AN ABSTRACT OF THE THESIS OF

Jonathan R. Thompson for the degree of Master of Science in Forest Resources presented on June 21, 2004.
Title: Historical Disturbance Regimes as a Reference for Forest Policy

Abstract approved:____

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Using the historical range of forest conditions as a reference for managing landscapes has been proposed as a "coarse-filter" approach to biodiversity conservation. By emulating historical disturbance processes, it is thought that forest management can produce forest composition and structure similar to the conditions that once supported the native biota. Although several examples of disturbance-based management exist, only recently has this concept been incorporated into policy. This thesis explored hypotheses related to disturbance-based forest policy through a literature review, policy analyses, and simulation experiments.

The primary objective of chapter 2 was to examine several examples disturbance-based forest management and evaluate their potential to transition into policy within North America. The review highlighted two Canadian provinces—British Columbia and Ontario—that have codified disturbance-based management but used distinct methodologies. Nearly all of the forests in these provinces are government owned, which assisted policy development. In addition, both policy-structures focused on emulating stand-replacing fires that are characteristic in boreal

forests; this minimized the costs and the degree of departure from conventional forest management. In much of the U.S., land tenure is complex and disturbance regimes vary widely; this presents difficult challenges for disturbance-based policy development.

In the third chapter, disturbance-based policies were developed that attempted to address these challenges. Using datasets from the Coastal Landscape Analysis and Modeling Study (CLAMS) and the Landscape Management and Policy Simulation model (LAMPS), the economic costs and ecological benefits of several policy structures were explored. The policies included two variants of the current policy structure and three policies reflecting various aspects of the natural disturbance regime. The study area was the 3-million hectare Oregon Coast Range. Four owner groups were recognized—forest industry, nonindustrial private, state, and federal. The management intentions of each group guided the application of policies. Disturbance-based policies were primarily addressed to clearcutting on private lands because it constituted the preponderance of harvesting in the region. Information on the Coast Range's historical fire regime was used as a reference to develop disturbance-based policies. 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. LAMPS projected landscape conditions, forest dynamics, management activities (clearcutting, thinning), and harvest volumes over the next century.

Simulated disturbance-based policies produced age-class distributions more similar to the historical range than those created by the current policy structure. The proportions of early seral and young forest were within the historical range within 100 yrs; within this timeframe, older forests moved closer to but were still below historical conditions. In contrast, patch size distributions were less similar to historical conditions. This was because, even after a ten-fold increase in the average harvest size, the clearcut size limit remained well below the average historical fire size. Also, this was due to the scale of the analysis, which treated multiple proximate harvest-units as individual disturbance events. Therefore, regions with a high density of clearcuts, which were ubiquitous in the current policy scenarios, more closely resembled the large historical fire size. In the near term, annual revenue produced by the disturbance-based policies was estimated to be 20 to 60 percent lower than the current policy. However, relative costs were reduced significantly through time. This reflected the degree of departure between the modern and historical disturbance regimes.

This simulation experiment suggested that policies attempting to reproduce historical conditions in the Coast Range would require federal forests to provide large patches of old forest that were common in the historical landscape. Employing public lands for this purpose would dampen costs to private landowners who would continue harvesting and provide young and early seral forest structure, which were also historically abundant. In addition, this experiment illustrated the difficultly of meeting regional-scale conservation goals across multiple private landowners and suggested that distributing costs and benefits equitably across large landscapes could be a significant challenge.

Historical Disturbance Regimes as a Reference for Forest Policy

by

Jonathan R. Thompson

A THESIS

submitted to

Oregon State University

In partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 21, 2004

Commencement June 2005

Master of Science thesis of Jonathan R. Thompson presented on June 21, 2004.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Jonathan R. Thompson, Author

ACKNOWLEDGEMENTS

I was very fortunate to end up working with some of best forest scientists in the business. The CLAMS research project (of which this thesis is a small part) is tackling some of the most interesting problems in the fields of ecology and natural resource management. Unlike most research in this field, CLAMS scientists seek to anticipate problems before they erupt in crisis. They are crossing scales of time and space to understand if one region, the Oregon Coast Range, can really be ecologically and socio-economically sustainable. I thank them for funding this project and allowing me to be part of something bigger than any master's project could be on its own.

I thank Norm Johnson, my major professor, for making available to me any opportunity he or I could dream up. I got a hell of an education over the past three years and Norm, more than anyone else, made that happen. His enthusiasm for forests and forestry issues is contagious. Thanks Norm. I also thank Tom Spies, my minor advisor. Tom has been an inspiration to the extent that I have chosen to spend the next several years under his guidance while working toward a PhD. Thanks Tom, for all your help with this project and for taking a chance on me with the next one. I thank Gordie Reeves who has also been an inspiration; his work on aquatic disturbance ecology is pioneering. Finally, to round out my all-star committee, I thank Robert Beschta for being my grad rep.

I owe Kevin McGarigal quite a debt of gratitude. Back in undergrad at UMASS, Kevin taught me to think at the "landscape-level" and encouraged me to go to OSU. His letter of recommendation for grad school is likely what persuaded Norm to take me on. So thanks Kevin, I owe you big.

Although my name is on the front of this thesis, it is truly the work of many generous researchers. Specifically, I thank Marie Lennette for all the work with LAMPS; she came in at night, on weekends, and worried on my behalf on a regular basis. I thank Keith Olsen for answering ten million GIS questions and for always seeming happy to do it. Thanks to Pete Bettinger who is the primary architect of LAMPS and was always generous with advice and solutions. Thanks to Mike Wimberly for supplying 250 LADS maps for my analysis. I thank Hamish Marshall for a surplus of witty banter and for helping me through my analysis. I thank Sally Duncan for keeping it all in perspective and for enjoying many green-drinks with me. I thank Jesse Abrams for helping me think-through my project when others would have simply fallen asleep. And many thanks to all my fellow grad students—this college draws in quite an impressive bunch.

Finally, and I don't care if it is cliché, I offer my most sincere thanks to Amanda Robillard, my soon-to-be-wife. She read a draft of every paper I wrote, endured my seven-days-a-week schedule, took care of the dog, fed me, laughed at me, and did all the things that needed doing for me to finish this project. She is amazing and I am lucky.

CONTRIBUTION OF AUTHORS

Jonathan Thompson is primarily responsible for the research and writing of this thesis. In addition, chapter three benefited from Norm Johnson, who assisted during development, analysis, and writing; Marie Lennette, who assisted with LAMPS modeling; Pete Bettinger who assisted with LAMPS modeling; Keith Olsen who assisted with GIS analysis; and Mike Wimberly who provided data from the LADS model.

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CHAPTER 1: General Introduction

There is an increasing need to develop forest management strategies that permit commodity production while also sustaining the ecological capacity of forests. One frequently cited approach is disturbance-based management, in which silvicultural systems are modified to emulate natural disturbance (The Nature Conservancy 1988; Hunter 1993; Cissel et al. 1994; Swanson et al. 1993; Morgan 1999; Bergeron et al. 2002). This approach rests on the assumption that native forest species have adapted to, and depend on a range of disturbance processes such as fire, wind, and flooding. Therefore, the greater the similarity between managed forests and the historical range of conditions, the more likely it is that native species will be sustained (Hunter 1991; Swanson et al. 1993). Rather than targeting a single historical condition, disturbance-based management seeks to maintain the landscape within its historical range (Swanson et al. 1993). This is thought to be a "coarse-filter" method for conservation (Hunter 1991) and has emerged as a paradigm for ecosystem management (Cissel et al. 1994; Lindenmyer and Franklin 2002; Wimberly et al. 2004).

For almost two decades, forest scientists and practitioners have experimented with disturbance-based approaches to management (e.g. Franklin and Foreman 1987; Hunter 1993; Bergeron and Harvey 1997; Cissel 1998; 1999; Andison and Marshall 1999; Stuart-Smith 2002; Palik et al. 2002; Armstrong et al. 2003). There is now a growing interest in transitioning from experimental management to forest policy (Bunnell 1998; McNichol and Baker 2004). To a limited extent, this has begun in North America (e.g. B. C. Ministry of Forests. 1995; OMNR 2001; Committee of

Scientists 1999) and more broadly through the Santiago Declaration of 1995 and the subsequent Montréal Process (1999) of criterion and indicators for sustainable forest management. However, to the extent that disturbance-based policies have been implemented they have been limited to government owned land. There remains much uncertainty with regard to the application of disturbance-base forest policies on the multi-owner, multi-objective landscapes typical in the U.S.

In this thesis we explored how disturbance-based management can be incorporated into forest policy. The second chapter is a review and analysis of forest policies in North America. We described the evolution of forest policies and their connection to the advances in the scientific understanding of forest ecology. We presented several examples of disturbance-based management to illustrate how regional differences in forest dynamics influence silvicultural strategies. Finally, two disturbance-base policy structures from Canada were highlighted. The first was the British Columbia Biodiversity Guidelines (B. C. Ministry of Forests. 1995) which focused on green-tree retention and generating age-class distributions that would be expected given the relevant "natural disturbance zone". The second was the Forest Management Guide for Natural Disturbance Pattern Emulation (OMNR 2001) for the province of Ontario, which attempted to emulate several attributes of the historical disturbance regime but focused on the size and shape of boreal wildfires. We examined the architecture of these policies and the potential for introducing similar policies in the U.S.

In the third chapter, we used the Landscape management and policy simulation (LAMPS) model, to explore some of the economic costs and ecological benefits of employing a disturbance-based policy structure. Our study area was the 2 million hectare Oregon Coast Range. This physiographic province contains many landowners, both public and private, and offered a challenging but realistic forum. We projected management activities (clearcutting, thinning), harvest volumes and revenues, and landscape conditions over the next century. Information on the region's historical fire regime was employed as a reference to inform forest policies. We used: (1) green-tree retention to emulate fire severity; (2) annual harvest area restrictions to emulate fire frequency; and (3) harvest-unit size regulations to emulate fire extent. The management intentions of four ownership groups—forest industry, nonindustrial private, state, and federal—guided our application of policies. We used disturbance-based policies to govern clearcutting on private lands because it constituted the preponderance of harvesting in the region. The published results of a stochastic fire simulator (Wimberly 2002), built for the Coats Range's historical disturbance regime, were used as a gauge to measure the policies against.

There is growing recognition of the importance and difficulty in evaluating the consequence of natural resource policy decisions over the long term and over large areas (Franklin 1993; Johnson et al. 1999; Spies et al. 2002c; Spies and Johnson 2003). The challenge intensifies when multiple landowners operate under distinct policy structures distributed across a landscape. However, because ownership plays a significant role in explaining the variability in forest structure and composition (Crow et al. 1999; Stanfield et al. 2003; Wimberly and Ohmann *in press*), it is necessary to consider how policies might interact with each other and with owner objectives. Simulation modeling has been used previously to project the effects of disturbance-based policies on a single ownership (Anidison and Marshall 1999; Cissel et al. 1999; Hemstrom et al. 2001); however, we our not aware of any other study that has simulated disturbance-based policies over multiple ownerships throughout an entire ecological province. Hopefully, this study can help policy-makers and the public consider the potential for natural disturbance regimes as a reference for forest policy.

CHAPTER 2: A Review and Analysis of Disturbance-based Forest Policies in Canada and the United States

Abstract

Formulating forest policies that sustain the economic values of forests while simultaneously acting as a coarse-filter conservation strategy is a major challenge facing natural resource policymakers. One method being advocated to meet this dual mandate is disturbance-based forest management. This strategy relies on the assumption that native forest species have adapted to disturbances such as wildfire, which can be emulated through forest management. Advocates of this approach believe that native habitat conditions can be restored by emulating fire severity, regional fire frequency, and fire extent. However, there is considerable disagreement as how to develop disturbance-based policies and as to whether they should be considered and viable approach to conservation. Within Canada, several provinces have codified disturbance-based management into policy but each used distinct methodologies. Within the U.S., this approach has been less widely embraced. In this review, several examples of disturbance-based management and policy are presented. The difficulties in transitioning from management to policy are discussed with specific attention paid to the differences between Canada and the U.S.

Introduction

Increasing human populations and demands on forest ecosystems preclude the reintroduction of unregulated disturbances such as wildfire and flooding. However, suppressing these processes may have detrimental effects on native species adapted to dynamic ecosystems (Holling 1973; Botkin 1990; Atwill 1994; Reeves et al. 1995; Franklin et al. 2002). Modifying anthropogenic disturbances, such as timber harvest, to better emulate natural disturbances has been offered as a partial solution (Hunter 1993; Reeves et al. 1995; Bergeron et al. 2002). Several silvicultural and simulation experiments have succeeded in reaching conservation goals by matching the spatial patterns (Franklin and Forman 1987; Andison and Marshall 1999), frequencies (Cissel et al. 1999), and residual structure (Stewart-Smith 2002) of historical disturbance regimes. Although many differences cannot be reconciled, utilizing the historical disturbance regime to inform forest management can be seen as choosing a point on a gradient of landscape conditions that is closer to the "natural" landscape than might be expected from traditional silviculture. Though still controversial, this strategy has accumulated enough public support to be included into forest policy in several regions of North America.

The primary objectives of this review are to provide examples of disturbance-based management, to show how those principles have been incorporated into forest policy, and to analyze the successes and failures of this approach to policy formulation. Disturbance-based forest policies from British Columbia and Ontario are highlighted.

Changing perceptions of forest ecology and forest policy

Scientific understanding of forest ecology has changed fundamentally over the past 30 years; the transition has been referred to as an "ecological revolution" (Botkin 1997). In essence, there has been a shift from a linear to a stochastic interpretation of forest development. Until recently, forest development was seen as balanced and predictable. It was assumed that if a forest could remain undisturbed, it would proceed predictably along a successional track, eventually reaching a static climax phase where it would remain indefinitely. It was further assumed that this condition was best for the forest and all the associated organisms (Botkin 1990). Our understanding of forests as constant and predictable was derived from the pioneers of ecological thought. First generation ecologists, Cowels (1899) and Clements (1905) sought to define the pathways that led to a stable state; the resulting theory is referred to as the "classical succession paradigm" (McIntosh 1999). Succession theory has dominated ecology texts and journals since, and has perpetuated the popular view of a "balance of nature" (Botkin 1990). Several widely used stand development models still retain a view of linear forest succession unaffected by the legacies of the disturbances that shape the stand (for a review of stand development models in the Pacific Northwest see Franklin et al. 2002).

One hundred years of ecological research has shown that forest development is neither constant nor predictable at any stage. To the contrary, forest ecosystems are more accurately characterized by continual change and unpredictability. Rather than a state of equilibrium, the typical developmental stage of a forest is now thought to be recovery from the last disturbance (Johnson and Agee 1988). Disturbance is commonly defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985). This broad definition includes an array of factors affecting forest ecosystems at many spatial and temporal scales (e.g. fire, flood, infestation, drought, windthrow). Some disturbances have been fundamental to the evolutionary influence on forests so that the continuation of disturbance is essential to maintain the native diversity (Attwill 1994). The cessation or alteration of the historical disturbance regime, beyond some threshold, can put native species at risk (Holling 1973). The effects of fire suppression in pyrogenic ecosystems provide clear evidence of this phenomenon (Arno 1980; Agee 1997).

In North America, since the days of Pinchot, our scientific understanding of forest dynamics has fed the policies regulating the use of forests (Cubbage et al. 1993; Hirt 1994). Today, forest policies are addressed primarily to forest management practices when conducting a timber harvest or to conservation of forest amenities such as clean water, aesthetics, or biodiversity. Policies that regulate the uses of forests have become more abundant and more prescriptive throughout the past half-century. Increased regulation of forest practices reflects society's increased interests in forests and ecosystem health (Hirt 1994; Ellefson et al. 1995).

Many forest policies were first developed under a "balance of nature" perspective and still retain the ideals of this view (Botkin 1997). These are typified by two general assumptions. First, disturbance should be removed from the landscape whenever possible. Second, we should retain desirable forests in a steady state into perpetuity. With a few notable exceptions (discussed in the following section), these assumptions are at the heart of most forest regulations in North America. The bulk of state-level forest regulations in the U.S. are centered on fire suppression, regeneration, and protection against insects, disease, and fungus (Ellefson et al. 1995). At the federal scale, the U.S. Forest Service has earmarked over one third of its 2004 budget for firefighting alone (USFS 2003). Additionally, policies addressed to the conservation of forests amenities, such as biodiversity conservation or water quality protection also employ a static view. For example, to protect attributes associated with stream and rivers, it is common policy to require riparian buffer strips along waterways; Oregon, for example, requires riparian management areas along fish bearing streams to reach a mature forest stage in a "timely manner" and maintain this condition indefinitely (ODF 629-635-0100). This strategy does not account for the dynamic nature of stream ecosystems and their reliance on disturbances to maintain native biodiversity (Reeves et al. 1995).

Although most forest policies still retain a static outlook toward forest ecology, there is a growing interest in using regional disturbance history to guide forest management. In some instances this has resulted in "let burn" policies for lightning-induced forest fires or policies promoting reintroduction of disturbance through prescribed fires or prescribed flooding (via damn releases). Modern society, however, cannot allow the full reintroduction of natural disturbance. Fires cannot be permitted to burn through communities or through forests valued primarily for timber. Nor can rivers be unregulated and allowed to meander through the valleys they once traveled. Now that society has chosen to restrain these processes, there is really no letting go. This has led many to advocate the use of anthropogenic disturbances as surrogates for the historical disturbance regime. The remainder of this paper will be focused on shaping forest management and policies to emulate natural disturbance regimes at landscape scales.

Natural disturbance as a template

Timber harvests are inherently different from natural disturbances. They are fundamentally different processes resulting in distinct environmental impacts. The most obvious distinction is the removal of the dead trees. In a post-natural-disturbance landscape, dead wood provides food and habitat, affects microclimate, and influences subsequent disturbances. In the case of fire, the comparison is between a mechanized and a chemical process; this results in untold differences to the ecology of the soil, nutrient availability and hydrologic functions. Pathogen and disease spread are distinct in the aftermath of fires versus timber harvest. Furthermore, timber harvests are often associated with expanding road networks, which offer increased access to remote areas. Therefore, the objective of a disturbance-based approach to silviculture is not to exactly mimic, but rather to incorporate as many attributes of a natural disturbance as possible given the socioeconomic constraints of the harvest.

Defining the historical range of variability (HRV) of forest ecosystem conditions can be useful as an array of reference conditions from which disturbance-based strategies can be developed. 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). Because there are few remaining examples of unimpeded natural disturbance regimes, examining evidence of the historical range of conditions offers a way to understand the conditions that supported the evolution of native species. The concept assumes all ecosystems changed continuously through time, but there were limits to the extent and magnitude of the changes. It is further assumed that native species have adapted to this range of conditions, therefore, maintaining an ecosystem within or near these conditions can act as a coarse-grain conservation strategy (Swanson et al. 1993; Cissel et al. 1994; Landres et al. 1999; Aplet and Keeton 1999; Kuuluvain 2002).

There are three primary attributes of natural disturbances that forest management can emulate (Hunter 1993). First, the frequency of timber harvests can be matched to the expected disturbance interval. Second, silvicultural operations can be designed to leave a legacy stand structure and composition on the site to more closely emulate the forest condition in the aftermath of a disturbance. Finally, harvests size and shapes can mimic the range of expected disturbances. For example, this may include large openings resulting from large fires or small gaps as would be expected from the fall of individual trees.

Disturbance-based management in North America

Explicitly matching forest practices to historical disturbance process is occurring, at least in experimental stages, throughout North America. Cissel et al. (1994) suggest a useful six step process for developing a disturbance-based landscape management plan: (1) Assess the historical and current disturbance regime; (2) integrate this information and define a desired landscape condition and management approach for areas of similar disturbance histories; (3) project this management into the future assuming no natural disturbance but include harvesting that approximates the historical disturbance regime; (4) analyze the resulting landscape pattern to see if adjustments are necessary to bring the landscape within the desired range of conditions; (5) adjust the frequency, severity or spatial distribution of harvest units as needed; (6) identify management actions that will encourage development of the desired landscape condition. This process has been used--both in part and in full--for several disturbance-based landscape management plans and silvicultural systems.

In the Northeastern U.S., Seymore et al. (2002) developed a graphical method whereby silvicultural systems were plotted relative to the range of historical disturbance sizes and frequencies. The northern hardwood forests, typical of their study area, were subject to relatively frequent, gap-level disturbance that resulted in a finely patterned mosaic dominated by late successional species. In contrast, large, stand-replacing disturbances were infrequent and mid-sized disturbances (1-100 ha) were virtually non-existent. They concluded that the majority of the landscape must be under a continuous canopy of multi-aged, late successional tree species in order to "faithfully" emulate a northeastern natural disturbance regime. The recommendation, therefore, is for a narrow range of harvest sizes, from single-tree selection to group selection no bigger than 0.1 ha, and a rotation of 80-120 years.

In eastern Canada, in the boreal and sub-boreal forests of Quebec, the disturbance regime, and hence a disturbance-based silvicultural system is quite different. Large, stand-replacing fires on rotations of 63-99 yrs and spruce budworm outbreaks have characterized the historical disturbance regime (Bergeron and Harvey 1997). Even-age harvest with retention of snags and green-trees may be used to emulate fire-originated forests while "careful logging" and smaller group selection followed by advance regeneration may mimic windthrow and insect outbreaks (Bergeron et al. 1999). In these and other northern systems, a traditional rotation-age may approach the historical disturbance cycle (35-60yrs). However, while a fully managed forest will have no stands older than the maximum rotation-age (Davis et al. 2001), a naturally disturbed boreal forest has been shown to follow a negative exponential age-class distribution, where over a third of the forest exceeds the fire cycle age (Johnson and Van Wagner 1985). The retention of some forests older than the fire cycle is therefore necessary to emulate a natural age-class distribution.

Group lightning strikes followed by gap-creating fires and windthrow dominates the disturbance cycle in longleaf pine of southeastern U.S.; this results in multiple cohorts of trees with regeneration occurring in canopy gaps (Palik et al. 1997). This system is also subject to infrequent hurricanes resulting in large-scale windthrow. Palik et al. (2002) suggest a variety of techniques be employed to emulate historical forest structure including irregular shelterwoods on 60-80 year rotations with variable retention. The resulting two-story forest will be similar in structure to the multi-aged old growth pine forests.

In the Northeastern Alberta, where fires have a 30 to 50 year mean fire return interval (MFRI) and are stand-replacing, Alberta Pacific Industries (AlPac) has taken several steps to align their operations with a natural disturbance approach (Stuart-Smith and Hebert 1996). They have increased both live and dead tree retention while simultaneously adding variability to cutblock shape to mimic a range of fire severities. A wider variety of cutblock sizes is being implemented to relate harvest size to the range of fire sizes expected and to conform to natural boundaries (ridges and moist areas). The frequency of AlPac's harvest has also been adjusted in some areas to emulate the historical rate of natural disturbance. Also in northern Alberta, is the Ecosystem Management by Emulating Natural Disturbance (EMEND) research project. Through a replicated landscape design, EMEND is seeking to answer questions related the similarity between fire severity and variable retention harvest in boreal forests (Spence et al. 2002). The EMEND team began installing a series of prescribed burns and correlated linear machine harvests in 1995 to address both economic and ecological questions related to emulating historical disturbances. Detailed results on the biological similarity of the post-disturbance landscapes are forthcoming (Spence 2001).

Fire is the dominant disturbance agent throughout the Pacific Northwest region of the U.S., though the scope and severity vary widely (Agee 1993). In the western Cascades of Oregon, on 23,900 ha of federally managed forest, a long-term landscape management plan has been developed based in part on a series of fire-history studies (Cissel et al. 1999). Analysis of historical fires was used to develop timber harvest rotation ages, the density of legacy structure, and the spatial pattern of cuts. The effects of this management approach were projected forward 200 yrs with a patch-based simulation model and compared to the previous management strategy; it was found to increase late successional habitat, produce larger patch sizes, and less edge density when compared to the previous management plan (Cissel et al. 1997; 1999). This landscape experiment has drawn contradictory reactions. On one side, an independent scientific advisory committee has cited it as an example of progressive environmental management suitable as a template for state-level policy development (IMST 1999). While on the other, environmental groups, who are opposed to logging old trees on federal land, see the plan as a guise to cut more timber. This raises interesting issues of using disturbance-based management on a multi-objective landscape that we consider further in the discussion.

Disturbance-based policies in North America

Moving from the types of experimental management discussed above, to including a disturbance-based philosophy in forest policies is a significant step. Although ecologists increasingly understand the role of disturbance regimes in maintaining ecosystem function, the effectiveness of using timber harvests to emulate historical disturbances is not as widely accepted. However, the technique has had enough support in some areas to result in forest policies based on historical disturbance regimes; British Columbia and Ontario are highlighted here (Table 1).

Table 1: Disturbance-based policies in British Columbia and Ontario (NDT = Natural Disturbance type. FEN = Forest Ecosystem Network)

Properties of Natural Disturbance that can be Mimicked (Hunter, 1993)	Attributes of Disturbance	British Columbia Biodiversity Guide Book 1995	Ontario Forest Management Guide for Natural Disturbance Emulation 2001
	Zoned by disturbance type	5 disturbance types (NDT) have been mapped; most policies based on biogeoclimactic type within NDT most cuts should be < 80ha	Each Forest Management Unit must establish a benchmark from historical data or a large protected area for use in defining HRV
Spatial Pattern	Size	specifies a range of cut sizes determined by NDT	Recommends a range of cut sizes with 20% > 260 ha in the boreal and 10% > 260 ha in the Great Lakes - St. Lawrence
	Shape	Recommends establishing Forest Ecosystem Networks (FEN) to maintain connectivity and interior habitat	recommends using natural contours while incorporating 10-36% in residual patches
	Arrangement of Disturbance (Connectivity & edge)	FENs should maintain connectivity and interior habitat	3m or 20yr green up time or separate cuts by an average of 200m (100m minimum)
Residual composition	Leave trees	Not quantified but recommends leaving a distribution of diameter classes including some potential cavity trees	live and dead trees well spaced at 25/ha, 6 of which must be large, live, potential cavity trees
	Remnant Patches	General structural attribute recommendations by NDT; Wildlife patch size dictated by the harvest history and size of cut;	2-10% in insular patches and 8-40% in peninsular patches depended on forest type and combustibility
	Standing and down dead wood	Policy conflict with utilization standards;	Leave all slash on site; spread chips back over site; 25 well spaced live and dead trees left per ha
	Seral stage distribution	Recommendations made for age class distributions by biogeoclimactic zones within NDTs	Age-class distribution should be within or moving towards the HRV
	Species composition	Maintain all rare (<2%) stand types;	Composition objectives must be moving towards HRV
Rate of disturbance		Indirectly through age-class distributions	Indirectly through age-class distributions

British Columbia

The process of incorporating natural disturbances into B.C. forest policy was first expressed in the Biodiversity Guidebook of the Forest Practices Code, issued in 1995 (B.C. Ministry of Forest 1995). The guidelines require a level of planning not required under the previous forest rules. The province was divided into five Natural Disturbance Types (NDTs), based on the province's various disturbance histories. The Ministry of Forests used the expected disturbance intervals to model the resulting age class distributions across the landscape. These were used to produce seral stage distribution targets. The ministry used twice the expected historical levels of early and half the expected levels of mature and old seral stages as a concession to timber interests (J. Parminter, B.C. Ministry of Forests, pers. com.). The guidebook also included recommendations specific to NDT patch size ranges, old seral stage retention levels, landscape connectivity, wildlife trees and wildlife tree patches, stand structure, species composition and down-wood. Management recommendations were related to the severity and spatial configuration of the historical fire-regime.

For example, NDT 2 is characterized by infrequent (~200 yr MFRI), stand initiating fire events. This zone includes much of the mid elevation, western slopes of the Canadian Rockies and Coastal Range. Recommendations for the portion of NDT 2 in a Coastal Western Hemlock (CWH) biogeoclimatic zone, state that >13% be managed in an "old" seral stage, >51% in mature + old, and >27% in early seral development. Patch sizes should be fairly evenly distributed between 40, 40-80, and 80-250 ha. Some cuts larger than 250 ha are also recommended to reduce fragmentation and emulate the large stand-replacing fires that occurred in this disturbance regime. In contrast, NDT 4 includes those portions of the province that evolved under a high frequency of stand maintaining, low severity fire. Most of the forests in NDT 4 are in the Okanogan Valley of south central B.C. and are composed primarily of ponderosa pine (*Pinus ponderosa*) and interior Douglas-fir (*Pseudotsuga menziesii*). Here the guidebook suggests a seral stage distribution of < 23% early, <51% mature and < 19% old forests. Partial cutting combined with smaller dispersed clearcutting is recommended to approximate the pattern of the natural landscape. The recommendations for stand structure and species composition are generally similar throughout NDTs. Here the goal is to retain the legacy of the pre-disturbance forest through standing and down wood, wildlife patches and retention of rare habitat types.

The B.C. Biodiversity Guidebook was ephemeral as a policy document; however, this was due to political and bureaucratic issues unrelated to the disturbance-approach per se. This issue is addressed further in the discussion.

Ontario

In the province of Ontario, a class environmental assessment, done as part of the development of the Crown Sustainability Act of 1994, stated "clearcuts should emulate natural disturbance and thus be a range of sizes including some above 260 ha" (Ontario Environmental Assessment Board 1994). To accommodate this and other components of disturbance-based forestry, the Ministry of Natural Resources developed the Forest Management Guide to Natural Disturbance Pattern Emulation (OMNR 2001). The guide is applicable to all crown-owned land managed under a clearcut or shelterwood silvicultural technique. All forest plans within this region must comply with the guide by 2004.

Historically, the fire-regime in the boreal and subboreal forests of Ontario consisted of many small fires that collectively impacted only a small area, and a few very large fires that impacted a relatively large area (Donnelly and Harrington 1978). This is the rationale behind eliminating the former maximum clearcut size of 260 ha. In the Great Lakes and St. Lawrence region, less than 10% of clearcuts should exceed 260 ha; in the boreal forests to the north, less than 20% should exceed 260 ha. Although more than 20% of historical fires in both regions were larger than 260 ha, the limits are set "to recognize public sensitivity to large clearcuts" (OMNR 2001).

Each Forest Management Unit must establish benchmarks from historical data or, if there is insufficient data, from a large protected area that maintains a natural disturbance regime. Landscape level direction in the guide is based on a provincial fire-history study (Donnelly and Harrington 1978) that analyzed spatial distribution of fires between 1910 and 1950, a period before effective fire-suppression. If regionally available, the ministry encourages the use of more detailed fire-history studies to develop the HRV of the Unit. The benchmarks set from these data are used to dictate the distribution of cut sizes and age-classes in the unit. Forest planning must describe how the managers intend to stay within or move toward the HRV.

The guidebook emphasizes the value of variable clearcut sizes and shapes. Large cuts are encouraged to de-fragment previous groups of small checkerboard clearcuts. Uneven edges that correspond to the topography and include large uncut peninsulas are also recommended to emulate the effects of fire behavior. Before a harvest can be scheduled adjacent to a large cut (over 260 ha), there is a green-up period of 20 years or 3-m regeneration tree height.

The disturbance emulation guide also incorporates stand-level considerations into planning. Structural legacy guidelines are based on a study of 42 burns in Northern Ontario (OMNR 1997). Harvest units must leave 2-10% insular patches and 8-40% peninsular patches. Individual live and dead trees must be retained at a rate of 25 per ha; six of which must be large diameter potential cavity trees. To further emulate the effects of fire and retain the benefits of the on-site biomass, the ministry recommends leaving all coarse slash on the site, spreading roadside chips back onto the unit and pile-burning all the fine woody slash.

Discussion

The policies discussed above are, in some respects, taken out of context. It is important to remember that all of what is written into policy is not implemented. In the case of the B.C. Biodiversity Guidebook, concern over the impact on timber production led to a split in the later stages of development creating three Biodiversity Emphasis Options—managers were given a choice as to their preferred level of mimicry. Additionally, the biodiversity guidebook was introduced parallel to a host of other guidebooks, each focused on different forest attributes. Even if each were considered reasonable by themselves, when considering them altogether, in addition to the associated legislation and regulations, it became rather overwhelming (J. Parminter B.C. Ministry of Forests pers. comm.). Subsequently, in 1998, the Guidebook was replaced by the Landscape Unit Planning Guide. Then, in 2002, all the guidebooks were effectively abandoned when the "Results-based Code" was introduced. The Ontario Forest Management Guide to Natural Disturbance Pattern Emulation has been met with stark criticism from environmental groups, some ecologists, and the media (e.g. Mittelstaedt 2001; Shindler 2001; Brooks et al. 2002). This has resulted in an incomplete implementation of the Guide and continued controversy over the premise of disturbance pattern emulation. However, the policy is still in tact and several clearcuts larger than 260 ha (the former upper-limit) have been implemented under the auspices of disturbance pattern emulation. These two sets of policies are discussed here because they represent some first attempts at explicitly using disturbance history to guide forest policy. In this respect, they offer much food for thought.

Perhaps the most significant achievement of these policies is their explicit use of historical disturbances to impose varying standards across their jurisdiction. Rather than develop a blanket set of policies, policy-makers have segregated the landscapes by disturbance histories and separate goals have been developed for each. Although these policies may not be deemed a success by other measures, they do represent an acceptance of the primary role that disturbance has played in maintaining the diversity of the provinces.

There are several reasons that Canada has out paced the U.S. in incorporating a disturbance viewpoint into forest policy. A primary reason may be linked to the differences in land tenure between the two countries. In Ontario, 87% of forests are owned and managed by the provincial government (OMNR 2003); in B.C., provincial ownership exceeds 95% (B.C. Ministry of Forests 2003). The high proportion of public ownership permits the type of centralized landscape planning that disturbance-based management requires. The multi-owner, multi-objective landscapes, typical of forest-lands in the U.S., can not easily accommodate landscape-level planning (though some federal holdings may be large enough). The difficulties of landscape planning for ecological objectives across multiple ownerships are well documented (Knight and Clark 1998; Spies et al. 2002; Thompson et al. *in press.*).

Expanding the scope of interest across multiple ownerships and forest-types highlights the major distinction between disturbance-based management and disturbance-based policy. Efforts to utilize disturbance-based management, on isolated ownerships can result in misappropriating forest attributes on a regional scale. For example, an ownership parcel containing primarily old forest may seem to have a surplus leading to accelerated harvesting of large trees. However even though that habitat condition is locally abundant it may be regionally limited. This is the case with many federally managed lands in the western U.S. Therefore, to protect underrepresented forest habitats, publicly managed forests may have to respond to the likely actions of surrounding landowners rather than experiment with disturbance-based management; this was one impetus for the protection of most of the federally owned late successional forests under the Northwest Forest Plan (FEMAT 1993).

The northern forests that dominate the Canadian landscape are also more accommodating to disturbance-based management than are the forests of the contiguous United States. Boreal and subboreal forests tend to experience stand replacing fires on relatively short fire return intervals (Johnson and Van Wagner, 1985). Popular methods of emulating this fire regime with silviculture have required little departure from traditional forest management (i.e. clear-cutting on 45-60yr rotations) and therefore required relatively little change from the status quo (Hunter 1993; Kuuluvainen 2002). In contrast, emulating small gap disturbances or low severity fire regimes that characterize much of the forested landscape in the U.S. requires significant adjustment and would likely come at a large economic cost.

The structure of current policy in the U.S. also acts as an impediment to creation of disturbance-based policies. Forest regulations in the U.S. have embraced a fine-filter approach to ensuring biodiversity protection. Through the 1973 Endangered Species Act and the viability clause of the 1983 implementation regulations for the National Forest Management Act, the U.S. has decided to tackle biodiversity conservation one species at a time. Alternatively, Canada, through these disturbance-based policies, has selected a coarse-filter approach; a philosophy that assumes managing for the types and proportions of native habitats historically present will provide for all the species dependent on these habitats.

There are limited examples of a shift toward disturbance-based forest policy in the United States. The 1976 National Forest Management Act (NFMA) requires the development of forest management plans for each of the National Forests. In 2000, updated NFMA regulations were adopted (though not generally implemented) and for the first time included a reference to using the historical disturbance regime to assist in an evaluation of ecosystem sustainability. Forest Service planners are to include "an estimation of the range of variability… that would be expected under the natural disturbance regime of the current climatic period." This information is to be compared to the current condition and used as insight "about the current status of ecosystem diversity" (36 CFR 219.20). Generally speaking, for the reason outlined above, the U.S. has been more reluctant to embrace disturbance-based forest policy.

Challenges of emulating disturbance regimes

There is much debate regarding the effectiveness of disturbance-based approaches to landscape management and much uncertainty as to how forest policy can be shaped by historical disturbance processes. For these reasons, it is worthwhile to examine the three attributes of historical disturbances that are often cited as most amenable to inform policy—frequency, size and shape, and legacy.

Emulating the frequency of disturbance

Disturbance frequency shows significant spatial and temporal variability and dictates the age-class distribution of forest ecosystems. Neither Ontario nor British Columbia deals explicitly with matching the frequency of harvest to the frequency of historical disturbance. Rather, disturbance frequency is implicitly addressed through the age-class distribution recommendations given in the B.C. guidebook. However, Andison and Marshall (1999) simulated the effects of the B.C. Biodiversity Guidelines and compared the results to a stochastic fire simulator; they found no convergence of harvest frequency and wildfire frequency.

There are several difficulties with developing policies to match the historical frequency of disturbance (Armstrong et al. 1999). Perhaps the greatest of which is the variable nature of natural disturbance cycles. In forests characterized by infrequent, stand replacing fires such as the coastal temperate rainforests of the Pacific Northwest, the landscape may be free of fire for 200 to 5000 years (Lertzman et al. 2002). Then, after periods of sustained drought, fires may burn hundreds of thousands of hectares in a season. In dryer forests, such as the Ponderosa pine forests of the intermountain west, mimicking the characteristically frequent and low-severity wildfires would result in the harvest of smaller less valuable trees. These disturbance regimes contrast starkly with the harvest schedules preferred for timber production. The difference between timber harvest and natural disturbance has been described as press versus pulse disturbances 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.

Strict adherence to a historical rate of disturbance to set timber harvest levels may assume that the area (or volume) disturbed by timber harvest is compensatory to the amount of disturbance suppressed. This is a precarious assumption. The precise effectiveness of fire suppression can never be known *a priori*, and estimates made *a posteriori* are speculative at best. Furthermore, short-term successes in fire suppression compound the difficulty of future suppression efforts. Also, using a "compensatory philosophy" to dictate the rate of harvest precludes the use of a disturbance-based approach in regions not subject to wildfire.

Armstrong et al. (1999) investigated the impacts of matching the rate of pre-suppression natural disturbances to timber harvest in the boreal mixed-wood forest of Alberta. Simulation modeling was used to estimate the volume of wood and area disturbed given three different estimates of the disturbance regime. Their analysis raises several important points. First, they show the wide range of harvest-levels that a natural disturbance model can produce depending on whether it is the area or the volume of forest being emulated. This is because emulating the area burned would include many low-volume, low-value stands. In contrast, an approach that matches the volume of trees disturbed can seek out the highest volume stands first. Next, they show how small differences in the estimated rate of historical disturbance can affect the harvest level. In their analysis, three reasonable estimates of historical fire rates are used to set timber targets; results yielded volume estimates that were orders of magnitude apart. This point emphasizes the importance of accurate reconstructions of regional historical ecology; unfortunately, most methodologies still include high margins of error (Baker and Ehle 2001; Keane et al. 2002).

Matching the extent of disturbance-events

Matching the size and shape of natural disturbance may be the most straight-forward piece to the disturbance emulation puzzle. Doing so may decrease fragmentation when compared to traditional timber harvesting (Franklin and

Foreman 1987; Li et al. 1993; Andison and Marshall 1999). Simulation of the potential impacts of B.C. Biodiversity Guidelines showed some successes in emulating the historical patch sizes and interior forest area when compared to the traditional policy structure (Andison and Marshall 1999). Reduced fragmentation has been shown, in some cases, to benefit native fauna (McGarigal and McComb 1995). However, choosing to match disturbance size may be more an ethical than an ecological question (Hunter 1993; Bunnell 1998). Fires have occasionally burned over massive extents, often encompassing hundreds of thousands of hectares in a season. Choosing to emulate fires of this size with clearcut harvests may have aesthetic consequences too great for society to accept. In this regard, Ontario's Forest Management Guide to Disturbance Pattern Emulation has received harsh criticism for using historical fires as a guide for clearcut size (for examples see Schindler 2001; Wildlands League and Tembec Industries 2001; Brooks et al. 2002). Although the guidelines explicitly state that the total amount of forest cut annually will not change, critics see larger cuts as an excuse to harvest more timber. The Ontario Ministry of Natural Resources was directed by the Crown Forest Sustainability Act (Ontario Environmental Assessment Board 1994) to "emulate natural disturbances and landscape patterns while minimizing adverse effects." The result was a policy that promoted several small, some mid-sized and a few large (> 260 ha) modified clearcuts. This distribution of disturbance sizes was consistent with the more than two-thousand pre-suppression fires studied by the ministry (McNicol and Baker 2002). The intended effect of these policies, according to the Ministry, is to concentrate the footprint of timber operations, leave large areas intact, and reduce the amount of edge associate with forest management (OMNR 2000).

Matching the size of small, wind-throw disturbances has also been investigated (Seymore et al. 2002). Here a balance must be found between maintaining the small gaps indicative of a tree fall, while making the harvest large enough to be both economically viable and capable of regenerating intolerant tree species. It is important to weigh the ecological benefits of single tree selection against the increases in roads and entries which may have adverse effects on biodiversity conservation.

Forest policy can also use historical disturbance regimes to guide the shape of disturbance. By using topography and microclimatic factors to guide harvest layout and incorporating peninsular and insular retention patches, a timber harvest can be made to better resemble the aftermath of a fire. Both BC and Ontario include provisions to emulate the shape of fires into their forest policies.

Dispersed patch clearcutting (20-80 ha) has been the dominant spatial distribution of timber harvests in the western U.S. and Canada for the last fifty years (Franklin and Foreman 1987; OMNR 2002). In regions subject to stand replacing fires, the size distribution is typically follows a log-normal curve—several small fires and a few very large burns that impacted the majority of the area disturbed (Wimberly 2002). Here again, there is a great disparity between the historical and modern disturbances. Several ecologists have suggested aggregating harvests to concentrate the impacts and spare large regions of forest (Hunter 1993; Reeves et al. 1995).

Using disturbance severity to guide retention standards

Emulating historical disturbance regimes with timber harvest must reach a compromise in the percentage of trees left on site, both live and dead. Strict emulation would kill but not remove any trees (e.g. prescribed burning); obviously, this is not desirable for commodity production. Forest policy can dictate some minimum numbers of trees to be left and their position within the harvest unit. Both the BC and Ontario policies have increased retention levels to better emulate a post disturbance landscape, though Ontario's regulations are far more explicit. From a conservation of biodiversity perspective, leaving both dead and live trees on site may be the most valuable element of emulating historical disturbances (Lindenmayer and Franklin 2002).

Even stand replacing fires will occasionally spare trees; this can be a function of the fire resistance of the tree, it's location within the landscape (i.e. topography, microclimate), or chance fire behavior (Agee 1993). Both B.C. and Ontario recommend that live trees be left in mesic or protected areas within the stand. Young live trees can be left at little cost but can add vertical structure well into the future and potentially become cavity trees after they die.

Natural disturbance also leaves an abundance of standing and down dead wood; these structures have been shown to play important roles in forest ecosystems (Harmon et al. 1986). Snags and down wood can be created throughout the stand to partially emulate the stand condition expected after a fire. Snags provide important habitat for bats and cavity-nesting birds, throughout the life of the stand (Raphael and White, 1984). Similarly, down wood is an important habitat feature to small mammals, lichens, and other vegetation (Harmon et al. 1986). These benefits provide a strong argument for forest policies requiring high retention standards. However, there is a clear trade-off between leaving trees on site and taking them to the mill; the economic costs of retention have been shown to be substantial (Birch and Johnson 1992). Policymakers must, therefore, find a compromise position that allows disturbance emulation to be both economically and ecologically viable.

Conclusions

Coinciding with an increased appreciation for the role of disturbances in shaping the diversity of forests is an effort to incorporate disturbance ecology principles into forest policy. This is a dramatic shift from traditional forest policy which has been focused on eliminating natural disturbances through static management. Research into the use of the historical range of variability of forest conditions to guide forest management is ongoing throughout North America.

Disturbance-based forest management has been integrated into forest policy in several regions of Canada. Ontario and British Columbia have developed explicit forest management policies based on their regional fire histories. Although these policies have not been universally accepted or implemented, they do represent some of the first attempts to develop a coarse-filter conservation strategy based on disturbance regimes over large regions. In B.C. the policies were centered around maintenance of the historic age-class distributions while in Ontario the emphasis is placed on matching the size of historical fires. Both provinces also include stand-level guidance such as increased retention standards and the use of topography to guide the harvest layout. In the U.S. disturbance-based forest policies are sporadic and have not been as accepted due in part to patterns of land tenure, the complexity of forest types, and the emphasis on fine-grain conservation strategies.

While conducting this review, four important considerations for developing policies based on historical disturbance regimes were observed:

(1) An understanding of the range of conditions that an unimpeded disturbance-regime will produce on a landscape is necessary to develop priorities for disturbance-based forest policies. Often, in areas where the disturbance regime has been altered, evidence of the historical landscape conditions (e.g. HRV) will be the best guide. However, the intent is not to reproduce historical landscapes, but rather to use disturbance theory to maximize the resilience of native species and ecosystems.

(2) Disturbance-based policies must be specific to the ecological rather than socio-political boundaries. Therefore, forest policies may vary throughout an administrative jurisdiction as was seen in British Columbia Biodiversity Guidelines and Ontario's Natural Disturbance Emulation Guide. This complicates the application of disturbance-based policies landscapes where ownership boundaries dictate the extent of a policy's jurisdiction. In situations where a disturbance-base approach is desired for an isolated

property, which is common on federal lands in the U.S., the condition of the surrounding ownerships may dictate the best role for emulating the historical landscape conditions.

(3) Policies should seek to emulate both stand- and landscape-scale features of a disturbance regime. Forest ecosystems are dynamic at all spatial and temporal scales and the evolution of native species was influenced by all scales of disturbance. Therefore, disturbance-based policies must consider the effects of stand-level processes such as the levels of standing and down wood as well the landscape-scale attributes such as connectivity, age-class distributions, and patch size, shape and pattern. It is likely that disturbance-based policies could benefit from hierarchical approaches to forest planning.

(4) Policies must provide for flexibility and multiple pathways. Rather than implementing the same strategy across the landscape, disturbance-based policies should seek to fill in a probability distribution that describes the range of expected conditions under the natural disturbance regime.

In several regions, disturbance regimes that were once dominated by wildfire are now dominated by timber harvest. Though many of the differences between the two processes can be reconciled, many can not. Therefore, in ecological terms, the success of a disturbance-based approach to forest management is measured by its ability to emulate the frequency, the spatial pattern, and the residual structure of the disturbances regime endemic to a region. Each of these attributes has unique obstacles to creating viable forest policy. Disturbance-based policies must incorporate provisions for as many attributes of a natural disturbance as possible, given the socioeconomic constraints of the harvest. Rather than precise mimicry, the objective is to create a landscape that is closer, on a gradient of conditions, to the outcome expected from a natural disturbance regime than could be expected under traditional forest policies.

CHAPTER 3: Historical Disturbance Regimes as a Reference for Forest Policy in the Oregon Coast Range, USA: A Simulation Experiment

Abstract

Policies that induce forest structures similar to those created by historical fire regimes have been suggested as coarse-filter approaches to conservation. Advocates of this approach believe that emulating the fire severity, regional fire frequency, and fire extent can restore native habitat conditions. Using datasets from the Coastal Landscape Analysis and Modeling Study (CLAMS) and the Landscape Management and Policy Simulation model (LAMPS), the economic costs and ecological benefits of several policy structures were explored. The policies included two variants of the current policy structure and three policies reflecting various aspects of the natural disturbance regime. The study area was the 3-million hectare Oregon Coast Range. Four owner groups were recognized—forest industry, nonindustrial private, state, and federal. The management intentions of each group guided the application of policies. Disturbance-based policies were primarily addressed to clearcutting on private lands because it constituted the preponderance of harvesting in the region. Information on the Coast Range's historical fire regime was used as a reference to develop disturbance-based policies. 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. LAMPS

projected landscape conditions, forest dynamics, management activities (clearcutting, thinning), and harvest volumes over the next century.

Simulated disturbance-based policies produced age-class distributions more similar to the historical range than those created by the current policy structure. The proportions of early seral and young forest were within the historical range within 100 yrs; within this timeframe, older forests moved closer to but were still below historical conditions. In contrast, patch size distributions were less similar to historical conditions. This was because, even after a ten-fold increase in the average harvest size, the clearcut size limit remained well below the average historical fire size. In the near term, annual revenue produced by the disturbance-based policies was estimated to be 20 to 60 percent lower than the current policy. However, relative costs were reduced significantly through time. This reflected the degree of departure between the modern and historical disturbance regimes.

This simulation experiment suggested that policies attempting to reproduce historical conditions in the Coast Range would require federal forests to provide large patches of old forest that were common in the historical landscape. Employing public lands for this purpose would dampen costs to private landowners who would continue harvesting and provide young and early seral forest structure, which were also historically abundant. In addition, this experiment illustrated the difficultly of meeting regional-scale conservation goals across multiple private landowners and suggested that distributing costs and benefits equitably across large landscapes could be a significant challenge.

Introduction

Natural forest dynamics can be used to inform and guide the development of silvicultural systems. By emulating historical disturbance processes, such as wind or fire, it is thought that 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). Some disturbances have been fundamental to the evolutionary history of forest ecosystems so that the continuation of disturbance is essential to maintain the native diversity (Attwill 1994). Therefore, emulating historical disturbance processes may provide habitat conditions similar to those that sustained native species. Although many differences between "natural" disturbance and timber harvests cannot be overcome (Brooks et al. 2002), 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 than might be result from traditional timber management practices.

There is considerable interest in the developing strategies to conserve biodiversity at multiple scales while simultaneously sustaining timber production. As a result, several forest scientists and managers have experimented with silvicultural systems that mimic the patterns created historical disturbance regimes. Disturbance is commonly defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985). Although this definition includes a variety of processes, most examples of disturbance-based management have focused on wildfires. Many have succeeded, through simulations and field experiments, in meeting conservation goals by matching the spatial distribution (Franklin and Forman 1987; Andison and Marshall 1999), frequencies (Cissel et al. 1999), and residual structure (McComb et al. 1993; Stewart-Smith 2002) of historical fire regimes.

Applying disturbance-based forest management to a region requires an understanding of the dynamics that supported the evolution of native species. European settlement has altered landscape patterns throughout North America; therefore, the historical range of variation (HRV) of ecosystem conditions must often be defined through examination of historical evidence (Landres et al. 1999; Swetnam et al. 1999). 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). The concept assumes ecosystems changed continuously through time but that there were limits to the extent and magnitude of the changes (Mogan et al. 1994; Applet and Keeton 1999). Several methodologies have been used to define the HRV of a region; among these are analysis of historical records, dendro- and paleo-ecological evidence, and simulation modeling (Morgan et al. 1994). Simulation modeling has the advantage of incorporating several different methodologies and extrapolating over relevant spatial and temporal scales to define the full range of potential historical conditions (Keane et al. 2002; Wimberly 2002). Once the HRV has been explicitly defined, it can be used as an array of reference conditions from which, disturbance-based strategies can be developed.

As acceptance of disturbance-based management grows, there is impetus to incorporate it into forest policy (Andison and Marshall 1999; Bunell and Johnson 1999; Armstrong et al. 2003). There are few examples of disturbance-based management codified into policy in North America. Some noteworthy exceptions include the British Columbia, Biodiversity Guidebook (B.C. Ministry of Forest 1995) and the Ontario Forest Management Guide to Natural Disturbance Pattern Emulation (OMNR 2001), where forest management guidelines were set explicitly with historical disturbance regimes as a reference. Policy-makers in the U.S. 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 the historical disturbance regimes to assist evaluations of ecosystem sustainability. Forest Service planners were to include "an estimation of the range of variability… that would be expected under the natural disturbance regime of the current climatic period" (36 CFR 219.20) in their evaluation of National Forest Plans. Implementing disturbance-based policies in the U.S. has unique challenges as compared to Canada.

Whereas most Canadian forests are centrally owned and managed, U.S. forest practices are governed by a variety of policy structures based on land tenure.

Throughout the mosaic of ownerships in western Oregon, logging has become the prevailing forest disturbance agent (Cohen et al. 2002). This has resulted in dramatic changes in forest structure (Wallin et al. 1996; Spies 1999; Wimberly and Ohmann *in press*) 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 forests of western Oregon, several silvicultural and simulation experiments have succeeded in 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, within which there was total prescriptive control. If the eventual goal is a change in regional forest structure and composition, the effects of disturbance-based policies need to be examined over multiple landowners and at large spatial-scales.

The primary objective of this study was to better understand the economic costs and ecological benefits of disturbance-based policies applied over a large, multi-owner province—the Oregon Coast Range. The recent development of a landscape policy simulator, parameterized for the region, provided a unique 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 to measure the policies against. Our specific objectives were the following: (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 resulting landscapes in terms of spatial metrics against the range of landscape conditions expected under the historical fire regime; and (3) Compare the resulting landscapes in terms of spatial metrics and economic indicators with the projected conditions under the current the policy structure.

Methods

Study Area

Our study area was the Oregon Coast Range Physiographic Province; it is approximately 3-million ha, and contains some of the most productive forests in the world (Spies et al. 2002a). 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 (Figure 1a). 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 (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*) and red alder (*Alnus rubra*).

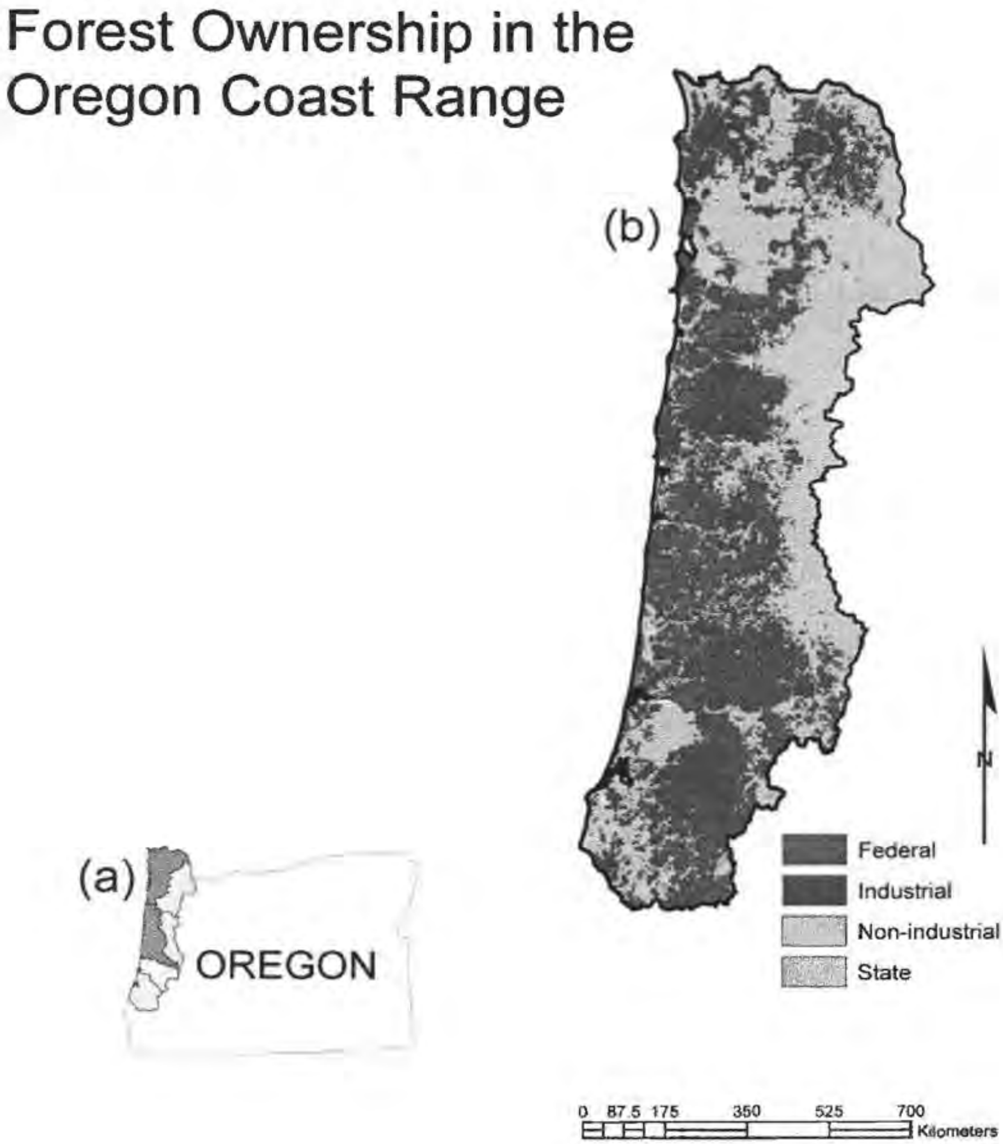

Figure 1: The Oregon Coast Range study area and ownership mosaic.
(a) The study area with megasheds delineated. The light green megasheds represent the Interior Climate Zone (from top to bottom: Northeast, Mideast, South, Umpqua); dark green megasheds represent the Coastal Climate Zone (North, Midwest). (b) The ownership mosaic of the Oregon Coast Range.

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

Wind and landslides significantly influence stand-level forest structure in the Coast Range (Wimberly and Spies 2001). However, historically, the primary disturbance agent controlling landscape-level forest structure and composition was wildfire (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, show 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; Hanson et al. 1991). The long fire return interval produced a landscape typically occupied by greater than 40% old forests (> 200 years) in variably sized patches often greater than 100,000 ha (Wimberly et al. 2000).

Since European settlement began in the late nineteenth 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. 2002c). Industrial forestlands comprise the majority of the forested hectares (~40%), followed by non-industrial private forests and federally managed lands (each approximately 23%), and the smallest ownership class is state forests (~14%) (Figure 1b). Ownership in the region explains a significant portion of the variability in forest structure; private industrial lands are associated with young forests, federally managed lands with mature forest cover, and non-industrial private (NIP) lands with a wide diversity of cover classes (Stanfield et al. 2003). Regional timber harvest is primarily regulated by market forces, the Oregon Forest Practices Act (OFPA), State Forest management plans, and federal land management policy (primarily the Northwest Forest Plan).

Logging has replaced fire as the prevailing disturbance agent affecting Coast Range forest structure. Virtually all private lands have been harvested at least once since European settlement (Ohmann and Gregory 2002) and most of the harvest-volume comes from clearcutting (Lettman and Campbell 1997). The timber harvest regime has had great influence on Coast Range forests. For example, the estimated proportion of old forests (> 200yrs) has been reduced from at least 40% in the historical landscape to less than 10% in the modern landscape (Wimberly et al. 2000). Over the past decade, since the adoption of the Northwest Forest Plan on federal lands, the vast majority of harvests occur on private lands.

Policies governing the modern disturbance regime (clearcutting) promote a landscape that differs from the historical range of conditions in three primary ways (Table 2): (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 m3 of down-wood retained per hectare, whereas fires 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 to 300 years (Teensma et al. 1991; Ripple 1994; Impara 1997; Long et al. 1998); in comparison, recent harvest rotations on private land have typically ranged from 50 to 100 years (Cohen et al. 2002), though, there is no explicit policy governing the frequency of harvest. (3) The 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, which limit timber harvests to 48 ha.

Table 2: A comparison of the Oregon Forest Practices Act and a Disturbance-based forest policy structure.

Attribute of Fire Regime	Method of Emulating	OFPA	Disturbance-based policy
Severity	Legacy structure	5 Snags or green-trees >28cm DBH plus 1.5m^3 down-wood per hectare	*Interior climate zone:* 40% of trees in clumps plus 12 green-trees >60cm DBH retained per hectare. *Coastal climate zone:* 10% of trees in clumps plus 12 green-trees >60cm DBH retained per hectare.
Frequency	Annual allowable harvest	5yr wait between adjacent clearcuts indirectly limits harvest	*Interior climate zone:* 5% of zone each 10yr-period. *Coastal climate zone:* 10% of zone each 10yr-period. (OFPA adjacency rules apply)
Extent	Clearcut size limit	48ha Clearcut size limit	Industrial clearcuts = 250ha NIP clearcuts ≤ 48ha

Overview of the Models

Policy Simulation

We used the Landscape Management Policy Simulator (LAMPS) (Bettinger and Lennette 2004) to simulate the effects of several forest policy structures. This simulation model was built as 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. 2002c). The following discussion draws heavily from previously published descriptions of the LAMPS model (e.g. Bettinger et al. 2000; Bettinger and Johnson 2003; Bettinger and Lennette 2004; Bettinger et al. *in prep.*)

LAMPS is a spatially explicit simulation model that tracks ownership, vegetation patterns, economic indicators, and biophysical characteristics of parcels of land in relation to their context within the surrounding landscape (Figure 2). 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 non-forest 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 (Bettenger et al. (*in prep.*)). LAMPS has the capacity to simulate landscape changes resulting from different policy structures at 5-year time-steps over a 100-year planning horizon (Bettenger and Lennette 2004).

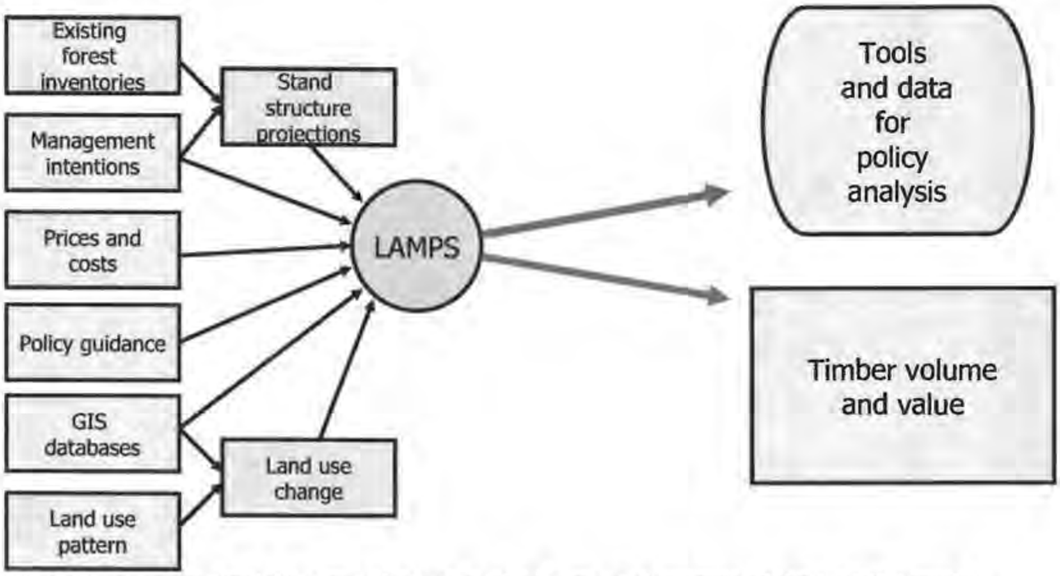

Figure 2: A conceptual diagram illustrating the inputs and outputs of the LAMPS model (adapted from Bettinger et al. 2001).

LAMPS simulations attempt to represent future landscape conditions and timber outputs under plausible management assumptions. To help 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 forest policy options to help land managers 'think-through' the landscape-scale effects across all ownerships (Bettinger and Lennette 2004).

Spatial Analysis Framework within LAMPS

Within LAMPS, forest dynamics are modeled at their smallest appropriate spatial scale and integrated within a larger hierarchical structure. LAMPS tracks forest structural conditions and models natural 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 (2,000–800,000 ha). The ownership group being simulated dictates which levels of this hierarchy are applied (Table 3). The spatial hierarchical structure is described in detail in Bettinger et al. (2004).

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. BSUs average about 0.30 ha and the shape of each BSU is defined by the aggregation of contiguous 25-m pixels that contain exactly the same descriptive information (vegetation class, slope class, distance from stream, owner, management unit, etc.). A "tree-list" (tree age, timber volume, etc.) is assigned to each BSU (Ohmann and Gregory 2002) and is updated at each time step. Approximately 30 million BSUs are tracked across the study area.

Management units are collections of BSUs that are assigned to a simultaneous activity. They are defined *a priori* through a process that delineates fifth-field watersheds, determines stream locations, and then subdivides watersheds into 6-10 ha areas using ancillary information regarding dominant vegetation and ownership boundaries.

Clearcutting is the major harvest activity on private land in the Coast Range and an analysis of the recent acreage distribution of clearcuts on private lands suggests that most clearcuts would have acreage equal to more than one management unit. Therefore, LAMPS uses a process to aggregate management units into harvest blocks based on the desired clearcut size (Bettinger and Johnson 2003). These clusters of management units are not permanently defined; rather, they are built dynamically, based on specified priorities, such as highest value. As a result, their shape may vary over time and can be used to fill in a distribution of clearcut sizes, such as the characterization of historical disturbances as described by Cohen et al. (2002).

It is also possible to create land allocations as a spatial subdivision within a larger landowner group. For example, five allocations are recognized on the federal forests: (1) Wilderness, (2) Late Successional Reserves, (3) Riparian Reserves, (4) Matrix, and (5) Adaptive Management Areas. Each allocation can be managed according to its own prescriptions. Fifth-field watersheds (Seaber et al. 1987) are also used to help direct and control management on some ownerships. For example, the Northwest Forest Plan calls for retention of certain amounts of late-successional forest at a fifth-field watershed-scale. Due to computer memory limitations, and the number of BSUs recognized, CLAMS scientists needed to model the Coast Range in six separate pieces. These parts, called megasheds, are divided along fourth-field watershed boundaries (Figure 1a).

Table 3: Levels of spatial data in LAMPS utilized by each owner group (from highest to lowest level) (from Bettinger, et. al. *In prep*).

Spatial data Structure	Owner group FI	NIP	State	Federal
Fifth-field watersheds			✓	✓
Land allocation	✓	✓	✓	✓
Harvest blocks	✓	✓		
Management units	✓	✓	✓	✓
Basic simulation unit	✓	✓	✓	✓

FI = Forest industry
NIP = Non-industrial private

Management Prescriptions

Management behavior is a function of the intentions of each landowner group and the policies that constrain activities over time and space. Prescriptions were developed for each of the four major landowner groups in the Coast Range. Prescriptions vary by owner, allocation, ecoregion, and initial vegetation class and are applied at the BSU scale. To develop the prescriptions, the CLAMS scientists relied on published forest plans, discussions with managers and planners, and surveys of landowners coordinated by the Oregon Department of Forestry (Johnson et al. *in prep.*).

Projecting Stand Characteristics

LAMPS uses BSUs to project the structural characteristics of forests over time as they grow and undergo natural and human disturbance (Bettinger and Lennette 2004). The architects of LAMPS chose an approach that produced detailed descriptions of live and dead trees in the stands because this information is necessary for many of their ecological and socio-economic response models. Two existing stand simulation models, calibrated for the Coast Range, were used: (1) ORGANON (Hann et al. 1997), a statistically based model of individual tree growth and mortality that is validated for conifers and some mixed stands up to 80 years of age, and (2) ZELIG.PNW (Busing and Garman 2002; Garman et al. 2003) a gap-phase succession model that simulates regeneration, growth, and mortality for a century or more. In LAMPS, ORGANON is employed for prescriptions that schedule regeneration harvest of stands younger than 100-years and ZELIG.PNW for prescriptions that either schedule regeneration harvest at ages greater than 100-years or never schedule regeneration harvest. Thus, ORGANON is used mainly for private lands, where relatively short rotations predominate and ZELIG.PNW for public lands where long rotations and forest reserves are common.

Since stand conditions are assigned to each BSU, LAMPS can represent spatial variability in stand structure and composition within the larger management units. The model of initial vegetation conditions was based on over 600 stand types (Ohmann and Gregory 2002). For each of these stand types, approximately 35 different management prescriptions were possible.

Regeneration Probabilities

After clearcutting activities have been simulated within LAMPS, a set of regeneration probabilities determine the type of forest that is regenerated. Regeneration decisions are made at the BSU level and each BSU within a clearcut unit has the possibility of returning as a predominantly conifer, hardwood, or mixed stand, or as an open area, where regeneration may be considered less than successful. The probabilities are a function of four characteristics of a BSU (landowner group, management intensity assumed, distance to the nearest stream, and pre-regeneration vegetation class) and allow stochastic elements to be incorporated into the modeling of a management scenario. Regeneration probabilities were developed from analysis of aerial photography (Kennedy and Spies *in press*) and other literature about transitions between conifers and hardwoods as a function of landownership and topography (Pabst and Spies 1999, Alig et al. 2000).

Natural Disturbances

Severe, infrequent wildfire is generally recognized as the major historical disturbance process that shaped the landscape-scale forests structure of the Coast Range (Agee 1993). In the past 50 years, fires have been effectively suppressed and the well-developed road network and fire control policies make future large fires unlikely (or, at least, unpredictable). Therefore, LAMPS does not simulate stochastic wildfire. However, LAMPS does model small gap disturbances (0.06 - 1.94 ha) with disturbance rate probabilities as a function of the size of each BSU. If a disturbance is suggested for a BSU in a time period, the BSU is assigned a regeneration tree list (i.e., re-established). The regeneration probabilities described above are used to determine the resulting vegetation class.

Additional details regarding the LAMPS model, including its treatment of growth and yield, spatial scheduling of harvests, transition probabilities, and the organization of spatial databases, can be found in Bettinger and Lennette (2004), Bettinger et al. (*in press*) and Bettinger and Johnson (2003).

Wildfire Model

The 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) (Wimberley et al. 2000; Wimberley 2001; 2002). LADS was originally developed to assess historical amounts of old forest in the Coast Range (Wimberley et al. 2000); it has subsequently been improved to better represent the shape and severity of the Coast Range's historical fire regime (Wimberley 2002). LADS is a probabilistic simulation model that uses a cellular automata approach to calculate fire ignition and spread. Fire shape is parameterized to mimic the shape of historical fires. Wimberly (2002) used probability distributions derived from a macroscopic charcoal analysis from a lake core (Long et al. 1998), a dendroecological study (Impara 1997), and historical documents (Teensma et al. 1991; Ripple 1994; Ripple et al. 2000) to calibrate LADS to the pre-European fire regime. No distinction was made between lightning and human ignited fires. Different probability distributions were used for the interior and coastal climate zones to reflect the regional climatic differences that controlled fire regimes. The range of possible landscape patterns was developed by running LADS for 50,000 years and calculating landscape summaries at two-hundred year intervals (Wimberly

2002). We developed additional summaries of the sample landscapes, beyond what was reported in Wimberly (2002), for use in this study.

The Simulations

Five policy alternatives were simulated in LAMPS to show the potential effects of disturbance-based policies in the Oregon Coast Range (Table 4). Two simulations were parameterized to model the 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, the North and Midwest, were treated as the coastal climate zone and four megasheds, the Northeast, Mideast, South, and Umpqua, were treated as the interior climate zone (Fig. 1a).

Table 4: Descriptions of the five policy simulations
(BSU = Basic simulation unit, see text for definition. NPV = Net Present Value).

POLICY	GOAL	FEDERAL	STATE	INDUSTRY	NON-INDUSTRIAL
Base25	Simulate the current policy structure	Northwest Forest Plan	Forest Plans	Oregon Forest Practices Act/Maximize NPV – Never Clearcut more than 24% of ownership in a period	Oregon Forest Practices Act / Historical tendencies
Base25/33	Simulate the current policy structure	Northwest Forest Plan	Forest Plans	Oregon Forest Practices Act/Maximize NPV – Cannot clearcut more than 24% of ownership in the 1st 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	Northwest Forest Plan	Forest Plans	Same as Base25/33 except: Retain 40% of BSUs and 12tpa in the interior zone & 10% of BSUs and 12tph in the interior zone	Same as Base25/33 except: Retain 40% of BSUs and 12tpa in the interior zone & 10% of BSUs and 12tph 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	Northwest Forest Plan	Forest Plans	Same as Sim(S) except: Area harvest limited to the natural fire rotation (100yrs in the Interior Zone & 200yrs in the Coastal Zone	Same as Sim(S) except: Area harvest limited to the natural fire rotation (100yrs in the Interior Zone & 200yrs 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	Northwest Forest Plan	Forest Plans	Same as Sim(S+F+E) except: Clearcut size increased to 250ha	Same as Sim(S+F)

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." Details and validation of many components of the base policy simulations, beyond what is given below, have been published previously in Bettinger et al. (*in prep.*), Spies et al. (2002c; *in prep.*) and Johnson et al. (*in prep.*). However, several changes were made to the previous Base policy scenarios to reflect advances in our ability to simulate the current policy and to accommodate the objectives of this study. One central change across all ownerships was a shift from five- to ten-year periods. To accommodate this, all harvest targets were doubled in even-numbered periods and zeroed-out in odd-number periods. As a consequence, all harvests occurred at year 7.5 of the 10-year period.

Disturbance-based policies were addressed to clearcut harvests on private lands because this accounted for most of the harvesting in the province. The first disturbance-based scenario emulated the severity of wildfires by increasing the number of trees retained after harvest. The next simulation maintained the increased retention standards but also emulated the expected frequency of fire in the region; to do this, we reduced the total number of hectares harvested in a period to what would be expected given the natural fire rotation. The final simulation maintained the retention and harvest area targets and also increased the harvest-block size on industrial lands closer to the extent of historical fires. Further details of the simulations are given below.

Base Policies (Base25 & Base25/33)

As we have discussed previously, LAMPS has the capacity to simulate the likely behavior of multiple ownership groups. In the Base policies we established the baseline policy strategies for federal, state, NIP, and industrial forests. The parameters described how we modeled each landowner group; these were held constant on federal and state lands through all of the simulations in this study. The parameters for private land were adjusted only where necessary to accommodate the disturbance-base policies, which are described later.

Federal.

The scheduling process on federal lands (USFS, and BLM) reflected the guidance in the Northwest Forest Plan (FEMAT 1993/ 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 clearcutting. To simulate the likely 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 clearcut harvests would come from mature forest (approximately 80-120 years) and commercial thinning would occur in young stands (approximately 30-80 years) as their conditions warranted. Clearcuts averaged less than six hectares and were selected randomly from the mature forest. Overall, the federal forests constituted less than two-percent of the total area clearcut within the study area during the simulation period.

State

Management actions on state lands were simulated to produce a high volume of timber on a steady flow, while achieving diverse structural conditions across the landscape (Oregon Department of Forestry 2001). LAMPS achieved the states structural goals by managing for the following four attributes: (1) the desired proportion of structural stages (regeneration, young, mature, multi-layered, old), (2) the desired patch sizes distribution different structural stages, (3) two layers of special management zones near streams, with increasingly protective strategies applied as you near the stream, and (4) special habitat anchors designated for mature and old forest. These structural goals guided and controlled the harvest location and level. A minimum clearcut 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. Clearcut harvests occurring in matrix lands averaged less than 6 hectares and retained 12 medium sized trees per hectare (tph) except for the midslope riparian zone in which 35 tph were retained during clearcutting. Clearcut harvest on state lands constituted less than three-percent of total clearcut area within the study area.

NIP

Several economic, environmental, and social forces influence the behavior of non-industrial private (NIP) forest owners. Research suggests, for example, that nonindustrial private forest owners base their forest management decisions on nontimber values, such as aesthetics and wildlife, in addition to timber production (Johnson et al. 1997), causing them to respond to economic forces in complex and sometimes unpredictable ways (Kline et al. 2000a, 2000b). Therefore, to simulate the actions of this diverse group, we used a probabilistic approach to model harvest decisions that that combined historical information and owner surveys with economic analysis obtained from the Oregon Department of Forestry (Lettman and Campbell 1997).

NIP harvest information from inventory plots taken in the early 1990s was used to estimate the probability of commercial thinning and regeneration harvest (clearcutting) 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 substantially increase in inventory and rotation age over time. This did not seem reasonable, especially since the premium for large trees that would be associated with the higher 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 build-up 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 Oregon State Forest Practices Act (OFPA) including a five year green-up period, a maximum clearcut size of 48.5 hectares, retention of five small trees per hectare, and retention of riparian buffers.

NIP behavior is inherently difficult to estimate because there are a multitude of owners with quite diverse objectives. It is clear, though, from an examination of their inventory that the trees eventually get cut—very little old growth remains on NIP lands (Ohmann and Gregory 2002). Our hypothesis of NIP behavior combines historical behavior and economic analysis. We believe they will continue to distribute activities among a variety of age classes using a combination of thinning and clearcutting. We further believe that they will continue to manage their forests at lower intensities and for longer rotations than the forest industry. We do not believe, however, that they, as a group, will grow more old forest than they have historically, especially with the loss of a price premium for large trees. Therefore, we chose a management strategy that continues to distribute the activities among a number of age classes while generally maintaining their target rotation age. It should be noted that these assumptions do result in a higher harvest than recently experienced. We will discuss later the sensitivity of our conclusions to these assumptions.

The distribution of clearcut sizes developed by the CLAMS scientists suggests NIP owners have a much higher percentage of cuts in the 1-40 acre class than do the forest industry, reflecting both the fragmented ownership of NIP and their management intentions. Some of this harvest might be patch cuts from 1-10 acres in which high valued trees are removed and some low valued trees are left resulting in the mixed stands described by Stanfield et al. (2003). Thus, "clearcutting" may be somewhat of a misnomer here and the difference between "thinning" and "clearcutting"—the two types of activities in our analysis—may not be as distinct as we represent it.

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 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 utilizing investment-efficient management regimes or management regimes can be modeled on landowner surveys (Sessions et al. 1990). Some authors acknowledge that it is likely industrial owner actions would 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 net present value or maximum sustainable harvest level) as possible (Sessions et al. 1990, 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 (Spies et al. *in prep.*). Some simulation studies suggest that this may continue (Johnson et al. *in prep.*) while others suggest there may be a short-term increase in harvest (Adams et al. 2002) reflective of individual firms maximizing their net present value.

Both hypotheses about industrial behavior are represented below through different simulations: (1) The Base25 simulation set a constant upper limit on hectares clearcut per 10 years period at approximately one-quarter of the industrial land. This approach resulted in a fairly stable harvest and slightly increasing harvest over time. (2) 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 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 equilibrium 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. It should be noted, though, that the average clearcut size diminished over time as it became more difficult to find adjacent parcels that meet the qualifications for clearcut harvest.

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 4). Ideally, we would have utilized both the Base25 and Base25/33 throughout the analysis. However, we felt the need to choose one due to the computational burden of carrying two hypotheses through the analysis. We choose to use Base25/33 after comparison to the 24 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—that did not seem realistic. The Base 24/33 simulation achieves the target rotation age sooner. (2) We recently experienced a major shift in industrial forest ownership that affected thousands of hectares. Ownership was transferred from a firm that retained significantly older timber to one that will likely quickly liquidate inventory older than its target rotation age. As Adams (2002) said, it is likely the actual schedule will fall between the hypotheses of constant flow and accelerated harvest of surplus inventory.

Consideration of thinning

Thinning in LAMPS is associated with particular prescriptions and triggered by encountering certain stand ages, stand conditions, slope, and the proportion of the parcel available for thinning. The algorithm works slightly differently for the different ownerships. We assume that the forest industry will thin from below to help develop crop trees, but only if significant revenue can be made—thus, thinning is limited to high volume stands on relatively flat ground. Not much thinning occurs in existing natural stands, which is consistent with recent industry behavior. However, we assume that regenerated (future) stands on flatter ground that are managed at higher intensities will be thinned once under the parameters used here. Thus, the amount thinned of these regenerated stands is roughly proportionate to the amount clearcut a few decades earlier (about 1/3 of the acres clearcut earlier), which may prove to be more than the industry is likely to do.

We assumed that NIP existing natural stands could be thinned once from above to remove the higher valued trees. Whether thinning occurred in any period depended on the Monte Carlo process used to select BSUs for harvest, the probability increased with age. Thus, the number of acres thinned was a function of how long the stand lasts; therefore, a reduction in clearcutting would trigger an increase in thinning. The rules for thinning of future stands are similar to that of the forest industry. Ideally, we would have allowed multiple thinnings in a stand. Thus, we probably underestimate the amount of thinning on NIP lands that would occur in all scenarios.

For state and federal lands, intermediate harvest is a function of age and stand condition, with multiple thinnings of a stand permitted in some prescriptions. We assume that they will thin on both steep and flat ground. On both ownerships, thinning is the predomanent activity as compared to clearcutting.

Disturbance-based simulations

The disturbance-based scenarios described below were used to incrementally introduce constraints on harvest scheduling which were thought to induce forest structure and composition similar to 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; OMNR 2002; Armstrong et al. 2003). Throughout these simulations we retained the parameters from the Base simulations to manage federal and state lands and focused disturbance-based strategies on to private lands where most timber harvests occur (Table 4).

Emulating Wildfire Severity (Sim(S))

Retaining large quantities of trees on-site after a harvest is a frequently advocated approach to emulating the severity of wildfire (Hunter 1993; McComb et al. 1993; Bergeron et al. 1999; Cissel et al. 1999; Stewart-Smith 2002). Therefore, the first disturbance-based simulation, termed Sim(S), increased the retention standards on private lands during clearcut harvest while maintaining the other parameters set in the Base25/33. After LAMPS scheduled a management-unit for clearcutting in the interior climate zone, 40% of the BSUs within the perimeter were randomly selected to be left uncut, in addition, 12 randomly selected trees per hectare (tph) >60 cm DBH were also retained. In the coastal climate zone, 10% of BSUs and 12 tph > 60 cm DBH were retained. The BSU retention is designed to emulate clumps of unburned trees skipped by a wildfire while individual trees were left to emulate those that survived a burn. The difference in fire severity between the two climate zones is consistent with dendrochonological studies done in the region; Impara (1997) found that fires in the coastal climate zone were more infrequent than in the interior zone and thus more fuel accumulated between fires making them more intense. We differentiate retention-levels between climate zones to represent the difference in severity.

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—rather than passively accepting the loss—they would seek to make-up that volume elsewhere on the landscape. Therefore, the per-period harvest volumes reported in the Base25/33 were set as targets in Sim(S). These targets were rarely met due to other constraints such as ownership boundaries, minimum rotation ages, and adjacency standards. However, the assumption that private landowners would seek to maintain the same volume as the Base25/33 did affect our results and the implications are discussed further in the discussion.

Emulating Wildfire Frequency (Sim(S+F))

To emulate the frequency of wildfire 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 (Hienselman 1973). NFR, for stand initiating fires in the Coast Range, is thought to be 100yrs in the interior climate zone and 200yrs 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 would likely be unacceptable. We, therefore, 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 multi-owner province such as the Coast Range requires some consideration of equitability between ownerships and sub-regions. We chose a method that distributed harvests evenly across megasheds within a climate zone and in the same proportions between ownership classes that were established in the Base25/33. We also utilized the federal forests to provide forests structure older than the fire rotation while also reducing the economic impact to private landowners. The following example illustrates the procedures we used to calculate the allowable per period harvest in each megashed: (1) The Midwest megashed (~530,000ha) is in the coastal climate zone with a NFR of 200yrs; 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 26,500ha. (2) During the Base25/33 simulation, 87% the clearcut 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 23,055ha for industry and 3180 for NIP (public lands were left unchanged). (3) These targets were then used to set the per-period, gross-harvestable-hectares; this meant the net harvest was reduced further when 10% of the BSUs along with 12tph were retained within each harvest-unit to emulate fire severity (as described in Sim(S)). This procedure was completed separately for all six megasheds and the results were aggregated for presentation in this thesis.

This approach allowed us to maintain the relative proportions of industrial and non-industrial harvest that existed under the base policy structure. Also, by establishing the NFR for the entire megashed and then allocating the disturbance only to private lands, we were able to dampen the costs to private landowners. However, there are limitations to this approach; they include an assumption that there will be no increase in harvest on public land and no significant wildfires throughout the province. It also creates a system where older forests only exist in megasheds with public lands and private landowners in megasheds with more public land can harvest a higher proportion of the acreage per period than can landowners on megasheds with less public land. The nuances of these limitations are elaborated in the discussion.

Emulating Wildfire 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 2002). Because historical wildfires in the Coast Range were very large, we increased the average industrial clearcut size from 25 to 250ha. Although this represented a ten-fold increase, it still did not approach the average size of historical wildfires in the Coast Range (estimated at 2220ha in the eastern climate zone and 7300ha in the west (Wimberly 2002)). However, several logistical issues, such as ownership boundaries, adjacency constraints, and model limitations, in addition to behavioral assumptions, led us to cap clearcut size at 250ha. This scenario is termed Sim(S+F+E).

All parameters developed for Sim(I+F), except those related to industrial clearcut units, were held constant in Sim(S+F+E). Non-industrial harvest size remained unchanged; this reflected non-industrial private landowner's smaller average property size, and was consistent with their tendency to harvest smaller units (Cohen et al. 2002; Stanfield et al. 2003). It also maintained a diversity of harvest sizes across the landscape which, we felt, better emulated the heterogeneity of patches characteristic of the historical fire regime. In order to facilitate an increased industrial clearcut size, several changes were made to the parameters controlling the LAMPS harvest scheduling process. The minimum harvest age was reduced from 25 to 20 years. 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. Finally, we removed the constraint that forced LAMPS to consider a ratio of the value and age of a parcel in favor of a criterion based exclusively on value.

Policy Analysis

LAMPS produced a series of reports and maps for each megashed and time-period. In order to analyze the intact landscape, megashed grids were joined in ArcInfo WorkStation (ESRI 1995) (Figures 3 & 4a-d). Likewise, the megashed reports, which described inventory and harvest activity, were aggregated for the entire province. To help understand, the economic effects, we calculated volume harvested per period, approximate net revenue per period, and overall net present value. Volume harvested per period is reported in terms of softwood, hardwood, and total volume. Harvest information was reported for private landowners while forest inventory and a series of spatial-pattern metrics were calculated across all landowners.

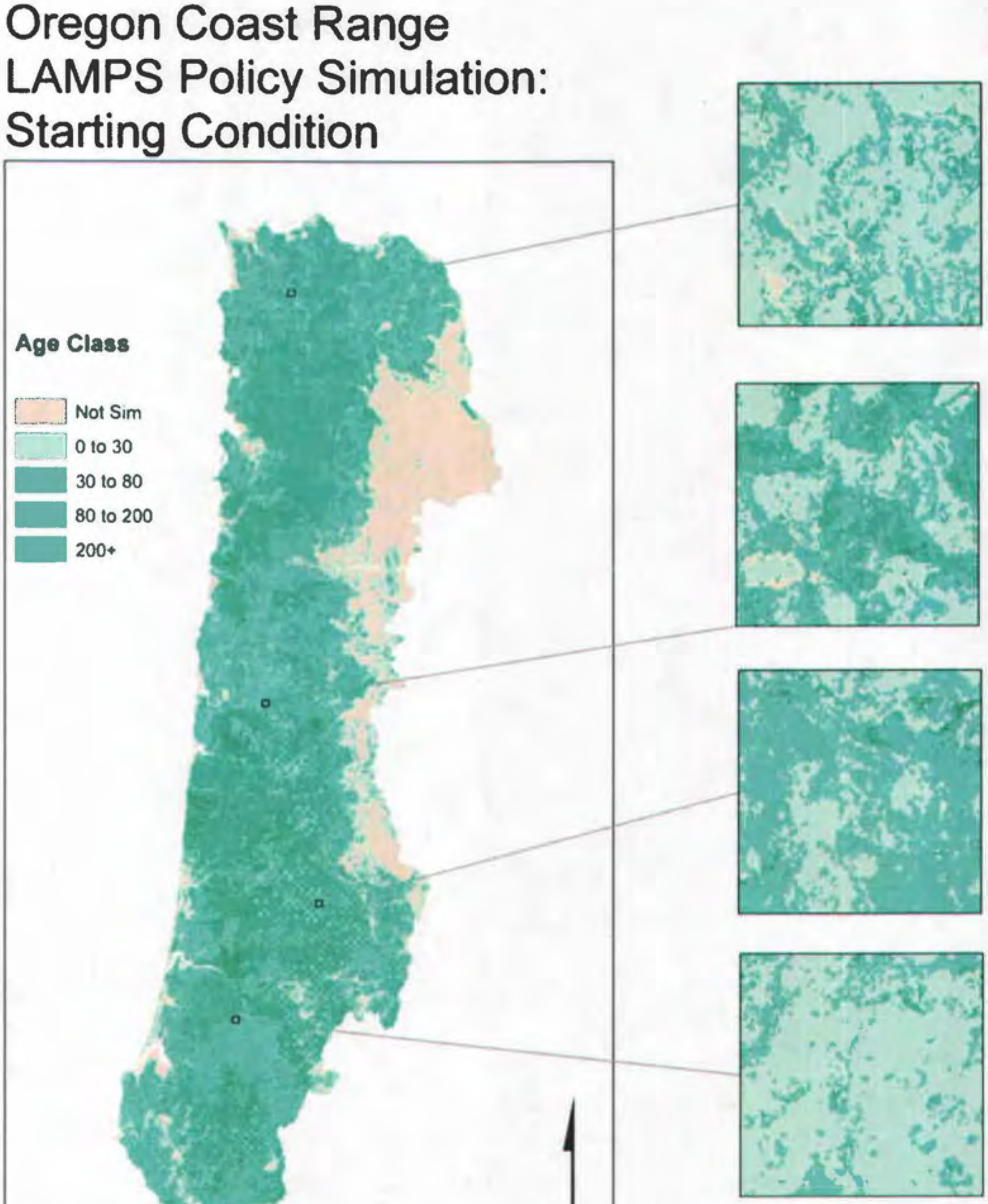

Figure 3: Forest age-classes at the start of all policy simulations

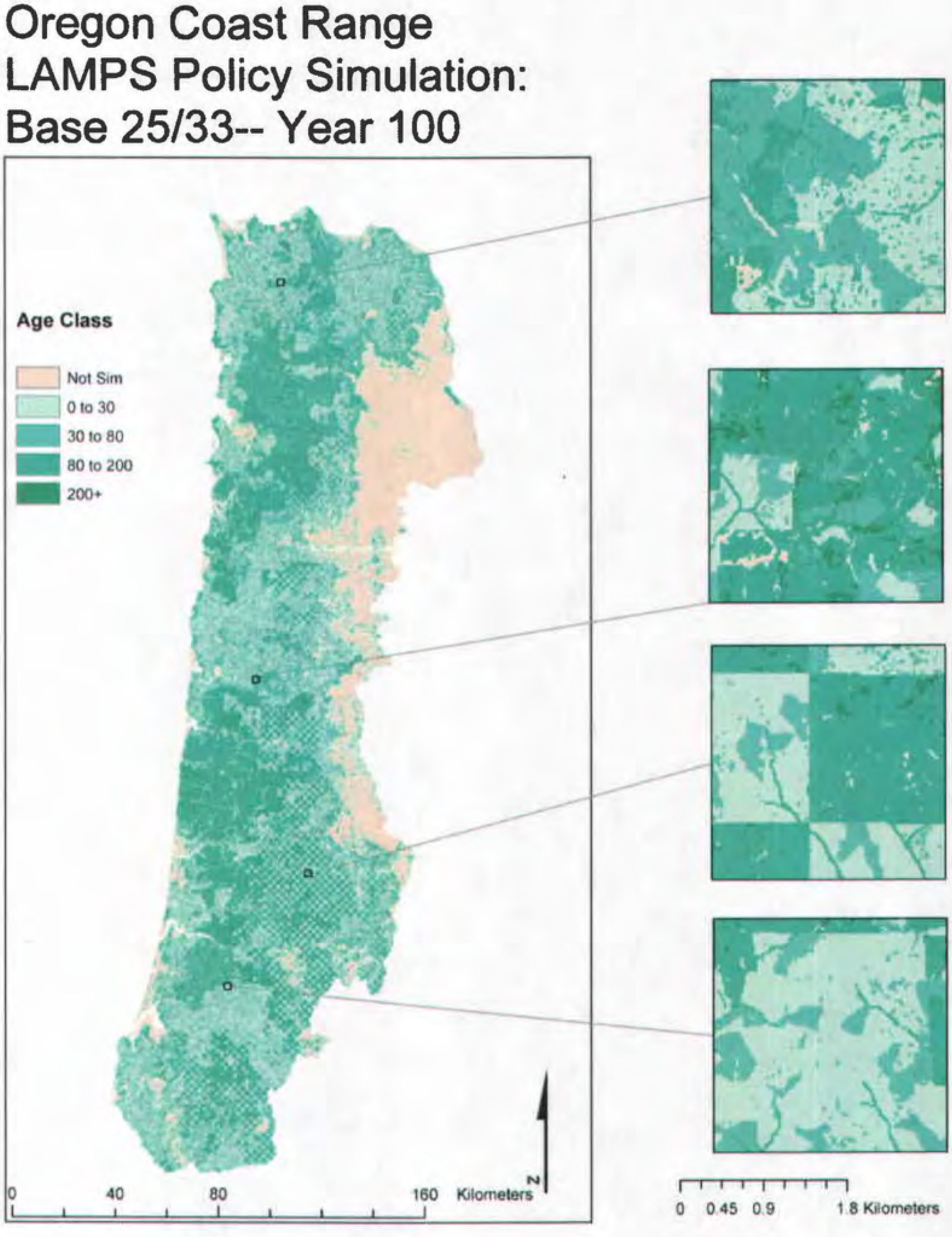

Figure 4: The age-class structure of the Coast Range after 100yr simulations of four policy alternatives. (a) Base25/33, (b) Sim(S), (c) Sim(S+F), & (d) Sim(S+F+E)

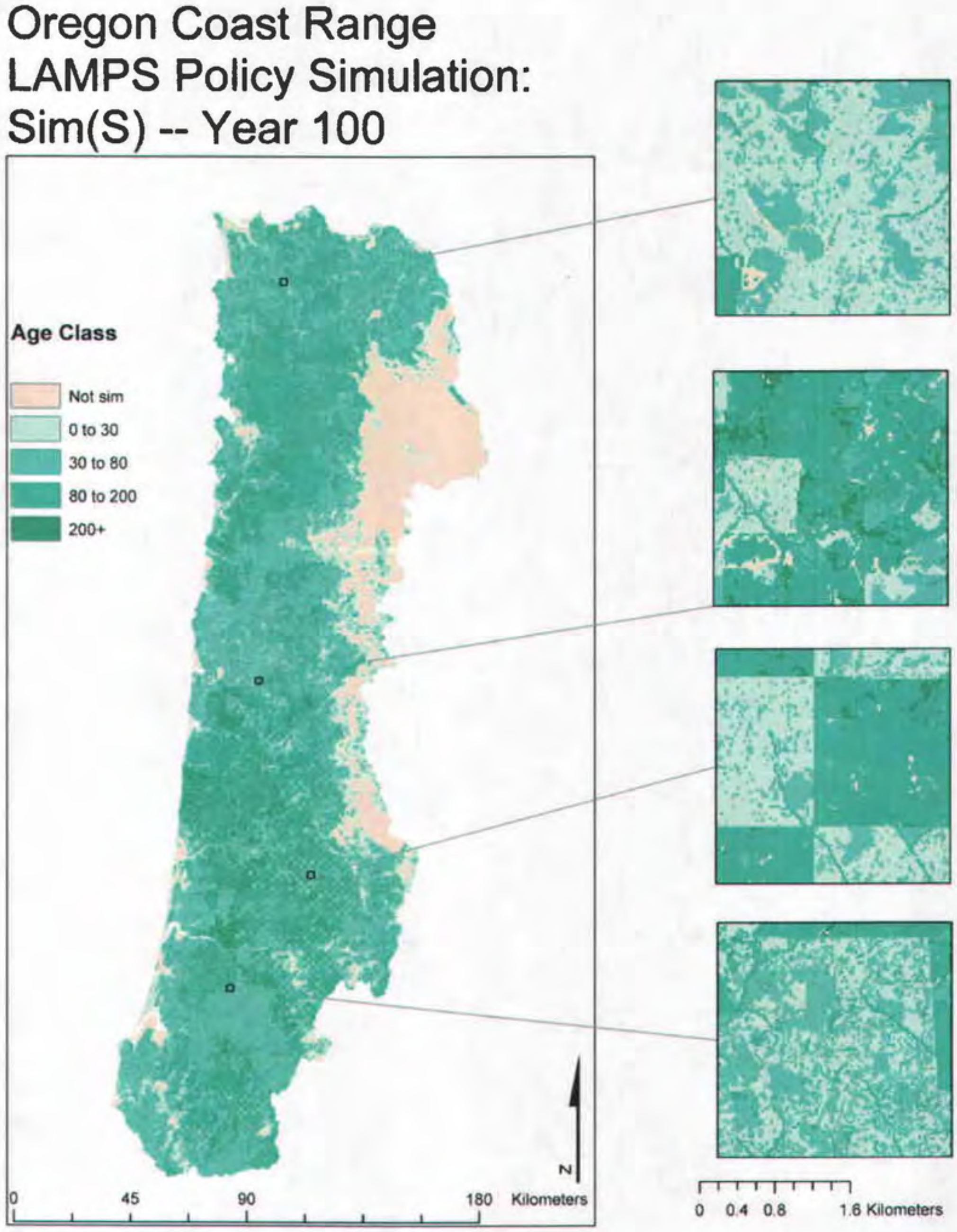

Figure 4b: (continued)

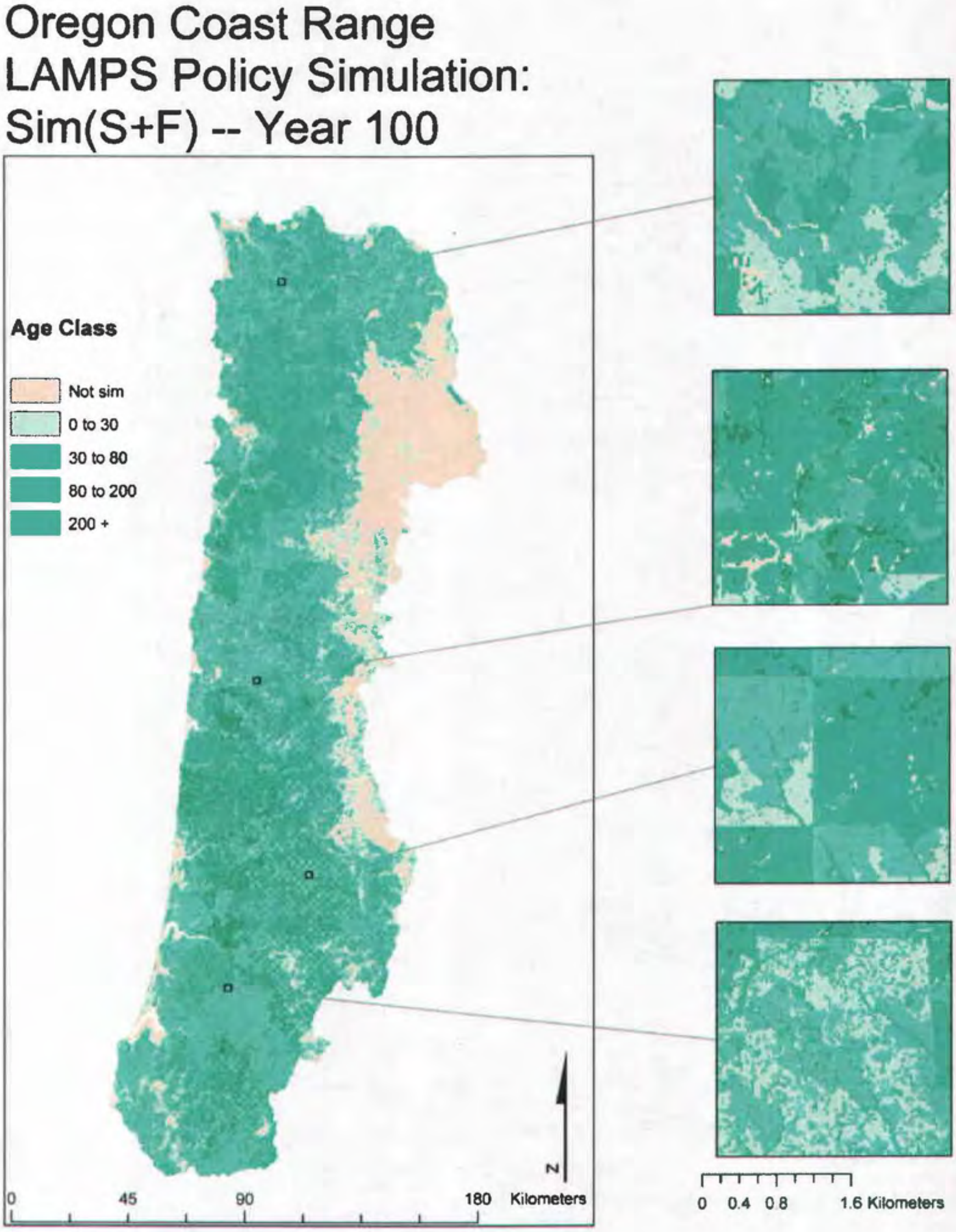

Figure 4c: (continued)

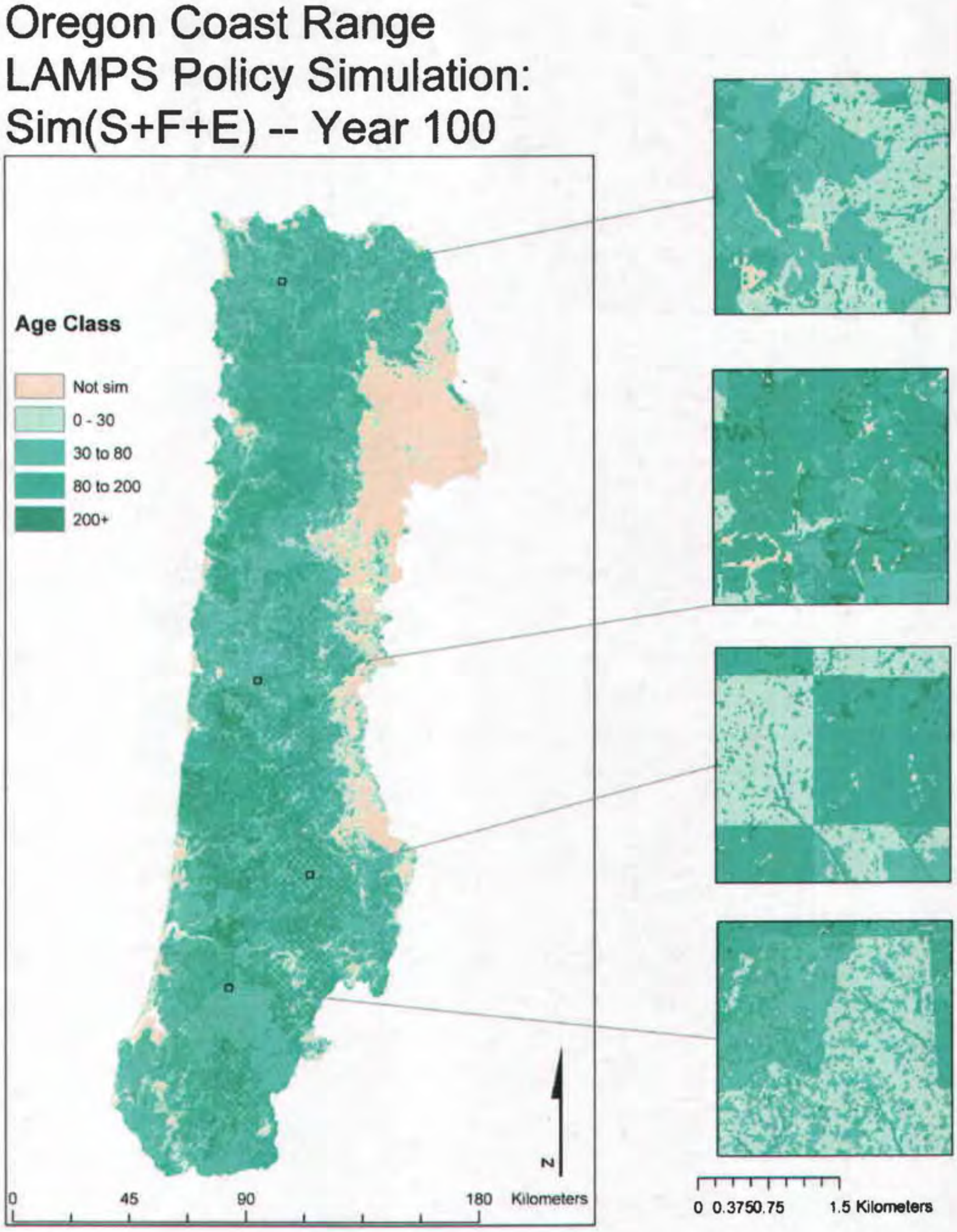

Figure 4d: (continued)

In the LAMPS simulations, we assumed one log price for softwoods and one for hardwoods along with a modest real price appreciation through time. In the LAMPS analysis, the starting prices, logging cost, and regeneration costs were derived from recent experience on our College Forests in the Coast Range. These prices and costs were used mainly to help select the most valuable stands on forest industry lands—the actual harvest level was determined through other mechanisms as described earlier. Because any price appreciation might be considered questionable, we used the starting prices from the LAMPS analysis in the valuations described below. We utilized a stumpage price of $767 m^3 ($325 MBF) for softwoods and $177 m^3 ($75 MBF) for hardwoods after deducting logging, hauling, timber sale preparation and administration, site preparation, planting, and suppression of competing vegetation (K. N. Johnson *unpublished data*). We used a relatively low price for hardwoods because a portion of the volume that we valued here will actually not make sawlogs. Because any hardwoods value is considered by some to be speculative, we also show the results while valuing only softwoods. While these might seem like overly simplistic assumptions, our primary purpose here is to approximate the relative effects of the different scenarios on net revenue in the short run and net present value over the planning periods.

To portray the differences between simulations in the near term, we report the average net revenue for the first 20-years of the simulations. Because private landowners are likely to value harvest volume in the present over the same volume in the future, discounted value (net present value) can offer insight into how these policy structures may be viewed (Davis, et al. 2000). Given that our simulations run

100-years into the future, though, the net present value (NPV) of these policy structures is difficult to estimate. We calculated the NPV at two interest rates—4% and 8%—independently for industrial and NIP volumes. Four percent is close to a low-end, long-term rate that might be used by a private owner (similar to the rate used by federal forests) and 8% is close to a high-end, long-term rate that might be used by the forest industry (Davis, et al 2000). To portray present value over the entire planning horizon, we reported NPV as a proportion of the Base25, by ownership, in a bar chart.

The forest inventory, an economic and ecological measure, was described in terms of dominant age class—0-30 yr (early seral), 30-80 yr (young), 80-200 yr (mature), and >200yr (old)—at 50-year simulated 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 co-dominant trees within each 25-m pixel (Ohmann and Gregory 2002). These structural classes had been defined previously to measure the HRV (Wimberly 2002) and, therefore, facilitated direct comparison.

Landscape pattern analysis was also defined in terms of the age-classes given above. In order to compare the effects of the policies to the HRV, the LAMPS grid was fit to the LADS extent using the Setmask feature in ArcInfo Workstation. There was >95% overlap between the two grids. The LAMPS 25-m age-grid was then rescaled to a 300-m grain size to match the spatial resolution of LADS. This was done with the Block Majority feature in ArcInfo Workstation. The two Base policies produced indistinguishable landscape patterns at this scale; therefore, we have treated them as one policy throughout our discussion of landscape pattern.

Five landscape metrics—relative area, largest patch, patch density, average patch size, and patch size standard deviation (PSSD)—were calculated separately for each age-class in years 0, 50, and 100. Metrics were calculated using APACK 2.22 Landscape Analysis Software (Mladenoff and DeZonia 2001). We selected these metrics because of their ease of interpretability, use in previous HRV analysis, and because they are not affected by the change in total forested area. The latter criterion was necessary to separate the changes in landscape structure related to the policies, from those changes related to urban and rural development. The relative area metric was similar to the inventory discussed above (in that it described the seral stage distribution); however, in this case, all ownerships were grouped together, it was expressed as a proportion, and it was measured after resampling to a $300m^2$ grain size (which allowed direct comparison to the LADS output). The analysis at a increased grain size primarily described coarse-grain landscape patterns and was not as influenced by rare and isolated patches (Turner et al. 1989). Patch density described the number of patches of a structural class per unit area. Average patch size and PSSD together characterized the distribution of patches across the landscape. A large PSSD value indicated the distribution of patches in a given structural class was skewed toward the tails of the distribution (McGarigal and Marks 1995). Largest patch was an important determinant of landscape structure because it represented the upward bounds of disturbance or patch size (Keane et al. 2002). Edge density was related to, but distinct from the patch metrics discussed above. Edge density described the configuration and degree of contrast between patches on a per unit area basis (McGarigal and Marks 1995); therefore, issues related forest fragmentation are often discussed in terms of edge (e.g. Chen et al. 1992; Franklin and Forman 1987). Simulations were compared against each other and against the HRV. The HRV for these metrics (excluding average patch size and PSSD) has been reported previously in Wimberly (2002).

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 (Figure 5). The two base policies achieved equilibrium at 38-40 yrs, although the Base25/33 got 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 yrs 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 and reached 80 and 72 yrs respectively.

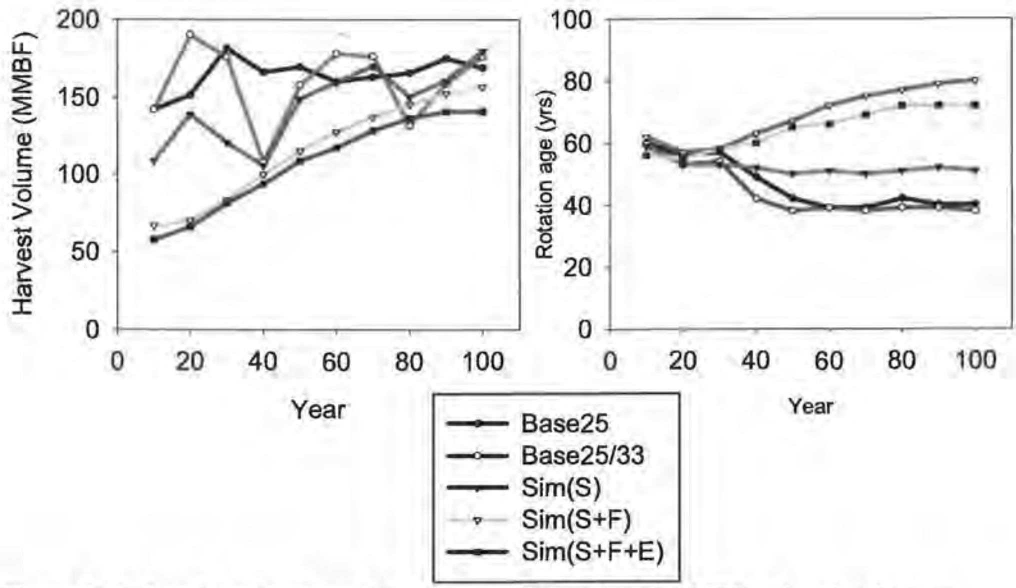

Figure 5: Industrial volumes and rotation ages throughout LAMPS policy simulations.

NIP

The Base policy simulations used stand-age as a determinant of NIP's propensity to harvest. Therefore, the rotation ages in the Base simulations reflect the combination of the probability structure that was input into LAMPS and the overall harvest targets—rotation ages dropped slowly to 60yrs and stabilized at that point (Figure 6). The green-trees retained in Sim(S) were eventual cut on a second rotation; this kept the rotation from dropping to 60yrs, like the Base, and resulted in stable rotation-ages through all periods at 67-69yrs. The constraints on the allowable harvest area in Sim(S+F) resulted in steadily increased rotations throughout the simulation from 68 to 96yrs.

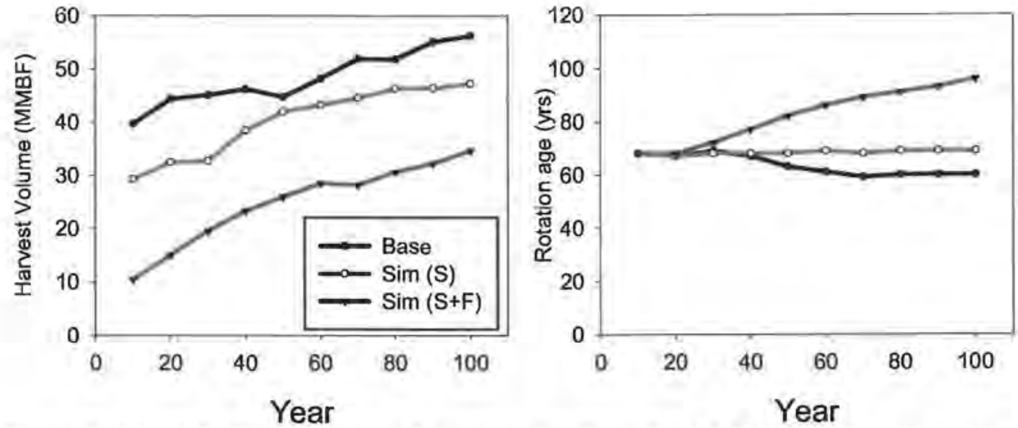

Figure 6: Non-industrial volumes and rotation ages throughout LAMPS policy simulations.

Harvested volume, area, and value

Industry

Sim(S) resulted in the highest gross harvested area (104% of Base25/33), but the actual net harvest area was considerably less than either of the Base policies (77% of Base25/33) (Tables 6 & 8). Gross harvest area is the number of hectares scheduled for harvest before accounting for the green-tree retention standards, whereas net harvest is the total hectares actually cut. In comparison to the Base25/33, the allowable harvest area restrictions in Sim(S+F) and Sim(S+F+E) reduced gross harvest area by more than 40% and net harvested area by almost 60%.

The Base25/33 resulted in more period-to-period variability in terms of harvest volume (Figure 5) than did Base25. Sim(S) used volume targets derived from the Base25/33 and, therefore, displayed similar variability. Over the duration of the simulations, the Base25 harvested the most volume while Sim(S+F+E) harvested the least (Tables 7 & 8). Under all policies, hardwoods constituted roughly 20% of harvest volume in the early periods but then diminish as planted conifers come of age (Table 9). 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 Base25/33, but in period-10, it harvested 80%. This was primarily the effect of older rotation ages (ie. higher volume stands) in the later periods. Thinning constituted a small percentage of the industrial harvest volume in all simulations (Table 5).

Table 5: Percentage of the area harvested by thinning.

	Industry	NIP
Base25	3.5%	4.8%
Base25/33	3.9%	4.8%
Sim(S)	2.9%	5.0%
Sim(S+F)	2.3%	12.0%
Sim(S+F+E)	2.4%	12.0%

Through the first 20 years the costs of disturbance-based policies ranged from approximately $120 to $290 million dollars annually when compared to the Base25/33 (Table 10). Revenue over this period was lowest for Sim(S+F) and Sim(S+F+E) due to the reduction in harvestable area. Over the length of the simulations, the greater the discount rate, the higher the cost of the disturbance-based policies (Figure 7). This was because the difference in volume was greatest in the short-term. Given our assumptions when we calculated NPV, the 0% discount was completely redundant with the total harvest volume. This analysis also showed why the Base25/33 might be valued by industry over the Base 24; the difference in revenue in the short term was more than 60 million dollars annually.

Table 6: Thousands of acres clearcut (CC) and thinned (TH) for each ownership group, policy alternative, and period.

	FEDERAL		INDUSTRY		NIPF		STATE		ALL OWNERS	
	CC	TH	CC	TH	CC	TH	CC	TH	CC	TH
BASE25										
1	2.9	91.4	581.8	57.6	165.2	36.3	22.9	96.2	772.7	281.5
2	4.9	35.6	588.4	38.4	172.4	33.5	24.0	67.9	789.7	175.4
3	3.5	87.6	584.0	18.0	149.5	22.7	18.1	111.2	755.1	239.4
4	5.0	20.5	528.1	216.5	136.8	14.3	20.2	78.7	690.0	330.0
5	4.5	26.4	542.6	227.6	119.9	16.1	18.7	49.5	685.7	319.5
6	4.8	7.6	539.8	232.9	115.2	19.9	16.3	44.4	676.2	304.9
7	4.5	3.5	533.4	150.0	113.8	21.0	2.7	132.2	654.3	306.7
8	4.3	4.9	509.6	217.7	106.9	22.1	10.0	102.6	630.8	347.3
9	4.3	4.5	528.2	211.7	106.1	20.6	27.9	26.5	666.5	263.2
10	4.0	4.8	526.4	208.1	106.5	18.7	24.6	27.0	661.4	258.5
Total	**42.8**	**286.8**	**5462.1**	**1578.5**	**1292.2**	**225.2**	**185.4**	**736.2**	**6982.5**	**2826.7**
BASE25/33										
1	2.9	91.4	581.8	57.6	165.2	36.3	22.9	96.2	772.7	281.5
2	4.9	35.6	798.7	38.4	172.4	33.5	24.0	67.9	1000.1	175.4
3	3.5	87.6	592.4	18.0	149.5	22.7	18.1	111.2	763.5	239.4
4	5.0	20.5	398.5	216.5	136.8	14.3	20.2	78.7	560.4	330.0
5	4.5	26.4	591.0	302.1	119.9	16.1	18.7	49.5	734.1	394.0
6	4.8	7.6	623.6	234.6	115.2	19.9	16.3	44.4	760.0	306.6
7	4.5	3.5	601.4	96.1	113.8	21.0	2.7	132.2	722.4	252.7
8	4.3	4.9	458.6	211.5	106.9	22.1	10.0	102.6	579.8	341.1
9	4.3	4.5	533.4	257.0	106.1	20.6	27.9	26.5	671.7	308.6
10	4.0	4.8	609.5	218.8	106.5	18.7	24.6	27.0	744.5	269.2
Total	**42.8**	**286.8**	**5789.0**	**1650.5**	**1292.2**	**225.2**	**185.4**	**736.2**	**7309.3**	**2898.7**
Sim(S)										
1	2.6	91.4	479.2	59.1	126.0	34.5	22.9	96.7	630.7	281.7
2	4.5	35.6	622.1	37.6	131.2	32.7	24.0	67.1	781.8	172.9
3	3.3	87.6	419.2	17.0	114.2	19.0	17.8	111.6	554.4	235.2
4	4.9	20.4	346.2	175.3	115.8	15.6	20.6	77.6	487.5	289.0
5	4.5	26.0	462.3	231.5	111.0	14.6	18.6	45.2	596.3	317.3
6	4.7	6.8	444.9	166.9	104.5	13.8	16.9	40.1	570.9	227.5
7	4.4	3.2	449.9	90.1	99.7	13.4	2.9	124.7	556.8	231.4
8	4.3	4.7	392.4	162.4	98.3	13.3	10.2	92.5	505.2	272.9
9	4.2	4.4	399.8	183.5	93.4	12.6	27.8	19.1	525.2	219.6
10	4.0	4.4	448.3	160.4	91.6	12.4	24.6	22.0	568.4	199.3
Total	**41.4**	**284.5**	**4464.3**	**1283.7**	**1085.5**	**182.0**	**186.2**	**696.5**	**5777.3**	**2446.8**
Sim(S+F)										
1	2.5	91.4	249.3	59.4	45.2	44.8	22.5	97.5	319.5	293.1
2	4.7	35.5	247.2	37.6	57.5	47.9	24.0	67.3	333.4	188.4
3	3.4	87.9	243.9	18.9	63.4	37.2	17.5	112.7	328.2	256.6
4	4.9	20.9	241.5	89.6	64.5	29.7	20.3	78.5	331.2	218.7
5	4.5	25.5	238.5	103.3	63.2	22.0	18.6	45.2	324.7	196.0
6	4.8	7.2	236.4	103.7	61.5	17.4	16.9	40.1	319.5	168.5
7	4.4	3.2	234.1	94.9	56.3	14.1	2.7	126.4	297.4	238.7
8	4.3	4.7	232.1	93.1	55.9	13.5	9.7	94.0	302.0	205.3
9	4.1	4.4	231.4	91.8	56.3	12.3	28.0	19.5	319.8	128.0
10	4.1	4.5	230.4	92.4	57.0	12.2	24.3	21.3	315.8	130.4
Total	**41.5**	**285.2**	**2384.8**	**784.8**	**580.8**	**251.2**	**184.5**	**702.5**	**3191.7**	**2023.6**
Sim(S+F+E)										
1	2.5	91.4	236.8	59.2	45.2	44.8	22.5	97.2	306.9	292.5
2	4.7	35.5	250.2	37.7	57.5	47.9	24.0	67.5	336.4	188.6
3	3.4	87.9	247.5	18.9	63.4	37.2	17.5	112.3	331.8	256.2
4	4.9	20.9	244.4	80.3	64.5	29.7	20.3	78.6	334.0	209.5
5	4.5	25.5	237.2	106.8	63.2	22.0	18.6	45.0	323.5	199.3
6	4.8	7.2	238.9	101.7	61.5	17.4	17.0	40.0	322.2	166.3
7	4.4	3.2	235.2	95.3	56.3	14.1	2.7	125.7	298.6	238.3
8	4.3	4.7	237.1	92.7	55.9	13.5	9.7	94.0	306.9	204.9
9	4.1	4.4	234.3	94.1	56.3	12.3	28.0	19.4	322.7	130.2
10	4.1	4.5	230.8	92.2	57.0	12.2	24.3	21.4	316.2	130.3
Total	**41.5**	**285.2**	**2392.4**	**778.7**	**580.8**	**251.2**	**184.5**	**701.0**	**3199.2**	**2016.1**

Table 6 (Continued) The same data as above expressed in thousands of hectares

	FEDERAL		INDUSTRY		NIPF		STATE		ALL OWNERS	
	CC	TH	CC	TH	CC	TH	CC	TH	CC	TH
BASE25										
1	1.2	37.0	235.4	23.3	66.8	14.7	9.3	38.9	312.7	113.9
2	2.0	14.4	238.1	15.5	69.8	13.6	9.7	27.5	319.6	71.0
3	1.4	35.5	236.3	7.3	60.5	9.2	7.3	45.0	305.6	96.9
4	2.0	8.3	213.7	87.6	55.4	5.8	8.2	31.9	279.2	133.5
5	1.8	10.7	219.6	92.1	48.5	6.5	7.6	20.0	277.5	129.3
6	2.0	3.1	218.4	94.2	46.6	8.1	6.6	18.0	273.6	123.4
7	1.8	1.4	215.8	60.7	46.0	8.5	1.1	53.5	264.8	124.1
8	1.7	2.0	206.2	88.1	43.3	8.9	4.0	41.5	255.3	140.6
9	1.7	1.8	213.8	85.7	42.9	8.3	11.3	10.7	269.7	106.5
10	1.6	1.9	213.0	84.2	43.1	7.6	9.9	10.9	267.7	104.6
Total	**17.3**	**116.1**	**2210.4**	**638.8**	**522.9**	**91.1**	**75.0**	**297.9**	**2825.7**	**1143.9**
BASE25/33										
1	1.2	37.0	235.4	23.3	66.8	14.7	9.3	38.9	312.7	113.9
2	2.0	14.4	323.2	15.5	69.8	13.6	9.7	27.5	404.7	71.0
3	1.4	35.5	239.8	7.3	60.5	9.2	7.3	45.0	309.0	96.9
4	2.0	8.3	161.3	87.6	55.4	5.8	8.2	31.9	226.8	133.5
5	1.8	10.7	239.2	122.3	48.5	6.5	7.6	20.0	297.1	159.5
6	2.0	3.1	252.4	94.9	46.6	8.1	6.6	18.0	307.6	124.1
7	1.8	1.4	243.4	38.9	46.0	8.5	1.1	53.5	292.3	102.3
8	1.7	2.0	185.6	85.6	43.3	8.9	4.0	41.5	234.6	138.0
9	1.7	1.8	215.9	104.0	42.9	8.3	11.3	10.7	271.8	124.9
10	1.6	1.9	246.7	88.5	43.1	7.6	9.9	10.9	301.3	109.0
Total	**17.3**	**116.1**	**2342.7**	**667.9**	**522.9**	**91.1**	**75.0**	**297.9**	**2957.9**	**1173.0**
Sim(S)										
1	1.0	37.0	193.9	23.9	51.0	14.0	9.3	39.1	255.2	114.0
2	1.8	14.4	251.7	15.2	53.1	13.2	9.7	27.2	316.4	70.0
3	1.3	35.5	169.6	6.9	46.2	7.7	7.2	45.1	224.4	95.2
4	2.0	8.3	140.1	70.9	46.8	6.3	8.3	31.4	197.3	116.9
5	1.8	10.5	187.1	93.7	44.9	5.9	7.5	18.3	241.3	128.4
6	1.9	2.8	180.0	67.5	42.3	5.6	6.9	16.2	231.1	92.1
7	1.8	1.3	182.1	36.5	40.3	5.4	1.2	50.5	225.3	93.7
8	1.7	1.9	158.8	65.7	39.8	5.4	4.1	37.4	204.4	110.4
9	1.7	1.8	161.8	74.3	37.8	5.1	11.2	7.7	212.5	88.9
10	1.6	1.8	181.4	64.9	37.1	5.0	9.9	8.9	230.0	80.6
Total	**16.8**	**115.1**	**1806.6**	**519.5**	**439.3**	**73.7**	**75.3**	**281.9**	**2337.9**	**990.2**
Sim(S+F)										
1	1.0	37.0	100.9	24.1	18.3	18.1	9.1	39.4	129.3	118.6
2	1.9	14.4	100.0	15.2	23.3	19.4	9.7	27.2	134.9	76.2
3	1.4	35.6	98.7	7.6	25.7	15.0	7.1	45.6	132.8	103.9
4	2.0	8.4	97.7	36.3	26.1	12.0	8.2	31.8	134.0	88.5
5	1.8	10.3	96.5	41.8	25.6	8.9	7.5	18.3	131.4	79.3
6	1.9	2.9	95.6	42.0	24.9	7.0	6.9	16.2	129.3	68.2
7	1.8	1.3	94.7	38.4	22.8	5.7	1.1	51.2	120.4	96.6
8	1.7	1.9	93.9	37.7	22.6	5.5	3.9	38.0	122.2	83.1
9	1.7	1.8	93.6	37.2	22.8	5.0	11.3	7.9	129.4	51.8
10	1.7	1.8	93.2	37.4	23.1	4.9	9.8	8.6	127.8	52.8
Total	**16.8**	**115.4**	**965.1**	**317.6**	**235.0**	**101.6**	**74.7**	**284.3**	**1291.6**	**818.9**
Sim(S+F+E)										
1	1.0	37.0	95.8	24.0	18.3	18.1	9.1	39.3	124.2	118.4
2	1.9	14.4	101.2	15.2	23.3	19.4	9.7	27.3	136.1	76.3
3	1.4	35.6	100.1	7.6	25.7	15.0	7.1	45.4	134.3	103.7
4	2.0	8.4	98.9	32.5	26.1	12.0	8.2	31.8	135.2	84.8
5	1.8	10.3	96.0	43.2	25.6	8.9	7.5	18.2	130.9	80.6
6	1.9	2.9	96.7	41.1	24.9	7.0	6.9	16.2	130.4	67.3
7	1.8	1.3	95.2	38.6	22.8	5.7	1.1	50.9	120.8	96.5
8	1.7	1.9	95.9	37.5	22.6	5.5	3.9	38.0	124.2	82.9
9	1.7	1.8	94.8	38.1	22.8	5.0	11.3	7.9	130.6	52.7
10	1.7	1.8	93.4	37.3	23.1	4.9	9.8	8.7	128.0	52.7
Total	**16.8**	**115.4**	**968.1**	**315.1**	**235.0**	**101.6**	**74.7**	**283.7**	**1294.7**	**815.9**

Table 7 Harvest Volumes in millions of Board Feet (MMBF). for each ownership group, policy alternative, and period.

	FEDERAL		INDUSTRY		NIP		STATE		ALL OWNERS	
	CC	TH	CC	TH	CC	TH	CC	TH	CC	TH
BASE25										
1	177	752	14216	411	3977	367	809	804	19179	2335
2	222	273	15145	367	4447	372	909	700	20722	1713
3	172	688	18162	274	4521	303	735	860	23590	2125
4	248	107	16614	1287	4633	235	881	733	22377	2362
5	249	165	16953	1345	4491	264	976	840	22669	2614
6	262	104	16015	1372	4836	343	974	883	22087	2702
7	268	68	16326	808	5212	370	215	1998	22021	3244
8	265	98	16571	1289	5202	415	545	1495	22583	3297
9	267	91	17518	1239	5531	393	1609	400	24926	2124
10	278	95	16912	1205	5625	374	1542	378	24357	2052
Total	**2408**	**2441**	**164432**	**9598**	**48476**	**3437**	**9194**	**9092**	**224510**	**24568**
BASE25/33										
1	177	752	14216	411	3977	367	809	804	19179	2335
2	222	273	19042	367	4447	372	909	700	24620	1713
3	172	688	17598	274	4521	303	735	860	23026	2125
4	248	107	10804	1287	4633	235	881	733	16566	2362
5	249	165	15787	1764	4491	264	976	840	21503	3033
6	262	104	17838	1372	4836	343	974	883	23910	2702
7	268	68	17682	500	5212	370	215	1998	23377	2936
8	265	98	13198	1225	5202	415	545	1495	19210	3234
9	267	91	15938	1508	5531	393	1609	400	23345	2393
10	278	95	17627	1262	5625	374	1542	378	25071	2109
Total	**2408**	**2441**	**159730**	**9971**	**48476**	**3437**	**9194**	**9092**	**219808**	**24941**
Sim(S)										
1	160	752	10879	422	2935	347	804	803	14777	2324
2	200	273	13897	360	3265	359	910	701	18272	1693
3	155	688	12062	258	3289	250	708	856	16214	2052
4	237	107	10557	999	3863	264	878	731	15535	2101
5	238	156	14887	1289	4218	274	985	771	20327	2489
6	244	87	15976	922	4343	267	983	795	21546	2070
7	251	63	17020	456	4471	277	211	1891	21954	2687
8	254	94	15044	893	4656	282	578	1359	20531	2628
9	256	86	16096	1033	4654	277	1610	300	22616	1695
10	259	87	17983	881	4738	277	1533	311	24513	1557
Total	**2253**	**2393**	**144402**	**7513**	**40430**	**2874**	**9200**	**8518**	**196286**	**21297**
Sim(S+F)										
1	156	752	6692	424	1042	454	799	804	8690	2433
2	203	272	7001	362	1503	544	916	695	9622	1874
3	159	688	8345	290	1958	519	689	868	11151	2366
4	236	109	10005	516	2333	513	879	731	13453	1869
5	239	153	11532	603	2606	443	989	765	15366	1964
6	247	92	12761	617	2861	385	982	802	16851	1895
7	250	63	13736	545	2840	317	204	1924	17029	2850
8	256	95	14567	524	3071	301	550	1375	18444	2296
9	258	87	15277	514	3235	287	1610	301	20379	1189
10	261	88	15672	524	3479	277	1513	304	20925	1192
Total	**2265**	**2398**	**115587**	**4920**	**24926**	**4041**	**9131**	**8569**	**151909**	**19927**
Sim(S+F+E)										
1	156	752	5783	419	1042	454	800	803	7781	2428
2	203	272	6605	364	1503	544	913	696	9224	1876
3	159	688	8148	293	1958	519	691	866	10956	2366
4	236	109	9385	455	2333	513	878	731	12832	1808
5	239	153	10884	622	2606	443	988	763	14717	1981
6	247	92	11740	592	2861	385	985	801	15833	1869
7	250	63	12863	543	2840	317	206	1915	16158	2838
8	256	95	13674	531	3071	301	550	1374	17551	2301
9	258	87	14079	531	3235	287	1610	300	19182	1204
10	261	88	14094	516	3479	277	1513	306	19345	1186
Total	**2265**	**2398**	**107256**	**4865**	**24926**	**4041**	**9134**	**8554**	**143581**	**19857**

Table 7 (Continued) The same data as above expressed in millions of cubic meters (Mm^3)

	FEDERAL		INDUSTRY		NIP		STATE		ALL OWNERS	
	CC	TH	CC	TH	CC	TH	CC	TH	CC	TH
BASE25										
1	0.42	1.78	33.55	0.97	9.39	0.87	1.91	1.90	45.26	5.51
2	0.52	0.65	35.74	0.87	10.49	0.88	2.15	1.65	48.90	4.04
3	0.41	1.62	42.86	0.65	10.67	0.72	1.73	2.03	55.66	5.02
4	0.59	0.25	39.20	3.04	10.93	0.55	2.08	1.73	52.80	5.57
5	0.59	0.39	40.00	3.17	10.60	0.62	2.30	1.98	53.49	6.17
6	0.62	0.24	37.79	3.24	11.41	0.81	2.30	2.08	52.12	6.38
7	0.63	0.16	38.52	1.91	12.30	0.87	0.51	4.71	51.96	7.66
8	0.63	0.23	39.10	3.04	12.28	0.98	1.29	3.53	53.29	7.78
9	0.63	0.22	41.34	2.92	13.05	0.93	3.80	0.94	58.82	5.01
10	0.66	0.22	39.91	2.84	13.27	0.88	3.64	0.89	57.48	4.84
Total	**5.68**	**5.76**	**388.01**	**22.65**	**114.39**	**8.11**	**21.70**	**21.45**	**529.78**	**57.97**
BASE25/33										
1	0.42	1.78	33.55	0.97	9.39	0.87	1.91	1.90	45.26	5.51
2	0.52	0.65	44.93	0.87	10.49	0.88	2.15	1.65	58.10	4.04
3	0.41	1.62	41.53	0.65	10.67	0.72	1.73	2.03	54.34	5.02
4	0.59	0.25	25.49	3.04	10.93	0.55	2.08	1.73	39.09	5.57
5	0.59	0.39	37.25	4.16	10.60	0.62	2.30	1.98	50.74	7.16
6	0.62	0.24	42.09	3.24	11.41	0.81	2.30	2.08	56.42	6.38
7	0.63	0.16	41.72	1.18	12.30	0.87	0.51	4.71	55.16	6.93
8	0.63	0.23	31.14	2.89	12.28	0.98	1.29	3.53	45.33	7.63
9	0.63	0.22	37.61	3.56	13.05	0.93	3.80	0.94	55.09	5.65
10	0.66	0.22	41.59	2.98	13.27	0.88	3.64	0.89	59.16	4.98
Total	**5.68**	**5.76**	**376.92**	**23.53**	**114.39**	**8.11**	**21.70**	**21.45**	**518.68**	**58.85**
Sim(S)										
1	0.38	1.78	25.67	1.00	6.92	0.82	1.90	1.90	34.87	5.48
2	0.47	0.65	32.79	0.85	7.70	0.85	2.15	1.65	43.12	4.00
3	0.37	1.62	28.46	0.61	7.76	0.59	1.67	2.02	38.26	4.84
4	0.56	0.25	24.91	2.36	9.11	0.62	2.07	1.73	36.66	4.96
5	0.56	0.37	35.13	3.04	9.95	0.65	2.32	1.82	47.97	5.87
6	0.58	0.21	37.70	2.17	10.25	0.63	2.32	1.88	50.84	4.89
7	0.59	0.15	40.16	1.08	10.55	0.65	0.50	4.46	51.80	6.34
8	0.60	0.22	35.50	2.11	10.99	0.66	1.36	3.21	48.45	6.20
9	0.60	0.20	37.98	2.44	10.98	0.65	3.80	0.71	53.37	4.00
10	0.61	0.21	42.44	2.08	11.18	0.65	3.62	0.73	57.84	3.67
Total	**5.32**	**5.65**	**340.75**	**17.73**	**95.40**	**6.78**	**21.71**	**20.10**	**463.18**	**50.26**
Sim(S+F)										
1	0.37	1.77	15.79	1.00	2.46	1.07	1.89	1.90	20.51	5.74
2	0.48	0.64	16.52	0.85	3.55	1.28	2.16	1.64	22.71	4.42
3	0.38	1.62	19.69	0.68	4.62	1.22	1.63	2.05	26.31	5.58
4	0.56	0.26	23.61	1.22	5.50	1.21	2.07	1.72	31.74	4.41
5	0.56	0.36	27.21	1.42	6.15	1.05	2.33	1.81	36.26	4.64
6	0.58	0.22	30.11	1.46	6.75	0.91	2.32	1.89	39.76	4.47
7	0.59	0.15	32.41	1.29	6.70	0.75	0.48	4.54	40.18	6.72
8	0.60	0.22	34.37	1.24	7.25	0.71	1.30	3.25	43.52	5.42
9	0.61	0.21	36.05	1.21	7.63	0.68	3.80	0.71	48.09	2.81
10	0.61	0.21	36.98	1.24	8.21	0.65	3.57	0.72	49.38	2.81
Total	**5.34**	**5.66**	**272.75**	**11.61**	**58.82**	**9.53**	**21.55**	**20.22**	**358.46**	**47.02**
Sim(S+F+E)										
1	0.37	1.77	13.65	0.99	2.46	1.07	1.89	1.90	18.36	5.73
2	0.48	0.64	15.59	0.86	3.55	1.28	2.15	1.64	21.77	4.43
3	0.38	1.62	19.23	0.69	4.62	1.22	1.63	2.04	25.85	5.58
4	0.56	0.26	22.15	1.07	5.50	1.21	2.07	1.72	30.28	4.27
5	0.56	0.36	25.68	1.47	6.15	1.05	2.33	1.80	34.73	4.67
6	0.58	0.22	27.70	1.40	6.75	0.91	2.32	1.89	37.36	4.41
7	0.59	0.15	30.35	1.28	6.70	0.75	0.49	4.52	38.13	6.70
8	0.60	0.22	32.27	1.25	7.25	0.71	1.30	3.24	41.42	5.43
9	0.61	0.21	33.22	1.25	7.63	0.68	3.80	0.71	45.26	2.84
10	0.61	0.21	33.26	1.22	8.21	0.65	3.57	0.72	45.65	2.80
Total	**5.34**	**5.66**	**253.09**	**11.48**	**58.82**	**9.53**	**21.55**	**20.18**	**338.81**	**46.86**

Table 8: Industrial clearcut harvest volume (MMBF) and gross and net clearcut area (thousands of acres) (see text for definitions of gross and net)

INDUSTRY	Base25			Base25/33			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	14201	582	582	14201	582	582	10867	642	479	6689	349	249	5780	327	237
2	15132	589	588	19028	797	799	13888	817	622	6997	347	247	6602	350	250
3	18149	585	584	17587	593	592	12054	554	419	8341	344	244	8144	350	247
4	16603	539	528	10797	412	398	10550	488	346	9997	343	241	9380	348	244
5	16941	562	543	15776	615	591	14878	647	462	11523	341	238	10879	339	237
6	16006	561	540	17829	646	623	15966	612	445	12752	340	236	11734	345	239
7	16304	553	533	17652	624	601	17010	623	450	13724	338	234	12856	342	235
8	16562	529	510	13188	478	458	15035	555	392	14556	337	232	13651	344	237
9	17509	548	528	15929	554	533	16087	557	400	15263	336	231	14072	342	234
10	16903	548	526	17617	634	609	17973	621	448	15664	336	230	14086	337	231
Total	**164309**	**5597**	**5462**	**159604**	**5934**	**5788**	**144308**	**6115**	**4463**	**115506**	**3410**	**2384**	**107183**	**3425**	**2392**

Table 8 (continued) Same data as above expressed in Mm^3 and thousands of hectares

INDUSTRY	Base25			Base25/33			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	34	236	235	34	236	235	26	260	194	16	141	101	14	132	96
2	36	238	238	45	323	323	33	331	252	17	140	100	16	142	101
3	43	237	236	42	240	240	28	224	170	20	139	99	19	142	100
4	39	218	214	25	167	161	25	198	140	24	139	98	22	141	99
5	40	227	220	37	249	239	35	262	187	27	138	96	26	137	96
6	38	227	218	42	261	252	38	248	180	30	137	96	28	140	97
7	38	224	216	42	252	243	40	252	182	32	137	95	30	138	95
8	39	214	206	31	193	186	35	225	159	34	136	94	32	139	96
9	41	222	214	38	224	216	38	226	162	36	136	94	33	138	95
10	40	222	213	42	257	247	42	251	181	37	136	93	33	136	93
Total	**388**	**2265**	**2210**	**377**	**2402**	**2343**	**341**	**2475**	**1807**	**273**	**1380**	**965**	**253**	**1387**	**968**

Table 9: Softwood (SW) and hardwood (HW) industrial harvest volume in MMBF

Industry	Base25			Base25/33			Sim(S)			Sim(S+F)			Sim(S+F+E)		
Period	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.
1	11729	2702	14430	11729	2702	14430	8826	2274	11101	5856	1070	6926	5024	988	6012
2	13209	2031	15240	16316	2822	19138	11888	2117	14005	6273	834	7107	5830	883	6713
3	16413	1891	18304	15912	1829	17742	10990	1210	12200	7799	703	8502	7560	751	8311
4	16558	1340	17899	11482	607	12089	10695	860	11555	9816	702	10519	9112	728	9840
5	17600	695	18295	16973	575	17548	15280	895	16175	11403	729	12132	10792	714	11507
6	16959	427	17386	18738	473	19210	16223	673	16896	12643	732	13375	11644	688	12332
7	16770	351	17120	17773	388	18161	16916	559	17475	13565	712	14276	12729	677	13405
8	17498	361	17859	14144	276	14420	15519	417	15936	14448	640	15088	13562	627	14189
9	18415	342	18757	17123	323	17446	16741	388	17129	15200	586	15786	14062	549	14610
10	17790	327	18117	18525	363	18888	18472	391	18863	15634	562	16196	14143	467	14609
Total	**162941**	**10467**	**173407**	**158715**	**10358**	**169073**	**141549**	**9785**	**151334**	**112636**	**7270**	**119906**	**104458**	**7071**	**111529**

Table 9: (Continued) The same data as above expressed in Mm^3

Industry	Base25			Base25/33			Sim(S)			Sim(S+F)			Sim(S+F+E)		
Period	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.
1	27.68	6.38	34.05	27.68	6.38	34.05	20.83	5.37	26.19	13.82	2.52	16.34	11.86	2.33	14.19
2	31.17	4.79	35.96	38.50	6.66	45.16	28.05	4.99	33.05	14.80	1.97	16.77	13.76	2.08	15.84
3	38.73	4.46	43.19	37.55	4.32	41.87	25.93	2.86	28.79	18.40	1.66	20.06	17.84	1.77	19.61
4	39.07	3.16	42.24	27.09	1.43	28.53	25.24	2.03	27.27	23.16	1.66	24.82	21.50	1.72	23.22
5	41.53	1.64	43.17	40.05	1.36	41.41	36.06	2.11	38.17	26.91	1.72	28.63	25.47	1.69	27.15
6	40.02	1.01	41.03	44.22	1.12	45.33	38.28	1.59	39.87	29.83	1.73	31.56	27.48	1.62	29.10
7	39.57	0.83	40.40	41.94	0.91	42.86	39.92	1.32	41.24	32.01	1.68	33.69	30.04	1.60	31.63
8	41.29	0.85	42.14	33.38	0.65	34.03	36.62	0.98	37.61	34.09	1.51	35.60	32.00	1.48	33.48
9	43.45	0.81	44.26	40.41	0.76	41.17	39.50	0.92	40.42	35.87	1.38	37.25	33.18	1.29	34.48
10	41.98	0.77	42.75	43.71	0.86	44.57	43.59	0.92	44.51	36.89	1.33	38.22	33.37	1.10	34.47
Total	**384.50**	**24.70**	**409.20**	**374.53**	**24.44**	**398.97**	**334.02**	**23.09**	**357.11**	**265.79**	**17.16**	**282.95**	**246.49**	**16.69**	**263.18**

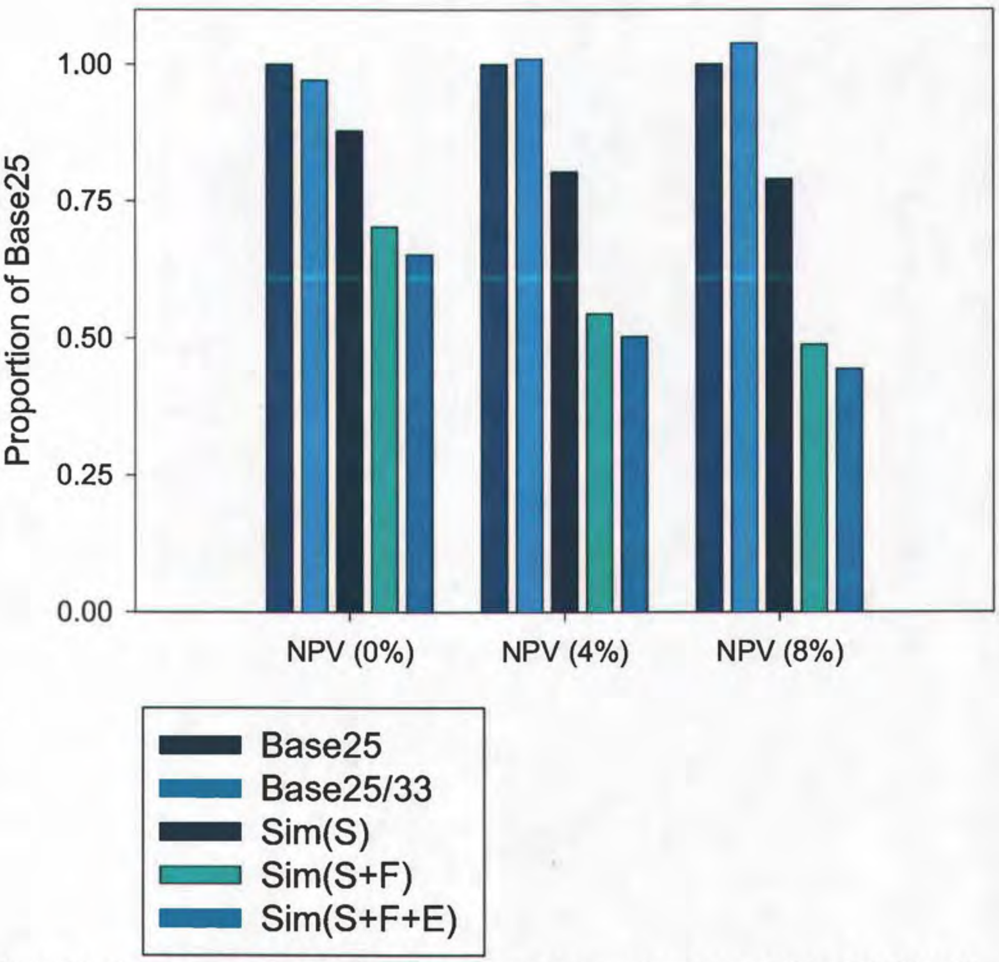

Figure 7: Net present value of industrial harvests expressed as a proportion of the Base25 simulation.

Table 10: Average annual revenue in millions of dollars over the first 20 years of the simulated policy structures.

	Average Annual Revenue		Annual Softwood Revenue	
	Industry	NIP	Industry	NIP
Base25	423	117	405	107
Base25/33	476	117	456	107
Sim(S)	353	87	337	80
Sim(S+F)	204	46	197	43
Sim(S+F+E)	183	46	176	43

NIP.

About one-third of NIP hectares were converted to other land uses over the planning horizon; this accounted for much of the declining NIP harvest. Sim(S) resulted in a gross harvested area 120% of the Base policies on NIP lands; the net harvested area was approximately 85% of the Base (Tables 6 & 11). The restrictions placed on allowable harvest area in Sim(S+F) reduced gross harvest area by approximately one-third and net harvest area by approximately one-half, when compared to the Base.

Under the Base policies, the volume harvested on NIP land was approximately one-third of industrial lands (Table 7 & Figure 7). Like industry, harvest volume initial had a significant hardwood component but this diminished through time (Table 12). Disturbance-based policies reduced the volume between 15% and 50% compared to the Base. Through the first 20 years the costs of disturbance-based policies ranged from approximately $30 to $85 million dollars annually. Unlike industrial lands, the differences in harvest-volume between the three policy alternatives were relatively constant throughout the one hundred year simulation. Therefore, the NPV of the policies were the same, regardless of discount rate, and reflected the difference in total volume (Figure 8). Like industry, the value of the policies was most significantly reduced when emulating the frequency of historical fires. NIP suffered a greater proportional loss that was surprising, at first glance, because their lands are concentrated in the interior climate zone, which had the shorter NFR (100yrs). 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. This point is elaborated in the discussion.

On NIP land LAMPS used thinning to meet volume targets. Therefore when disturbance-based policies constrained the area clearcut, LAMPS increased the area thinned to maintain a higher harvest volume. Thinning increased from approximately 5% to 12% when the area clearcut was reduced (Table 5). This may better represent how landowners would react to clearcut restrictions, but again, estimating how partial harvest might off-set clearcutting restrictions was beyond the scope of this study

Table 11: Non- Industrial clearcut harvest volume (MMBF) & gross and net clearcut area (thousands of acres) (see text for definition of gross and net)

NIP	Base			Sim(S)			Sim(S+F)		
Period	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC
1	3977	165	165	2935	187	126	1042	81	45
2	4447	172	172	3265	190	131	1503	95	58
3	4521	149	149	3289	162	114	1958	101	63
4	4633	141	137	3863	168	116	2333	101	65
5	4491	124	120	4218	163	111	2606	99	63
6	4836	119	115	4343	153	104	2861	97	62
7	5212	118	114	4471	147	100	2840	90	56
8	5202	111	107	4656	146	98	3071	90	56
9	5531	110	106	4654	139	93	3235	89	56
10	5625	111	106	4738	136	92	3479	89	57
Total	**48476**	**1321**	**1292**	**40430**	**1590**	**1085**	**24926**	**933**	**581**

Table 11 (continued) Same data as above expressed in Mm^3 and thousands of hectares

NIP	Base			Sim(S)			Sim(S+F)		
Period	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC	Vol.	Gross CC	Net CC
1	9.4	67	67	6.9	75	51	2.5	33	18
2	10.5	70	70	7.7	77	53	3.5	39	23
3	10.7	60	60	7.8	66	46	4.6	41	26
4	10.9	57	55	9.1	68	47	5.5	41	26
5	10.6	50	49	10.0	66	45	6.2	40	26
6	11.4	48	47	10.2	62	42	6.8	39	25
7	12.3	48	46	10.6	59	40	6.7	36	23
8	12.3	45	43	11.0	59	40	7.2	36	23
9	13.1	44	43	11.0	56	38	7.6	36	23
10	13.3	45	43	11.2	55	37	8.2	36	23
Total	**114.4**	**535**	**523**	**95.4**	**644**	**439**	**58.8**	**377**	**235**

Table 12: Softwood (SW) and hardwood (HW) non-industrial harvest volume in MMBF

NIP	Base			Sim(S)			Sim(S+F)		
Period	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.
1	3100	1243	4343	2311	965	3277	1097	397	1495
2	3511	1303	4814	2617	999	3617	1557	488	2045
3	3705	1113	4818	2676	857	3533	1945	527	2472
4	3935	924	4859	3341	776	4117	2303	541	2845
5	4074	673	4747	3819	665	4484	2510	530	3040
6	4656	512	5169	4022	579	4601	2743	495	3238
7	5159	409	5568	4265	480	4745	2705	437	3142
8	5275	329	5604	4505	421	4926	2975	392	3367
9	5632	278	5910	4576	350	4926	3145	368	3513
10	5736	257	5993	4690	317	5007	3380	363	3743
Total	**44784**	**7041**	**51825**	**36823**	**6410**	**43233**	**24362**	**4539**	**28900**

Table 12: (Continued) The same data as above expressed in Mm^3

NIP	Base			Sim(S)			Sim(S+F)		
Period	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.	SW Vol.	HW Vol.	Tot. Vol.
1	7.32	2.93	10.25	5.45	2.28	7.73	2.59	0.94	3.53
2	8.29	3.07	11.36	6.18	2.36	8.53	3.67	1.15	4.83
3	8.74	2.63	11.37	6.31	2.02	8.34	4.59	1.24	5.83
4	9.29	2.18	11.47	7.88	1.83	9.72	5.44	1.28	6.71
5	9.61	1.59	11.20	9.01	1.57	10.58	5.92	1.25	7.17
6	10.99	1.21	12.20	9.49	1.37	10.86	6.47	1.17	7.64
7	12.17	0.97	13.14	10.06	1.13	11.20	6.38	1.03	7.41
8	12.45	0.78	13.22	10.63	0.99	11.62	7.02	0.93	7.95
9	13.29	0.65	13.95	10.80	0.83	11.62	7.42	0.87	8.29
10	13.54	0.61	14.14	11.07	0.75	11.82	7.98	0.86	8.83
Total	**105.68**	**16.62**	**122.29**	**86.89**	**15.13**	**102.02**	**57.49**	**10.71**	**68.20**

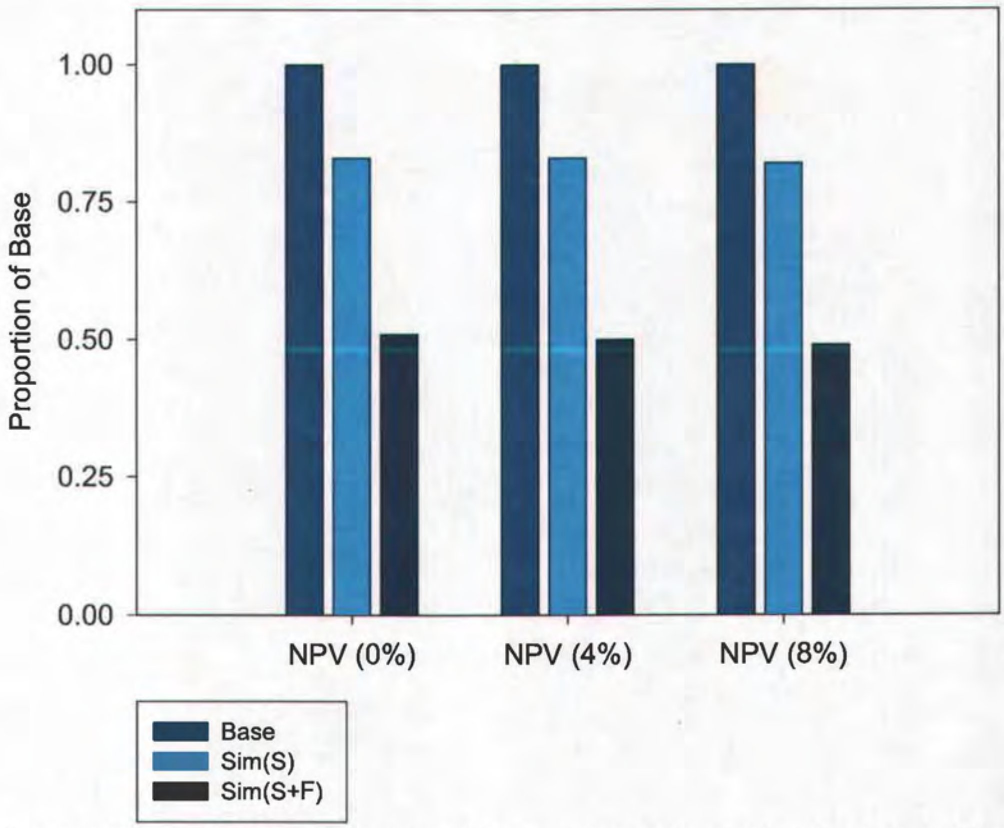

Figure 8: Net present value of non-industrial harvests under three policy structures and three rates of discount expressed as a proportion of the Base25 simulation.

Forest Inventory

The five policy structures produced distinct inventories by the end of the one hundred year simulations (Figures 9 & 10). 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 Northwest Forest Plan 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 one hundred years, irrespective of the policy structure.

Though trends in the inventory were similar on both private landowner groups, NIP landowners maintained a higher proportion of their land in the young forest class than did the industry (Figures 9 & 10). Under the Base policy, early seral quickly became the dominate age-class on industrial lands; this was primarily driven by the 40yr rotation-age. All of the simulations resulted in a decline of young forests associated with the aging federal forests, but the Base policies resulted in the most precipitous decline because it 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).

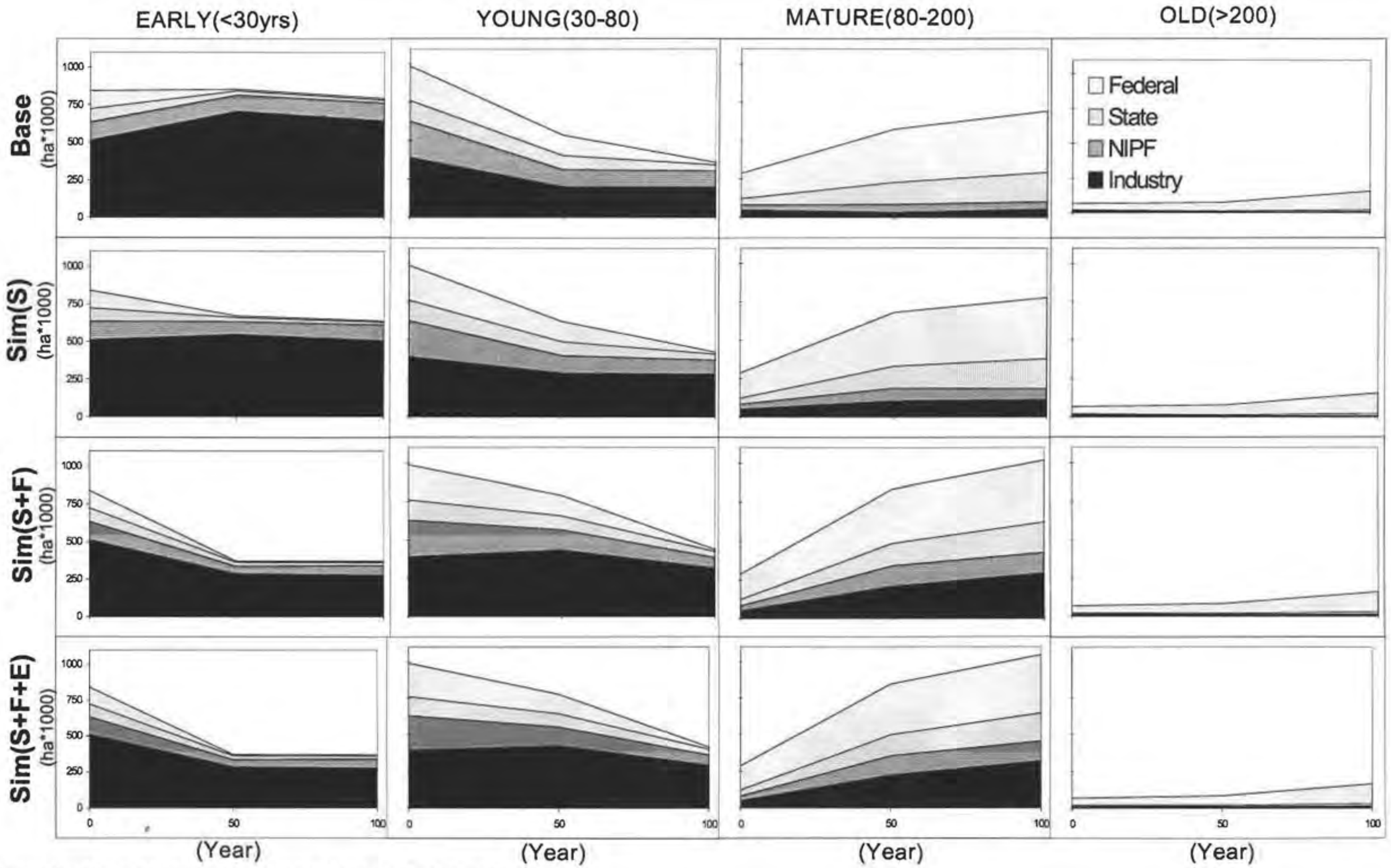

Figure 9: Forest Inventory by age-class and policy structure

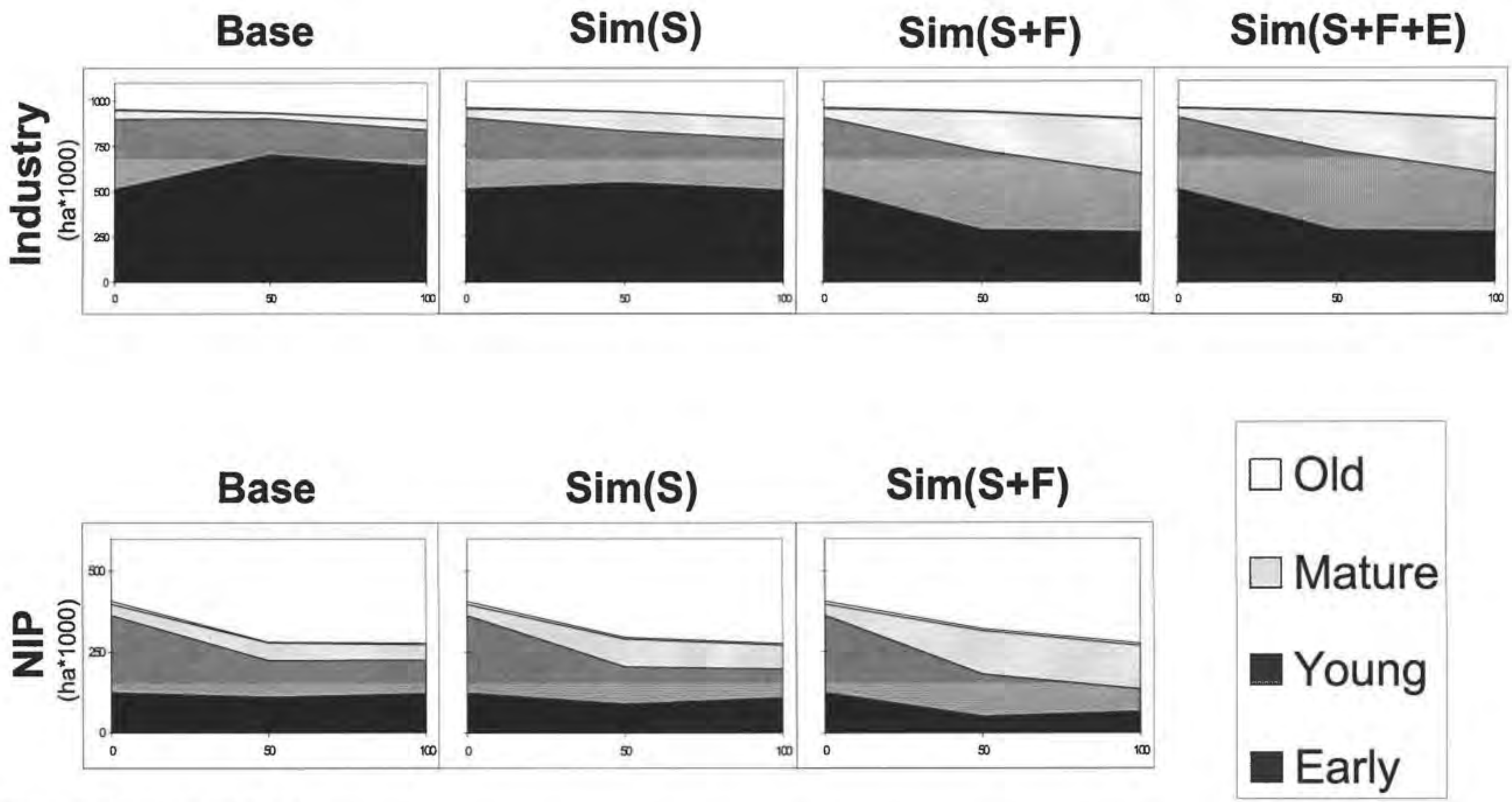

Figure 10: Inventory by owner.
(Note the reduction in total private area over time due to urban and rural development).

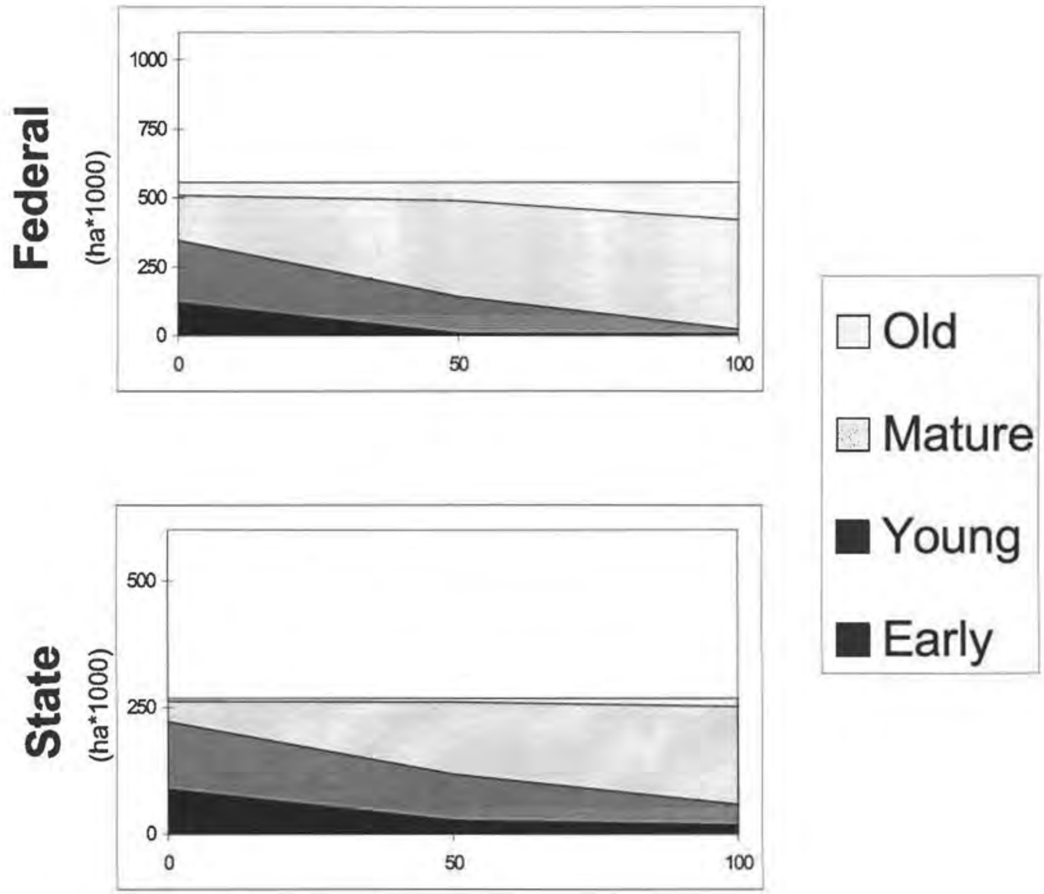

Figure 10: (Continued)

Landscape structure and HRV

Old forests were, historically, the most abundant age class on the landscape (Wimberly et al. 2000; Wimberly 2002; Nonaka 2003). In contrast, the starting condition had less than 5% old forests and instead was dominated by early seral and young forests (Ohmann and Gregory 2002). The future landscape, as simulated here, resulted in two potential scenarios: (1) Under the Base policy 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 mature forests increased beyond the HRV. (2) Under Sim(S+F) and Sim(S+F+E) the proportion of early and young forest declined 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 (Figure 11).

The LADS simulations indicated the historical landscape had, on average, a low density of large but variably sized early seral patches. This is reflective of the large size and patchy nature of historical Coast Range fires (Figure12a-d). Conversely, early seral patches were, on average, less than 5% as large as the HRV, they were less variable in size, and were greater in number. Though no simulation was able to produce an early seral patch structure within the HRV, the Base and Sim(S) trended closer than did Sim(S+F) and Sim(S+F+E). Young patches were also smaller and more abundant than the HRV; the simulations only increased the difference. The PSSD for young patches began within the HRV but the variation was quickly reduced below this standard. Interestingly, at the start of the simulation, the average patch size, PSSD, patch density, and largest patch metrics describing the mature forest class were within the HRV. Through time, however, the average size and PSSD increased beyond the bounds of the HRV. Again, the Base policy and Sim(S) trended closer to HRV than did Sim(S+F) and Sim(S+F+E). Old forest patches were below the HRV for all patch-size metrics throughout all simulations.

The HRV of edge density, for early and young patches, was considerably less than the starting condition (Figure 13). The gap between HRV and the policy simulations was reduced in all scenarios, though Sim(S+F) and Sim(S+F+E) were more effective at reducing early patch density than the others. The amount of mature forest edge began below the HRV, the Base policy and Sim(S) increased and remained within the HRV throughout the simulation. Sim(S+F) and Sim(S+F+E) finished the simulation with values above the HRV for mature forests. Edge density of old forest patches was, historically, significantly higher than the starting condition and remained so throughout the policy simulations.

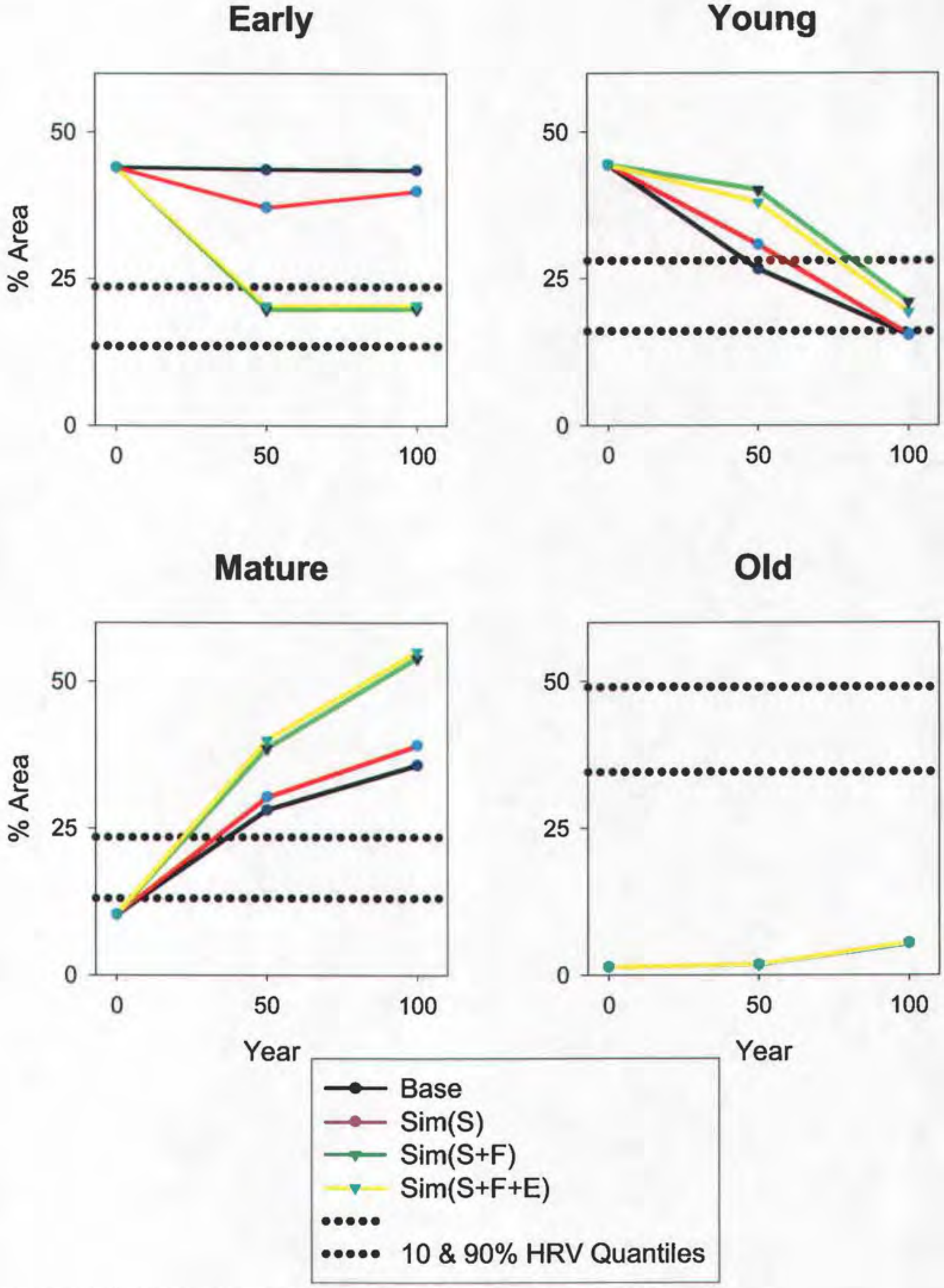

Figure 11: Relative area in each age-class throughout the simulations. Dotted lines represent the historical range of variability (HRV).

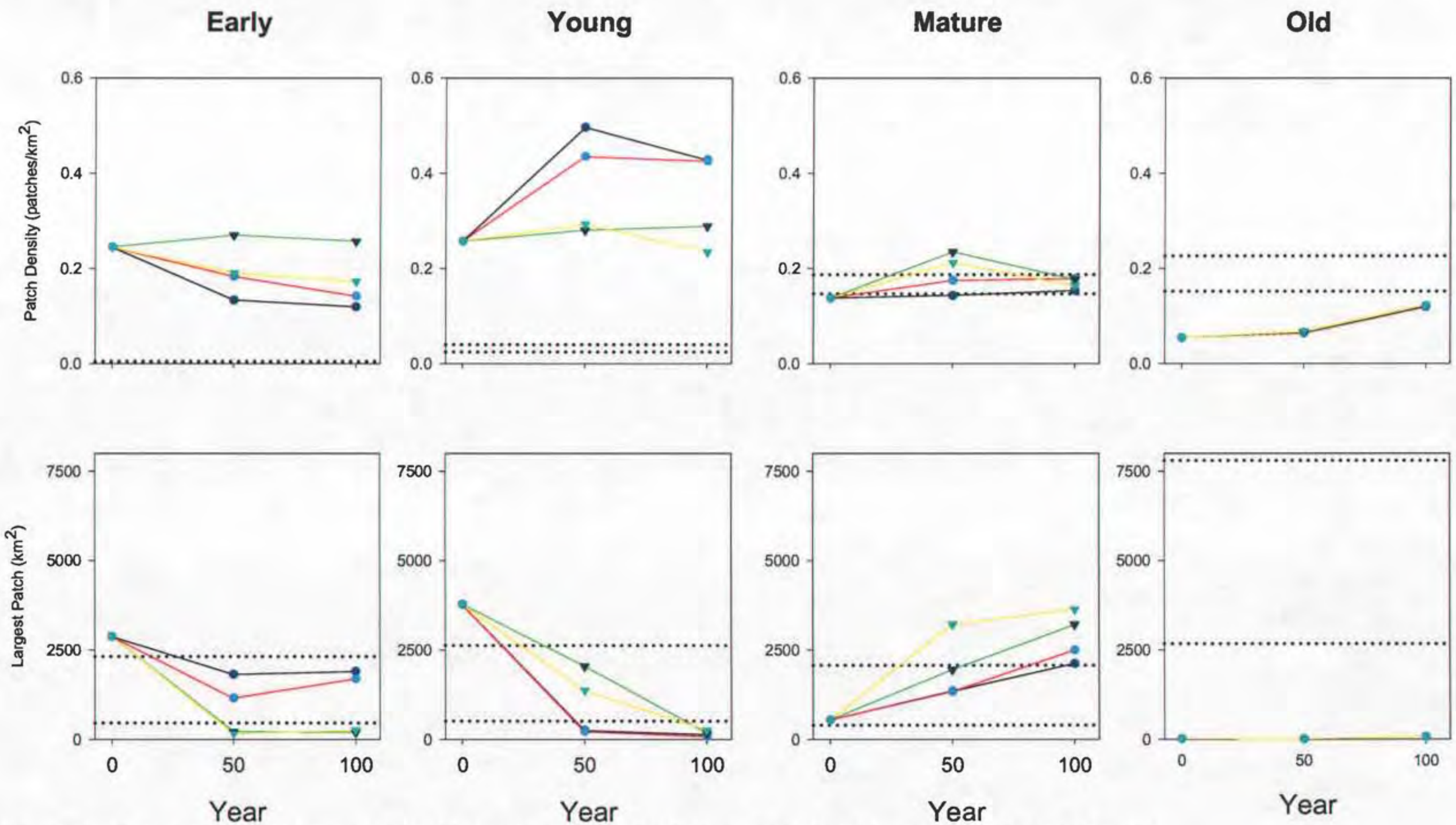

Figure 12: Patch Density (A); Largest Patch Index (B); Average Patch Size (C); & Patch Size Standard Deviation (D); Dotted lines represent the historical range of variability (HRV).

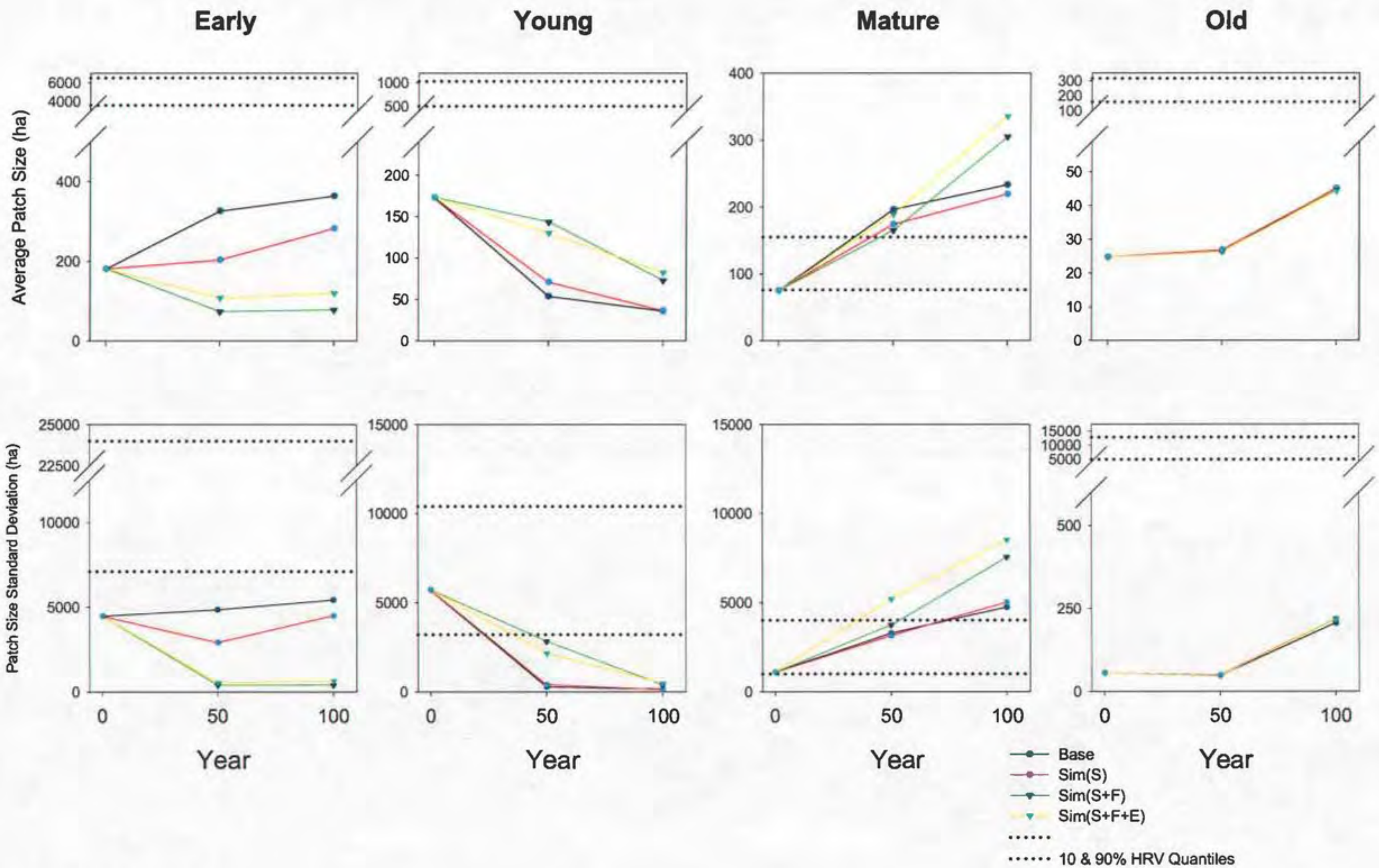

Figure 12: (Continued)

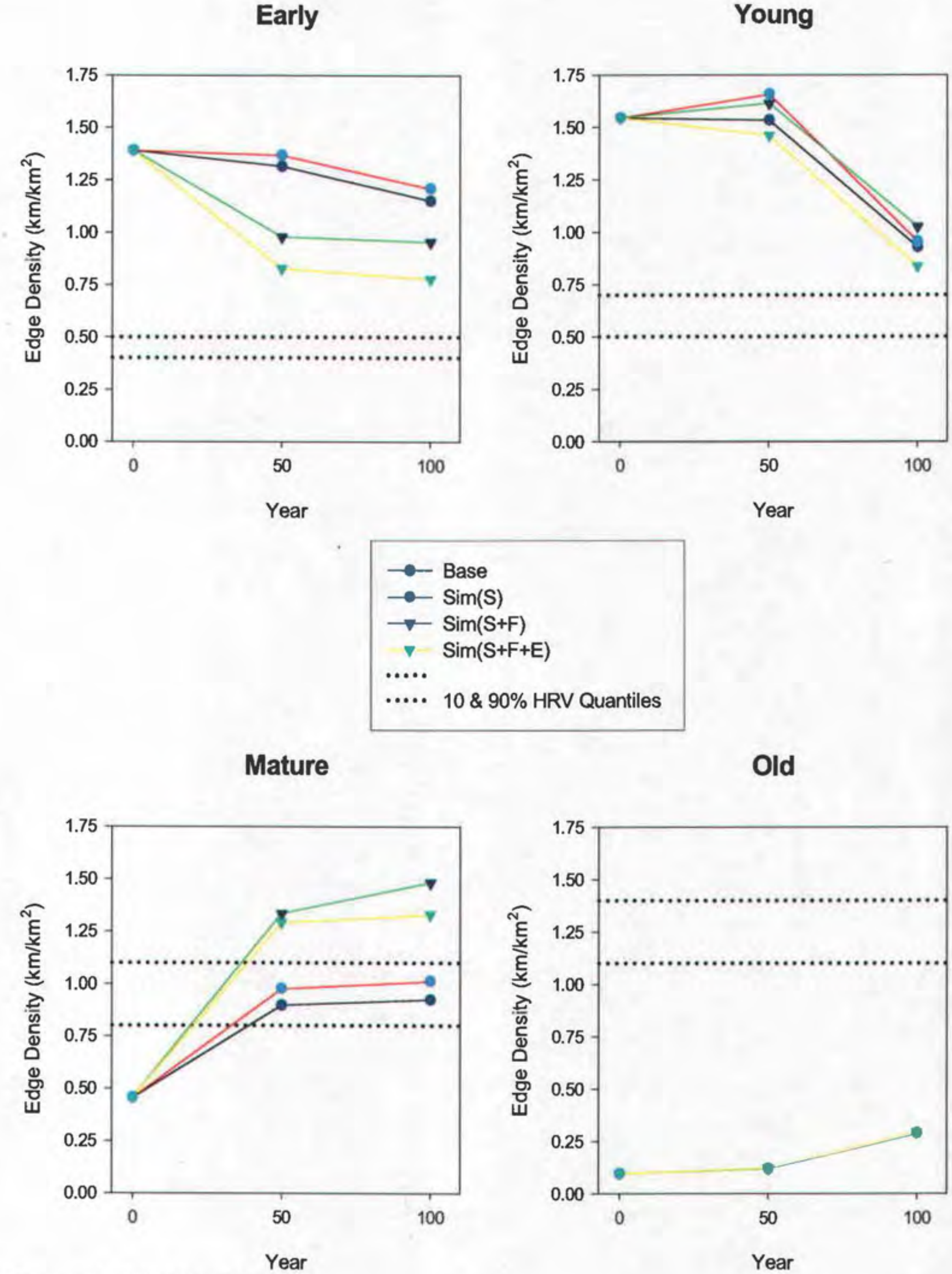

Figure 13: Edge Density
Dotted lines represent the historical range of variability (HRV).

Discussion

Both Base policy simulations operated within the confines of the Oregon Forest Practices Act (OFPA), which is considered among the stronger state forests policies with regard to environmental protection (Ellefson et al. 1995). Oregon is one of six states with comprehensive and enforceable forest practices acts. The Act has roots in reforestation standards but has expanded to cover most forest operations and provide some level of protection for soil, air, water, fish, wildlife, and other forest resources (Ellefson et al. 1995; Garland 1996). Increasingly, however, there are calls for the Oregon Board of Forestry to reassess how the OFPA addresses environmental protection (IMST 1999; Lorensen 2003); many of these concerns stem from the loss of anadromous fish habitat. Ecologists and scientific advisory panels have suggested the current approach to protecting fish-bearing streams—primarily through riparian buffers—has no analog in nature, and therefore, does not provide adequate salmonid habitat conditions (Reeves et al. 1995, IMST 1999). There are similar concerns regarding the dissimilarity between historical and modern forests within terrestrial systems in Oregon (Hansen et al. 1991). These concerns have led the Oregon Board of Forestry to investigate ways to improve the way the OFPA protects forest habitat (Lorensen 2003)

There is growing consensus that conventional strategies to resource protection, both within the OFPA and U.S. forest 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; Johnson and

Spies 2003). Though there is impetus for change, landowner actions are typically not considered with respect to adjacent ownerships (Sample 1994; Thompson et al. *in press.*). 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 the state. The OFPA offers few provisions for dealing with the cumulative effects of habitat alteration or resource degradation. Alternative approaches to forest policy that operate at the stand- and landscape-scale are needed. Emulating historical disturbance regimes through forest management is a frequently cited way to accomplish this goal (Hunter 1993; Reeves et al. 1995; Cissel 1998; 1999; IMST 1999; Franklin and Lindenmayer 2002).

Challenges of a landscape approach over multiple owners

In general, the Base policies developed for this study were consistent with other LAMPS simulations of the current policy structure (Spies et al. 2002c; Bettinger et al. *in prep.;* Johnson et al. *in prep.*) The primary conclusion of this and other studies was forest structure in the Coast Range will continue to be bifurcated between public and private lands (Spies et al. 2002c; Bettinger et al. *in prep.*). In these simulations, private lands continued to be dominated by a high density of early seral and young patches. This was reinforced by a dramatic shift of young forests to early seral forests on industry lands in the first 50-years. The Base policies also simulated the maturation of federal forests; this is the effect of the Northwest Forest Plan. 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 a proportion of mature forests that is above the HRV. However, a continuation of these simulations, beyond the one hundred-year 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 this way, the Northwest Forest Plan did more to move the forest composition of the Coast Range toward the HRV than did any provisions in the disturbance-based policies.

These results demonstrated 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). This would contrast with current federal policy, which effectively allows no clearcut harvests. Meanwhile, the surrounding private lands, unaffected by the change in policy, would continue to harvest on short rotations, consistent with their management objectives. The likely outcome of this approach over the long-term would appear to be an 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. Wimberly et al. (2000) found, when measuring the HRV of old forests in the Coast Range, 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, with regard to old forests in the Coast Range, that the entire province was the appropriate scale to define the HRV. Therefore, in this hypothetical example, applying a disturbance-based approach to federal forests may push the Coast Range further from its historical condition than would maintaining the current policy structure. In contrast, the disturbance-based policy simulations that we applied to private lands was able to move the Coast Range closer to historical conditions than would the current policy. By focusing policy changes only on those forests currently slated for harvest, the federal forests can be utilized to provide large patches of old forest that were characteristic of provincial historical conditions and are unlikely to be found within the private ownerships. In short, a regional perspective on a disturbance-based approach to managing federal forests in the Coast Range may include little or no harvesting.

What might this mean for the future of federal forest policy in the Coast Range? Currently, the Northwest Forest Plan (NWFP) is not meeting the anticipated harvests levels and there are calls from the timber industry to increase harvests. However, our analysis suggests that federal forest are needed to reduce the deficit of mature and old forests across the landscape. Therefore, those who favor a coarse-filter approach, based on reproducing the historical age-class distribution, would likely favor a reduction in the NWFP's anticipated harvest level and a moratorium on the harvest of mature and old forests.

Relegating public lands to old forests is plausible given their status under current policy; however, implementing a policy that substantially restricts harvest across private lands would be more challenging. Implementing a policy structure like Sim(S+F) or Sim(S+F+E), would require the State to allot an allowable harvest-area over multiple private ownerships. We chose to allocate harvests at the megashed-scale (several 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 sub-region. However, because the amount of harvest was rationed based on the expected area disturbed 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 more harvestable area than private owners in megasheds with little public land. Within the Coast Range, NIP lands are concentrated in megasheds where there is little public land. Therefore, NIP suffered a greater cost than did industry that was located in megasheds with large blocks of federal land. This was simply an artifact of the ownership pattern. However, it raises substantial equity concerns with regard to the way forest policies are implemented on a multi-owner province. Policy-makers would likely face several trade-offs and potential legal hurdles to coordinated harvest levels across multiple private landowners (Thompson et al. *in press*).

The Costs of Disturbance-based Policies

Most of the private lands under consideration in these simulations are managed for timber first and then for other forest amenities (Lettman and Campbell 1997). Therefore, when assessing potential changes in forest policy, landowners' judgments will likely hinge on the costs, in NPV, of implementing new policies. It is clear from these simulations that a disturbance-based policy structure in the Coast Range would come at a cost—the magnitude of which would depend on the attributes of disturbance being emulated.

Sim(S) effectively replaced the 5-small-tph retention standard in the OFPA with guidelines that require 10% or 40% of the volume retained in clumps (depending on climate zone) in addition to 12-medium-tph. Unlike later simulations, Sim(S) did not put any constraints on the total area harvested; this allowed landowners to try and make up for the lost timber elsewhere on the landscape. As a result, the total gross harvested area was highest in this simulation. However, the net harvested area and total harvest volume was significantly lower than the Base policies. Emulating fire severity through increased retention resulted in costs from three primary sources: (1) The cost of the volume left on-site. (2) The cost of reduced growth and yield associated with the over-story shade on regenerating, shade-intolerant Douglas-fir. The individual tree growth model used on private land within LAMPS was sensitive to this level of retention (Birch and Johnson 1992) However, it should be noted that Rose and Muir (1997) argued using retrospective analysis on green-tree retention sites in the western Cascades, that the model is too sensitive. Hence, these costs may be slightly exaggerated in this study. (3) The increased operational cost and expense associated with the complex harvest layout. Green-tree retention at levels lower than those simulated, have been shown to substantially increase operations costs (Kellogg et al. 1996). Our calculation of NPV does not include any costs from the latter category. But, given the first two and assuming a 4% discount rate, Sim(S) was valued 17% below the Base25/33 for NIP and 21% below for industry (the reduction was higher when an 8% discount rate was assumed). Industry suffered much of this cost in the earlier periods because they were able, when returning to a site for the next rotation, to harvest the large over-story trees and leave a young cohort of green-trees to meet the retention standard. As a result, the highest industrial harvest volume in Sim(S) occurred in period-10. NIP did not experience a similar reduction in cost over time because they tended to harvest on longer rotations and their lands were concentrated in the interior climate zone where the retention standards were highest.

The costs associated with emulating the frequency of disturbance far exceeded the other constraints in this experiment. Sim(S+F) reduced the NPV of harvest by 45% on industrial land and 50% on NIP land when compared to the Base25/33 and assuming a 4% rate of discount. These costs reflected the discrepancy between the historical fire regime and modern rotation ages. Again, industry suffered much of these costs in the early periods. Later into the simulations, as the average rotation-age increased, they were able to harvest more volume from the allowable harvest area.

Although these costs may seem high, they were lower than they might have been when compared to 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; in this way, the federal forest policy could be interpreted as a subsidy to private land owners. However, 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 an estimate of the area burned over the next century could be established, this amount could be subtracted from the allowable harvest area; this would increase the costs of the policy.

In these simulations, emulating the extent of disturbance-events was represented through a constraint that required all industrial harvests be 250 ha. This was a ten-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 five-percent 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. These costs would likely be reduced in a "real world" setting because we have not accounted for any savings associated with the economics of scale.

Simultaneously emulating the severity, frequency and extent of Coast Range disturbances resulted in a 35% reduction in total harvest volume over the next century when compared to the Base policies. The cost, when evaluated as NPV, was even higher on industrial land because much of their volume was lost in the near-term. In fact, our estimates suggest annual revenue with disturbance-based policies could be 25 to 60% lower than with the current policy, over the first twenty years. The magnitude of these costs is reflective of the degree of departure between the modern and historical disturbance regimes. Given this, it likely that a disturbance-based approach, as simulated here, would be highly unpopular with those who value their forests primarily as a source of revenue.

For three reasons, these should be seen as the maximum cost of these policies: (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 was has been witnessed over the past several decades. On industry, in both base policies, we assumed rotation ages would drop to 40 yrs in the first few decades. Here, the initial pulse of harvest we simulated to achieve a 40 yr rotation represents a higher harvest rate has been witnessed historically. If the Base harvest volumes turn out to be too high, then the costs of the disturbance-base policies will be smaller than we have portrayed. (2) The forest industry and NIP owners might react to constrained clearcut rates by increasing their commercial thinning. We recognized some increased thinning on NIP lands in reaction to these constraints. On industry lands, we actually simulated a decrease in thinning with clearcut constraints. This was an artifact of the model structure, which scheduled most thinning after the creation of new stands through clearcutting. 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 in order to recover revenue lost from clearcutting restrictions. (3) In scenarios where regional harvest volume was reduced significantly, it is likely that prices would increase in response. This is simply a function of supply and demand. The resulting increase in stumpage prices would offset some of the costs associated with the disturbance-based policies.

The costs presented are sensitive to the assumed stumpage prices we used to calculate revenue. As noted earlier, softwood volume was valued at \$767 m^3 (\$325 MBF) and hardwoods were valued at \$177 m^3 (\$75 MBF). Actual stumpage prices will undoubtedly change through time under any policy scenario. Furthermore, these prices may be deemed too high by some and too low by others; they are simply one estimate based on recent experiences in the Coast Range. Therefore, 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 potential effects of changes in forest policy.

In addition, the costs described in this experiment are unique to disturbance-regime of the Oregon Coast Range and to the manner in which we chose to emulate it. Furthermore, it is probable methods could be developed which reduce the costs while still retaining many of the ecological benefits. For now, 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 as been so widely embraced in the boreal forests of Canada and Fennoscandia (e.g. B.C. Ministry of Forests 1995; OMNR 2001; Kuuluvainen 2002).

The Effects on landscape structure

Our analysis supported the findings of other studies that have shown forest structure in the Coast Range is outside of the HRV (Wimberly et al. 2000; 2004; Nonaka 2003). This was true for virtually all measures, with the exception of some mature forest patch metrics and the size of the largest early seral and young patches. The greatest deviation from the HRV was associated with the amount and configuration of old forests. These findings were similar to those from other regions of the Pacific Northwest (Wallin et al. 1996; Agee 2003). Our simulations revealed several challenges for returning to the HRV through changes in forest policy. The legacy of past management, diverse owner objectives, and the inherent differences between silviculture and natural forest dynamics precluded a simple route back to historical conditions. In this section we discuss some challenges in for using forest policy to promote changes in landscape structure.

Previous research has shown that reintroducing the historical fire regime on the modern landscape would not return the landscape to the HRV in the next century (Nonaka 2003). Therefore, it wasn't surprising that emulating the fire regime with management didn't return the landscape to the HRV either. Similar to the reintroduced fire regime, we were constrained in moving toward the HRV by the legacy of timber harvests (Nonaka 2003). Several decades of dispersed patch clearcutting on public and private lands has produced unprecedented landscape conditions (Franklin and Foreman 1987; Wimberly and Ohmann *in press.*). The age-class distribution has shifted toward early seral and young forests and created patch structure dominated by small, uniformly sized, early seral patches. Therefore, disturbance-based policies need to promote old forests in large but variably sized patches. As we mentioned previously, current federal policy did more to accomplish this goal than did the revised policies on private land. However, the disturbance-base policies were more effective at moving mature and old forests toward HRV than were the Base policies. This contrasted with reintroducing the natural fire regime that may fragment and reduce the proportion of old forest through fires before returning the landscape to the HRV (Nonaka 2003).

Sim(S+F) and Sim(S+F+E) created much higher levels of mature forest than did the other simulations. This was the effect of emulating fire frequency. Several of the metrics describing the mature forests moved closer to, or passed through, the

HRV. Those that passed through, such as relative area, average patch size, and PSSD, may move the landscape toward HRV in the long term as they age into the old forest class, which was consistently below the HRV. In contrast, the patch metrics describing early seral forests in Sim(S+F) and Sim(S+F+E) often trended away from the HRV, while the Base policies and Sim(S) trended toward it. Our scale of analysis often viewed the abundant, adjacent harvest-units in the Base and Sim(S) as a single, early seral patch. This, in effect, increased the size of disturbed patches closer to the size of historical fires. For example, the largest early seral patch was 1900ha in the Base compared to just 318ha in Sim(S+F+E). Interestingly, the transition to 250ha harvest units in Sim(S+F+E) made very little difference in moving the patch size metrics toward HRV when compared to Sim(S+F). This was true despite the fact that Sim(S+F+E) increased the average industrial harvest size by a factor of ten. Again, this is a matter of scale. Given the average historical fire size is greater than 5000ha, an increase to 250ha harvest-units did not appreciably effect the greater patch size distribution. Further questions related to emulating historical fire sizes might benefit from examination of even larger harvest units. On the other hand, choosing to emulate very large fires with clearcut harvests may have aesthetic and ethical consequences too great for society to accept. Indeed, there has been great public outcry over this approach to emulating disturbance size in Ontario (Schindler 2001; Brooks et al. 2002).

Sim(S) ended up looking very much like the base policies. It used retention of live trees, both individually and in clumps, to emulate the variable intensity of wildfires. This approach to emulating natural disturbance has been widely proposed and experimented with (Hunter 1993; B.C. Ministry of Forests 1995; Cissel et al. 1999; Spence et al. 2002). In addition to the lack of a harvest-area restriction, there are at least two reasons this policy produced landscape structure similar to the Base policies': (1) The higher volume in and relatively slow growth rate of the retained trees resulted in them being cut on the second rotation. Therefore, few lived longer than two rotation lengths and never aged into older structural classes. (2) The scale at which we measured the landscape neglected fine-scale structural elements. Scaling up to a $300m^2$ grain size caused many of the retained trees to be "washed out." It is likely that Sim(S) would have had a greater effect on the simulated landscape if our analysis was done at a finer resolution. Also, the ecological effects of the increased retention may be better observed at the stand-level. Indeed, many other studies have found similarities in faunal and floral ecology between post fire stands and harvests with green-tree retention (Hansen et al. 1995; 1991; Schieck and Hobson 2001; Stuart-Smith 2002).

Narrowing the gap

In this study, three attributes of the region's natural fire regime were incorporated into forest policy—the live-tree legacy, the average rate of fires, and the spatial extent of individual fires. Emulating these characteristics is an attempt to recognize the role disturbance has played in maintaining forest structure. However, these policies fall short of truly mimicking the natural disturbance regime. If the policy-makers choose to manage with natural disturbance as a reference, several additional attributes could be incorporated into forest policy may narrow the gap; however, some differences are impossible to overcome.

Our simulation retained only live trees after harvest; yet, in the Coast Range, post-fire landscapes contained large quantities of down and standing dead wood that persisted for centuries (Spies et al. 1988; Nonaka 2003). Dead wood plays a key role in forest ecosystems by providing habitat for many terrestrial organisms, adding structural complexity in regenerating forests, moderating extremes in the microclimate, and enriching soil nutrients (Harmon 1986; Spies 1998; Marcot et al. 2002). Although it was not included here, a disturbance-based policy structure could easily accommodate a dead wood requirement. The OFPA currently requires just $0.6m^3$ of down wood and two small standing trees, dead or alive.

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 level (Franklin and Dyrness 1988; Wimberly and Spies 2001; Wimberly 2002); in contrast, current policy requires high density plantations that are "free to grow" within five years of harvest (Oregon Forest Practices Act). 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. In the simulations presented here, as in many forest planning situations, the placement of a harvest-unit was determined, in part, by the value of the timber and the costs of removing it. Generally speaking, stands with larger trees are cut before stands with smaller trees. And, to reduce logging costs, flat sites are selected before sites on steep slopes. This prioritization is contrary to the pattern of disturbance under the region's historical fire regime (Agee 1993). Small trees, with thin bark, are more likely to be killed by fire than large trees with thick bark. Additionally, fire travels over steep slopes more frequently than over flat ground. From and managerial perspective, it would be possible to configure harvest-units across a landscape in a manner more consistent with an expected pattern of wildfire. However, like all the examples given, further analysis is needed to compare the ecological benefits of emulating attributes of disturbance to the anticipated economic costs.

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 the dead trees which 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 to 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-grain 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. 2002c; 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 have painstakingly incorporated human population growth estimates, stochastic gap-level disturbances, management intentions for specific ownerships, peer-reviewed tree growth and regeneration models, and several other components to produce reliable predictions. Yet, many other factors, such as a road network and future climate change are not explicitly included. Consequently, although the trends and generalities produced by LAMPS are probably accurate, the specific outputs are only a best estimate made under many assumptions and constraints.

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. Experts agree that average temperature will rise moderately during the next century throughout the Pacific Northwest (Bachelet et al. 2001; Lenihan et al. 2003; Neilson 2004). Many models predict that this will be accompanied by increased winter precipitation (Hamlet 2004) but the timing of this is confounded by a drought that is occurring on a continental scale (Nielson 2004). Because the maritime climate of the Coast Range has historically not resulted in significant snowfall, the Coast Range is buffered from the abrupt transition from snow to rain that the Cascade mountains will likely experience. The Coast Range, like most forested regions, will experience changes in disturbance regimes that will impact the composition and configuration of vegetation (Aber et al. 2001; Dale et al. 2001; Nielson 2004). Higher temperatures may increase native insect and disease populations while also raising the region's vulnerability to exotic pathogens (Nielson 2004). Summer droughts, higher temperatures, and increased biomass production may result in more frequent fires and hinder fire suppression. Given these uncertainties, the LAMPS simulations should be viewed with caution and an eye to the unknown. Under some scenarios of climate change, disturbance-based policies, if implemented, would need to accommodate changes in the natural disturbance regime and our ability to suppress fire. However, there is no way to incorporate climate change effects at the resolution necessary for this analysis; therefore, we feel that the steady state assumptions used here are the best approximation of future forest trends in the Coast Range.

In evaluating the merits of disturbance-based policies we focused on coarse-filter measures such as relative abundance, and patch structure. While this approach adequately characterizes some changes in forested landscape structure, other effects may best be measured a fine-grain scale (Lindenmayer et al. 2000). For example, emulating fire severity through green-tree retention has been shown to benefit species associated with all stages of forest development (Hansen 1995; Stewart-Smith 2002). Unfortunately, our analysis is at too coarse of a scale to adequately characterize these benefits. This was exacerbated for the spatial metrics, which required rescaling the grain size from 25-m to 300-m. During the change in resolution, much of the retention structure was lost. A better understanding of the ecological effects will require further research. CLAMS scientists have developed a series of landscape-scale wildlife habitat models (McComb et al. 2002; Spies et al. *in prep.*) that could be used to evaluate specific species response to disturbance-based policies.

Summary and Conclusions

Emulating regional disturbance regimes through forest policy is a frequently cited way to implement coarse-grain 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 to inform annual harvest targets to match the frequency of fire. Finally, the clearcut size limit was increased to emulate the historical fire extent. These changes in policy represented a major departure from the current policies governing timber harvest in the region.

The simulations indicated that the current policy structure governing private land is antithetical to maintaining or restoring historical landscape forest structure. In contrast, the current federal-lands policy is restoring historical landscape conditions. The ownership mosaic and the legacy of timber harvest constrained the disturbance-based policies from returning the landscape to the historic range of variability for most measures. However, these policies did result in an age-class distribution more similar to historic conditions than did the current policy structure. 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. Even still, the policies resulted in significant costs, as much as a 60% reduction in annual 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 in 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, just paying for the alteration of the landscape that has occurred over the last century.

In a related context, a coarse-filter 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*) on to the federal Endangered Species Act provides 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*), Coho salmon (*Oncorhynchus kisutch*), and chum salmon (O. keta). The full economic impact of the listings may yet to be seen. Thus, the costs presented here may not necessarily be unique to a coarse-filter approach; they may just be the costs of meeting conservation goals generally.

CHAPTER 4: General Conclusions

"To achieve our objective of conserving the vast majority of biological diversity, it is critical that we plan and assess at the level of landscapes and regions as well as ecosystems" (Franklin 1993). Here Franklin expresses what has become a near consensus among ecologists: a regional view of management actions and policy decisions is essential to ensure ecosystem sustainability. However, there remain several barriers and little institutional support to facilitate large-scale, cross-ownership forest management. This is, in part, due to the lack to scientific information and analytical tools needed to examine policy strategies over long time-frames and wide spatial extents (Bettinger and Johnson 2003). The CLAMS project, through models like LAMPS, is addressing this problem and allowing scientists and policy-makers to heed Franklin's call. This thesis provides an example of the latest capabilities and tools available.

Through this thesis, we have found one of the primary challenges to planning at regional scales in the U.S. is coordinating actions across multiple landowners. In chapter 2, we examined disturbance-based policies applied over government-owned lands in Canada. In chapter 3, we attempted to apply what we had learned through landscape simulations of disturbance-based policies. However, our policy structures differed from the Canadian examples in that we applied then to a multi-owner province, the Oregon Coast Range. We built on existing policy structures and behavioral trends. We employed public lands to meet distinct objectives and to subsidize cost to private landowners. We also tried to anticipate private landowners' reactions to new policy constraints. Although this methodology is complex and replete with assumptions, we believe that it deals appropriately with the difficult nature of natural resource management. We are not aware of any similar attempts to examine disturbance-based policy at this scale. Our results raise difficult questions related to how to implement policy that varies across a landscape while insuring some degree of equity across landowners when doing so.

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