

Final Report
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Project A5. Assess the Scientific Basis for Standards/Practices at the Stand, Management
Unit, Landscape and Regional Level: Oregon Coast Range

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Abstract

The overall goal of the project was to assess the potential consequences of forest management policies on biological diversity, carbon, and timber production at multiple scales for a large forested area in Oregon's Coast Range and to suggest tools and policies that might contribute to achievement of regional conservation goals. We conducted this work with models and data from an existing study, the Coastal Landscape Analysis and Modeling Study (CLAMS). In addition, we developed a number of new tools for assessing biological diversity. These include landslide and debris flow potential models, focal species models and new models to estimate timber harvest based on economic behavior. Under current policies and practices, our simulations suggest an increase in the area dominated by large conifers along with a decline in the area of hardwoods and heterogeneous open forests. Further, the simulations suggest a decline in the landscape diversity within ownership combined with sharply contrasting conditions between ownerships. Timber harvest should remain roughly at current levels, coming mostly from the forest industry, while carbon storage increases over time. Alternative scenarios were examined to address the decline in biodiversity that may occur under current policy; management strategies to increase the amount of retention at final harvest appear particularly promising. Thinning of federal plantations was also examined and suggests that such treatment would improve habitat for at least one species and but did not significantly affect habitat quality for late successional species during the simulation period of 100 years. More generally, this analysis demonstrates that the problems of forest sustainability must be examined across multiple ownerships. Species and ecosystems do not follow legal boundaries but the policies of different owners set the template for biodiversity in a region. Landscape-level, cross-ownership simulations will be needed to assess the magnitude of the effects of forest management policies on biodiversity. The analysis also demonstrates that changes in stand level practices can have landscape and regional impacts on biodiversity making it important to recognize fine scale, stand-level characteristics such as number and size of wildlife legacy trees. In addition, the analysis demonstrates that multiple measures of biodiversity are needed to characterize the diversity of responses of species and ecosystems to forest management. No single measure of biodiversity is adequate. This project has produced number of results that could be useful to forest managers. First, the particular models and results should be useful to forest managers in the Coast Range as they grapple with maintenance of biodiversity. Second, the more general findings and general approach should be of value to policy makers, managers, and analysts in forested regions of the United States. Finally, the articles being prepared for Ecological Applications should provide a unique and useful synthesis of an interdisciplinary project that examines biodiversity in a multi-owner region.

Key Findings

Our simulations suggest the following trends and outcomes for forests of Oregon's Coast Range:

- *An overall trend of increasing area of forests dominated by mature and old-growth conifers and species associated with those habitats, such as the red tree vole (Phenacomys longicaudus) and foliose canopy lichens (Lobaria spp).*
- *A new, highly contrasting forest landscape pattern is developing, characterized by older conifer forests (>100 years) on public lands and young conifer forests (<40 years).*
- *The area of biologically diverse hardwood and heterogeneous open forests (recently disturbed forests with remnant trees and shrub dominance) is declining.*
- *Overall landscape diversity will decline somewhat but diversity within ownerships declines strongly. Landscape diversity within individual ownerships will decline more strongly than across ownerships as different dominant-use policies took effect.*
- *The lands of the forest industry will provide most of the timber harvest in the future; existing harvest levels can be sustained into the future under existing policies.*
- *Carbon levels of coastal forests will increase over time with most of the increase occurring on federal and private lands.*
- *A relatively small portion of the stream network in the Coast Range is important for providing sediments and large woody debris to streams to maintain salmon habitat. These areas can be defied through spatial analysis.*
- *Increasing the number of leave trees in clearcuts on private land would reduce the contrast in habitat between the ownerships and provide more structurally diverse early successional habitat, resulting in improved habitat for several species.*
- *Thinning of plantations on federal lands would improve habitat for at least one species (olive-sided flycatcher) but not significantly affect habitat quality for late successional species such as the northern spotted owl during the next 100 years. More research is needed to fully understand thinning effects at landscape scales.*

Several general conclusions can be drawn from this work:

- *Forest management policies can strongly affect biological diversity.*
- *Landscape-level, cross-ownership simulations are needed to assess the effects of forest management policies on biodiversity.*
- *Changes in stand level practices can have landscape and regional impacts on biodiversity; landscape simulations will need to recognize fine scale, stand-level characteristics.*
- *Multiple measures of biodiversity are needed to characterize the diversity of responses of species and ecosystems to forest management.*

- *Spatial analysis can identify those portions of the landscape crucial to conservation of biodiversity, thus reducing the cost of achieving biodiversity objectives.*
- *Spatial projections are a powerful way to visualize the effects of management at broad scales and can effectively communicate to policy makers and the public a comprehensive picture of the interactions of forest management and biodiversity.*
- *We now have the tools to examine other management alternatives and communicate them to policy makers in a variety of ways*

Introduction

Policy makers, managers, scientists and the public are struggling to find new approaches to forest management that conserve native biological diversity while providing for commodity production. Ecosystem science can inform forest policy debates by providing information to policy makers and the public on the ecological and economic consequences of different forest management practices. The effects of forest management on regional biodiversity can be examined from at least three different perspectives or scales: 1) manipulations of vegetation at the stand level (e.g. amount of vegetation removed or retained in a logging unit); 2) allocation of management intensity in space and time at landscape scales (e.g. reserves, pattern of riparian buffers and areas for intensive forest management); and 3) pattern of forest land use relative to other land uses (e.g. agriculture or development). Opportunities to improve management for conservation goals may be found within any one of these areas. Spatial modeling approaches can be used to evaluate effects of current policies on biological diversity and understand possible consequences of alternative policies.

Purpose

Many problems of sustainability are local and regional in nature, making generalizations difficult. However, important fundamental questions do exist that transcend regional boundaries. For example, the question “What are the ecological and economic consequences of mixing reserve, multiple use and intensive timber management approaches in the same region?” is relevant to many forested areas. Other fundamental questions include:

What are the aggregate effects on biodiversity in a region of forest policies that are developed independently of each other?

How do estimates of the effects of policies on biodiversity differ among ecological indicators?

How can we use multi-scale spatial models and data to understand and communicate the effects of forest policies on biodiversity?

Our purpose in this study was to address these and other questions using the Oregon Coast Range as a case study. We assessed the scientific basis of recent forest conservation policies at multiple scales across the entire Coast Range Physiographic Province in Oregon and compared the ecological and socio-economic effects of selected alternative policies. We took advantage of databases and models from an existing research project, the Coastal Landscape Analysis and Modeling Study (CLAMS) (www.fsl.orst.edu/clams), to meet the needs of the NCSSF Program (Spies et al. 2002). Our overall goals were (1) to assess the potential consequences of forest management policies on biological diversity, carbon, and timber production at multiple scales and (2) to develop tools and information to support forest biodiversity policy-making at broad

scales. Our specific objectives were:

1. Estimate how biodiversity, carbon storage, and timber production might change over 100 years under current management strategies.
2. Identify possible gaps or deficiencies in current plans in terms of regional biological diversity goals
3. Identify options for changes to forest policies at multiple scales that might improve potential to achieve regional conservation goals, and evaluate benefits and costs of selected alternatives of forest management
4. Develop new tools for evaluating policy effects on biodiversity

The funding from NCSSF enabled us to conduct research that we would otherwise not be able to do under the overall CLAMS effort. Specifically the NCSSF funds enabled us to: 1) improve our characterization of how landowners will behave under conservation approaches; 2) estimate carbon storage; 3) develop three new focal species models for terrestrial biodiversity; 4) develop a landslide and debris flow risk model that could be used to characterize habitat potential for salmonids; 5) conduct more in depth analysis of how policies affect biodiversity and what alternatives might be available.

Summary of Results

Changes in biodiversity, carbon, and timber under current policy. We projected future conditions under current policy and identified a number of trends:

An overall trend of increasing area of forests dominated by mature and old-growth conifers and species associated with those habitats. The acreage of forests dominated by very large conifers projected to increase by nearly 300% (Figure 1 and 2). However, these amounts though would still be at the lower limit of historical levels (Wimberly et al. 2000). The acreage of habitat projected for red tree voles is projected to increase by 25% (Figure 3), with most of the habitat concentrated on public lands. Acreage of habitat for low mobility canopy lichens such as *Lobaria oregana*, is projected to nearly double (Figure 4) with most of the habitat concentrated on public lands.

A new, highly contrasting forest landscape pattern developed, characterized by older conifer forests (>100 years) on public lands and young conifer forests (<40 years) on private lands (Figure 2). The Northwest Forest Plan calls for 67-90% of the federal forests to be in reserves of various kinds that allow harvest only to achieve ecological objectives (i.e., late-successional forest). In addition, new plans for state forests call for attaining a variety of forest structures including older conifer forest. Since 2/3 of the private forests are in forest industry ownerships, their management will dominate the private forest landscape; our projections suggest that most industry land will be managed on rotations of 35-45 years. Management of family forest lands (nonindustrial lands) is

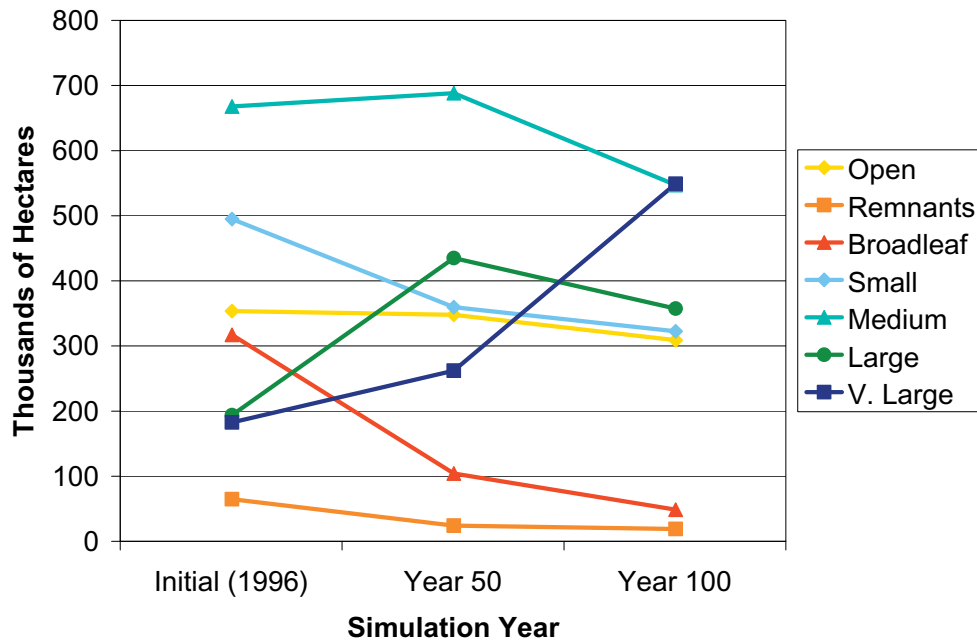


Figure 1. Projected changes in area of forest types by year. Open= <40% tree canopy cover; Remnants = < 40% tree canopy cover with at least one 50 cm dbh remnant tree per hectare, deciduous = hardwood basal area > 65%; Small = stands with quadratic mean diameter (qmd) of 0-25 cm, Medium = qmd 26-50; Large = qmd 51- 75 cm; Very Large = qmd > 75 cm.

harder to predict but, if the past is a guide, few acres with forests over 100 years of age will exist on those ownerships.

The area of some ecologically important habitat types declined. Hardwoods and heterogeneous open forests (recently disturbed forests with remnant trees and shrub dominance) projected to strongly decline (Figure 1 and 2). Acreage of forests dominated by hardwoods projected to decrease by 85% due to overtopping by conifers on all owners, reforestation practices on industrial land that suppress competing vegetation, and State forest practice regulations for private and state land that require “free to grow” conditions in reforestation within a certain number of years after final harvest. Open forests with remnant trees projected to decrease by 20%. Most planned openings will be created on forest industry lands though clearcutting (the dominant harvest method) with only a minimum remnant tree requirement under State forest practices. Openings from wildfire or other large disturbances (which are infrequent in the Coast Range) could counter this trend.

Overall landscape diversity declines somewhat but diversity within ownerships declines strongly. Landscape diversity within individual ownerships declined more strongly than across ownerships as different dominant-use policies took effect (Figure 5). Applying the Simpson diversity index to 34 size and cover classes suggests that diversity on each ownership group will decline over time (Figure 5) with the greatest decline on the national forests. Looking across ownership, however, we see a much more modest

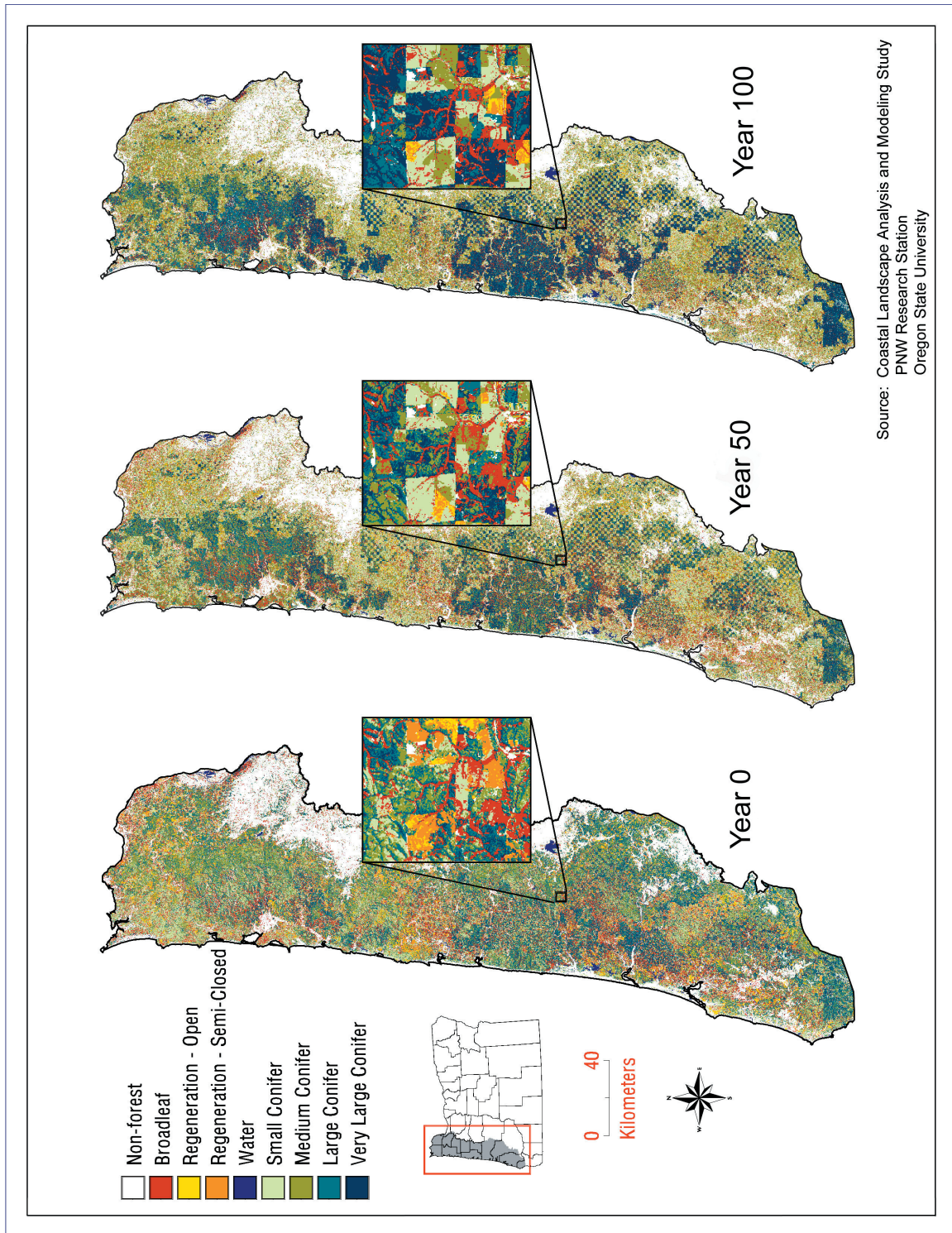


Figure 2. Simulation changes in patterns of vegetation cover types of the Coast Range at year 0, 50 and 100 under current policy.

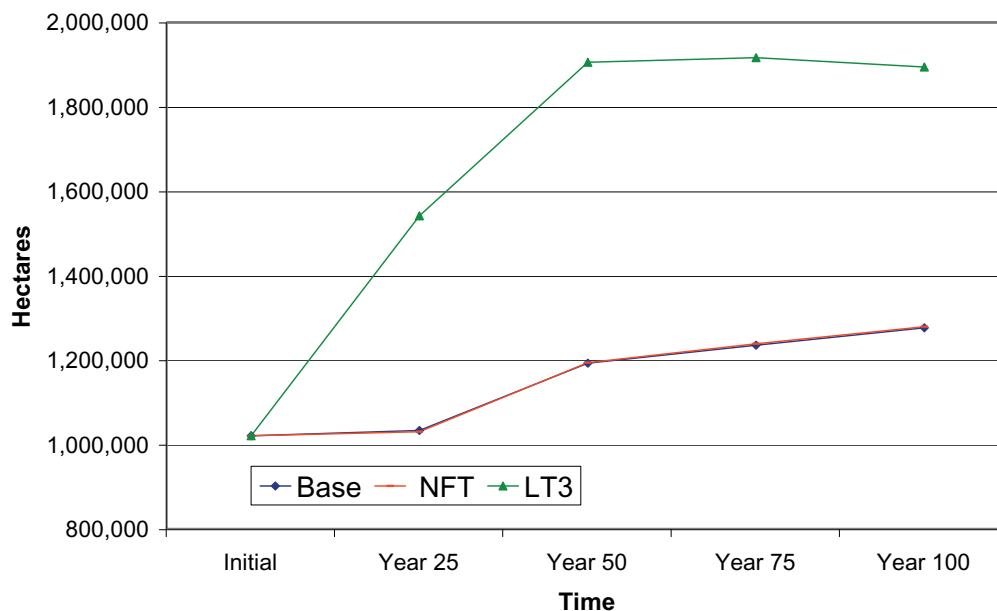


Figure 3. Projected changes in amount of moderate and high quality habitat for the red tree vole under three scenarios: Base = current policy; NFT = no thinning of federal forests; LT3 = green tree retention on private forest lands.

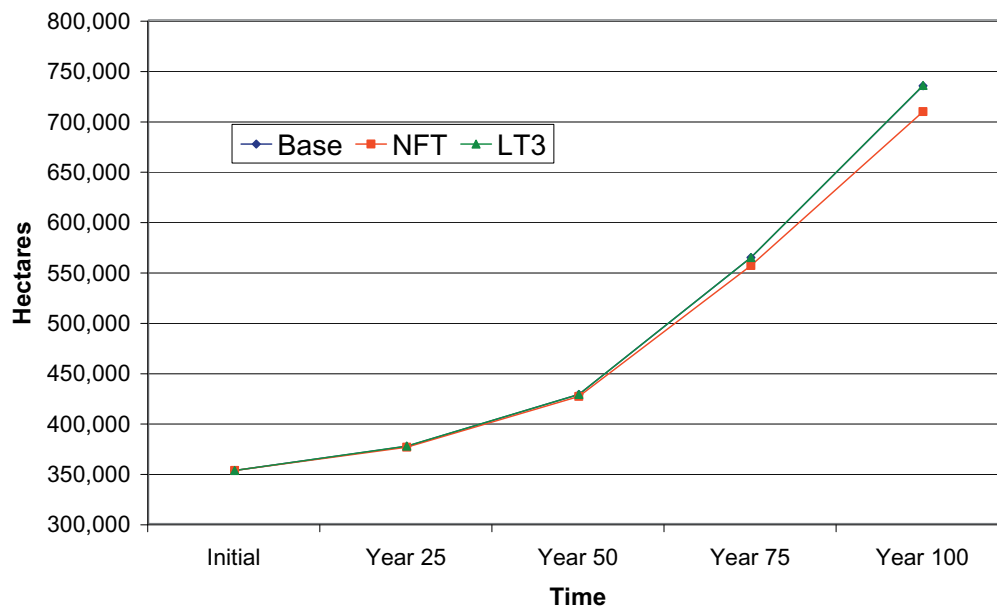


Figure 4. Projected changes in potential habitat for low mobility canopy lichens under three scenarios: Base = current policy; NFT = no thinning of federal forests; LT3 = green tree retention on private forest lands.

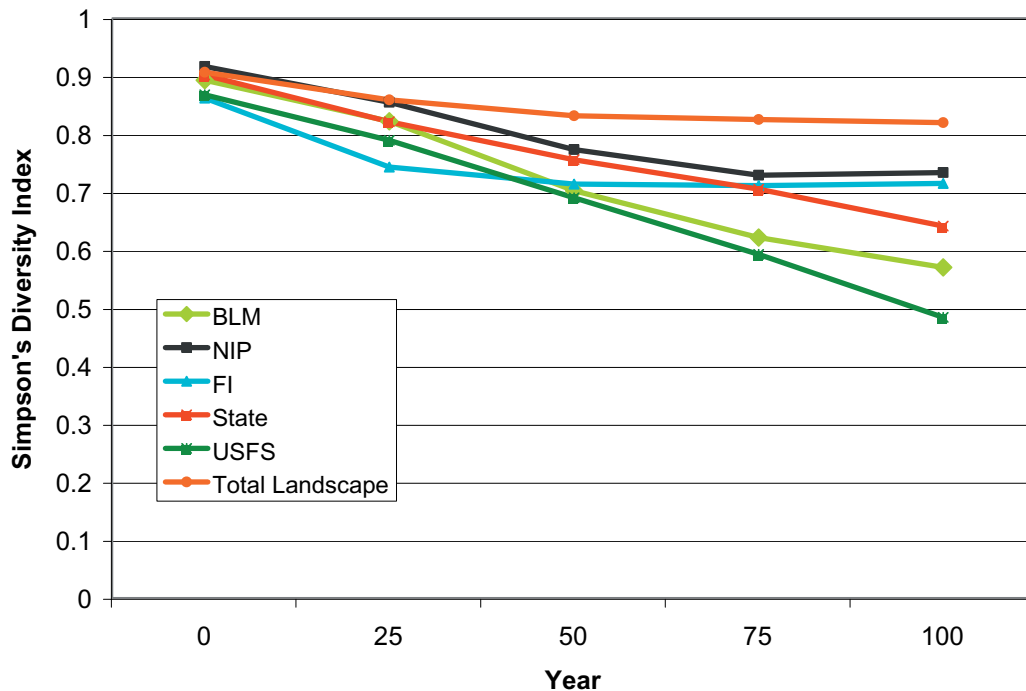


Figure 5. Projected changes in Simpson's diversity index (for 34 forest size and cover types) by ownership. BLM = Bureau of Land Management; NIP = Nonindustrial Private; FI = Forest industry; State = State of Oregon; USFS = USDA Forest Service.

decline as the different land ownerships assume different roles in the provision of various kinds of forest structures.

The lands of the forest industry will provide most of the timber harvest in the future; existing harvest levels can be sustained into the future under existing policies (Figure 6 and 7). Future timber harvest is dominated by private lands, especially industrial land. Timber harvest on federal lands declines in second half of century as stands age and are no longer eligible for thinning.

Carbon levels of coastal forests will increase over time with most of the increase occurring on federal and private lands (figure 8 and 9). Total storage on and off site is projected to increase by 75%. Strongest increases in mid and north Coasts, and lowest in Northeast and mid valley associated with an increase in stand age on public forests.

Possible gaps or deficiencies in current policies and evaluation of alternatives. Many of the projected changes are consistent with current federal and state policies and plans. For example, the increase in acreage of mature and old growth forests is the desired outcome of the Northwest Forest Plan for federal lands. However, some changes may not have been widely known or anticipated when policies were developed. The increase in area of older conifer forest types is matched by a decline in area of other forest types that provide biologically diverse and unique habitat. Possible undesirable changes include:

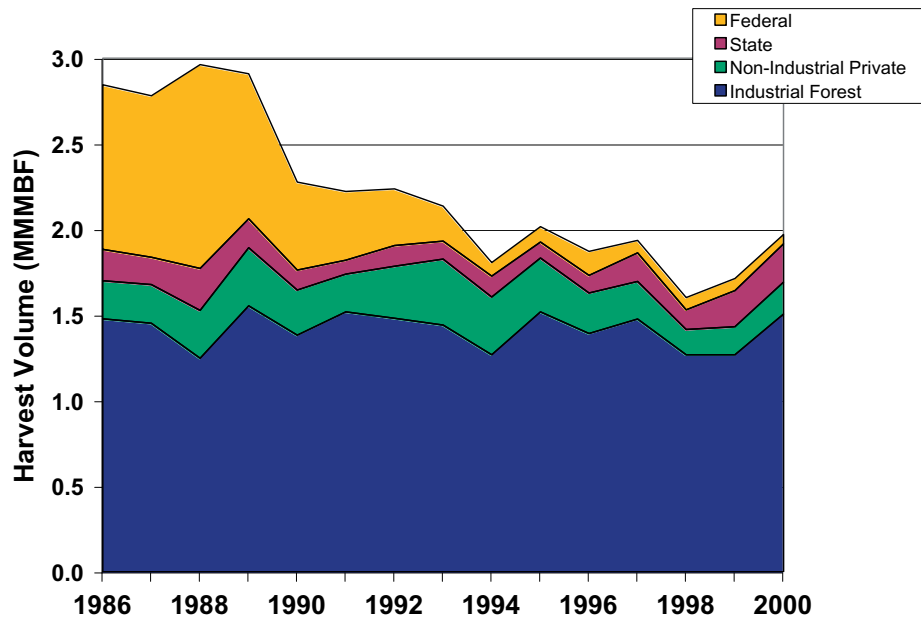


Figure 6. Past timber harvest by owner in the Oregon Coast Range.

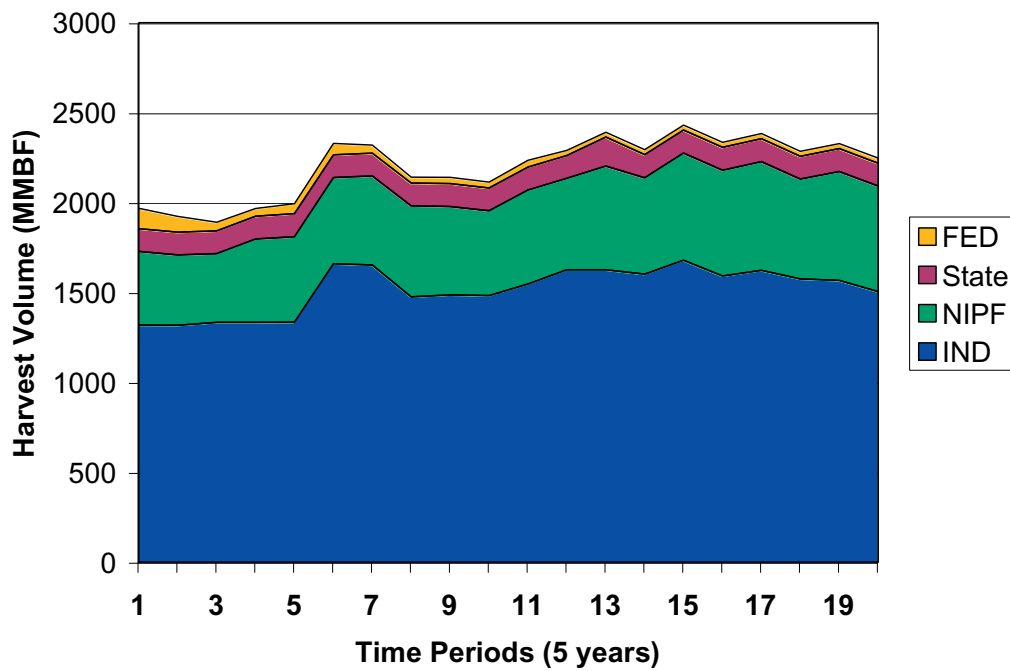


Figure 7. Projected annual timber harvest by owner in the Oregon Coast Range under current policies.

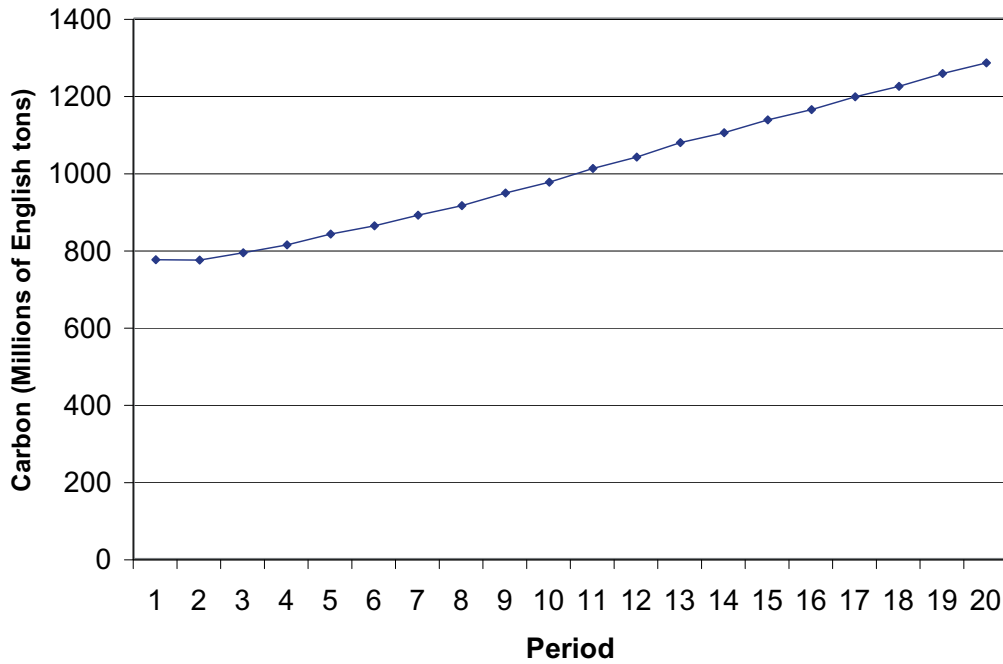


Figure 8. Projected total carbon storage in the forest and in forest products by period. Each period equals 5 years.

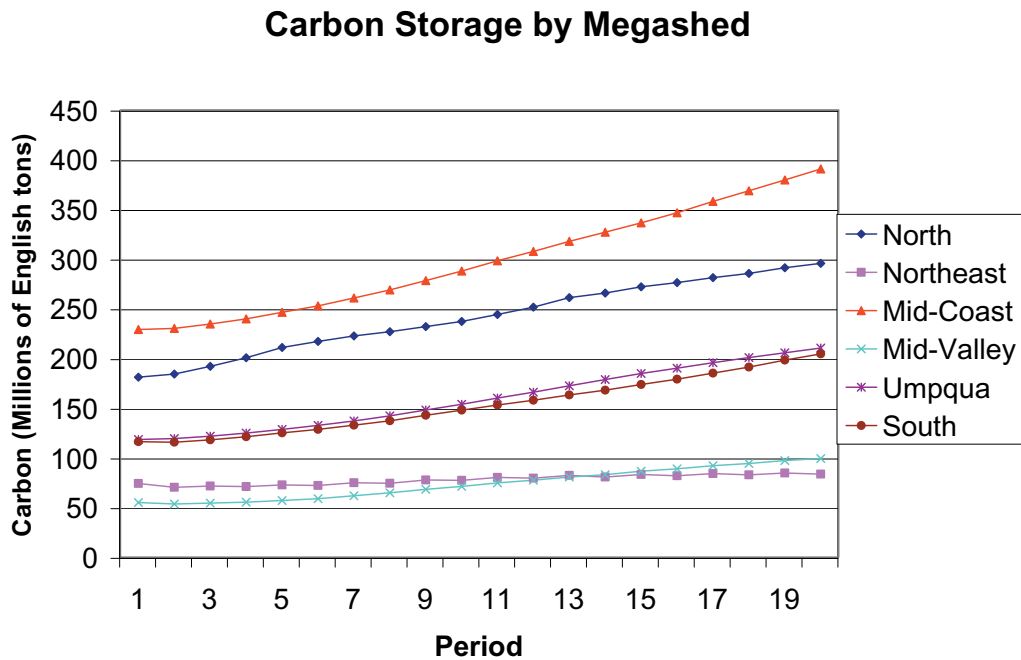


Figure 9. Projected changes in carbon storage by megashed (subregion) in the Oregon Coast Range.

- Increasing contrast in habitat conditions and lowering of habitat diversity across and within ownerships could restrict distribution of some species and processes and lower the resilience of the landscape to disturbances that propagate within one type of forest (e.g. young or old forests).
- Declines in hardwood forests and associated species diversity
- Declines in diverse early successional forests and associated species. These included open forests with remnant trees and snags and shrubby open forests
- Middle-age forests (50 to 150 years) decline and eventually will not be replaced on federal lands through any planned action.

Increasing the number of leave trees in clearcuts on private land would reduce the contrast in habitat between the ownerships and provide more structurally diverse early successional habitat, resulting in improved habitat for several species. We identified one alternative that would blur the contrast in habitat between the ownerships and provide more structurally diverse early successional habitat. Under this alternative the number of leave trees in clearcuts on private lands was increased to 5 conifers/ha >60 cm dbh and 7 conifers/ha >30 cm dbh. Under the State Forest Practices Act only 5 live or dead trees >30 cm dbh must be left in clearcuts. Increasing the number of leave trees on private land following harvesting resulted in substantial increases in habitat compared with current policy for two of the focal species, red tree vole and western bluebird. Habitat for red tree voles by at least 50% (Figure 3) and habitat for western bluebirds by almost 400% (Figure 10)

Thinning of plantations on federal lands improved habitat for at least one species and but did not significantly affect habitat quality for late successional species such as the northern spotted owl during the simulation period (100 years). We examined an alternative in which thinning in plantations on federal lands did not occur. We did this to evaluate the effects of the current policy, which allows thinning in plantations to promote habitat diversity. Stopping thinning in plantations on federal lands reduced habitat acres for the olive-sided flycatcher but had little effect on amount of habitat for other late successional species, such as the red-tree vole and northern spotted owl. The no-thinning alternative reduced the acreage of forests dominated by very large conifers. Thinning increased acreage of habitat for Olive-sided flycatcher but had no effect on habitat acreage for late successional species at 100 years (Figure 11). The expected positive effects of thinning may occur after 100-year period we examined. Thinning in young plantations on federal lands did not result in adverse impacts on late successional species and some positive benefits for species requiring more open stand conditions. Thinning would have beneficial effects on other species groups that we did not model (e.g. understory shrubs and herbs).

New tools for evaluating effects of policy on biodiversity. We developed a number of new tools for assessing biological diversity. These include landslide and debris flow potential models, focal species models and new models to estimate timber harvest based on economic behavior. The landslide and debris flow models were not applied to any of the policy scenarios but could be applied in the future. Uncertainty exists in the level of

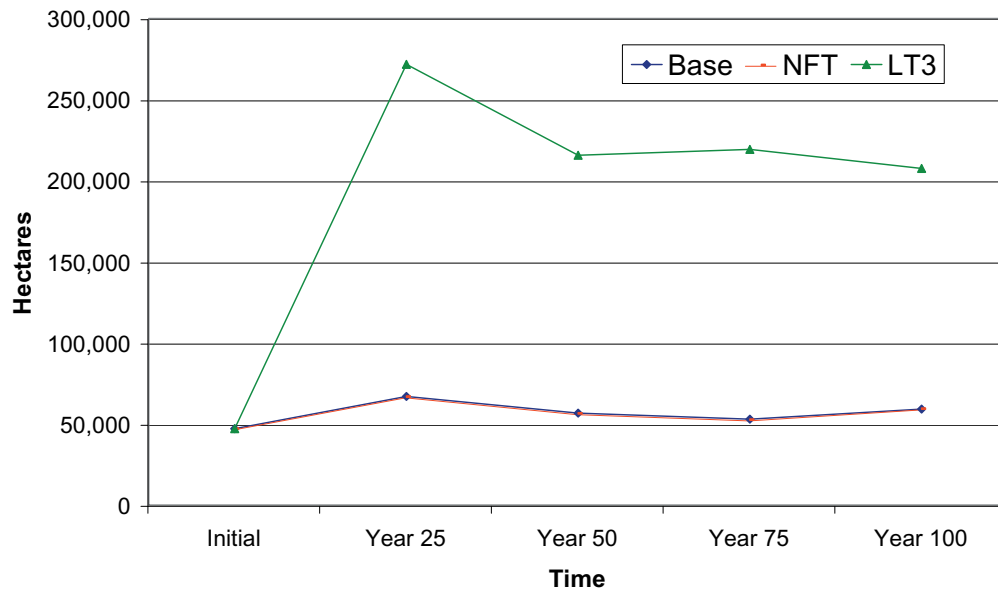


Figure 10. Projected changes in area of moderate to high quality habitat for the western blue bird under three alternative scenarios (See figure 4).

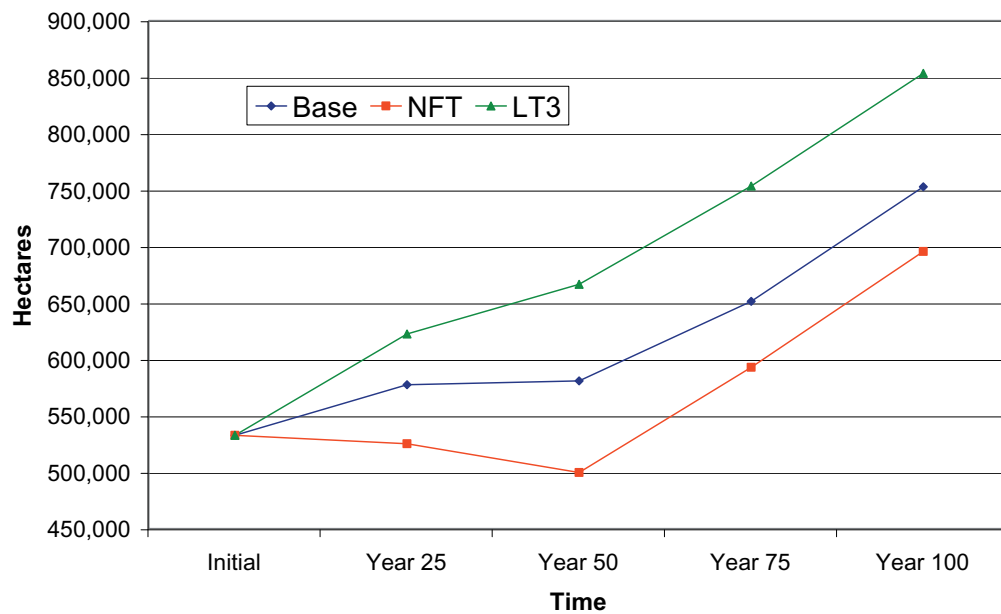


Figure 11. Projected changes in area of moderate to high quality habitat for the olive-sided flycatcher under three alternative scenarios.

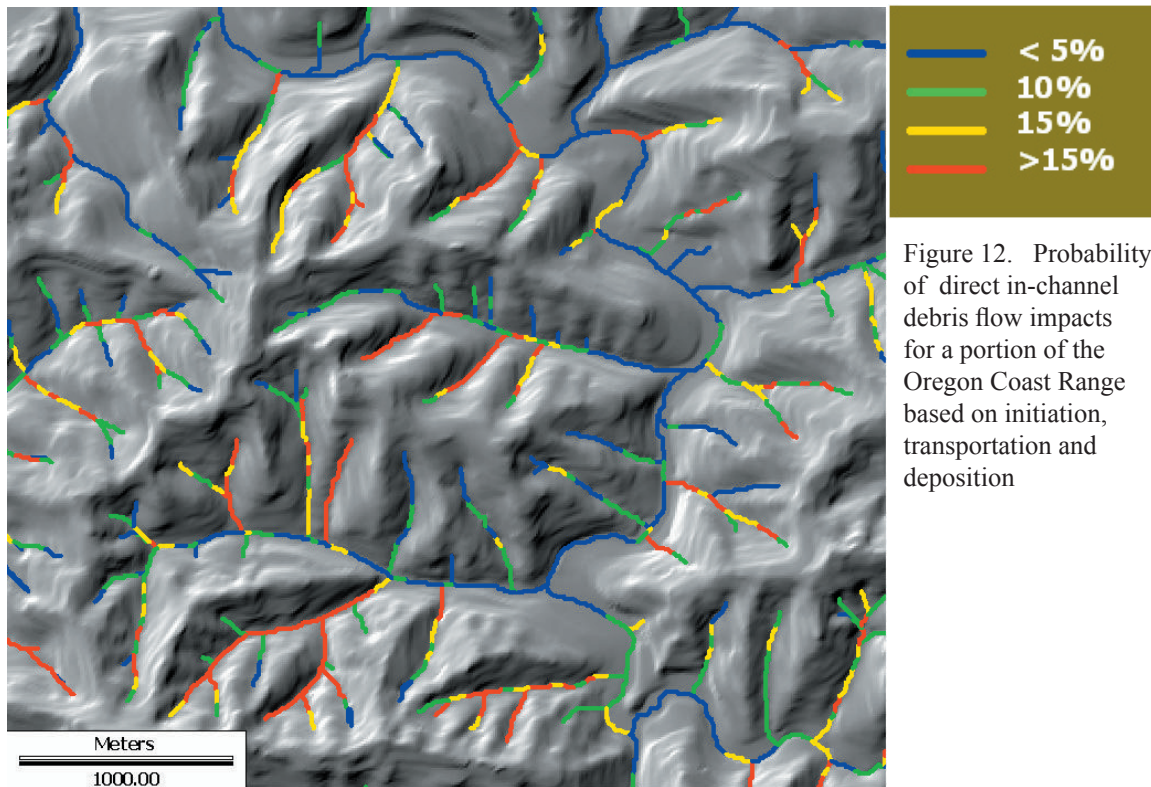


Figure 12. Probability of direct in-channel debris flow impacts for a portion of the Oregon Coast Range based on initiation, transportation and deposition

management intensity that private landowners will apply in the future. The effects of this uncertainty on estimates of biodiversity effects are not known.

The small basins that are important sources of sediments to fish bearing streams can now be identified through a new spatial analysis model. This model indicates that a relatively small portion of the stream network in the Coast Range is important in producing landslides and debris flows that provide sediments and large woody debris to streams and thus help maintain salmon habitat (Figure 12). The model was successfully verified at two study sites. It can be used to evaluate new policies for riparian areas.

Focal species habitat models were developed for the red tree vole, canopy lichens, and the beaver. The new focal species models can be used to evaluate alternative policies. The beaver model indicates that the highest habitat potential occurs along the Coast and Willamette Valley margin (Figure 13). Interior areas have low habitat potential although locally high value areas occur. The high quality beaver habitat areas may also correspond to and improve habitat for salmon species such as Coho. These lowland stream habitats, which have been heavily altered by agriculture and development, are potential biological hotspots, i.e. habitats to many species.

The elk model was more challenging to develop than originally expected, requires information about distribution of forage plants, which is not available with current models. Consequently, more research is needed here.

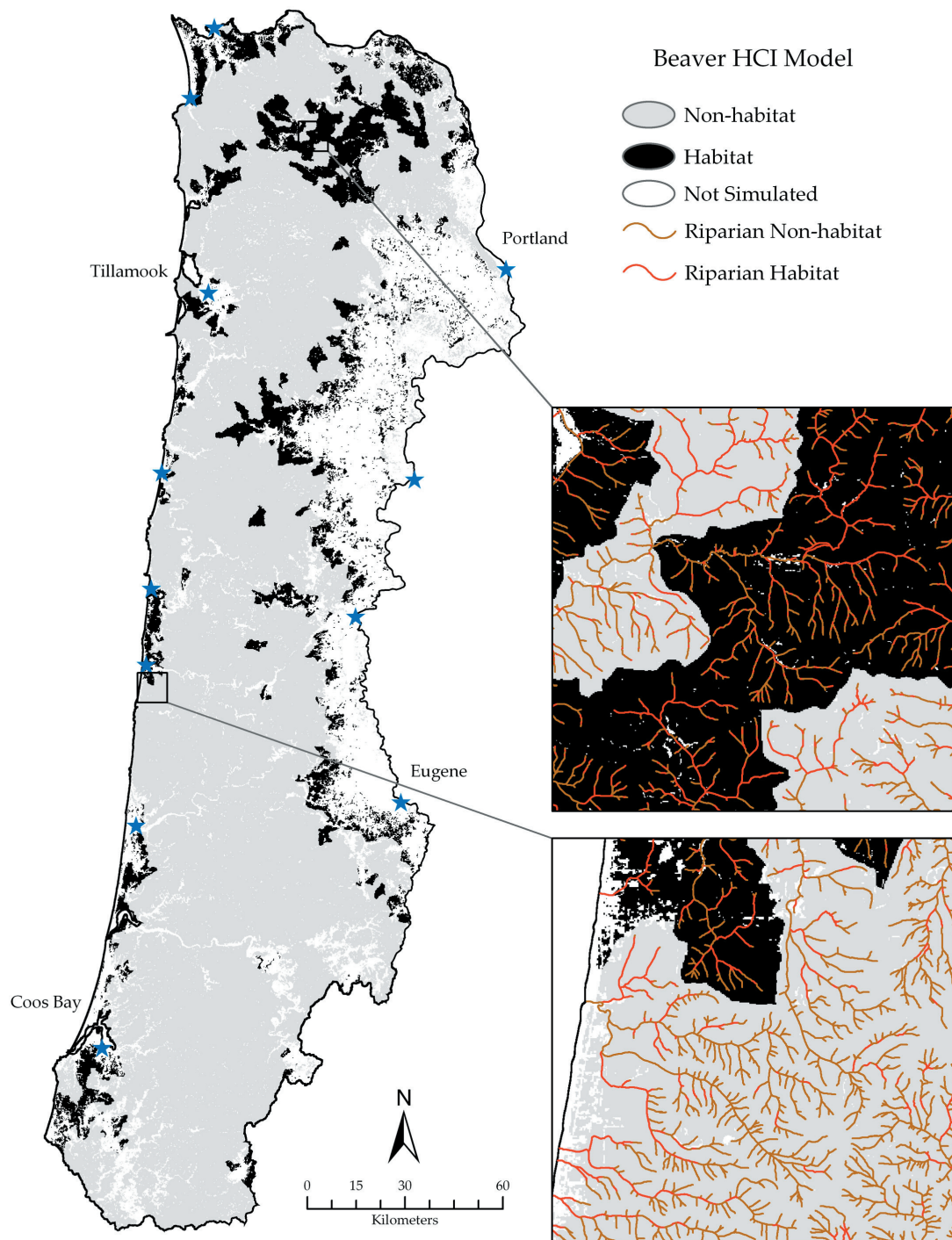


Figure 13. Distribution of moderate to high quality beaver habitat potential in the Oregon Coast Range.

We successfully calibrated LAMPS to WORTS to improve ability of landscape model to represent economic behavior of industrial owners, who provide the majority of the timber in the region.

General Conclusions. The following conclusions are relevant to forest management and biodiversity issues outside the Coast Range.

Forest management policies can strongly control biological diversity. Consequently, it is important to assess policy effects when considering biodiversity and sustainable forestry practices.

Landscape-level, cross-ownership simulations are needed to assess the magnitude of the effects of forest management policies on biodiversity. The problems of forest sustainability must be examined across multiple ownerships. Species and ecosystems do not follow legal boundaries but the policies of different owners set the template for biodiversity in a region. Assessments that focus on only one ownership do not provide a complete picture of the changes in a region and policies developed in a piecemeal fashion in a region can result in loss of diversity or declines in some habitat types.

It is important to recognize fine-scale, stand-level characteristics in estimating biodiversity effects of regional policies. Changes in stand level practices can have landscape and regional impacts on biodiversity. Therefore it is important that the simulation recognize fine scale, stand-level characteristics such as number and size of wildlife legacy trees and tree growth after thinning.

Multiple measures of biodiversity are needed to characterize the diversity of responses of species and ecosystems to forest management. No single measure of biodiversity is adequate.

Spatial analysis can identify those portions of the landscape crucial to conservation of biodiversity, thus reducing the cost of achieving biodiversity objectives. Identifying the headwall areas most likely to make lasting contributions to stream sediments, as done here, will enable policy-makers to make major improvements in protection of salmon habitat at modest cost.

Spatial projections are a powerful way to visualize the effects of management at broad scales. They can effectively communicate to policy makers and the public a comprehensive picture of the interactions of forest management and biodiversity.

We now have the tools to examine other management alternatives and communicate them to policy makers in a variety of ways. We plan to seek funding from various sources to continue our work.

Approach

Our general approach to meeting the objectives relied heavily on existing data bases and models developed in CLAMS. The CLAMS system already had spatial databases on vegetation (see www.fsl.orst.edu/clams/gnn for more information)), topography, streams, watersheds, ownership, roads, and land use. Other databases include forest inventory plots and a compilation of data from several different wildlife and fish habitat studies that have been conducted in the province in the last 20 years. At the core of our models is the Landscape Policy and Management Simulator (LAMPS), a custom GIS model that can simulate how forest structure and composition would change across the entire province under different management practices as well as under the influence of small-scale natural disturbances such as disease and wind. The GIS outputs from LAMPS were then exported to spatial biodiversity models (see below), which estimate habitat quality for plants, animals, and fish based on the simulated stand and landscape information. The sections below describe specific methods.

Landscape Simulations. We simulated landscape dynamics using LAMPS model, (Bettinger et al. In review) which incorporates the diverse objectives of the five major landowners (US Forest Service, Bureau of Land Management, State, Forest Industry and Nonindustrial Private). LAMPS is a spatially-explicit, dynamic simulation model that examines forest development across long time frames with both deterministic and stochastic processes, while recognizing the juxtaposition of land resources (ownership boundaries, streams, watersheds) in simulating activities across the landscape. It emphasizes the projection of forest conditions over time as a result of stand growth and harvest undertaken by the different landowners to achieve their disparate objectives. It was developed in the CLAMS project under the leadership of Dr. Pete Bettinger (Bettinger et al. In review).

Landscape change was simulated for 100 years with a 5-year time step. The model includes changes resulting from timber harvest, including clear cutting and thinning, small stochastic disturbances and land use change. Vegetation development following disturbance was simulated using ORGANON, a growth and yield model, on private forestlands and ZELIG, an ecological succession model, on public lands where forest structure and rotation ages exceed those of the growth and yield model. ZELIG was calibrated to ORGANON over the first 80 years of growth.

In order to recognize various levels of spatial detail across the landscape, a number of GIS databases were needed, including a classified Thematic Mapper (TM) satellite image of forest vegetation, a 10-m digital elevation model (DEM), and databases describing land ownership, land allocations, ecoregions, watersheds, and streams. Three GIS databases (vegetation, streams, and management units) were specifically developed for landscape simulations. The vegetation database was developed by classifying a satellite image based on techniques described in (Ohmann and Gregory 2002).

LAMPS utilizes a hierarchal spatial structure that has aggregations of pixels of like properties at its most basic level aggregated up through nine nested levels to the entire Coast Range, with the use of different members of the hierarchy a function of the owner group being simulated. We describe here those levels of the hierarchy used to represent private landowners:

1) Basic Simulation Units. Homogenous response units (called a Basic Simulation Unit (BSU)) were needed for simulating forest structure, harvest and growth. Each BSU is defined by the aggregation of contiguous 25-m pixels that contain exactly the same landscape information (vegetation class, slope class, distance from stream, owner, management unit, etc.). BSUs average about 0.30 ha in size. Forest structure information (a tree list) was assigned to each BSU using a “nearest neighbor” approach (see Ohmann and Gregory 2002). In that approach, a plot from the 1995-1997 remeasurement of permanent sample plots on non-federal forestlands in western Oregon conducted by the USDA Forest Service’s Forest Inventory and Analysis Unit was assigned to each BSU based on the similarity of the pixel and the plot.

2) Management Units. It is unrealistic to assume that management will occur BSU-by-BSU. Therefore, spatially contiguous BSUs are combined into management units that will be assigned activities at the same time based on ownership, physical features, and vegetation types. Management units average approximately 5 hectares.

3) Harvest Blocks. Clearcutting is the major harvest activity on private land in the Coast Range and an analysis of the recent acreage distribution of clearcuts suggests that most clearcuts would have acreage equal to more than one management unit. Therefore, we aggregate management units into harvest blocks based on the desired clearcut size. However, these clusters of management units are not permanently defined. Rather they are built dynamically based on the specified priorities (such as highest valued stands) and as a result vary over time. (Bettinger and Johnson 2003) describe the dynamic, deterministic harvest block development process within LAMPS.

This spatial delineation results in a very large simulation model—one with over 5,000,000 BSUs for the Coast Range. Therefore, we divided the area into 6 “megasheds” which we simulate individually.

Within LAMPS the set of forest industry landowner is modeled as if they acted as a single group, except for a few owners who wish to use longer minimum harvest ages than the average. We assumed that the goal of the forest industry landowner group in western Oregon is generally to maximize profit, although we recognized that the group as a whole historically has harvested a relatively stable amount of volume over time (Lettman and Campbell 1997).

The LAMPS model lacked an aggregate demand/supply model to guide private actions. In lieu of that approach, we simulate private forest industry behavior as follows: 1) We assume that the forest industry will schedule its most valuable stands first in each

period. To consider management units for clearcutting in a period, the net value of each management unit is calculated. Then, the highest value management units (composed of BSUs of different characteristics) are selected as the “seeds” around which to build clearcuts of sizes to obtain the desired size-distribution of harvest unit sizes. 2) The aggregate level of forest industry activity is modeled by either setting periodic volume targets or utilizing binary search to find the maximum even-flow level of timber harvest volume over time. In recent simulations (including the ones reported here), a two-stage process was used to set the aggregate harvest level: 1) a non-declining yield level was estimated and 2) that level was raised through time, in a later simulation, to ensure that the industry rotation age stabilized at 40-50 years of age.

Management prescriptions for forest industry owners were based on a survey coordinated by the Oregon Department of Forestry and discussions with industry groups and individual owners. We assumed that clearcut stands on forest industry lands would be promptly regenerated with commercial species and with control of competing vegetation, consistent with the state forest practice rules for private forests. We recognized a variety of management intensities on industry land ranging from natural regeneration and harvest to plant, precommercial thinning, fertilization and, perhaps, commercial thinning. The distribution of lands among management intensities were assigned to management units on industry land based on the probabilities of management intensity derived from an unpublished survey of the forest industry, conducted in 1998 by the Oregon Department of Forestry. This survey indicated that most industry lands would be managed at the medium-high or medium management intensities.

A number of alternative management trajectories were then developed for each BSU, reflecting the different management intensities described above, that portray stand characteristics through time along with timber yields. These stand structure and timber yields derive from the ORGANON model (Hann et al. 1997). These alternative management trajectories, along with their yields and costs, provide the set of choices available to owner groups to maximize their wealth in the context of the demand relationships faced through time.

Biodiversity Indicators. Biodiversity responses to the landscape are modeled using a set of spatial focal species habitat capability index models and stand and landscape structure indices. These models are developed as expert opinion models that use the spatial information from the LAMPS model as inputs (McComb et al. 2002). The model outputs are index scores that range from 0 to 1 and represent the capability of the patch and surrounding landscape to provide conditions important to survival and reproduction of a particular species or the level of stand structural development. The spatial resolution of these models is 25 meters and they are run on the full extent of the CLAMS study area using a 5-year time step. Models typically contained both a stand or patch-level structure component and a landscape component. A 3 by 3 grid of 25-meter cells was used to assess the stand level habitat and the average values were then assigned to the center pixel. If landscape context was included in the model the area around the 3 by 3 grid was assessed for habitat quality and an index score then assigned. The final index score

for the center pixel was a weighted combination of the stand and landscape level indices. The 3 by 3 grid is then moved one pixel and the whole process is repeated until every pixel is assessed. In some cases, we were able to test the predictions of the models using independent existing data on the occurrence of wildlife species (McComb et al. 2002). In most cases this type of information did not exist and models were evaluated by at least two independent ecologists. The reviews were then used to modify the models. In all cases we conducted a sensitivity analysis to determine the relative importance model variables. The stand structure indicator is an old-growth index model (Spies and Franklin 1988) that is based on density of large trees, variation in tree size, density of large snags, volume down wood and stand age.

Additional landscape level metrics were calculated using Fragstats (McGarigal and Marks 1995). A small set of key landscape metrics, such as patch composition, patch size, edge density and landscape diversity were calculated. Patch types were developed from the fine scale stand structure and composition data provided in the spatial model of initial vegetation conditions (Ohmann and Gregory 2002). A total of 34 different patch types were used. They represented 4 different canopy tree sizes, 3 classes of species composition based on hardwood/conifer proportions, tree canopy cover, and density of large remnant trees in open and young forest stands.

Additions to the CLAMS Modeling Capability through this Project.

Economic Behavior on Forest Industry Lands. As mentioned above, we lacked an aggregate supply/demand model of private landowner behavior in the LAMPS model. To overcome that problem, we have developed the capability to utilize the harvest decisions of the Western Oregon Timber Supply System (WORTSS), an intertemporal model of private timber harvest and forest management decisions in western Oregon. In that matching, we turned to the characteristics of the harvest that might have the most significant ecological effect. The primary purpose of the LAMPS model is to enable people to understand the ecological implications of different policies. In the case of private industry, these effects might be most simply registered through two measures: 1) amount, size, and spatial distribution of clearcuts through time and 2) final harvest age. It might be argued that clearcutting (and the associated roading) provides the most significant disturbance associated with management of forest industry lands. Final harvest age is an indicant of the ages and sizes of trees that might be on the forest industry landscape. (This last sentence may be fairly subtle for some readers. It assumes that FI cuts oldest first and doesn't maintain any inventory older than harvest age.)

We wanted the LAMPS simulations match the forest industry harvest behavior from WORTS period-by period by megashed. Because of differences between the two models in the amount of forest land in each megashed, we utilized the *percentage* of acres clearcut each period in a megashed from the WORTS analyses.

In addition, we also wished to match future final harvest ages. We accepted differences in final harvest ages in the first few periods (due to different starting inventories) but

we wanted the two models to give similar results in the long run. In some megasheds, matching final harvest age meant that we had to harvest a higher percentage of the industry forest in LAMPS than the percentage found in the WORTS analysis because of some differences in how the models allocate harvest decisions to the available acres.

Shifting from the older approach to estimating forest industry harvest behavior (nondeclining yield modified by the desire to have a final harvest age over time between 40 and 50 years) to the newer approach (match WORTS percentage harvested per period and long-term final harvest age) affected period-to-period fluctuation in harvest more than the overall average percentage of acres harvested.

In sum, we have successfully integrated an economic behavior model for the forest industry into LAMPS. Future CLAMS analyses can utilize this capability to better capture likely industry behavior.

Carbon Flux. We estimated carbon flux using LAMPS output. Tree carbon (C) was estimated for each 5-yr period, by owner, by 5-yr age class for softwood, hardwood, and mixed species stands. Soil carbon was also estimated but we did not estimate forest floor carbon or understory carbon. We tracked harvested C, processed C, and C lost to manufacturing, loss of C to wood products each period, and gain C in wood products each period.

An initial estimate of C stored in wood products in the Coast Range was made. This will give us an estimate of the offsite carbon storage for each 5-yr period, to which I add the onsite C. Biomass yields for snags and coarse woody debris (the only component of slash that we track) were calculated for each time period and added to the carbon onsite C each period. The decay functions used for the snags and logs come from a modified version of a coarse woody debris model (Mellen and Ager 2002).

The second method to estimate carbon flux was to use landscape-scale carbon model (LANDCARB). LANDCARB is a model that calculates changes in carbon stores at the landscape level. The existing version of LANDCARB (Cohen et al. 1996) considered only two highly aggregated pools of carbon, live and dead stores and assumed changes in mineral soil carbon were minimal. We upgraded this model to consider a finer breakdown of live and dead carbon pools (i.e., boles, branches, roots, leaves and their counterparts of detritus) and mineral soil carbon. Tests of the new model version indicate that the dynamics of live pools of LANDCARB match those from a stand-level model (STANDCARB, Harmon and Marks 2002). We are in the process of testing the degree the dead and soil pools match this detailed model and this has taken longer than anticipated. The improved version of LANDCARB has been used to examine the effects of increasing the interval between harvests and the legacy of carbon left on the site. Carbon stores increased as the interval between harvests increased and as the legacy left after harvest increased. This generally matches the results found using LAMPS. These results were reported at the 10th Cary Conference and the 4th North American Forest Ecology Workshop. We are continuing to test the model and once the dead and soils

tests are completed we will run it for the entire study area for the conservation strategies we assessed. In a related piece of work we have created a disturbance history database for western Oregon that goes back several 100 years. This was based on recent thematic mapper-based disturbance histories and a 1930's map of forest condition. This database is essential to have given that future carbon stores are highly dependent on the pools left by several generations of disturbances (i.e., legacies can last 100+ years).

Habitat Models. We developed new indicators of biological diversity for three focal species, canopy lichens (e.g. *Lobaria spp.*), red tree vole (*Phenacomys longicaudus*) and beaver (*Castor canadensis*). The models were developed as multi-scale habitat capability models using information in the literature and expert opinion following the general approach outlined in McComb et al. 2002). The basic components of these models described in Table 1. For the lichen model habitat capability increases with stand age, density of remnant trees, and proximity to source areas of propagules (thali). For the red tree vole habitat capability increases with diameter of the stand, percentage of Douglas-fir in the stand, canopy closure and canopy heterogeneity. For the beaver habitat capability increases with decreasing stream gradient, decreasing stream order and increasing valley width up to about 25 meters, where the valley width effect levels off. The beaver model is based entirely on physical features of the stream and not on current vegetation.

We had originally intended to develop a habitat capability model for Roosevelt elk but were unable to complete the task given the difficulties in estimating some of the variables needed for the model. Populations of Roosevelt elk are increasing in western Oregon (ODFW 2003). Given the myriad of values placed on Roosevelt elk, it is important to know where and when habitat quality for the species might be sufficient to provide the opportunity for population growth, maintenance, or reduction. In western Oregon, forage quality and quantity seem to be particularly important in influencing elk habitat quality (Cook 2002, Davis et al. 2003).

Although thermal cover has been purported to influence habitat quality for elk in previous habitat quality models (Wisdom et al. 1986), recent work by (Cook et al. 1998) question this assertion. Consequently, models of elk habitat quality should place more emphasis on forage quality and quantity less on thermal cover and the juxtaposition of food and cover across a landscape. Hence, the challenge is to identify forage plants selected by elk in the region and develop methods to project the availability of those plants across the Oregon Coast Range. Projecting shrub and small tree occurrence across the Coast Range is possible using the GNN approach of (Ohmann and Gregory 2002), but to date this method is restricted to prediction of tree species. We also have the potential to predict shrub cover by broad species groups, but not shrub biomass by combinations of forage species.

Landslide and debris flow models. A model was developed that characterizes channel susceptibility to debris flow impacts and hillslope susceptibility to landslides. Research on landslides and debris flows in humid mountain environments (e.g., Benda and Cundy 1990, Montgomery and Dietrich 1994) aided the development of the model. Knowledge

gained from these and other studies, together with constraints imposed by available data, guided our choice of model parameters for characterizing debris flow locations over broad areas. Available data consist of 10-meter DEMs, forest cover derived from 30-meter-resolution satellite imagery (Ohmann and Gregory 2002), and roads from 1:24,000 US Geological Survey digital line graph (DLG) data. With the resolution of these data, we used field surveys and air-photo inventories of landslides and debris flows (Bush et al. 1997, Robison et al. 1999).

Except for very limited spatial extents, it was not feasible to quantify, or even identify, all of the factors that can affect landslide initiation or the extent of debris flow runoff. We therefore took a probabilistic approach to developing a model that could be applied over large areas. We characterized hillslopes by the probability of debris flow initiation and traversal, and channels by the probability of debris flow scour, transitional flow, and deposition. The model characterizes probabilities relative to two of the main attributes that control landslide initiation and debris flow runoff: topography and forest-cover (e.g., Sidle et al. 1985, Soeters and van Western 1996). Probabilities estimated by the model are based on the proportion of observed sites with similar attributes that were similarly affected by debris flow occurrences based on landslide and debris flow mapping. The model calculates probabilities based on spatial proportions. In essence, if one were to randomly select a site on a map containing landslide initiation sites plotted as points, the model estimates the probability that the selected site lands on a plotted initiation point. Likewise, if one were to randomly choose a point in the channel network, the model estimates the probability of that point having been mapped with debris flow scour or deposition.

Deliverables

1. Set of technical papers will be submitted to the journal *Ecological Applications* in the spring of 2004. These papers will communicate the results to a technical audience and provide a critical scientific review of the work. The following papers are being prepared:

1. Assessing forest biodiversity policies across ownerships with spatial models: Introduction and synthesis of findings—Thomas Spies (PNW Research Station) and K.N. Johnson (Oregon State University) et al.
2. Current patterns of biological diversity in a multi-ownership region based on vegetation composition and structure. Janet Ohmann and T. Spies (PNW Research Station), M. Gregory (OSU)
3. A landscape management and policy simulator for assessing ecological and socio-economic effects of forest management—Pete Bettinger (University of Georgia), K. Norman Johnson (Oregon State University)
4. Effects of current and alternative forest biodiversity policies on forest resources,

- timber production and Socio-economic conditions—K. Norman Johnson (OSU) Garber-Yonts (PNW), Kline (PNW) et al.
5. Assessing biodiversity with multiple indicators. T. Spies and B. McComb (EPA) et al.
 6. Landslide and debris flow risk and implications to aquatic habitat and forest policy—Dan Miller (Earth Systems Institute), Kelly Burnett, Gordon Reeves et al.
 7. Aquatic habitat potential and trends in a multi-ownership region—Kelly Burnett and Gordon Reeves (PNW Research Station).
 8. Lessons learned—Sally Duncan (Oregon State University), K.N. Johnson and T.A. Spies
-
2. PowerPoint presentation of results. This will be put on the CLAMS website and made available to managers and policy makers and the general public
 3. PNW Science findings on CLAMS to be submitted in 2004. This will reach an audience of several thousand across the U.S., many of whom are managers and policy makers
 4. PNW Innovation Fair (February 25, 2004), Portland Oregon. World Forestry Center, Miller Hall, 4033 SW Canyon Road Portland, OR. Sponsored by PNW Research Station - Western Forestry and Conservation Association. A set of presentations on new innovations in natural resource science and management for forest managers and policy makers.

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References

- Benda, L. E., and T. W. Cundy. 1990. Predicting deposition of debris flows in mountain channels. *Canadian Geotechnical Journal* **27**:409-417.
- Bettinger, P. S., and K. N. Johnson. 2003. Spatial scheduling of forest management activities using a dynamic deterministic harvest block aggregation process. *Journal of Forest Planning* **9**:25-34.
- Bettinger, P. S., M. Lennette, K. N. Johnson, T. A. Spies, A. Herstrom, J. P. Brooks, and J. Sessions. In review. A landscape management and policy simulator for assessing ecological and socio-economic effects of forest management. *Ecological Modelling*.
- Bush, G., C. McConnel, C. C. Loyd, K. Musser, B. Metzger, and H. Plumley. 1997. Assessment of the effects of the 1996 flood on the Siuslaw National Forest. USDA Forest Service, Siuslaw National Forest, Corvallis, OR.
- Cohen, W. B., M. E. Harmon, D. O. Wallin, and M. Fiorella. 1996. Two decades of carbon flux from forests of the Pacific Northwest. *BioScience* **46**:836-844.
- Cook, J. G. 2002. Nutrition and food. Pages 259-349 *in* D. E. Toweill and J. W. Thomas, editors. *North American Elk: ecology and management*. Smithsonian Institution Press, Washington D.C.
- Cook, J. G., L. L. Irwin, L. D. Bryant, R. A. Riggs, and J. W. Thomas. 1998. Relations of forest cover and condition of elk: a test of the thermal cover hypothesis in summer and winter. *Wildlife Monographs* **141**.
- Davis, R. W., J. G. Cook, R. C. Cook, L. C. Bender, and L. Irwin. 2003. Baker Lake relicensing: elk forage mapping study. Internal Report National Council on Air and Stream Improvement.
- Hann, D. W., A. S. Hester, and C. L. Olsen. 1997. ORGANON user's manual: Edition 6.0. Department of Forest Resources Oregon State University, Corvallis, Oregon.
- Harmon, M. E., and B. Marks. 2002. Effects of silvicultural treatments on carbon stores in forest stands. *Canadian Journal of Forest Research* **32**:863-877.
- Lettman, G., and D. Campbell. 1997. Timber harvesting practices on private forest land in western Oregon. Oregon Department of Forestry, Salem, Oregon.
- McComb, W. C., M. T. McGrath, T. A. Spies, and D. Vesely. 2002. Models for mapping potential habitat at landscape scales: An example using northern spotted owls. *Forest Science* **48**:203-216.
- McGarigal, K., and B. J. Marks. 1995. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-GTR-351 United States Forest Service, Pacific Northwest Research Station.
- Mellen, K., and A. Ager. 2002. A coarse wood dynamics model for the western Cascades. Pages 503-516 *in* W. F. J. Laudenslayer, P. J. Shea, B. E. Valentine, C. P. Weatherspoon, and T. E. Lisle, editors. *Symposium on the ecology and management of dead wood in western forests*. Pacific Southwest Research Station, Reno, Nevada.
- Montgomery, D. R., and W. E. Dietrich. 1994. A physically based model for the topographic control of shallow landsliding. *Water Resources Research* **30**:1153-1171.

- Ohmann, J. L., and M. J. Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in coastal Oregon, USA. *Canadian Journal of Forest Research* **32**:725-741.
- Robison, G. E., K. E. Mills, J. Paul, J. Dent, and A. Skaugset. 1999. Storm impacts and landslides of 1996: Final Report 4. Oregon Department of Forestry, Salem, OR.
- Sidle, R. C., A. J. Pearce, and C. L. O’Laughlin. 1985. Hillslope stability and land use. American Geophysical Union, Washington, D. C.
- Soeters, R., and C. J. van Western. 1996. Slope instability recognition, analysis, and zonation. Pages 129-177 *in* A. K. Turner and R. L. Schuster, editors. Landslides investigation and mitigation. National Academy Press, Washington D. C.
- Spies, T., and J. F. Franklin 1988. Old-growth and forest dynamics in the Douglas-fir region of western Oregon and Washington. *Natural Areas Journal* **8**:190-201.
- Spies, T. A., G. H. Reeves, K. M. Burnett, W. C. McComb, K. N. Johnson, G. Grant, J. L. Ohmann, S. L. Garman, and P. S. Bettinger. 2002. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. *in* J. Liu and W. W. Taylor, editors. Integrating Landscape Ecology into Natural Resource Management. Cambridge University Press, Cambridge, United Kingdom.
- Wimberly, M. C., T. A. Spies, C. J. Long, and C. Whitlock. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. *Conservation Biology* **14**:167-180.
- Wisdom, M. J., L. R. Bright, C. G. Carey, W. W. Hines, R. J. Pederson, D. A. Smithey, J. W. Thomas, and G. W. Witmer. 1986. A model to evaluate elk habitat in western Oregon. R6-F&WL-216-1986, USDA Forest Service.

APPENDIX:

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