probability distributions that we apply to individual pieces of land, with the scale of application depending on the decision being considered.

In addition, we model fine-scale stochastic elements (e.g., small natural patch disturbances) to incorporate uncertainty and heterogeneity at fine scales. Again, we turn rates of disturbance into probability distributions for application spatially, with the probability of disturbance a function of position on the landscape.

We evaluated the resulting potential variability in LAMPS results using the coefficient of variation associated with harvest amounts and distribution of the forest among different species groups and age classes (See Appendix for details). The coefficient of variation was relatively low in most cases, except where an owner group had very few hectares in the category being analyzed. From this analysis, we concluded that recognition of randomness in the spatial location of actions and impacts does not significantly affect the aggregate results of our analysis. Thus, we report a single simulation here to illustrate our approach.

Results

Land use change under current policies

With expected development, we project a 6% reduction in the industrial forest available for commercial timber production over the next 100 years and a 36% reduction in private nonindustrial forest. Most of this change in land use occurs in the northeast portion of the CLAMS region near Oregon's major urban/suburban center (Fig. 1b). The projections take into account Oregon's land-use laws that mandate zoning to control urban sprawl and maintain prime agricultural and forest lands.

Forest structures, activities, and outputs associated with the current policies

Under our simulations, the total area of large and very large conifer/mixed forest increases while the amount of small conifer/mixed and broadleaf forest declines (Table 3, Fig. 4). The area of open forest (a temporary condition after clearcutting) does not change

TABLE 3. Recent vegetative condition and projected future vegetative condition of the forests of the Coast Range of Oregon under current policy (all values are percentages).

	Total		Federal		State		Industry		NIPF†	
Category	1996	2096	1996	2096	1996	2096	1996	2096	1996	2096
Open	16	15	7	1	7	0	23	26	16	17
Remnant	3	1	2	0	2	5	3	0	4	0
Broadleaf	14	2	7	1	11	2	12	1	28	6
SC/M‡	22	15	14	0	22	2	30	28	14	16
MC/M§	29	25	29	2	37	9	27	38	30	43
LgC/M¶	8	16	18	30	12	27	3	6	6	16
VLC/M‖	8	26	23	67	9	55	2	1	2	2

† Nonindustrial private forests.
‡ Small-diameter conifer and mixed-species stands.
§ Medium-diameter conifer and mixed-species stands.
¶ Large-diameter conifer and mixed-species stands.
‖ Very-large-diameter conifer and mixed-species stands.

significantly while the amount of open forest with remnants declines.

The ownership signature becomes increasingly obvious in the pattern of vegetative conditions over time (Table 3, Fig. 4). Federal forests will be dominated by stands of large and very large conifers (the deep blue area in the west central portion of Fig. 4b) as will state forests (the deep blue area in the northern portion of Fig. 4b). Forest industry lands generally will be covered by open (recently clearcut) areas and small- and medium-sized conifer forests, except near streams, while nonindustrial private lands will have a mixture of sizes reflective of the different objectives of this ownership category.

The projected increase in the area of the large-diameter class on private lands is probably an upper limit. The potential overestimate arises from assumptions about how private landowners will manage riparian areas adjacent to fish-bearing streams. It is assumed that private landowners will occasionally thin a portion of the riparian management area to the basal area limit allowed in the forest practice rules using a thinning approach that does not affect average stand diameter. This approach can overestimate the area in large-diameter stands for at least two reasons: (1) in some situations, land owners might take more of the large trees than assumed, leaving the smaller trees to meet the basal area limit and (2) in some situations, landowners might meet the requirement by leaving trees in a portion of the riparian management area (usually closest to the stream) and clear-cutting the remainder in conjunction with upland harvest.

The decline of remnant structures on private land may be overstated. The actions of nonindustrial landowners are notoriously difficult to simulate. We assumed they would leave only the minimum number of trees at harvest to meet the state forest practice rules (about 5 small trees/ha). Some would undoubtedly leave more and larger trees given their multitude of objectives.

Our simulations suggest that it would be possible to maintain, or almost maintain, the harvest level of recent history (after the significant reduction in federal harvest) under the management strategies modeled for the different landowners (Fig. 2). Most timber harvest volume over the projection period comes from forest industry lands, with nonindustrial lands providing much of the rest (Fig. 2). In terms of timber production per hectare, private lands again dominate (Table 4), with the productivity of industrial lands slightly increasing over time and that of nonindustrial lands sharply increasing.

Federal lands provide relatively little harvest volume, but even that harvest activity occurs mostly in the first few periods as a result of thinning in plantations in Late-Successional Reserves to increase structural diversity (Fig. 2). The state produces a moderate volume at a constant level over the planning periods. Over the 100-year planning period, forest industry lands produce, per hectare, more than 20 times the timber volume of federal lands (Table 4).

Most volume in the first decade (and beyond) comes from clearcutting rather than commercial thinning, but we see a marked difference in public vs. private harvest activity (Table 5). Whereas federal and state harvest activities are dominated by thinning, forest industry activities focus on clearcutting. Nonindustrial actions focus on a combination of patch cutting and thinning.

Our simulations need to be qualified in a number of ways. First, we estimate that industry lands currently produce approximately 10 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ of commercial volume and that this production will rise to approximately 13 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ in the long run (Table 4). These levels are almost 40% below recently published estimates for managed stands in the Douglas-fir region (Talbert and Marshall 2005). In the short-run, the differences arise most probably because our simulations cover all stands, not just managed stands, and allocate some forest to riparian buffers to meet state forest practice rules. In the long run, they arise most probably because we model a lower management intensity (without fertilization and genetic improvement), allocate some forest to riparian buffers, and assume that some regeneration failure will occur. We believe that these

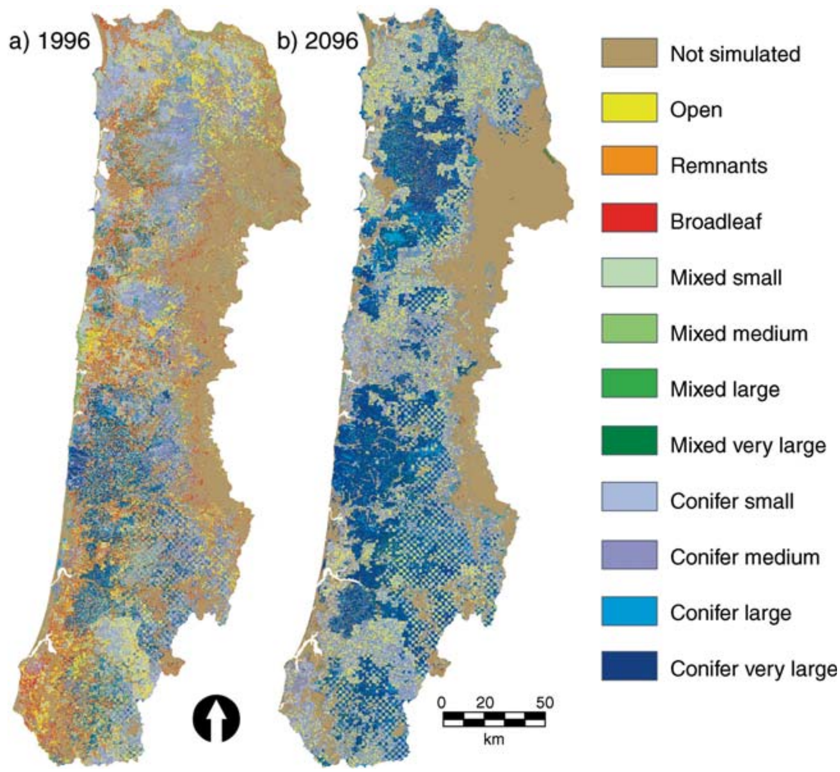

FIG. 4. (a) Distribution of the forests of the Coast Range among vegetation classes in 1996 and (b) the projected distribution in 2096 under the current policy.

productivity levels reflect a conservative industrial scenario for a large landscape; higher productivity levels would also be possible.

Second, our simulations show a large future increase in harvest volume from nonindustrial private land, compared with that during recent history, at the same time the land base for timber production shrinks. Part of the difference is explained by our assumption that more of the hardwood volume of the stands will be marketed than has occurred in the past. Also, we assume that yields from future managed stands will be higher than yields from existing natural stands. Still, achieving these yields in the long run will be difficult.

Third, we believe that our projections underestimate regeneration harvests on State lands. We can portray the large amount of thinning under the state plan to accelerate the development of the mature and multi-layered structural stages, but we have difficulty achieving the desired amount of regeneration harvest. Thus, the projections overestimate the amount of older forest on state lands in 100 years and underestimate harvest volume by 25–50%.

Economic effects under the current policies

Conifers dominate the harvest, providing at least 80% of the volume in most periods, with most hardwoods coming from nonindustrial lands. Based on current prices and costs, annual revenue to landowners could total 500–600 million dollars, with the major source of revenue variability associated with volume and value of hardwoods that will be harvested. Approximately 70% of that revenue would go to the forest industry and 20% to nonindustrial landowners. (The remaining 10% would be generated by state or federal harvests.)

According to Garber-Yonts et al. (2004), Oregonians indicate the highest willingness-to-pay, among the biodiversity measures evaluated, for increasing the amount of forest devoted to achieving old-growth characteristics. On average, respondents indicated an annual household willingness-to-pay of $380 to increase old growth forests from 5% (current amount) to 35% of the age class distribution—something close to the

TABLE 4. Projected wood production under current policy in the Coast Range of Oregon (all values are $m^3 \cdot ha^{-1} \cdot yr^{-1}$).

Category	Average	Federal	State	Forest industry	NIPF†
First decade	6.0	1.4	3.4	9.9	5.0
Long run‡	8.1	0.4	4.0	12.7	12.3
All planning§	7.2	0.5	3.8	11.8	8.8

† Nonindustrial private forests.
‡ Last 50 years.
§ Over 100 years.

TABLE 5. Projected annual harvest during the first decade under current policy in the Coast Range of Oregon.

	Area (thousands of hectares)					Volume (millions of hectares)				
Category	Total	Federal	State	Forest industry	NIPF†	Total	Federal	State	Forest industry	NIPF†
Clearcut	26.5	0.1	0.8	19.3	6.3‡	11.4	0.1	0.5	8.7	2.1‡
Thin	12.3	4.4	4.1	2.4	1.4	1.5	0.6	0.6	0.1	0.2
Total	38.8	4.5	4.9	21.7	7.7	12.9	0.7	1.1	8.8	2.3

Note: Key to categories: clearcut, a regeneration harvest that removes all trees (state and federal "clearcuts" actually retain a portion of the stand); thin, a harvest intermediate in the life of the stand that removes some trees.
† Nonindustrial private forests.
‡ Includes patch cutting.

increase that might occur in the long run under current policy. The study also found respondents indicated resistance to change in conservation policy that translated into an annual $153 cost per household, i.e., respondents resisted changing from current policy to any other policy which the study attempted to monetize. Aggregating willingness-to-pay, net of the resistance to change, over all households in the state amounts to approximately 300 million dollars per year that people say they would be willing to pay to increase the amount of old growth forest.

We estimate that the forest industry would employ approximately 20 000 people to process the harvest from the Coast Range in the near term. In the longer term, those numbers could increase, as the harvest gradually climbs (Fig. 2), but also might decrease with the development of labor-saving efficiencies.

Alternative policies

We projected very low levels of open and young forests with remnant trees under current policy on private lands (Table 3), where most regeneration harvest (clearcutting) occurs (Table 5). While our simulations probably understate the amount of trees left at harvest on nonindustrial private land, they do suggest a future decline in this structural category. Since management of state forests produces this structure, we applied the state forest strategy (leave 12 average-sized trees per hectare) to private lands. That significantly increased the area of stands with remnant trees at a cost of 5%–7% reduction in harvest on private lands. Based on current stumpage revenue, this policy would cost private landowners up to 25–30 million dollars per year and cost perhaps 1000 jobs.

Under current policy, we simulated the thinning of plantations on federal lands in the first few decades to increase structural diversity in keeping with the plans of the federal agencies. We also simulated a scenario in which such thinning was not allowed. Our analysis suggests that elimination of this thinning would substantially reduce the proportion of the plantations on federal land that shift from the large to the very large conifer category by the end of the simulation period (thinning enabled half the thinned area, approximately 28 000 ha, to shift by end of the simulation period). Also lost would be millions of cubic meters of timber harvest volume and perhaps 750 jobs in the forest industry over the first 20 years of the simulation associated with the thinning.

DISCUSSION

While these simulations are just a portrayal of the future under assumed conditions, they provide a structured way to think about future outcomes of current policies. We discuss here some potential implications of our results in terms of forest structure, timber harvest, and economic effects, along with the major uncertainties surrounding our simulations.

Forest structure

Our projections suggest that the forests of the Coast Range will shift from a relatively fine-grained mosaic of vegetation to a coarser-grained one that is strongly correlated with ownership. This change reflects the divergence in management policies between public and private land that began in the 1990s. Without major natural disturbance on public land, we would expect this sorting of vegetative condition by owner to develop in the future. Whether this outcome is politically acceptable is another matter. The loss of young forest on federal land, as an example, will reduce the amount of diverse early seral forest in the Coast Range and could reduce populations of popular big game species such as black-tailed deer (*Odocoileus hemious columbianus*) and elk, (*Cervus elaphus*) which forage in these early seral vegetation types (Johnson and O'Neil 2001).

We show a sharp decline during the first few decades in stands dominated by broadleaf trees. This decline in hardwoods occurs for at least two reasons. On federal, state, and nonindustrial private lands, it comes primarily from conifers growing up and overtopping hardwoods. On industrial forest land, the hardwood decline comes primarily from harvest of hardwood stands and their replacement with conifers, using herbicides to control competing vegetation. Assuming the simulations approximate future hardwood abundance, they raise issues about the adequacy of state policy to protect hardwoods and to encourage people to grow them. Reversing these effects on hardwoods, though, would require some fundamental changes in forest policy.

As discussed above, our results suggest the occurrence of relatively little early seral forest with remnant trees in the future, and that application of state forest legacy policies to private lands would provide significant amounts of this vegetation type. With the well-documented association of some forest species with forests with live and dead legacy structures (Johnson and O'Neil 2001), the further decline of this habitat could become a biodiversity concern.

Timber harvest

While we projected a fairly constant harvest by the forest industry, economic models suggest the possibility of increased short-term industry harvest for the Coast Range (Adams et al. 2002) because some stands are beyond economic maturity. Also, the recent purchase of substantial industry hectares in the Coast Range by Timber Investment Management Organizations (TIMOs) that sell stumpage from the timber lands suggest an increased sensitivity to maximizing returns from timberlands. In the long-run, we expect that either scenario would produce about the same distribution of industry hectares among different forest structure classes, assuming the same long-term rotation age, but the harvest level would oscillate into the distant future under the scenario that increases near-term harvest above the sustainable level.

The rotations on forest industry land (40–50 years) could potentially result in reduction in site productivity that would preclude continuing timber harvest at these relatively high levels. While this productivity reduction is theoretically possible, little evidence exists to show that it will occur. One study (Harmon et al. 1986) suggests that yield would not decline significantly for hemlock stands for at least seven 30-year rotations. Still, questions continue about whether repeated high-yield rotations will result in site depletion.

The significant difference in forest structure and timber production on federal lands as compared to private lands is an example of a landscape pattern that some argue might not be an effective way to achieve both forest conservation and timber production (Lindenmayer and Franklin 2002). Little research exists, however, to help us understand the ecological and socioeconomic trade-offs associated with different spatial patterns of timber production and conservation.

Economic effects

The forests of the Coast Range play a multitude of roles in the lives of the people who live there and people throughout Oregon. Here we utilized three different measures of the economic/social effects of policies: (1) land use, (2) timber production, and (3) conservation value.

Development of forest land for urban and rural residential uses will continue at rates reflecting the interplay of the potential value of lands for these uses and Oregon's land use regulations. Taken together, it appears that development will be the highest valued use of forest land around the edges of the Coast Range and in the river valleys that run through it.

Timber production will continue to be a major economic use of much of the remaining private forest land in the Coast Range for two reasons. As discussed above, we estimated net revenue to landowners of more than a half billion dollars a year from timber harvest on these lands. Also, other land uses would not be practical for many of the steep, remote lands in the interior Coast Range.

The willingness-to-pay estimates suggest that Oregonians also value the existence of old forests. These estimates come from a hypothetical market rather than a real market and represent only a snapshot of public preferences; they should be used with caution. Still, they suggest that the citizens of Oregon value old growth in a very real sense and that many would be adverse to plans that call for more harvest of these forests.

Major uncertainties

These simulations are our best estimate of the effects that current and selected alternative policies will have on land use, forest structure, and timber production in the Coast Range. A variety of uncertainties, though, could affect the long term implications of these policies. Six major sources of uncertainty stand out.

First, and foremost, the potential effects of climate change in the Coast Range are unclear. Considerable debate continues over whether the expected increased temperatures will result in increased moisture, and over the season in which the moisture might occur.

Second, more land might be devoted to cities, towns, and individual dwellings than projected here, since our projections depend in part on the continuation and effectiveness of existing land use laws. Recently adopted initiatives will make it easier to perforate the landscape with individual dwellings and small developments, reducing the potential contribution of the forests to conservation of biodiversity and timber production.

Third, questions have recently arisen about the global competitiveness of the Douglas-fir-based forest industry of the Coast Range. For a global comparison, our estimates of commercial wood production on industrial lands are only half of the estimates for plantations in the Southern Hemisphere (Talbert and Marshall 2005). The much higher productivity of these Southern Hemisphere plantations raises questions about the future competitiveness of forest industry investments in the Coast Range. If the forest industry shifts its investments elsewhere, the intensity of management will decrease which in turn, might have the unintended effect of increasing forest diversity.

Fourth, recent sales of large blocks of industry forest to TIMOs have created added uncertainties about how this land will be managed. The TIMOs seem focused on return on investment from the timberlands, rather than providing raw material to a processing plant. Thus, they could be more interested in land development (for housing) and other nontraditional money-making ideas than is the forest industry.

Fifth, an outbreak of Swiss needle cast, a native disease, has greatly reduced the growth of Douglas-fir plantations in the fog zone near the coast in areas that were naturally heavily forested with western hemlock. While the causes of this outbreak have not been established, aspects of intensive forest management (Douglas-fir monoculture, nitrogen fertilization) have been suggested as potential reasons for the increased susceptibility of Douglas fir to this disease (Thies and Goheen 2002) making the long-term future of plantation forestry in that area somewhat uncertain.

Sixth, we have not simulated the effects of wildfire on the future forests of the Coast Range. As discussed in Spies et al. (2007), wildfires of any size occur infrequently in the Coast Range. Thus, they are difficult to simulate over our planning horizon. Over longer time frames, we would expect that wildfires would reduce the amount of old forest and increase the amount of young forest as compared to the simulations reported here.

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APPENDIX

The effect of random variables on the LAMPS simulations (*Ecological Archives* A017-002-A1).