Integrating Natural Disturbances and Management Activities to Examine Risks and Opportunities in the Central Oregon Landscape Analysis

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Introduction

Management of diverse landscapes in the interior Pacific Northwest requires consideration of the integrated effects of natural disturbances and management activities on natural resource conditions. The opportunities for managing lands depend on widely varying objectives of owners, vegetation conditions, environmental settings, natural disturbances and other factors. Likewise, the risks that land managers encounter include natural disturbances, unforeseen consequences of management activities, changing political, social, and economic environments, and others. Land managers and those who influence or set land management policy need to examine the short and long-term potential effects of different management approaches using methods that: 1) integrate the effects of natural disturbances and management activities on vegetation and resource conditions, 2) consider landscape-wide characteristics and trends across all ownerships, 3) maximize the effects of limited budgets and personnel through cooperation across agencies and ownerships, 4) use a modeling approach that is flexible, powerful, easy to understand, and integrative.

Issues

A partnership of federal and state agencies and non-government organizations developed a shared effort to generate landscape-wide vegetation data, landscape models, and related information. The Interagency Mapping and Assessment Project (IMAP) addresses several landscape assessment and analysis issues, including 1) limited and declining funds to perform landscape assessments and analyses of potential effects of various management options on resources of interest, 2) an increasing lack of highly skilled people to perform landscape analyses, 3) a desire to avoid conflicting answers to broad questions that cross ownerships and interests, 4) the need for integrated analyses that include many management and natural disturbances across a broad range of ownerships, vegetation conditions, and environments, 5) a consistent basis for monitoring the effectiveness of management activities at achieving policy goals across large landscapes, 6) the desire for relatively simple and understandable approaches to landscape analysis and policy evaluation. Key issues for all these landscape analysis, planning, and assessment activities include, among others, fire risks, forest conditions, wildlife habitats, old forests, timber products. In addition, policy makers and others want to consider long-term sustainability of landscape resources and conditions given various management approaches.

Integrated landscape models

Landscape simulation models may be used to assist in understanding the potential reaction of large landscapes to various management and policy approaches (e.g. Bettinger et al. 2005; Hann et al. 1997; Hemstrom et al. 2004; Mladenoff and He 1999; USDA and USDI, 2000). Advances in modeling techniques, computer technology, and geographic information systems (GIS) have made it possible to model large landscapes at increasingly finer scales of spatial and temporal resolution (Barrett 2001, Bettinger et al. 2005). In much of the Pacific Northwest of North America, resource planning models have focused primarily on conifer succession and management while representing other ecosystem elements as byproducts (e.g., Johnson et al. 1986; Alig et al., 2000). Although progress has been made in the formulation of multi-objective goals in landscape simulations (e.g., Sessions et al. 1999; Wedin 1999), there remain many challenges to building landscape planning models that include all of the important disturbance processes that influence change. For example, previous efforts have often not included widespread, chronic disturbances such as ungulate herbivory. The net, synergistic effects of various disturbances (e.g., fire, insects, management activities, and large herbivores) across a large ecologically diverse landscape are of particular interest to policy makers, scientists, land managers, and others. Our approach treats vegetation as discrete types and management activities and natural disturbance as transitions among those types to project the long-term net effects of alternative management scenarios across a large landscape, building on the work of Hann et al. (1997) and Hemstrom et al. (2004).

Study Area

The Central Oregon Landscape Analysis (COLA) study area consists of about 275,000 ha in 7 watersheds (5th field hydrologic unit code drainages or HUC5s) in the southern portion of the upper Deschutes subbasin (fig. 1). Ownerships are mixed and include about 142,000 ha of federal general forest, 24 000 ha of federal late successional forest reserves established by the Northwest Forest Plan (USDA, USDI 1994), 51,000 ha of wilderness and similar areas, and 59,000 ha of private lands. Our ownership/allocation data includes two classes of private land (forested and non-forested) that were combined for this study. In addition, we didn't have maps of wildland-urban interface area (WUI) at the time of our analysis, so we used private lands as a proxy for WUI. Those who attend the workshops agreed that this was generally reasonable, especially since this effort is to test the concept of using landscape models to help people develop input to land management planning efforts.

Land ownership and allocation

We divided the land into 4 different ownership/allocation combinations that changed the way management activities were implemented and which activities were allowed. Federal general forest was forested land managed by the USDA Forest Service or USDI Bureau of Land management and made up about 54% of the area (about 123,000 ha). General forest land was outside reserves and can be managed with a variety of treatments for multiple uses. We did not allow stand regeneration harvests (clearcuts or shelterwoods) in general forests because those practices are not likely to be used in the near future on federal general forests. Private lands include small ownerships and industrial forestry ownerships that make up about 28% of the area (about 64,000 ha). These could be managed with a wide variety of treatments. For the purposes of this exercise, however, we assumed that private lands were a proxy for wildland-urban interface areas (WUI). WUI was an important stratification because fuel treatments are generally the highest priority management activity on private lands in this landscape. Unfortunately, at the time of our analysis we did not have a useful locally-generated map of WUI, so used private lands as a reasonable surrogate. In other, less developed landscapes, private lands might well be focused on forest products or other resources. A consequence of our use of private lands for a surrogate for WUI was a potential over-estimate of the rate of fuel treatments and an under-estimate of other treatments on private lands in the study area.

Reserves were publicly owned lands (usually managed by the Forest Service or BLM) designated for special consideration and management (3% or about 7,000 ha). These are usually late successional reserves under the Northwest Forest Plan (USDA,USDI 1994) or other similar areas. These might, in some scenarios or under some conditions, be managed with thinning or other fuel reduction treatments. However, they are generally designated for emphasis on old forest structure and similar conditions. Wilderness was legally designated land managed for natural characteristics and included wilderness, State Parks, and similar areas (15% or about 34,000 ha). Only natural disturbances (wildfire and insect/disease activity) were modeled in wilderness.

Potential Vegetation

We recognized 8 different potential vegetation types, based on maps provided by the Deschutes National Forest and, for gaps in those data, information gathered during the Interior Columbia Basin Ecosystem Management Project (Hann et al. 1997). These range from the lowest elevation juniper woodlands to alpine parklands:

1. Juniper woodland: Shrub steppe areas generally capable of supporting grass, shrubs and juniper.

2. Dry ponderosa pine: Areas capable of supporting Ponderosa pine but not, generally, Douglas-fir or other tree species. These are the transition areas between the forest and juniper woodland or shrub/steppe.

3. Mixed conifer dry: Dry grand fir and Douglas fir potential vegetation types. Historically these areas consisted mostly of large, open, ponderosa pine stands maintained by frequent ground fire (average 10-20 year fire return interval).

4. Mixed conifer moist: Areas typically dominated by a variety of species, including ponderosa pine, Douglas-fir, white fir, sugar pine, incense cedar, and others. Under historical conditions, these somewhat wetter areas had less frequent natural fire than the dry mixed conifer type and were often dominated by large, widely spaced ponderosa pine.

5. Lodgepole pine dry: Lodgepole pine stands growing primarily on pumice soils. Soil and microsite conditions restrict other conifer species.

6. Upper montane cold: High elevation types dominated by Engelmann spruce, mountain hemlock, white fir, subalpine fir, lodgepole pine and other species. These types are mostly restricted to reserves or wilderness in the study area.

7. Upper montane moist: High elevation types that reflect a west-side influence. Pacific silver fir, noble fir, Douglas-fir, and other species occur. These types are mostly restricted to reserves or wilderness in the study area.

8. Subalpine parkland: Very high elevation areas of tree islands dispersed in an alpine shrubland and grassland. These types are mostly restricted to reserves or wilderness in the study area.

Methods

Existing vegetation

We developed 337 combinations of vegetation structure classes (Table 1) and cover type (Table 2) to represent existing and potential future vegetation conditions. Cover types were based on the dominant species in the upper-most canopy layer and included several classes of developed land (e.g. urban, agriculture, etc.). Structure class depended on the size, density per unit area and canopy layering, for forested lands and on the dominant life form and canopy cover for shrublands and grasslands. Our structure classification was carefully designed to address important issues regarding wildlife habitats (Johnson and O’Neil 2001), fire and fuels, and various commercial forest products. Combinations of cover type and structure class within potential vegetation types formed the basic vegetation classes in our models.

Current vegetation data was developed using Gradient Nearest Neighbor (GNN) methods as described by Ohmann and Gregory (2002). This process imputed approximately 1600 inventory plots to 30m pixels using a statistical relationship between LANDSAT-TM imagery and other geographic data with conditions of pixels at the plot locations. While GNN works reasonably well for forested lands in the Pacific Northwest, it has not been developed or tested for grasslands, shrublands, and other non-forest vegetation. Where GNN data were unavailable, we used vegetation composition and structure attributes from Oregon GAP (2006). Cover and structure data were summarized to stateclasses within strata of watershed, ownership/land allocation, and potential vegetation type. These estimates of area by stateclass by stratum were the initial conditions for our modeling process. Since our vegetation stateclasses did not distinguish single versus multi-story forest structure, we assumed that all open stands (< 40% canopy cover) were single story and all dense stands (>60% cc) were multi-story. In addition, we assumed that large tree stands of medium density were evenly split among single story and multi-story structure and that all very large tree stands with more than 40% canopy cover were multi-story.

State and Transition Models

We use state and transition models (STM) to project the integrated effects of natural disturbances and management treatments on vegetation. Vegetation composition and structure within plant association strata define each “state”. These states are connected by transitions that indicate either the effect of successional vegetation development over time, or the effect of disturbance (Hemstrom et al. 2004). This approach expands transition matrix methods that represent vegetation development as a set of transition probabilities among various vegetative states (e.g., Horn 1975; Cattelino et al. 1979; Noble and Slatyer 1980; Westoby et al. 1989; Laycock 1991; Keane et al. 1996; Hann et al. 1997). For example, grass/forb communities be dominated by closed forest following tree establishment over a period of time or might remain as grass/forb communities following wildfire (fig. 2). Alternatively, management activities or low severity wildfire may generate more open forest conditions. State changes along the successional, time-dependent paths are usually deterministic and without disturbance or management all the vegetation would ultimately accumulate in one state. Because disturbances or management activities may change the course of vegetative development at any point, very little or no vegetation may actually accumulate in the state representing the end point of succession.

We developed and ran our models with the Vegetation Dynamics Development Tool (VDDT; Beukema et al., 2003). VDDT has been used in several landscape assessments and land management planning efforts in the interior northwestern United States (e.g. Keane et al. 1996; Hann et al. 1997; Merzenich et al. 2003) and elsewhere (Hann and Bunnell 2001, Merzenich and Frid 2005). Although VDDT is a non-spatial model, managers and others generally wish to examine the spatial distribution of vegetation conditions and disturbances in some spatial way. Consequently, we run models using strata of land ownership and allocation and potential vegetation types within watersheds so that we may display results about the spatial distribution of landscape characteristics without implying pixel or stand-level accuracy. Watershed-scale results can be aggregated for broader analysis, but are likely fine enough for most mid-scale (e.g. 100000 ha and larger land units) assessments, planning efforts, and policy analysis.

Assumptions

The models we use and assumptions we make to run different scenarios are reflect how we think the ecosystem might work based on expert opinion, the existing literature, and some finer-scale stand-level silvicultural models (like the Forest Vegetation Simulator or FVS). We think our estimates are reasonable, but these are only models. Our stand treatment prescriptions need to be further tested and refined to see if they would actually be suitable for implementation on the ground and produce the results we assumed. We did not factor in the economic costs and returns that might make such treatments unrealistic in some landscape situations. Rather we assumed that those treatments would be implemented even if they did not produce positive net revenue. In addition, real life may produce results much different than our estimates because: 1) odd or unusual events could occur, 2) we may not understand the system sufficiently well, 3) there may be some error in our models that we don’t know about, 4) we haven’t factored in climate change that may alter fire, insects/disease, and other disturbances, and 5) people probably won’t follow any one of our scenarios. But, the scenarios are useful to illustrate the kinds of things that would likely happen given a particular management approach. They also help us understand where our knowledge about the ecosystems is most critically incomplete.

<u>Wildfire assumptions</u>. We used wildfire probabilities for reference conditions from the interagency LANDFIRE effort (Shlisky and Hann 2003, LANDFIRE 2006). Reference conditions were assumed by Shlisky and Hann (2003) and LANDFIRE (2006) to be the disturbance and vegetation characteristics that existed over a long period of time prior to about 1850 and, consequently, prior to wildfire suppression (Table 3). We modified reference condition wildfire probabilities for the current period, which includes fire suppression, through discussions with local fire managers and other experts. In keeping with the estimates provided by LANDFIRE (2006), we split wildfire into three severity levels, depending on the degree of mortality in above-ground plants (low severity killed 0-25%, mixed severity killed 25-75%, and high severity killed more than 75%).

Since the acreage burned by wildfire varied substantially from year to year due to the effects of weather, fuel conditions, and chance, we used random streams of fire years to model year-to-year variability. We assumed that wildfire variability changes with landscape scale, being higher in small areas (e.g. watersheds of 14000 to 90000 ha) and lower in large areas (e.g. the Deschutes subbasin of >800000 ha). The LANDFIRE (2006) wildfire probabilities were developed for very large landscapes with, consequentially, relatively low annual variability. After discussions with local fire experts and examination of the relatively few data available, we assumed that 80 % of years produce normal or average amounts of wildfire, 15 % generate high amounts of wildfire, and 5 % produce extreme amounts of wildfire at the scale of the entire upper Deschutes subbasin. Essentially, every hectare burned in a normal year, 16 ha burned in a high year, and 200 ha burned in a severe year. At the scale of watersheds, however, we assumed that even in severe years most of wildfire occurs in large fires that may impact only a few watersheds, but burn most of the area within the affected watersheds. At this scale, we assumed that 95 % of years produced normal amounts of wildfire, 5% produced high amounts, and 1% produced extreme amounts (Table 4). However, for every hectare burned in a normal year at the watershed scale, 65 ha burned in a high year, and 810 ha burned in a severe year. We ran 30 simulations of each scenario using random stream of fire years and display the average and variability of wildfires.

Treatment assumptions. We used a fixed set of silvicultural treatments to model our scenarios. These may not be the most effective possible. We suspect that with more time and careful consideration of silvicultural options, a more effective set of treatments might be designed. In addition, our modeling process does not optimize treatment selection or timing. The treatments we used were simplified in terms of timing, exact effects at the stand level, and other factors compared to the full suite of treatments that might be applied. However, our treatments represent typical, commonly implemented kinds of activities that might occur on the various ownerships and allocations in the study area based on discussions with local land managers and silviculturists.

Regeneration harvests were shelterwood or clearcut harvests that replaced the existing stand. These treatments were not applied on federally managed lands, a reflection of current management policy. Regeneration harvests were applied to private lands. Salvage was harvest of dead trees following stand-replacement wildfire or insect outbreaks. Salvage occurred on federal general forest and private land, but not in reserves or wilderness. We assumed that areas that had been harvested with regeneration methods or salvaged would be planted to quickly become seedling/sapling stands.

Several thinning and partial harvest prescriptions were used. Precommercial thinning was assumed to be stocking control of young stands at age 15. Stands were thinned from closed to open condition. Commercial thinning was harvest of trees across all diameter classes to reduce stand density to open structure. We assumed that trees greater than 51 cm DBH[1] could be harvested on private lands but not on lands administered by the Forest Service, again a reflection of Forest Service land management policy. Partial harvest was commercial thinning from below in closed stands to reduce stand density, favor fire-resistant tree species (e.g. ponderosa pine), and increase average tree diameter. The resulting stands were open, single-story, and less susceptible to stand replacing fire. We distinguished several different kinds of partial harvests: 1) harvest of some trees in stands that were generally less than 13 cm DBH; 2) a heavy commercial thin or selection cut harvest applied to large stands where most trees are over 13 cm DBH; 3) a heavy commercial thin or selection cut applied to older, dense, multi-story stands that move them from a high density to a medium density while maintaining multi-story structure and conditions favored by some wildlife species; 4) a heavy thinning of medium density stands to produce open, single-storied structure; and 5) commercial thinning or selection treatments applied to open stands to maintain open conditions. For purposes of simplicity, we do separate these different partial harvests in the following discussion of scenario effects.

Several treatments were designed solely to reduce fuels. Mechanical treatments to reduce fuels were applied to closed stands beyond the age of precommercial thinning. Closed stands were converted to open, low density conditions. Prescribed fire was underburning applied to low density stands of fire tolerant

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[1] Diameter at breast height, 1.37 m.

species (e.g. ponderosa pine) to maintain open stands of fire-tolerant tree species. We assumed a small portion of these inadvertently became mixed or high severity fires.

For the purposes of reporting, we combined regeneration, partial harvest, and commercial thinnings into a category called "commercial harvest;" harvests that might produce enough saw-log sized material to be of commercial interest. We combined pre-commercial thinning and mechanical fuel treatment into a "non-commercial harvest" because the majority of material available from treatment would likely be too small to be used for saw timber. We also included a category for prescribed fire treatments that did not produce material for harvest, but may have other social (e.g. smoke) and economic (e.g. forest worker wages) effects.

Calibrating and calculating transitions

A significant objection to using state and transition models has been that they often rely on expert opinion for transition paths, rates, and probabilities (Hemstrom et al. 2004). Stage et al. (1995) and Hemstrom et al. (2004) suggested using forest stand growth models to calibrate state and transition models. Empirical data (e.g. inventory plots) could be projected in a stand growth model and the rates of growth could be used to calibrate the time required for growth and succession-related transitions in a state and transition model. Likewise, stand growth models that allow projections of the results of management activities or other disturbances (e.g. wildfire) could be used to estimate the most likely pathways of vegetation change following disturbance and the yield streams resulting from management activities.

We used the Forest Vegetation Simulator (also known as the Prognosis Model; Stage 1973, Wycoff et al. 1982, Crookston et al. 1999) and the Landscape Modeling System (McCarter 1997, McCarter et al. 1998) to simulate growth and development of inventory data. The inventory data were tree lists from plots collected as part of the Forest Inventory and Analysis (FIA; Anonymous 1992) and Continuous Vegetation Survey (CVS; Max et al. 1996) inventories collected by the USDA Forest Service. These inventories consist of plots collected on a fixed grid across the United States (FIA) and on National Forest lands in Oregon and Washington (CVS). Detailed data on vegetation structure and composition were collected on each plot and plots are re-measured over time. We assembled the inventory plots for our study area (approximately 1500 plots) and developed classification rules to place each plot into one of our vegetative states. We used the FVS model to grow the trees from each plot and recorded how long it took for plots to change from one class to another and the pathways for class change. We used then estimated average transition times and paths for the deterministic growth-related transitions. We also designed a small set of standard management treatments (regeneration harvest, commercial thinning, partial harvest, pre-commercial thinning, prescribed fire, and mechanical fuel treatment) and simulated these treatments on the plots in each forested stateclass. We classified the tree lists that resulted from treatment into stateclasses and used those estimates to generate the dominant transition paths resulting from management activities. These stand treatment simulations also provided estimated yield streams from each treatment, which we used to assign estimated yield streams to our VDDT model simulations. Because we had a limited number of inventory plots in each stateclass, we lumped several of our modeled silvicultural treatments into each of the relatively few treatments modeled with FVS.

Public input and scenario development

We held meetings in Bend and Klamath Falls, Oregon, in September 2005 to develop a set of management scenarios. Local members of the public and representatives from government land management agencies were invited to help us develop reasonable alternatives that might address differing perspectives about how the federal lands in the area might be managed. We used the results of these meetings to design four management scenarios for modeling. All scenarios were run for 300 years and 30 Monte Carlo simulations to allow the occurrence of rare events and generate estimates of long-term disturbance variability and forest development trends.

Scenario 1 - Active fuel treatment in wildland/urban interface, no management on federal lands

The primary emphasis was to actively treat fuels on private land (WUI) with at least 25% of the dry lodgepole pine areas treated with partial harvests, precommercial thinning, mechanical treatment, commercial thinning per decade. The long term objective was to maintain the level of medium and dense stands on private lands to less than 10% of the total. No treatments other than continued fire suppression occurred on public lands. We assumed that mechanical fuel treatments would be used rather than prescribed fire on private lands to maintain reduced fuel levels.

Scenario 2 - Active fuel treatment in wildland/urban interface, maximize multi-story large tree forests on federal lands

This scenario carried forward the active fuel management of WUI from scenario 1 and managed federally managed lands to produce large trees and maximize the amount of multi-storied large and very large tree habitat. The objective was to increase habitat for wildlife species associated multi-story stands containing many large and very large trees (e.g. > 51 cm DBH). A multi-layered canopy and large dead trees are also important (Wisdom et al. 2000). An understory tree layer develops naturally with fire suppression on most forested environments in the study area. The initial thinning prescriptions were designed to create and maintain open stands of fire tolerant tree species that could grow to large size (e.g. >51 cm DBH) relatively quickly while reducing risk of loss to high-severity wildfire. In addition, we developed a thinning treatment to reduce the risk of losing exiting large and very large trees to wildfire by thinning from below from high to medium stand density while retaining part of the smaller tree component to provide multi-story characteristics. These stands then went through a period of re-establishment of the small tree understory, and increasing danger of stand-replacing wildfire, until the treatment was applied again. Our treatment regime on federally-managed general forest lands included:

1) Precommercially thinning all stands at age 15.
2) Treating 5 % of high density and 2.5 % of medium and high density stands in ponderosa pine, mixed conifer dry, and mixed conifer moist environments each year after the initial precommercial thinning to maintain open conditions until the stands reached large tree size. After stands reached large tree size, thinning ceased to allow development of understory trees until the stands became very large tree sized.
3) Lightly thinning dense stands of very large trees in mixed conifer dry and mixed conifer moist types from below at an annual rate of 10 % to reduce fire and insect losses while maintaining most of the multi-story structure.
4) Alternately thinning and underburning open stands of smaller trees in ponderosa pine dry, mixed conifer dry, and mixed conifer moist types to reduce fuels.
5) Mechanically thinning lodgepole pine dry stands at a rate of 4% annually.
6) Salvaging dead wood in 25% of the stands that had experienced wildfire and insect outbreaks.
7) Treating reserves at ½ these rates and wilderness not at all.

Scenario 3 - Active fuel treatment in wildland/urban interface, move federal general forest lands toward historical conditions

This scenario calls for the same active management of private lands (WUI) as scenario 1, but federally managed general forest lands outside wilderness were managed to reduce fuels and high-severity wildfire risks while moving forests toward conditions assumed to be typical of those prior to 1850. Management in reserves was designed to reduce stand densities and fuel levels while maintaining large and very large trees and multi-story canopies.

We used the reference condition VDDT models developed by LANDFIRE Rapid Assessment (LANDFIRE 2006) as a basis for historical disturbance regimes, including wildfire return intervals and insect outbreaks on federal general forest lands. We added state classes to the LANDFIRE (2006) reference condition models to reflect the variety of structural conditions required by our issues, but retained the overall wildfire return intervals by fire severity class (Table 3). We used a variety of treatments to mimic the reference disturbance regimes and reach long-term stable conditions with, generally, more abundant single storied forest structure than presently occurs, especially in the drier potential vegetation types. We approximated historical conditions by applying prescribed fire to mimic historical wildfire frequencies on general forest lands. Reserves were treated with half the intensity of federal general forests because the late successional reserves are intended to provide more abundant large and very large tree multi-story forest habitat than federal general forest lands.

Results and Discussion

Scenario 1 - Active fuel treatment in wildland/urban interface, no management on federal lands

Large and Very Large Tree Forests

Both multi-story and single story large and very large tree forests increased over the 20 decade simulation period under Scenario 1 (fig. 3). Multi-story large and very large tree forests increased from about 30% of the landscape area in the first decade to almost 40% in the 10th decade then declined to about 32% in the 19th decade. Amounts of multi-story large and very large forest varied by ownership/allocation class. They were most abundant in wilderness, initially rising to cover nearly 20% of wilderness land area, then dropping to less than 15% over the last 100 years (fig. 4). Multi-story large and very large tree forests increased from about 5% to over16% on federal general forest lands for the first 150 years of the simulation period then declined to about 14% over the last 50 years. Multi-storied large and very large tree forests declined very slowly or remained relatively constant at less than 5% of the land area in both WUI and reserves.

The pattern of initial increases over the first 100 to 150 years followed by declines over the last 50 years was an interesting result of two interacting trends. Forest growth and development in the presence of wildfire suppression increased multi-story large and very large tree forests from currently low levels that reflect many decades of forest management, past wildfires, and past insect outbreaks. Recently low levels of timber management on federal general forests and no future timber management on those lands under Scenario 1 allowed growth and development of multi-story large and very large tree forests across much of the entire landscape. The other trend was for increasing high severity wildfire and insect outbreaks as multi-story forests that were highly susceptible to those disturbances became increasingly abundant. Our model integrated those trends to produce an initial rise then a decline in multi-story large tree forests over 200 years under Scenario 1. Our model, and the assumptions upon which it is based, suggest that this form of passive management on federal lands might limit multi-story large tree forests in this landscape to about 30% of the landscape area on a long-term basis and that an initial increase to higher levels might not be sustainable over a longer time frame.

Single story large and very large tree forests increased very slowly under Scenario 1 from about 9% to about 15% of the entire landscape area, on average, over 200 years (fig. 5). Much of the increase occurred in WUI, where active fuel treatments selectively produced open forest structures (fig. 6). The picture on federal general forests was more complex (fig. 6). Single story large and very large tree forests declined on general forest lands for the first 6 to 7 decades, and then began an uneven rebound to eventually exceed initial conditions by the 19th decade. Reserves and wilderness contained very little single story forest structure through out our simulation period.

Scenario 1 seemed to have mixed effects on large and very large single tree forests, but produced a slow increase across the landscape as a whole. Most of this increase came from WUI lands where active fuel treatment favored single story forest structures. Wilderness and reserves contained very little single story large and very large tree forests for two reasons. Wilderness areas and, to a lesser degree, reserves are at higher-elevations where the background fire regime produces mixed and high severity wildfires at intervals of decades or longer, favoring multi-story forest structures. Fire suppression produces a similar fire regime on federal general forests, many of which were likely dominated by single story large and very large tree forests prior to European settlement.

Wildfire

High severity wildfires burned variable average amounts of the landscape over time (fig. 7). Comparison of high severity wildfire in Scenarios 2 and 3, which used understory fuel treatments to help achieve management objectives, to Scenario 1 indicate that the fuels treatments reduced the area impacted by high severity wildfires by at least 20% in most years (fig. 7). The spike in high severity wildfire in Scenarios 2 and 3 in the 3rd decade is an artifact of the very low level of all wildfire in that decade, which magnified minor differences between the scenarios. While high severity wildfire was proportionately highest in WUI areas (fig. 8), these areas were almost entirely in open conditions occupied by grass/forb/shrub communities. Grass/forb/shrub communities are highly susceptible to wildfires that kill most of the above ground vegetation (our definition of high severity) but such wildfires are much more easily controlled than those burning in dense forests. The other ownership/allocation categories were largely forested throughout our simulations and are, hence, more comparable regarding fire effects. Of the forested ownerships/allocations, federal general forests were most highly impacted by high severity wildfire, on average, throughout the simulation period under Scenario 1, followed by wilderness and reserves (fig. 8). High severity wildfires were especially important in the second, 14th, and 19th decades due to the sequences of fire years in our 30 Monte Carlo simulations.

Management Activities

All commercial timber activities were limited to WUI lands in this scenario. Mechanical fuel treatments and stand thinnings in scenario 1 remained nearly constant over the first 10 decades after a small rise in the first decade (fig. 9). All treatments occurred in WUI lands in order to meet fuel reduction objectives. As a consequence, the proportion of WUI lands in dense forest conditions declined from current levels, where they occupy over 25% of WUI land area, to less than 10% on average over the first 10 decades. Likewise, prescribed fire occurred only on WUI lands and, after an initial ramp-up, averaged about 700 ha per year treated (fig. 10). Scenario 1 produced very little commercial timber harvest over the first 10 decades (fig. 11). On average, about 2000 ha were treated per year with activities that might produce commercial timber products and another 600 to 700 ha by mechanical fuel treatments and thinnings. We assumed that prescribe fire would not generally be used in WUI areas and there were no fuel treatment activities on any other lands in this scenario.

Scenario 2 - Active fuel treatment in wildland/urban interface, maximize multi-story large tree forests on federal lands

Large and Very large Tree Forests

Scenario 2 produced intermediate levels of both multi-story and single story large and very large tree forests (figs. 3, 5). Contrary to our design objectives, Scenario 2 did not produce as much multi-story large tree forest as Scenario 1, though differences were slight. Initial increases in multi-story large and very large tree forests over the first 10 decades were eliminated by declines over the last 10 decades, especially over the last 5 decades. In fact, our Scenario 1 and 2 simulations produced, on average, about as much multi-story large tree forest at the end of 20 decades as existed at the beginning. Most of the decline in multi-story large and very large tree forests under Scenario 2 occurred in wilderness areas and federal general forests, especially during the second half of the simulation period (fig. 12). While multi-story large and very large tree forests increased substantially on federal general forests over the first 15 decades, nearly tripling from about 5% to about 15% of landscape area, they declined substantially in the last 3 decades. Most of the declines in multi-story large and very large tree forests in both wilderness and federal general forests were due to increasing wildfire and insect outbreaks as multi-story large and very large tree forests became abundant in the whole landscape over the last 10 decades. Perhaps alternative approaches to protecting and developing multi-story large tree forests on federal general forests could be formulated and might be more successful. This also suggests, at least given assumptions in our models, that currently high levels of multi-story large and very large tree forests in wilderness areas is perhaps an artifact of fire suppression and other factors and may not be sustainable in the long run in the study area.

Single story large and very large tree forests continually increased across the entire landscape under Scenario 2, nearly tripling after 20 decades (fig. 5). Much of the increase occurred in federal general forests where they increased from less than 5% of the area in the first decade to nearly 20% of the area in the 19th decade (fig. 13). Single story large and very large tree forests also increased in WUI areas, doubling from less than 5% to more than 10% of WUI area over 200 years. Increases in federal general forests and WUI were due to thinning to produce large trees quickly in the first case and very active fuel treatments in the second. Single story large and very large tree forests remained at very low levels in reserves and in the wilderness. Perhaps alternative treatment types and schedules that might be more effective at meeting Scenario 2 objectives would produce larger amounts of multi-story large and very large tree forests and small amounts of single story large and very large tree forests.

Wildfire

Scenario 2 produced intermediate levels of high severity wildfire compared to the other two scenarios (fig. 7) because some fuel treatments occurred on federal general forests and in reserves to foster early development of large trees. As a result, the area burned in high severity wildfires was, on average, about two-thirds that in Scenario 1. As in Scenario 1, the highest proportion of high severity wildfire was in open forests dominated by grass/forb/shrub communities in WUI (fig. 14) where high severity wildfires are relatively easy to control. Federal general forests experienced considerably lower amounts of high severity wildfire compared to Scenario 1, but amounts in reserves and wilderness were similar to those under Scenario 1.

Management Activities

Management activity levels in WUI were the same as in the other scenarios because treatments were identical. Projections for scenario 2 produced about 5,900 to 6,100 ha of commercial treatment activities over 10 decades (fig. 11). Treatment rates were highest in the first decade then stabilized as current vegetation conditions, disturbances, and forest growth rates moved toward long-term stable conditions. A spike to almost 4,700 ha occurred with salvage following a large wildfire outbreak in the 9th decade. Mechanical fuels and things were highest in the second decade as the initial round of mechanical fuel treatments peaked (fig. 9). Prescribed fire was highest in the 3rd and 4th decades, about 800 ha per year, as fire replaced mechanical fuel treatment for fuel reduction and then slowly declined to about 600 ha per year on average in the 10th decade (fig. 10).

Scenario 3 - Active fuel treatment in wildland/urban interface, move federal lands toward historical conditions

Large and Very large Tree Forests

Scenario 3 produced the lowest overall abundance of multi-story large and very large tree forests (fig. 3). Our simulations reduced multi-story large and very large tree forests, on average, from about 30% of the landscape area in the first decade to less than 20% in the 20th decade. The same downward trend seen in Scenarios 1 and 2 occurred in wilderness areas where multi-story large and very large tree forests declined from about 16% in the first decade to less than 10% in the 19th decade due to increasing wildfire and insect outbreaks (fig. 15). Multi-story large and very large tree forests also declined from about 6% of federal general forests to a minimum of about 2% in the 4th decade but rebounded slightly in the 19th decade.

Conversely, Scenario 3 produced abundant single story large and very large tree forests across the entire study area (fig. 5). Single story large and very large tree forests initially occupied less than 10% of the study area, but increased 5-fold to 50% by the 19th decade. This increase was most impressive on federal general forest lands where single story large and very large tree forests increased by 7-fold on average, from less than 5% to nearly 35% of general forest area (fig. 16). There were also smaller increases in WUI and reserves. Our treatments under Scenario 3 seemed to be very effective at converting much of the forested land to single story large and very large tree forests over 200 years. Though the trend was flattening after 200 years, single story large and very large tree forests were still increasing across the landscape as a whole.

Wildfire

Our simulations of Scenario 3 produced the lowest over-all rates of high severity wildfire (fig. 7). Overall proportions of area burned in high severity wildfires was generally 30% or more below those of Scenario 1 and 5% to 10% lower than those in Scenario 2. Decade 3 was anomalous due to very low total area burned in all three scenarios so that comparisons magnified the effects of only a few hectares difference among the scenarios. WUI areas experienced the highest proportion of high severity wildfire, again in grass/forb/shrub dominated open forests where wildfire is most easily controlled (fig. 17). Of the other three ownership/allocation classes, wilderness areas were most highly impacted by high severity wildfires, in contrast to Scenarios 1 and 2, especially after the 3rd decade. Federal general forests, on the other hand, became increasingly less vulnerable to high severity wildfire compared to both Scenarios 1 and 2 as understory fuel treatments began to have a noticeable effect.

Management Activities

Considering all ownerships and allocations together, this scenario produced about 6,200 to 6,800 ha of commercial timber harvest per year (fig. 11). An initial spike in decade 2 reflects salvage following a relatively severe wildfire year. Mechanical fuel treatments and thinnings occurred on about 1,200 ha per year in the first decade, rose to nearly 2,000 ha in the second decade, then began a continuing decline to about 1,300 ha over the remaining 8 decades (fig. 9). Scenario 3 produced the highest levels of prescribe fire (fig. 10). Prescribed fire area rose continuously from about 800 ha per year in the fist decade to about 1300 ha per year in the 4th decade and stabilized at that level. The initial ramp-up took place as the first round of mechanical fuel treatments on federal general forests reduced fuel levels so that prescribed fire could be used for subsequent fuel treatments.

Variability

Our models show high levels of variability over 30 Monte Carlo simulations, especially for some scenarios and some attributes. For example, the mean trend in multi-story large and very large tree forests under Scenario 2 was an initial increase for about 150 years, followed by a decline for 50 years and, possibly, relatively stable levels from 200 to 300 years (fig. 18a). However, amounts of this forest type within 1 standard deviation of the mean at 100 years ranged from about 30% to over 50 % and variation continued to increase. By 150 years, a plus or minus 1 standard deviation range covered a span of 30% to 70% of the land area in this forest structure. The same scenario produced somewhat lower, but still large, variability for single story large and very large tree forests (fig. 18b). In this case, a range of plus or minus one standard deviation went from less than 10% to about 30% at year 200.

In fact, none of the individual simulation runs that comprise the 30 Monte Carlo set for multi-story large and very large tree forests under Scenario 2 looked anything like the mean trend. A randomly selected example (fig. 19a) illustrates typical results. In this example, multi-story large and very large tree forests began at about 20% of the landscape area, rapidly rose to over 60%, crashed as a result of high severity disturbances to about 20% at year 100, rapidly rose to about 40% by year 150, crashed again at year 170 to less than 15%, and began a sustained rise to over 60% by year 300. The sharp changes of amounts in a few years illustrate the effect of sharp size class boundaries that would not occur in models that tracked finer detail in tree size class. The pattern, however, suggests that multi-story large tree forests may be subject to boom-and-bust abundance under Scenario 2, at least given our model assumptions. Single story large tree forests experience similar but less pronounced boom-and-bust patterns in Scenario 2 (fig. 19b).

The variability patterns for large and very large tree forests under Scenario 3 are interestingly different (figs. 20a and 20b). As one might expect given Scenario 3 objectives, multi-story large and very large tree forests are much less abundant than single story large and very large tree forests overall. But an example single run, typical of all 30, shows the dominant single story large and very large tree forests to increase for 150 years to about 80% of the landscape area then undergo relatively small fluctuations that range between 60% and 80% of the landscape area. Our interpretation, based on our modeling assumptions, is that single story large and very large tree forests are more stable and sustainable at high levels in the study area than multi-story large tree forests. This agrees with other studies that indicate single story large and very large tree forests were the dominant forest structure in drier forest environments of the interior Pacific Northwest (e.g. Hann et al. 1997, Agee 2003, Hessburg and Agee 2003).

Conclusions

The models we used and the assumptions they embody reflect how we think the landscape disturbance and management processes might work to control landscape characteristics in the study area. Our models were based on expert opinion, the existing literature, and calibration by finer-scale stand-level silvicultural models. We think our estimates are reasonable, but these are only models. Our stand treatment prescriptions need to be further tested and refined to see if they would actually be suitable for implementation on the ground and produce the results we assumed. We did not factor in the economic costs and returns that might make such treatments unrealistic in some landscape situations. Rather we assumed that those treatments would be implemented even if they did not produce positive net revenue. In addition, real life may produce results much different than our estimates because: 1) odd or unusual events could occur, 2) we may not understand the system sufficiently well, 3) there may be some error in our models that we don't know about, 4) we haven't factored in climate change that may alter fire, insects/disease, and other disturbances, and 5) future management likely would not follow any one of our scenarios. But, the scenarios are useful to illustrate the kinds of things that would likely happen given a particular management approach. They also help us understand where our knowledge about the ecosystems is most critically incomplete.

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Figure 19. One randomly selected example simulation run showing amounts of multi- and single story large and very large tree forests under Scenario 2 in the Five Buttes Study area, central Oregon, USA. Central straight lines indicate mean value averaged over the 0-150 and 150-300 year time periods.

Figure 20. Variation in amounts of multi-story large and very large tree forests under Scenario 3 in the Five Buttes Study area, central Oregon, USA. Central straight lines indicate mean value averaged over the 0-150 and 150-300 year time periods.

Tables

Table 1 – Forest structure class definitions for the Five Buttes Study area, central Oregon, USA.

Structure class	Tree canopy layers[1]	Overstory canopy cover[2]	Dominant tree DBH[3]
		(%)	cm
Grass forb	none	tree <10, shrub <15	NA
Shrub	none	tree <10, shrub >15	< 2.5
Seedlings/saplings	1	≥ 10	≥2 to 13
Pole tree – open	1	≥ 10 to 40	≥13 to 25
Pole tree- medium	1	≥ 40 to 70	≥13 to 25
Pole tree – closed	1	≥ 70	≥13 to 25
Small tree – open	1	≥10 to 40	≥25 to 38
Small tree – medium	1+	≥ 40 to 70	≥25 to 38
Small tree –closed	1+	≥ 70	≥25 to 38
Medium tree – open	1	≥ 10 to 40	≥38 to 51
Medium tree– medium	1+	≥ 40 to 70	≥38 to 51
Medium tree– closed	1+	≥ 70	≥38 to 51
Large tree – open	1	≥ 10 to 40	≥51 to 76
Large tree –medium	1+	≥ 40 to 70	≥51 to 76
Large tree –closed	1+	≥ 70	≥51 to 76
Very large tree – open	1	≥ 10 to 40	≥76
Very large tree –medium	1+	≥ 40 to 70	≥76
Very large tree –closed	1+	≥ 70	≥76

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[1] Height of the tallest tree layer divided into 3 equal vertically spaced portions. A layer has = 15% canopy cover in one of the three height strata. The cover of taller strata that have less than 15% cover is added to the next shorter stratum.

[2] The vertical projection of all tree canopy as a percent of ground covered; absolute canopy cover.

[3] Diameter Breast Height (1.4 meters)

Table 2. Forest cover type classes used in the Five Buttes Study area, central Oregon, USA.

Cover type	Dominant species[1]
Not vegetated	None – rock, water, ice, etc.
Developed land	Variable – agriculture, suburban, urban, etc.
Grass/shrub	Various grass, forb, and shrub species
Juniper	Western juniper *(Juniperus occidentalis* Hook.)
Ponderosa pine	Ponderosa pine *(Pinus ponderosa* P.& C. Lawson)
Douglas-fir/white fir	Douglas-fir *(Pseudotsuga menziesii* (Mirbel) Franco) and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.)
White fir	White fir, Douglas-fir, and other conifers
Lodgepole pine	Lodgepole pine *(Pinus contorta* Dougl. ex Loud.)
Hardwoods	*Bigleaf maple (Acer macrophyllum* Pursh, *Alnus rubra* Bong.,) Oregon white oak (*Quercus garryana* Dougl. ex Hook.), and red alder (*Alnus rubra* Bong.)
Douglas-fir/oak	Douglas-fir and Oregon white oak
Western hemlock	Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Douglas-fir, and western redcedar (*Thuja plicata* Donn ex D. Don)
Pacific silver fir	Pacific silver fir *(Abies amabilis* (Dougl. ex Loud.) Dougl. ex Forbes), noble fir (*Abies procera* Rehd.), and Douglas-fir
Mixed conifer	Variable mixtures of white fir, Douglas-fir, Engelmann spruce *(Picea engelmannii* Parry ex Engelm.), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and other conifers at upper elevations
Subalpine parkland	Mosaic of subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), mountain hemlock, and Engelmann spruce at high elevations

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[1] Plant species names from USDA, NRCS (2006). The PLANTS Database (http://plants.usda.gov, 22 June 2006). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

Table 3. Average wildfire return intervals under reference conditions (prior to 1850) for potential vegetation groups in the Five Buttes study area, central Oregon, USA (from LANDFIRE 2006).

Potential Vegetation Type	Fire Severity Class	Average Fire Interval	Average Annual Fire Prob.	LANDFIRE Rapid Assessment Model[1]
		years		
Juniper	Replacement	1000	0.001	R#JUPIse Western Juniper Pumice
	Mixed	500	0.002	
	Surface	NA		
	All	333	0.003	
Ponderosa pine dry	Replacement	125	0.008	R#PIPOm Dry Ponderosa Pine - Mesic
	Mixed	50	0.02	
	Surface	8	0.125	
	All	7	0.153	
Mixed conifer dry	Replacement	115	0.0087	R#MCONdy Mixed Conifer - Eastside Dry
	Mixed	75	0.0133	
	Surface	25	0.04	
	All	16	0.062	
Mixed conifer moist	Replacement	200	0.005	R#MCONms Mixed Conifer - Eastside Mesic
	Mixed	150	0.0067	
	Surface	400	0.0025	
	All	71	0.0142	
Lodgepole pine dry	Replacement	125	0.008	R#PICOpu Lodgepole Pine - Pumice Soils
	Mixed	450	0.0022	
	Surface	NA		
	All	98	0.0102	
Upper montane cold	Replacement	185	0.00541	R#ABLA Subalpine Fir
	Mixed	800	0.0013	
	Surface	NA		
	All	150	0.0067	
Upper montane moist	Replacement	500	0.002	R#ABAMup Pacific Silver Fir--High Elevation
	Mixed	1100	0.0009	
	Surface	NA		
	All	344	0.0029	
Subalpine parkland	Replacement	350	0.0029	R#ALME Alpine and Subalpine Meadows and Grasslands
	Mixed	750	0.0013	
	Surface	NA		
	All	239	0.00420	

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[1] LANDFIRE (2006)

Table 4. Fire year sequences in the entire upper Deschutes subbasin (approximately 800,000 ha) and for individual watersheds (approximately 50,000 ha).

Analysis area - size	Fire year type		
	Normal	High	Severe
Upper Deschutes subbasin			
Fire year frequency	80%	15%	5%
Area multiplier	1	40	500
Huc5 watersheds			
Fire year frequency	95%	4%	1%
Area multiplier	1	160	2000

Figures

Figure 1. The Five Buttes study area in central Oregon, USA.

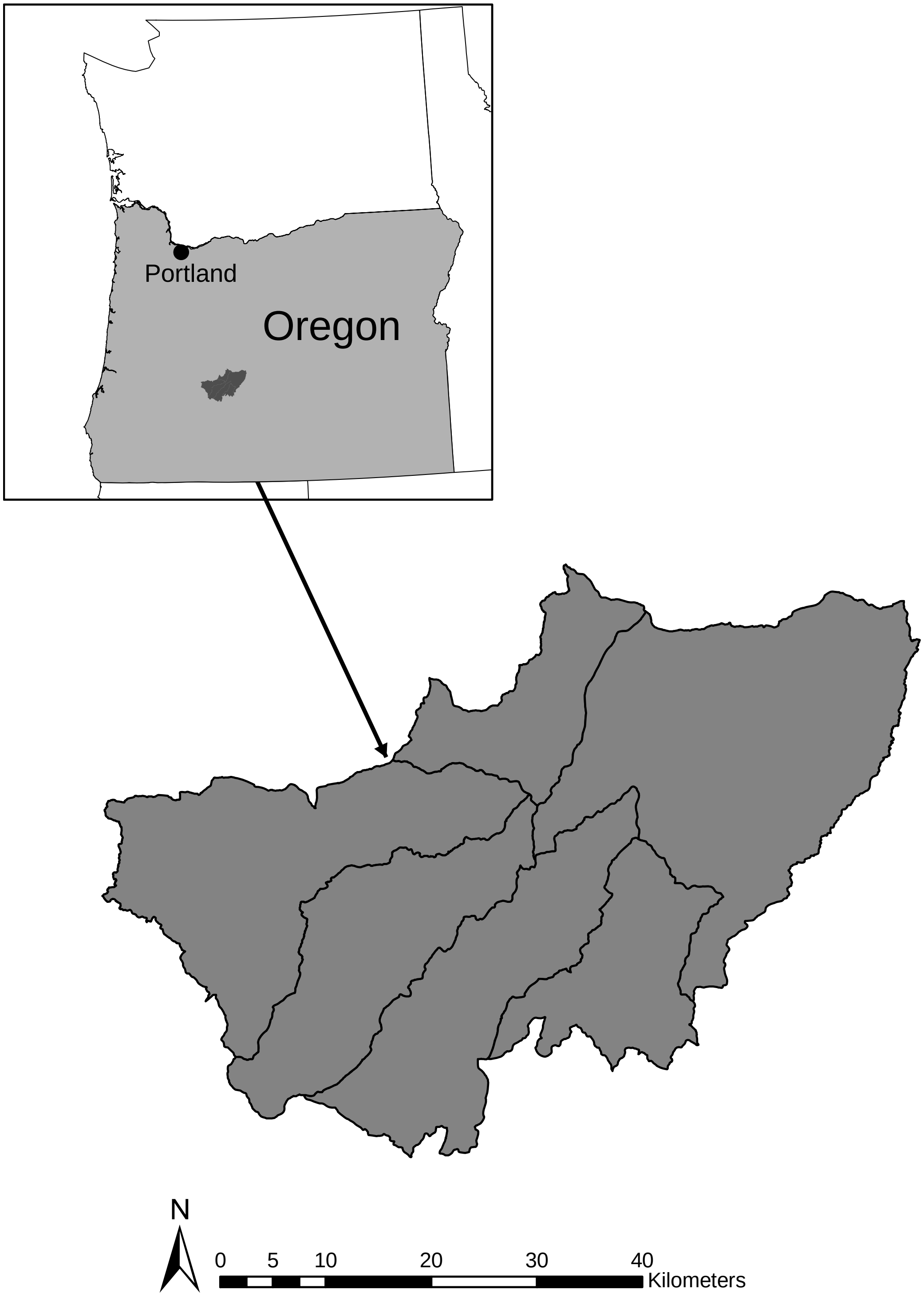


Figure 2. Example state and transition model for a hypothetical landscape with three vegetation types lined by succession, wildfire disturbances, and management treatments.

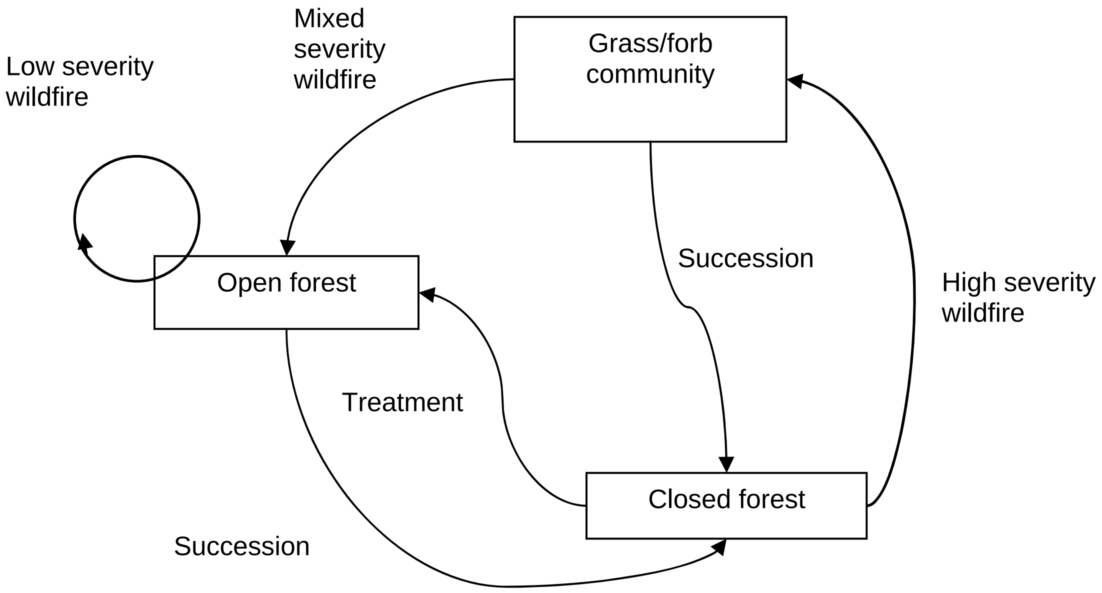


Figure 3. Proportion of the study area in multi-story large and very large tree structure classes by scenario in the Five Buttes Study area, central Oregon, USA.

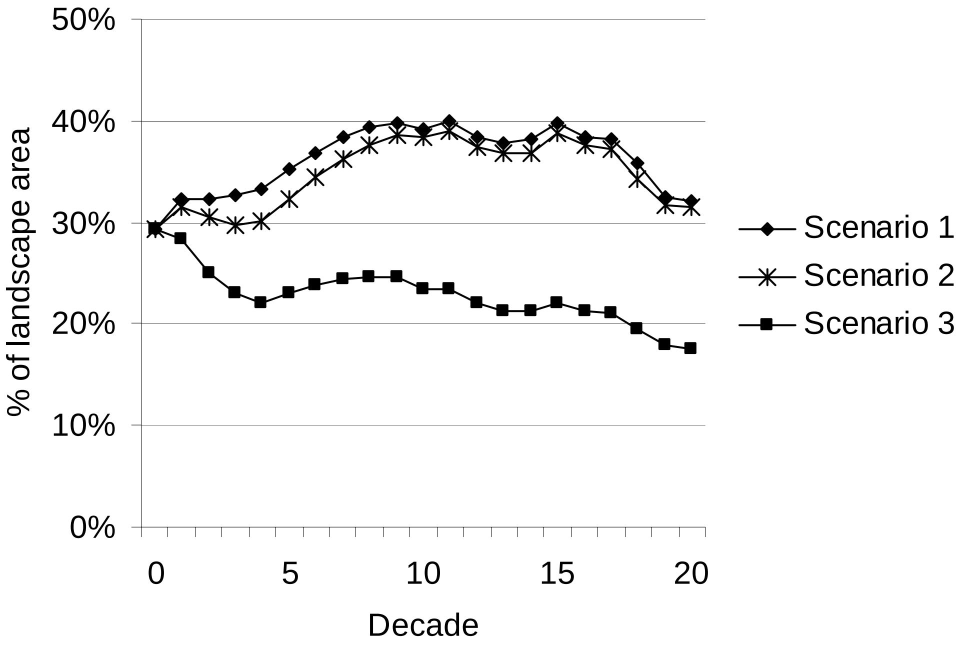


Figure 4. Proportion of ownership/allocation class in multi-story large and very large tree forests under Scenario 1 in the Five Buttes Study area, central Oregon, USA.

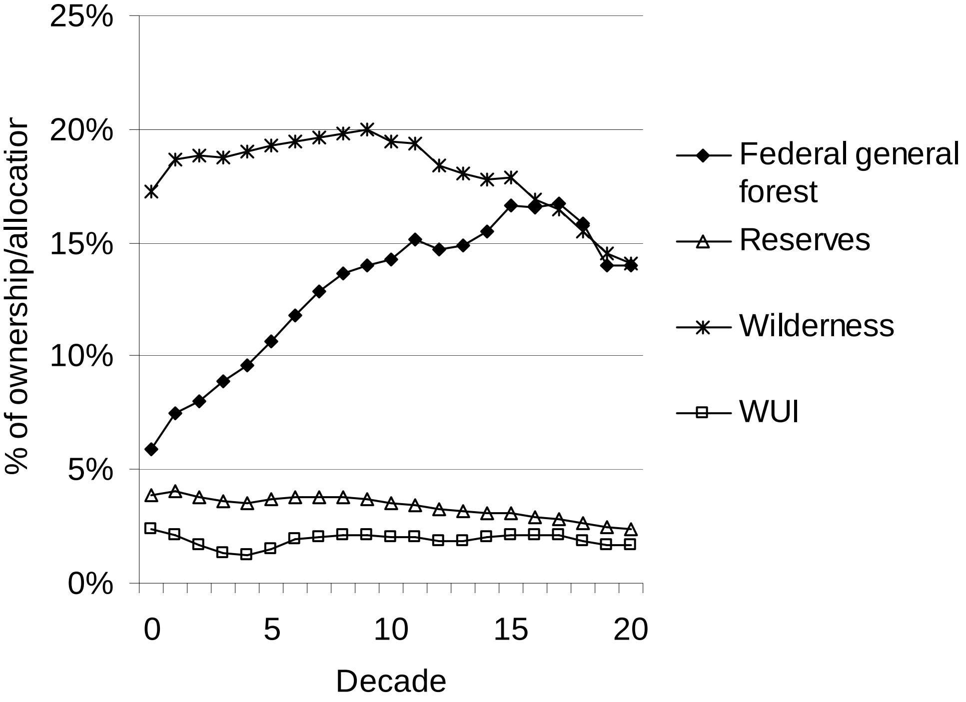


Figure 5. Proportion of the study area in single-story very large and large tree structure classes by scenario in the Five Buttes Study area, central Oregon, USA.

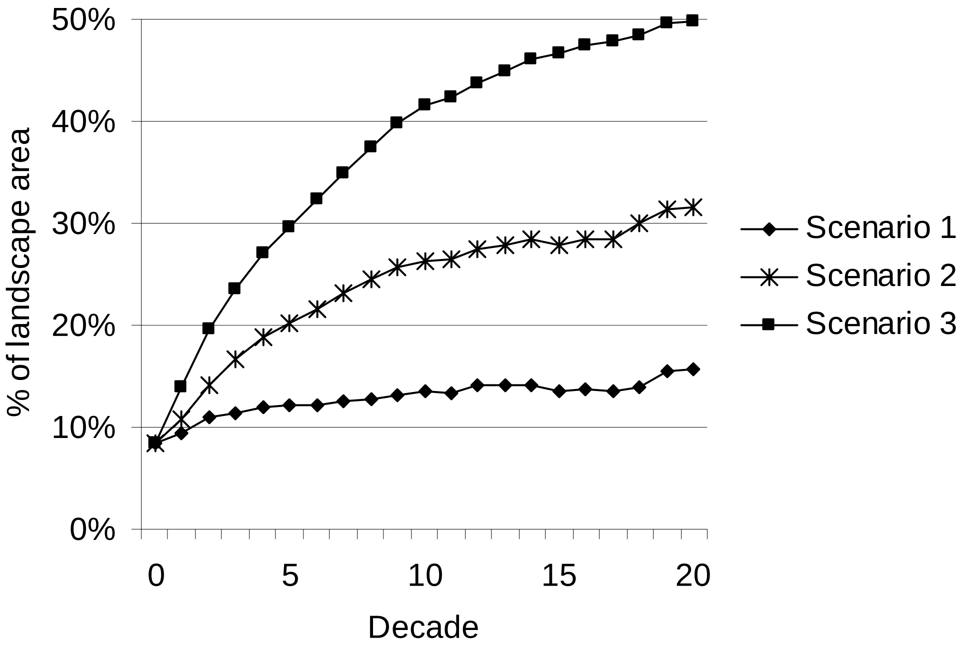


Figure 6. Proportion of ownership/allocation class in single story large and very large tree forests under Scenario 1 in the Five Buttes Study area, central Oregon, USA.

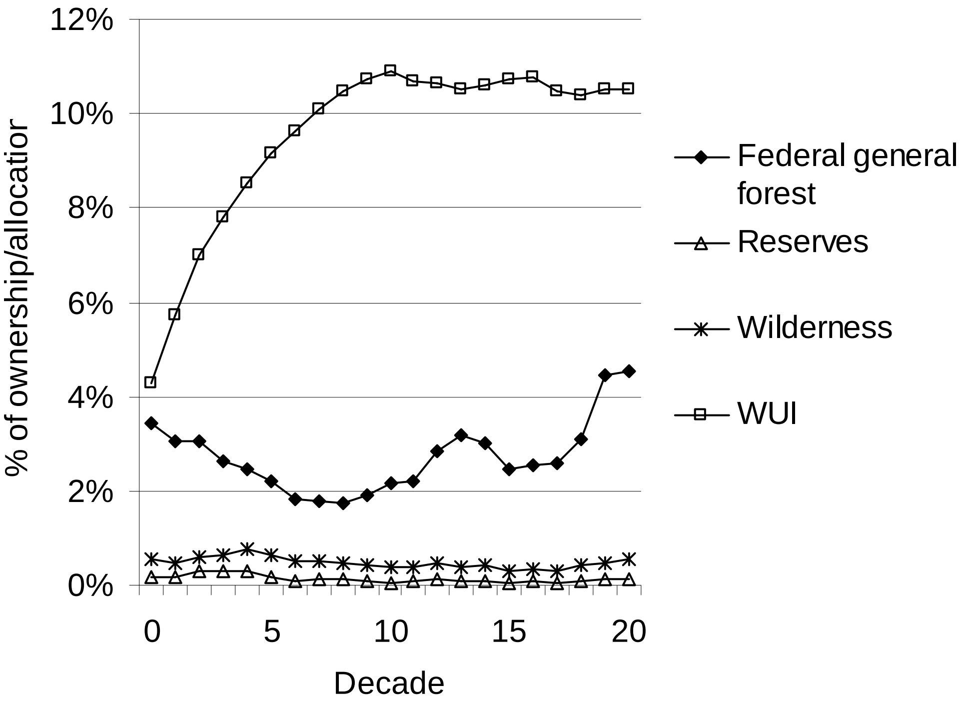


Figure 7. Area affected by high severity wildfire under Scenarios 2 and 3 compared to Scenario 1 in the Five Buttes Study area, central Oregon, USA.

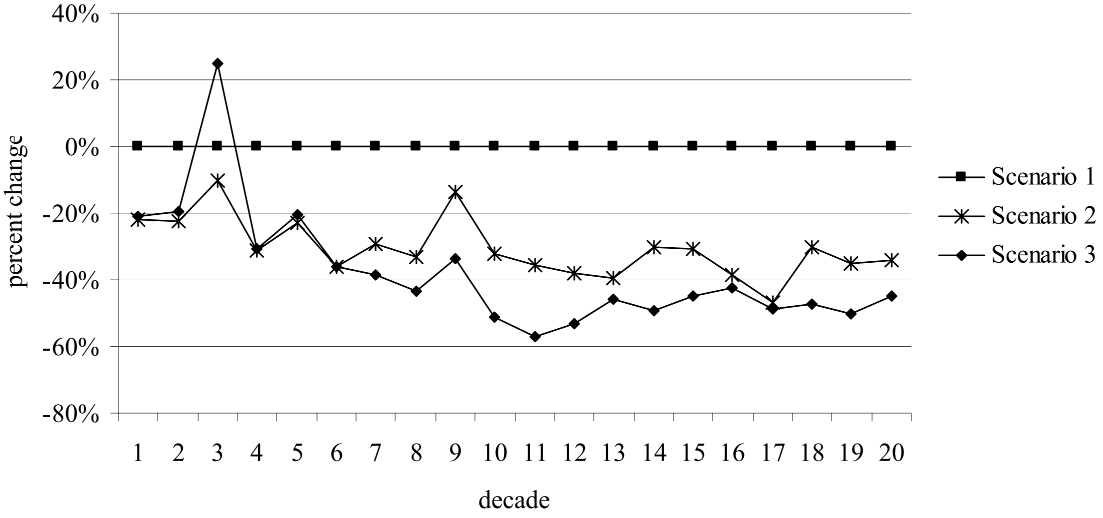


Figure 8. Area affected by high severity wildfire under scenario 1 in the Five Buttes Study area, central Oregon, USA.

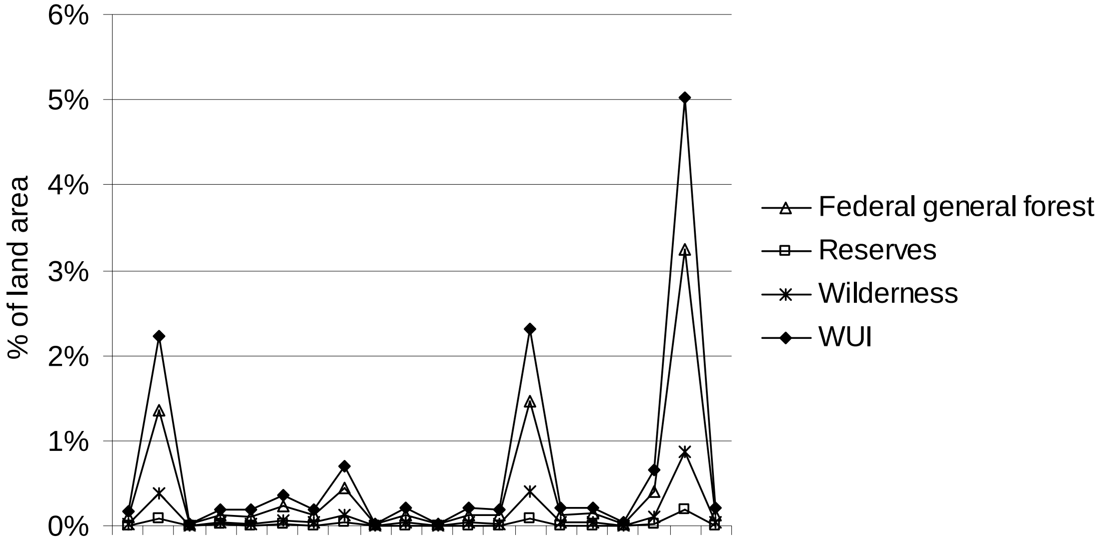


Figure 9. Area treated with mechanical fuel treatments and thinnings by scenario in the Five Buttes Study area, central Oregon, USA.

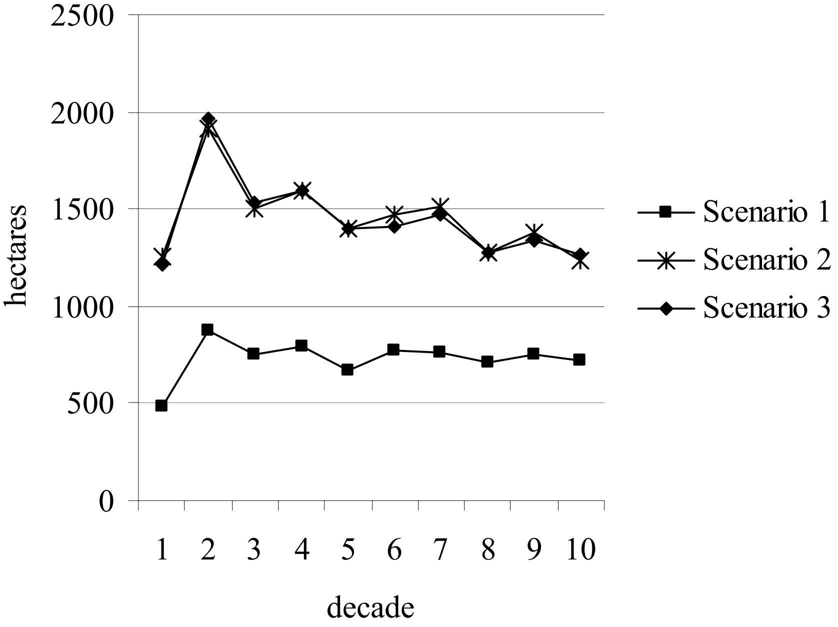


Figure 10. Area treated with prescribed fire by scenario in the Five Buttes Study area, central Oregon, USA.

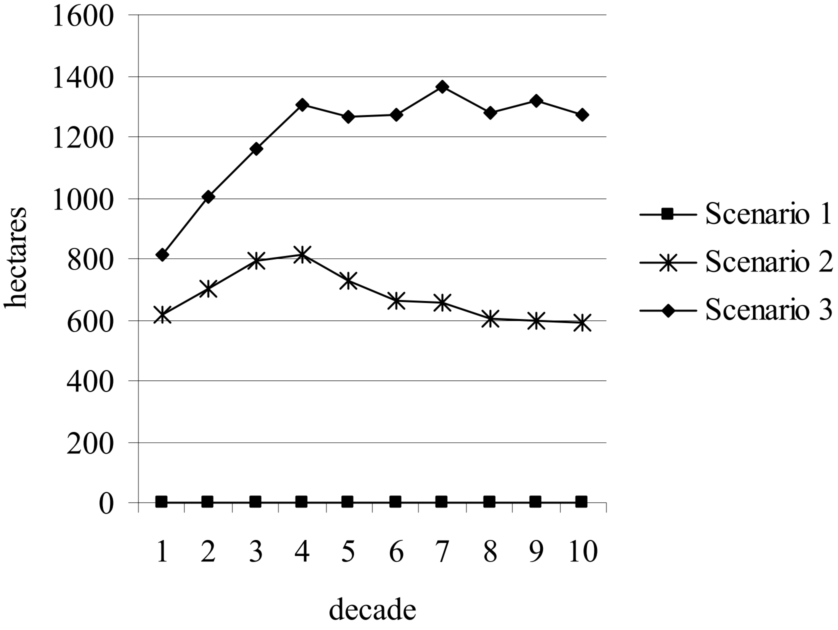


Figure 11. Area treated with management activities that may produce commercial timber products by scenario in the Five Buttes Study area, central Oregon, USA.

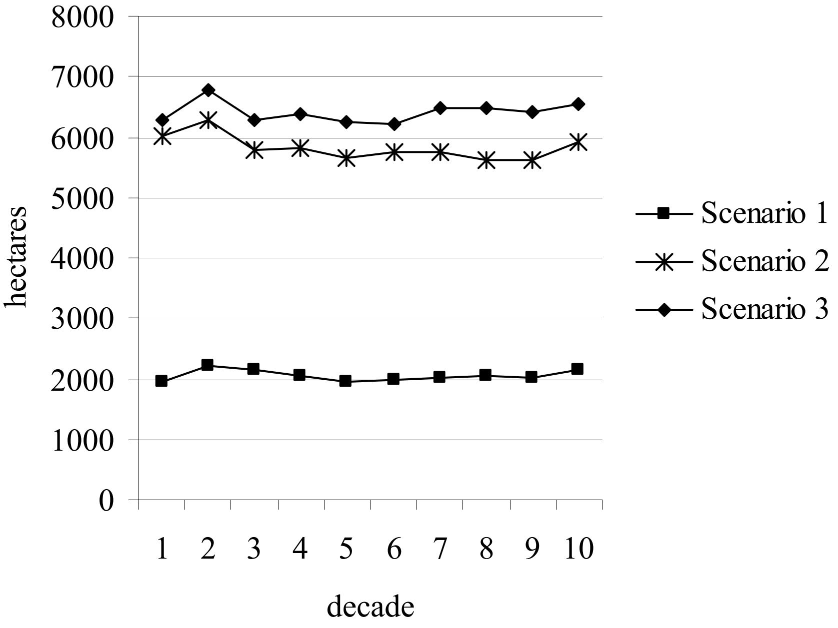


Figure 12. Proportion of ownership/allocation class in multi-story large and very large tree forests under Scenario 2 in the Five Buttes Study area, central Oregon, USA.

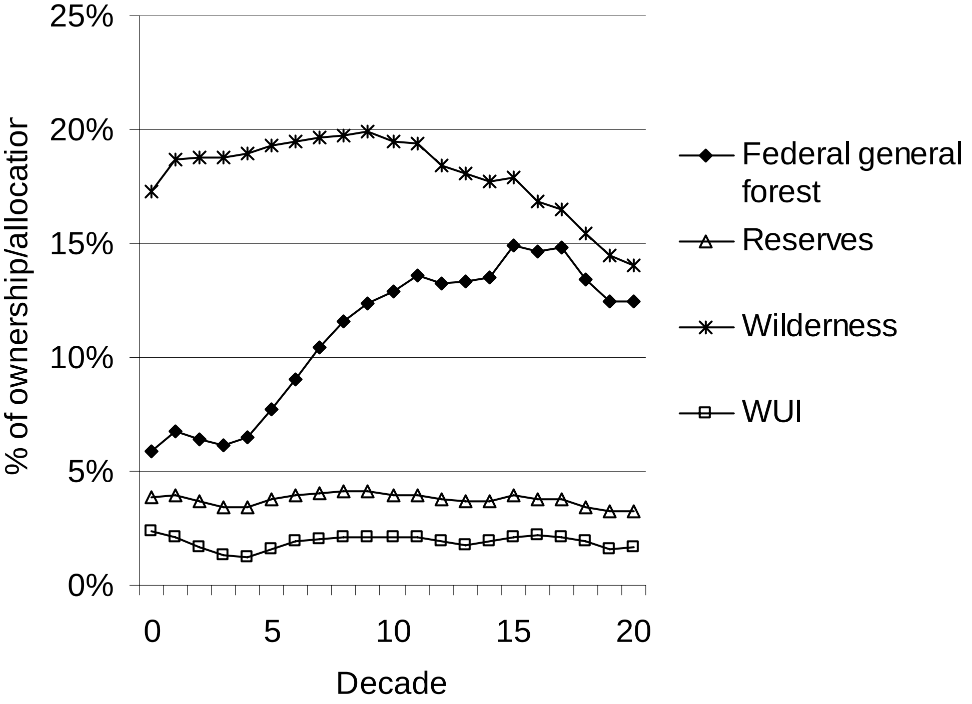


Figure 13. Proportion of ownership/allocation class in single story large and very large tree forests under Scenario 2 in the Five Buttes Study area, central Oregon, USA.

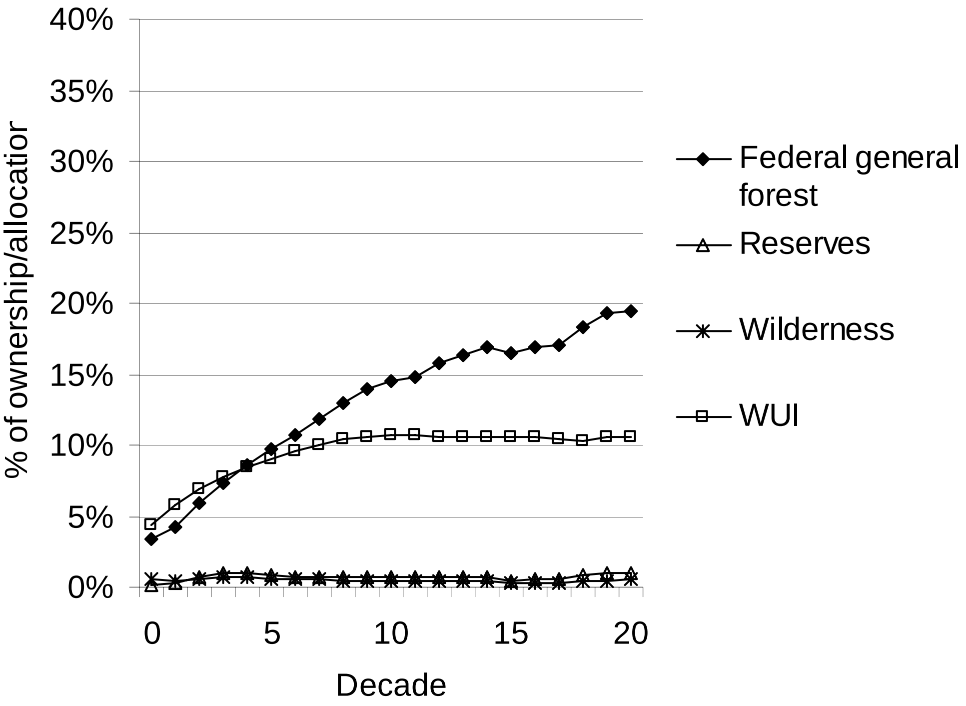


Figure 14. Area affected by high severity wildfire under scenario 2 in the Five Buttes Study area, central Oregon, USA.

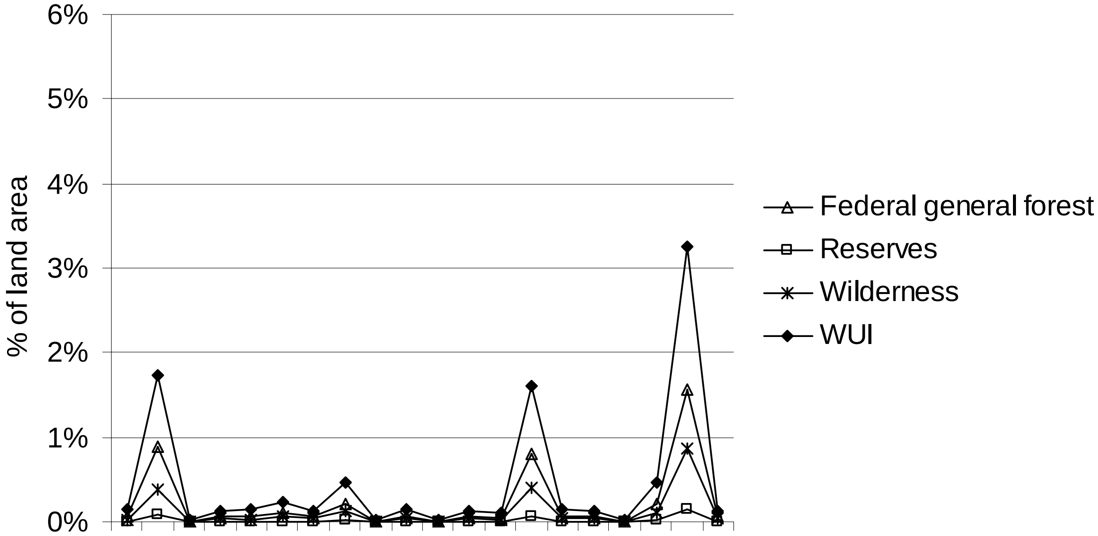


Figure 15. Proportion of ownership/allocation class in multi-story large and very large tree forests under Scenario 3 in the Five Buttes Study area, central Oregon, USA.

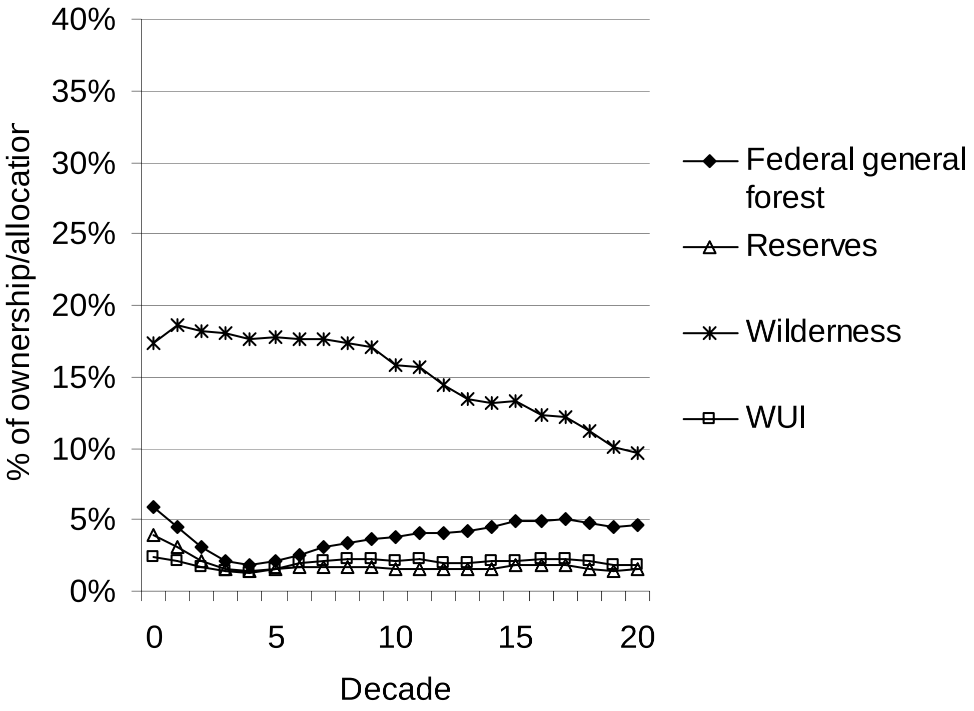


Figure 16. Proportion of ownership/allocation class in single story large and very large tree forests under Scenario 3 in the Five Buttes Study area, central Oregon, USA.

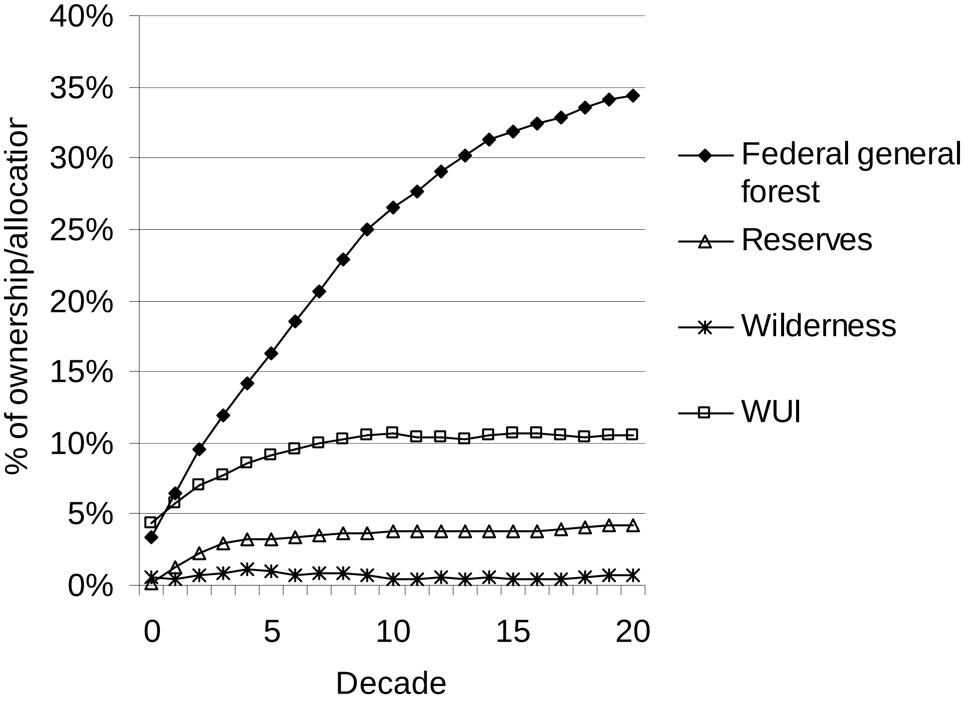


Figure 17. Area affected by high severity wildfire under scenario 3 in the Five Buttes Study area, central Oregon, USA.

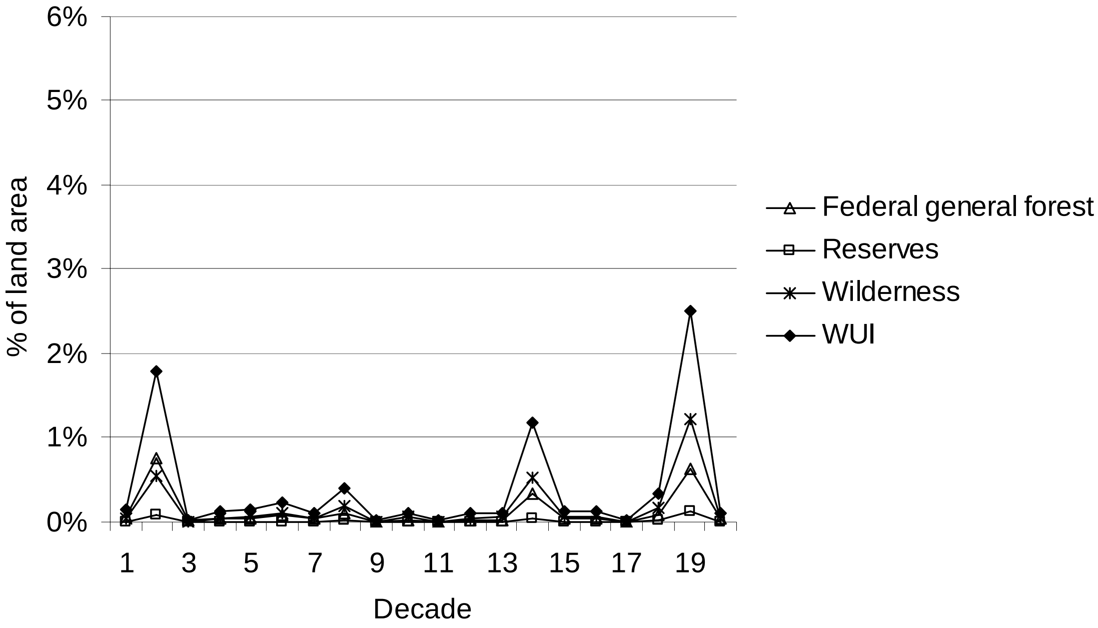


Figure 18. Variation in amounts of multi- and single story large and very large tree forests under Scenario 2 in the Five Buttes Study area, central Oregon, USA. Upper and lower lines are plus and minus one standard deviation from the mean.

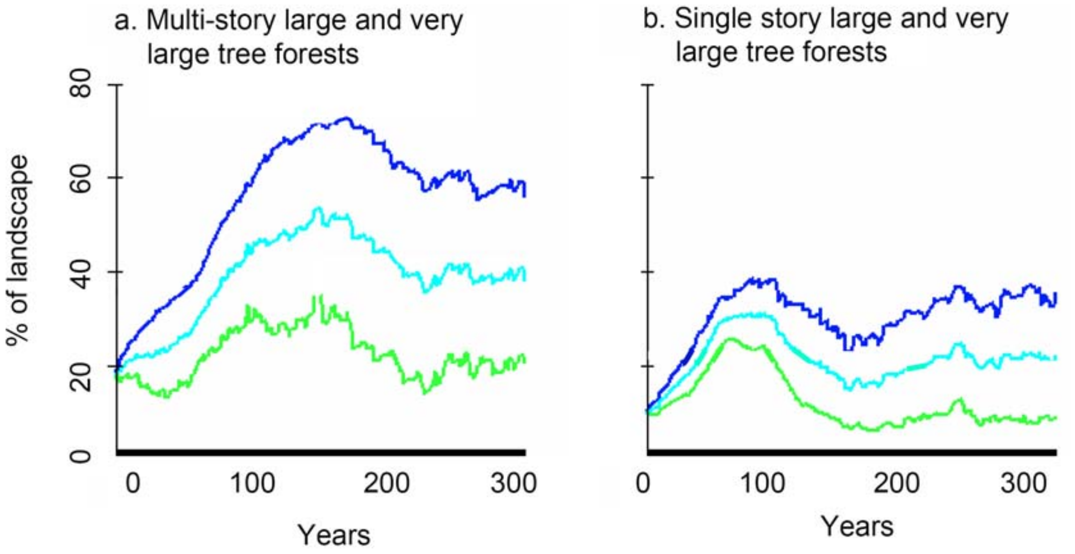
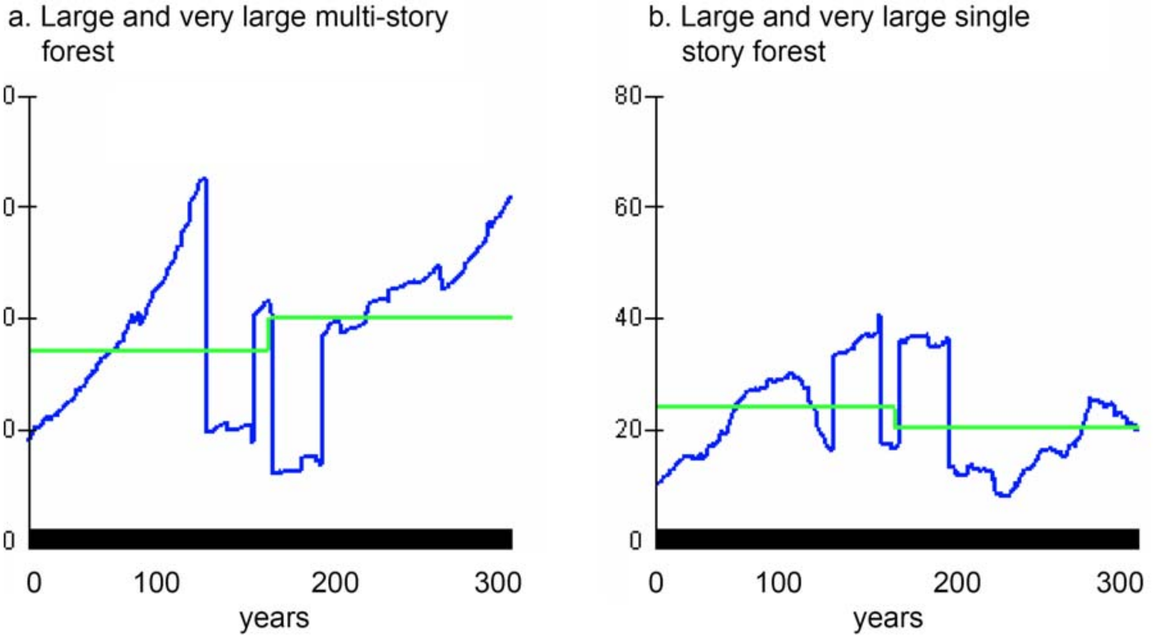


Figure 19. One randomly selected example simulation run showing amounts of multi- and single story large and very large tree forests under Scenario 2 in the Five Buttes Study area, central Oregon, USA. Central straight lines indicate mean value averaged over the 0-150 and 150-300 year time periods.



a. Large and very large multi-story forest

b. Large and very large single story forest

Figure 20. Variation in amounts of multi-story large and very large tree forests under Scenario 3 in the Five Buttes Study area, central Oregon, USA. Central straight lines indicate mean value averaged over the 0-150 and 150-300 year time periods.