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

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Abstract

We used state and transition models to integrate natural disturbances and management activities for a 275 000-ha landscape in the central Oregon Cascades. The landscape consists of a diverse mix of land ownerships, land use allocations, and environments. Three different management scenarios were developed from public input: (1) no management except wildfire suppression on federally managed lands, (2) manage Federal lands to increase multistory forests of large and very large trees, and (3) manage Federal lands to move toward historical conditions. All scenarios treated privately owned lands as if they were wildland-urban interface (WUI) areas and all recognized wilderness, reserves, and general forests within federally managed lands. Models were run for 200 years and 30 Monte Carlo simulations to include variability in fire years and other natural disturbances. Passive management on federally managed lands resulted in small increases in single-story and multistory large-tree forests and increases in high-severity wildfire and insect outbreaks. Managing toward multistory large- and very-large-tree forests resulted in minor increases in those forest types and increased wildfire and insect outbreaks. Contrary to intent, this scenario did not generate appreciable increases in multistory large- and very-large-tree forests. Managing toward historical conditions resulted in strong increases in single-story large- and very-large-tree forests and decreases in high-severity wildfire and insect outbreaks. All three scenarios resulted in conversion of most WUI to open grass, shrub, and forest conditions.

Keywords: Forests, landscape ecology, management, modeling, natural disturbances, Oregon.

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 landscapewide 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.

A partnership of Federal and State agencies and nongovernment organizations developed a shared effort to generate landscapewide 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

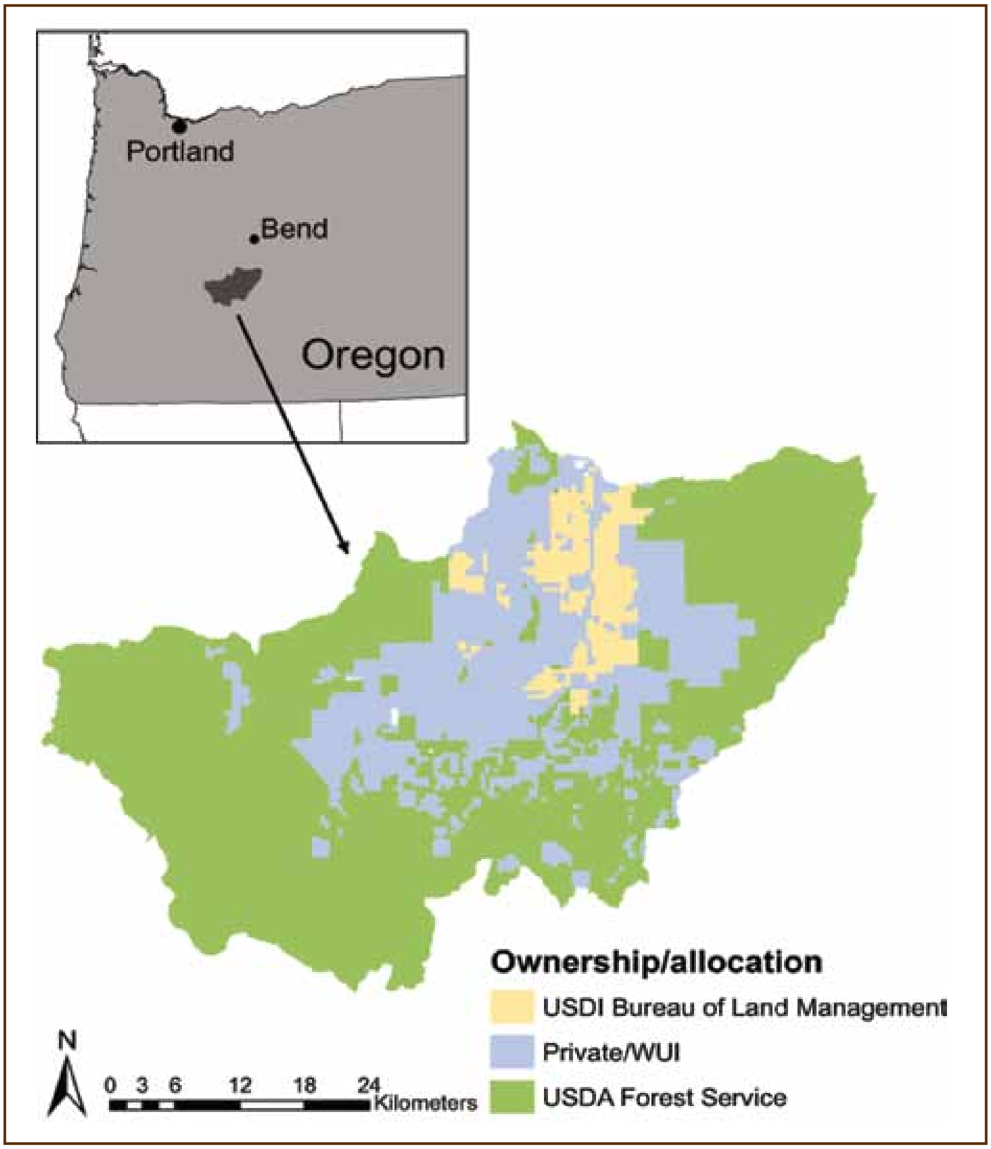

Figure 1—The Five Buttes study area in central Oregon, U.S.A. WUI = wildland-urban interface.

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; and (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, and timber products. In addition, policymakers and others want to consider long-term sustainability of landscape resources and conditions given various management approaches.

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 and others 2005, Hann and others 1997, Hemstrom and others 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 and others 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., Alig and others 2000, Johnson and others 1986). Although progress has been made in the formulation of multiobjective goals in landscape simulations (Sessions and others 1999, Wedin 1999), there remain many challenges to building landscape planning models that include all of the important disturbance processes that influence change. The net, synergistic effects of various disturbances (e.g., drought, fire, insects, and management activities) across a large, ecologically diverse landscape are of particular interest to policymakers, 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 and others (1997) and Hemstrom and others (2004). Although we do not specifically include drought and other climatic effects, their impacts are manifest in our annual wildfire and insect probabilities.

Study Area

The study area consisted of about 276 000 ha in seven watersheds in the southern portion of the upper Deschutes subbasin (Figure 1). Vegetation ranged from low-elevation shrublands, meadows, ponderosa pine and lodgepole pine forest to high-elevation parkland and spruce-fir and mountain hemlock forests. Ownerships were 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 and USDI 1994), 51 000 ha of wilderness and similar areas, and 59 000 ha of private lands.

Private lands constituted about 28 percent 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 were generally the highest priority management activity on private lands in this landscape. A consequence of our use of private lands as a surrogate for WUI was a potential overestimate of the rate of fuel treatments and an underestimate of other treatments on private lands.

Reserves were publicly owned lands (usually managed by the Forest Service or BLM) designated for special consideration and management (3 percent or about 7000 ha). These were usually late-successional reserves under the Northwest Forest Plan (USDA and USDI 1994) or other similar areas. Under some conditions, they may be managed with thinning or other fuel-reduction treatments. However, they were generally designated to maintain old forest structure and similar conditions. Wilderness was legally designated land managed for natural characteristics and included wilderness, state parks, and similar areas (15 percent or about 34 000 ha). Only natural disturbances (wildfire and insect/disease activity) were modeled in wilderness.

We recognized eight 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 and others 1997). These ranged from the lowest elevation juniper (*Juniperus occidentalis* Hook.) woodlands to alpine parklands:

1. Juniper woodland—shrub steppe areas generally capable of supporting grass, shrubs, and juniper but not closed forest.
2. Dry ponderosa pine (*Pinus ponderosa*)—areas capable of supporting ponderosa pine forests but generally not Douglas-fir (*Pseudotsuga menziesii*) or other tree species. These were transitional between forest and juniper woodland or shrub/steppe.
3. Mixed conifer dry—grand fir (*Abies grandis*) and Douglas-fir forests at lower elevations and in relatively dry environments. Historically, these areas consisted mostly of large, open, ponderosa pine stands maintained by frequent ground fire (average 10- to 20-year fire return interval).

Table 1—Forest structure class definitions for the Five Buttes study area, central Oregon, U.S.A.

Structure class	Tree canopy layers	Overstory canopy cover	Dominant tree d.b.h.
		Percentage	*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	≥ 1 3 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

4. Mixed conifer moist—forests dominated by a variety of conifer species, including ponderosa pine, Douglas-fir, grand fir, sugar pine (*Pinus lambertiana* Dougl.), incense-cedar (*Calocedrus decurrens* (Torr.) Florin), western larch (*Larix occidentalis* Nutt.) 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 (*Pinus contorta*) dry—lodgepole pine stands growing primarily on pumice soils. Soil and microsite conditions restricted other conifer species.
6. Upper montane cold—high-elevation forests dominated by Engelmann spruce (*Picea engelmannii*), mountain hemlock (*Tsuga mertensiana*), grand fir, subalpine fir (*Abies lasiocarpa*), lodgepole pine, and other species. This type occurred mostly within reserves or wilderness.
7. Upper montane moist—high-elevation forests that largely reflected westside climatic influences. Pacific silver fir (*Abies amabilis*), noble fir (*Abies procera*), Douglas-fir, and other species generally dominated.
8. Subalpine parkland—high-elevation mosaics of tree islands, alpine shrublands, and grasslands largely within reserves or wilderness.

Methods

We developed 337 combinations of vegetation structure classe (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 uppermost canopy layer and included several categories of developed land (e.g., urban, agriculture, etc.). Structure class depended on the size, tree density per unit area, and canopy layering for forests or 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, fire and fuels, and various commercial forest products. Combinations of cover type and structure

Table 2—Forest cover type classes used in the Five Buttes study area, central Oregon, U.S.A.

Cover type	Dominant species
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.)
Grand fir	Grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), Douglas-fir, and other conifers
Lodgepole pine	Lodgepole pine (*Pinus contorta* Dougl. ex Loud.)
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

class within potential vegetation types formed the basic vegetation state-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 1,600 inventory plots to 30-m pixels using a statistical relationship between LANDSAT-TM imagery and other geographic data and inventory plots. In general, GNN methods are best at predicting forest structure (e.g., diameter of dominant and codominant trees) but less accurate for canopy tree species (Ohmann and Gregory 2002). Correlation between predicted and observed quadratic mean diameter of dominant and codominant trees in the Oregon Coast Range was about 0.8, whereas that for tree species richness was about 0.53 (Ohmann and Gregory 2002). Where GNN data were unavailable, we used vegetation composition and structure attributes from Oregon GAP (2006). Cover and structure data were summarized to state-classes within strata of watershed, ownership/land allocation, and potential vegetation type. These estimates of area by state-class by stratum were the initial conditions for our modeling process.

We used state-and-transition models to project the integrated effects of natural disturbances and management treatments on vegetation. Vegetation composition and structure within plant association strata defined each state. States were connected by transitions that indicated either the effect of successional vegetation development over time, or the effect of disturbance (Hemstrom and others 2004). This approach expanded transition matrix methods and represented vegetation development as a set of transition probabilities among various vegetative states (Cattelino and others 1979, Hann and others 1997, Horn 1975, Keane and others 1996, Laycock 1991, Noble and Slatyer 1980, Westoby and others 1989). For example, grass/forb communities might be dominated by closed forest following tree establishment over a period of time or might remain as grass/forb communities following wildfire. Alternatively, management activities or low-severity wildfire may generate more open forest conditions. State changes along the successional, time-dependent paths were usually deterministic, and, without disturbance or management, all the vegetation could ultimately accumulate in one state. Different management scenarios were developed to represent alternative landscape objectives and, hence, management treatments.

We developed and ran our models with the Vegetation Dynamics Development Tool (VDDT) (Beukema and others 2003). VDDT has been used in several landscape assessments and land management planning efforts in the Interior Northwestern United States (e.g., Hann and others 1997, Keane and others 1996, Merzenich and others 2003) and elsewhere (Hann and Bunnell 2001, Merzenich and Frid 2005). Although VDDT is a nonspatial model, managers and others often need to understand the spatial distribution of vegetation conditions and disturbances. Consequently, we ran models using strata of land ownership and allocation and potential vegetation types within watersheds so that we could display results about the spatial distribution of landscape characteristics without implying pixel or stand-level accuracy. All scenarios were run for 200 years with 30 Monte Carlo simulations to allow the occurrence of rare events and generate estimates of long-term disturbance variability and forest development trends. We compared decadal average area treated with different treatments and disturbances across our three scenarios to examine trends that would have been more difficult to visualize in highly variable annual outputs. Average annual area in various forest types, however, was not as variable and was displayed on a yearly basis.

Forest Growth and Management Treatments

Our models include a set of assumptions and definitions that form the basis of transition rates and directions. In general, transition rates and directions were developed from a combination of inventory data and the Forest Vegetation Simulator (FVS) (Dixon 2002), the published literature, and, where necessary, expert opinion. The inventory data were tree lists from plots collected as part of the Forest Inventory and Analysis (FIA) (Barrett 2004) and Continuous Vegetation Survey (CVS) (Max and others 1996) inventories collected by the USDA Forest Service. There are over 1,600 inventory plots in the larger landscape study area. Each of these plots was assigned to one of our VDDT model state-classes, and FVS was used to project the rate and direction of growth transitions. We also modeled a set of management activities using FVS and the inventory data to estimate yield streams from management activities (Hemstrom and others 2006). We used a fixed set of silvicultural treatments to model our scenarios. 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, based on discussions with local land managers and silviculturists, our treatments represent typical, commonly implemented kinds of activities that might occur on the various ownerships and allocations in the study area. Management treatments included:

1. Regeneration harvests on private lands only.
2. Salvage following stand-replacement wildfire or insect outbreaks on Federal general forest and private land, but not in reserves or wilderness.
3. Tree planting in areas that had been regeneration harvested or salvaged.
4. Precommercial thinning from closed to open condition at age 15.
5. Commercial thinning of trees across all diameter classes to reduce stand density to open structure. We assumed that trees greater than 51 cm in diameter at breast height (d.b.h.) could be harvested on private lands but not on lands administered by the UDSA Forest Service, a reflection of current management policy.
6. 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.
7. 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.
8. Prescribed fire was underburning applied to low-density stands of fire-tolerant 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 commercial harvest category that might produce enough saw-log-sized material to be of commercial interest. We combined precommercial thinning and mechanical fuel treatment into noncommercial harvest because the majority of material available from treatment would likely be too small to be used for sawtimber.

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

Potential vegetation type	Fire severity class	Average fire interval	Average annual fire probability	LANDFIRE rapid assessment model
		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	

Wildfire

We used wildfire probabilities for historical or reference conditions from the interagency LANDFIRE effort (LANDFIRE 2006). Reference conditions were assumed by 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). Current wildfire probabilities were estimated from 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 aboveground vegetation: (1) 0- to 25-percent mortality was low severity, (2) 25- to 75-percent mortality was mixed severity, and (3) more than 75-percent mortality was high severity. We recognized that wildfire probabilities, and those of insect outbreaks, reflected larger externalities such as regional drought and

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

ignition patterns but did not explicitly include drought effects.

We used random streams of fire years to model year-to-year variability in area burned owing to the effects of weather, fuel conditions, and chance. For example, regional climate may produce a series of dry years with abundant lightning ignitions. In this case, wildfire probabilities would be substantially higher compared to average years. Our modeling process included randomly drawn sequences of normal, high, and extreme wildfire years to simulate annual variability in natural disturbances. We also assumed that wildfire variability changes with landscape scale, being higher in small areas (e.g., watersheds of 14 000 to 90 000 ha) and lower in large areas (e.g., the Deschutes subbasin of over 800 000 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 percent of years experience normal or average amounts of wildfire, 15 percent experience high amounts of wildfire, and 5 percent experience extreme amounts of wildfire at the scale of the entire upper Deschutes subbasin. Essentially, for 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 wildfire would occur in large fires that impact only a few watersheds but burn most of the area within affected watersheds. We assumed that 95 percent of years produced normal amounts of wildfire, 4 percent produced high amounts, and 1 percent produced extreme amounts at the watershed scale (Table 4). In essence, 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.

Wildfire probabilities were set by vegetation cover, structure, and potential vegetation type. However, wildfire probability is not just a function of the vegetation conditions in a single state class. We used landscape condition feedback to increase overall wildfire probabilities when the landscape contained abundant dense forests and to decrease them when overall forest conditions were more open. We assumed that abundant dense forests meant highly contiguous fuels and increased landscape susceptibility to large, difficult-to-suppress wildfires.

Management Scenarios

In 2005, we held meetings in Bend and Klamath Falls, Oregon, 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 Federal lands in the area might be managed. We used the results of these meetings to design four management scenarios for modeling. Because fuel and fire hazards in WUI were an overriding concern, fuel treatments in WUI described for scenario one were included in all three scenarios.

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

Scenario 2—

Active Fuel Treatment in Wildland/Urban Interface, Maximize Multistory Large Tree Forests on Federal Lands

Federal lands were managed to produce large trees and increase habitat for wildlife species associated with multi-storied stands that contained many large and very large trees (more than 51 cm in d.b.h.). With fire suppression, an understory tree layer will develop naturally on most forested environments in the study area. In these areas, early management activities included thinning prescriptions to create and maintain open stands of fire-tolerant tree species that could grow to a large size relatively quickly while reducing risk of loss to high-severity wildfire. In addition, stands dominated by large and very large trees were infrequently thinned from below to reduce stand density while retaining some smaller trees. Our treatment regime on federally managed general forest lands included:

1. Precommercial thinning of all stands at age 15.
2. Treating 5 percent of high-density and 2.5 percent 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 trees reached large 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 from below in dense stands of very large trees in mixed conifer dry and mixed conifer moist types at an annual rate of 10 percent to reduce fire and insect losses while maintaining most of the multistory 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 percent annually.
6. Salvaging dead wood in 25 percent of the stands that had experienced wildfire and insect outbreaks.

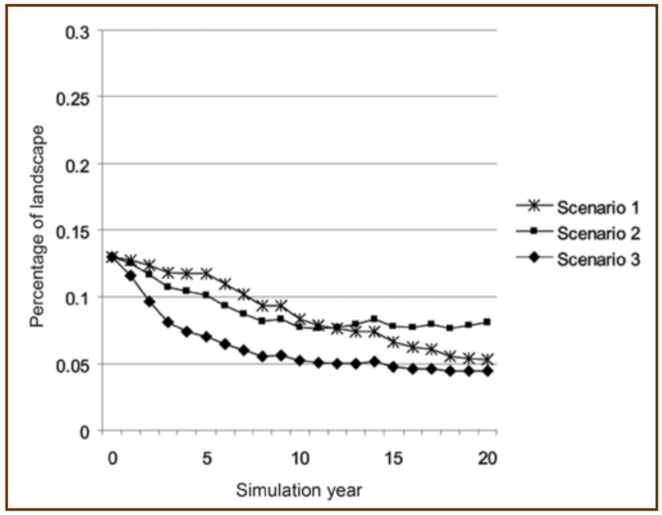

Figure 2—Percentage of the landscape in multistory large and very large tree structure classes by scenario in the Five Buttes area, central Oregon, U.S.A.

7. Treating reserves at one-half these rates and wilderness not at all.

Scenario 3—

Active Fuel Treatment in Wildland/Urban Interface, Move Federal General Forest Lands Toward Historical Conditions

Federal general forest lands outside wilderness were managed to reduce fuels and high-severity wildfire risks while moving forests toward historical conditions, i.e., conditions assumed to be typical prior to about 1850. Management in reserves was designed to reduce stand density and fuel levels while maintaining large and very large trees in generally open forest conditions.

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 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 favor single-storied forests of fire-tolerant conifers, especially in the drier potential vegetation types. We applied prescribed fire to mimic historical wildfire

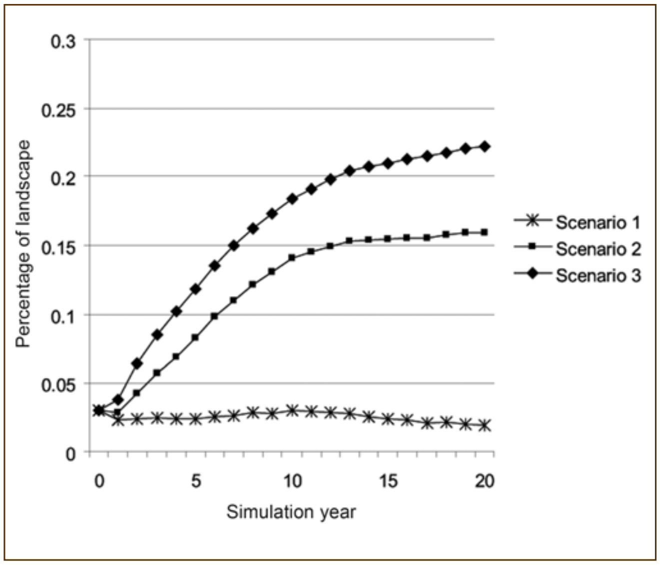

Figure 3—Percentage of the landscape in single-story very large and large tree structure classes by scenario in the Five Buttes area, central Oregon, U.S.A.

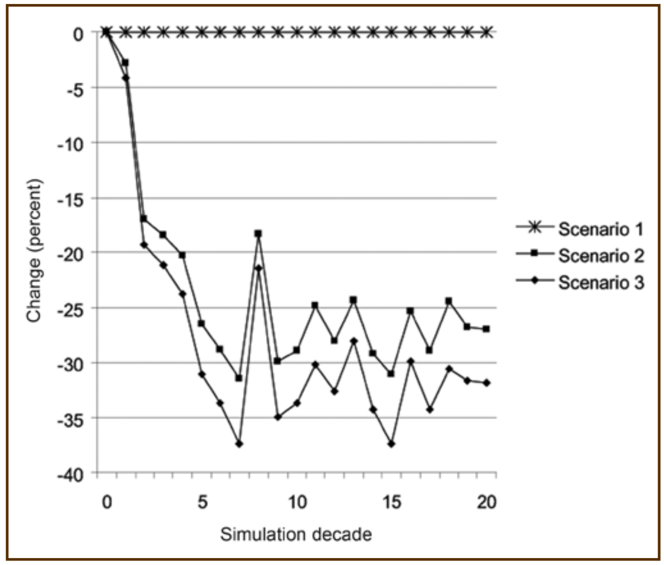

Figure 4—Percentage change in average decadal area affected by high-severity wildfire under scenarios 2 and 3 compared to scenario 1 in the Five Buttes study area, central Oregon, U.S.A.

frequencies on Federal 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 multistory forest habitat than Federal general forest lands. Wilderness areas were not treated except with wildfire suppression.

Multistory large- and very-large-tree forests declined over the 200-year simulation period under scenario one owing to a combination of wildfire and insect outbreaks (Figure 2). This suggests, based on our modeling assumptions, that passive management on Federal lands in the study area might produce no more than about the current abundance of large- and very-large-tree forests in the study area and that those forest conditions might decline on a long-term basis.

Single-story large- and very-large-tree forests remained relatively constant at about 2 percent of the landscape area under scenario 1, on average, over 200 years (Figure 3). The relatively low levels of single-story large- and very-large-tree forests that did occur resulted from an uncommon coincidence of slow regeneration of small trees and random low- or moderate-severity wildfire.

High-severity wildfires burned more landscape area under scenario 1 than scenarios 2 and 3 (Figure 4).

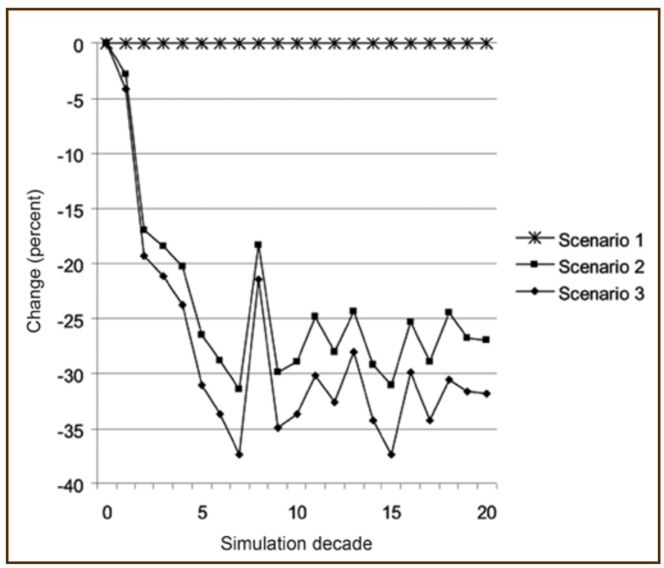

Figure 5—Average decadal area treated with mechanical fuel treatments and thinnings by scenario in the Five Buttes area, central Oregon, U.S.A.

High-severity wildfire was proportionately greatest in WUI areas dominated by grass, forb, and shrub communities. Although these communities are highly susceptible to wildfires that kill most of the aboveground vegetation, wildfires in such vegetation are much more easily controlled than those burning in dense forests. The other ownership/allocation categories were largely forested throughout our

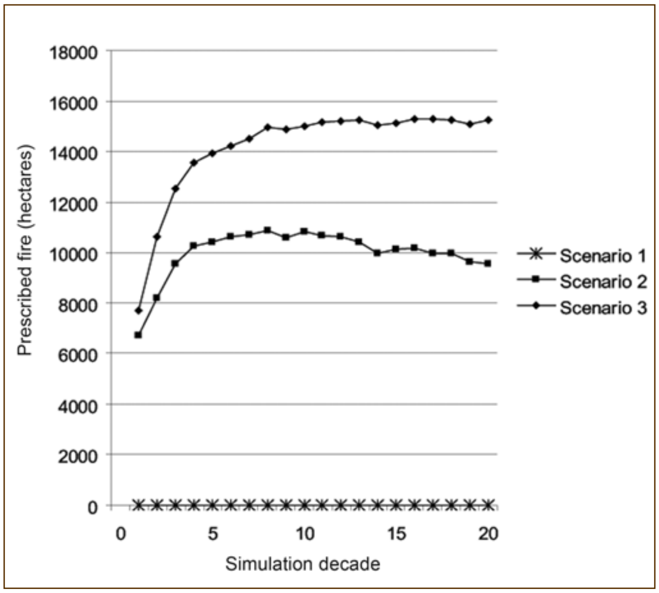

Figure 6—Average decadal area treated with prescribed fire by scenario in the Five Buttes area, central Oregon, U.S.A.

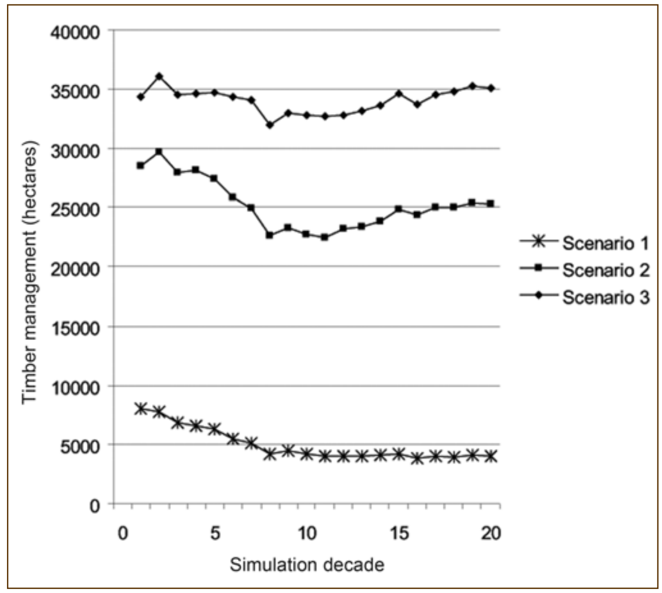

Figure 7—Average decadal area treated with management activities that may produce commercial timber products by scenario in the Five Buttes study area, central Oregon, U.S.A.

simulations. High-severity wildfire affected Federal general forests somewhat more than other ownership/allocation classes because Federal general forests were mostly in lower elevation, drier environments subject to higher fire probabilities.

Mechanical fuel treatments and stand thinnings only occurred on private lands under scenario 1 and remained below 1000 ha treated per decade (Figure 5). Likewise, prescribed fire treatments only occurred on Federal lands and were absent under scenario 1 (Figure 6). Treatments that might produce at least some commercial timber products averaged less than 10 000 ha per decade under scenario 1 and slowly declined to about 5000 ha per decade in the last ten decades (Figure 7).

Scenario 2 produced moderate amounts of multistory large- and very-large-tree forests (Figure 2). Contrary to our design objectives, scenario 2 did not increase multistory large tree forest by much compared to current conditions. In fact, scenario 2 produced lower amounts of multistory large- and very-large-tree forest than scenario 1 for the first 100 years. Both scenarios 1 and 2 simulations produced, on average, about half the current amount of multistory large-tree and very-large-tree forest at the end of 200 years. Perhaps alternative approaches to protecting and developing multistory large-tree forests on Federal general forests could be formulated and might be more successful than our scenario 2. This also suggests, at least given assumptions in our models, that current levels of multistory large- and very-large-tree forests in the study area are perhaps an artifact of fire suppression and other factors and may not be sustainable in the study area over the long run.

Single-story large- and very-large-tree forests substantially increased across the entire landscape under scenario 2 (Figure 3). Much of the increase occurred in Federal general forest, and WUI was due to thinning to produce large trees quickly in scenario 2 and very active fuel treatments that produced open stands in scenario 3. Single-story large- and very-large-tree forests remained at very low levels in reserves and in the wilderness.

Scenario 2 produced lower levels of high-severity wildfire compared to scenario 1 (Figure 4). Even though fuel treatments were not extensive in scenario 2, some did occur 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 20 percent to 30 percent less than in scenario 1, especially after the first two decades. As in scenario 1, the highest proportion of high-severity wildfire in scenario 2 was in open

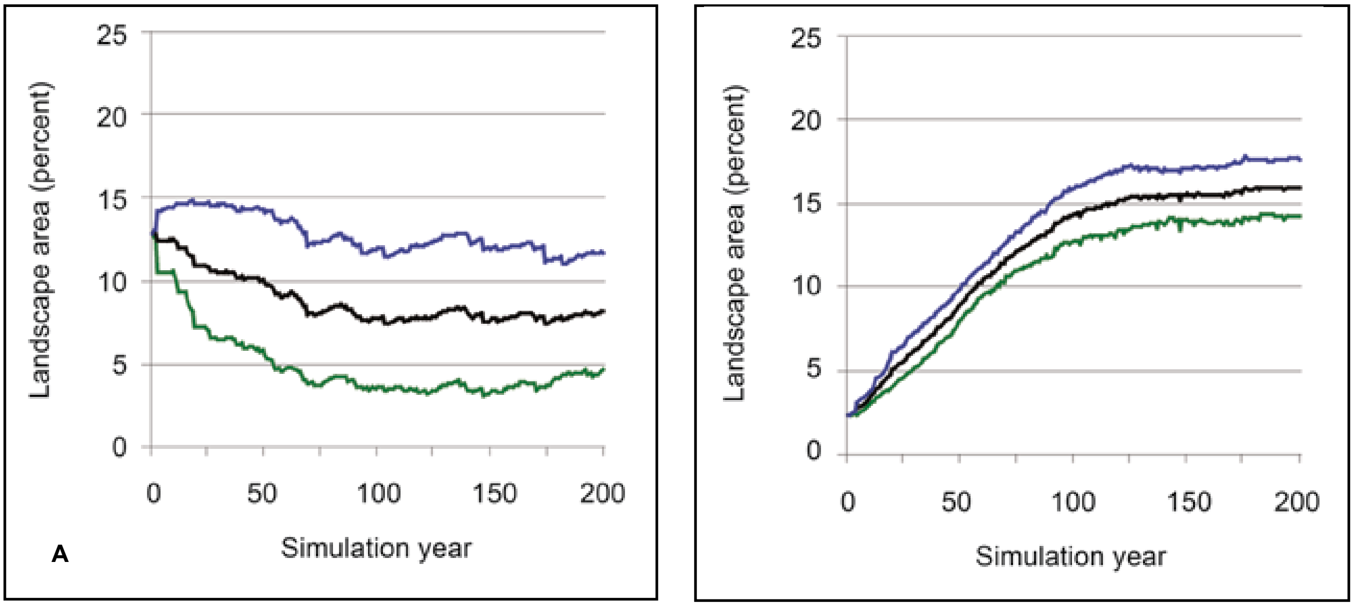

Figure 8—Variation in amounts of multi- and single-story large- and very-large-tree forests under scenario 2 for 30 Monte Carlo simulations in the Five Buttes area, central Oregon, U.S.A. Upper and lower lines are plus and minus one standard deviation from the mean.

forests dominated by grass/forb/shrub communities in WUI. High-severity wildfires are relatively easy to control in open grass/forb/shrub communities compared to high-severity wildfire in dense forest. From a wildfire protection perspective, active fuel treatment changed potential fire behavior rather than eliminating wildfire. Federal general forests experienced considerably lower amounts of high-severity wildfire compared to scenario 1, owing to fuel treatment effects, but amounts in reserves and wilderness were similar to those under scenario 1.

Management activity levels were higher in scenario 2 than in scenario 1 due to thinnings to promote large tree development in Federal general forests. Scenario 2 produced about 25 000 ha of commercial treatment activities per decade over 20 decades (Figure 7). Mechanical fuel treatment rates declined slightly after the first decade, then varied over the remaining 19 decades. Mechanical fuels and thinning were highest in the first decade as the initial round of mechanical fuel treatments peaked (Figure 5). Prescribed fire rose to about 10 000 ha per decade as fire replaced mechanical fuel treatment for fuel reduction, then remained at relatively stable levels (Figure 6).

Scenario 3 produced the lowest overall abundance of multistory large- and very-large-tree forests (Figure 2). Multistory large- and very-large-tree forests declined from about 13 percent of the study area to a minimum of about 4 percent at the end of the simulation. Much of the decline occurred in the first 100 years as dense forests burned or were killed by insect outbreaks. Initial declines on Federal general forests were due to thinnings designed to quickly move dense forests to more open conditions followed by thinnings and fuel treatments at maintenance levels.

Conversely, scenario 3 produced abundant single-story large- and very-large-tree forests (Figure 3). Single-story large- and very-large-tree forests initially occupied less than 5 percent of the study area, but increased fourfold to over 20 percent by the end of the simulation. Increases were nearly greatest on Federal general forest lands due to active thinning and fuel treatment. Smaller increases occurred in WUI and reserves that were treated at lower rates. 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. Landscape levels (about 20 percent) at 200 years were lower than those estimated by Hann and others (1997) for historical conditions in the southern Cascades area in Oregon and Washington (about 57 percent).

Scenario 3 also produced the lowest overall rates of high-severity wildfire (Figure 4). After the first five

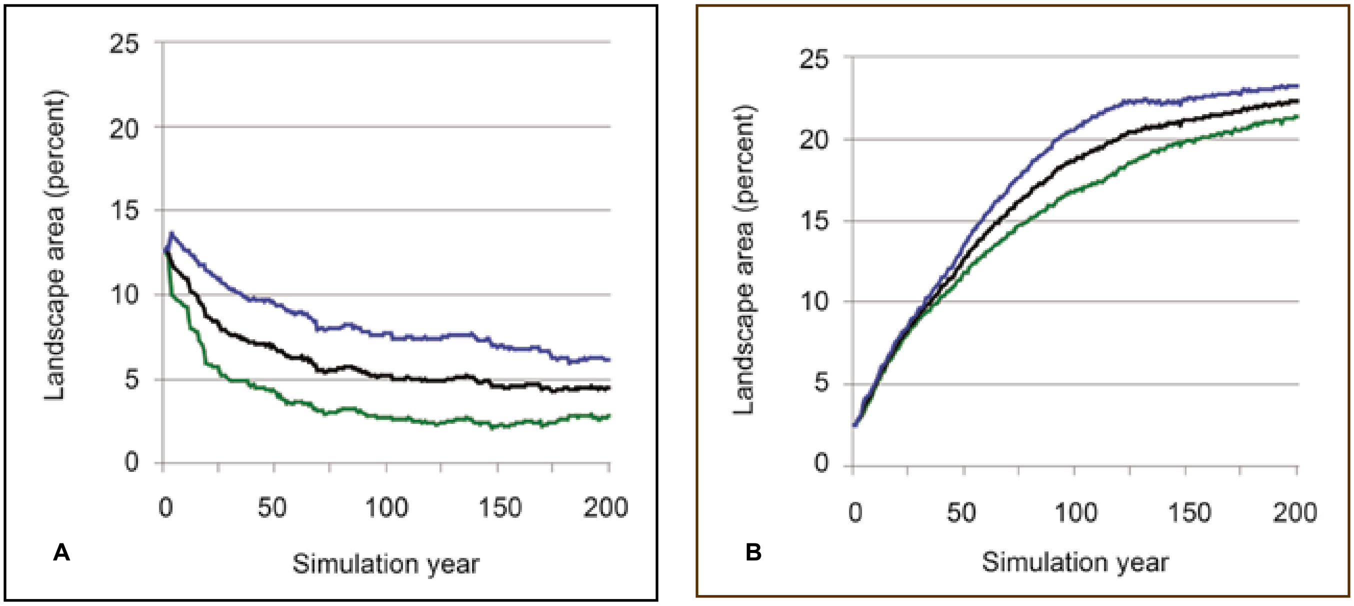

Figure 9—Variation in amounts of multi- and single-story large- and very-large-tree forests under scenario 3 for 30 Monte Carlo simulations in the Five Buttes area, central Oregon, U.S.A. Upper and lower lines are plus and minus one standard deviation from the mean.

decades, the proportion of area burned in high-severity wildfires was generally 30 percent or more below that in scenario 1 and 5 percent to 10 percent lower than that in scenario 2. WUI areas experienced the highest proportion of high-severity wildfire, again in grass/forb/shrub-dominated open forests where wildfire is most easily controlled. Of the other three ownership/allocation classes, wilderness areas were most highly impacted by high-severity wildfires, in contrast to scenarios 1 and 2. This resulted from fuel treatments that reduced wildfire outside wilderness. Federal general forests, on the other hand, experienced lower levels of high-severity wildfire compared to both scenarios 1 and 2 owing to fuel treatment effects.

Scenario 3 produced about 35 000 ha of commercial timber harvest per decade (Figure 7). Mechanical fuel treatments and thinnings occurred on about 9000 ha in the first decade, then varied between 6000 and 7000 ha per decade after that (Figure 5). Not surprisingly, given the emphasis on reducing fire risks and generating open forests on Federal general forests, scenario 3 produced the high levels of prescribed fire (Figure 6). The initial ramp-up in prescribed fire took place over the first four decades after initial mechanical fuel treatments reduced fuel levels so that prescribed fire could be used for subsequent fuel treatments.

Variability

Results for several important landscape characteristics were highly variable over 30 Monte Carlo simulations in our study area. For example, whereas the multistory large- and very-large-tree forests under scenario 2 averaged about 8 percent of the landscape area at year 100, one standard deviation above and below the mean ranged from about 12 percent to less than 4 percent of the landscape area (Figure 8a). The same scenario produced lower variability for single-story large- and very large-tree-forests (Figure 8b). In this case, the mean at 200 years was about 16 percent and the standard deviation, plus or minus 2 percent. In our study area, and given the assumptions in our model, multistory large- and very-large-tree forests seem to be potentially less abundant and subject to more variability than single-story large- and very-large-tree forests, even in a scenario designed to increase multistory large- and very-large-tree forests.

Variability patterns for large- and very-large-tree forests under scenario 3 were similar to those in scenario 2 (Figures 9a and 9b). As one might expect given scenario 3 objectives, multistory large- and very-large-tree forests were much less abundant than single-story large- and very-large-tree forests overall. Single-story large- and

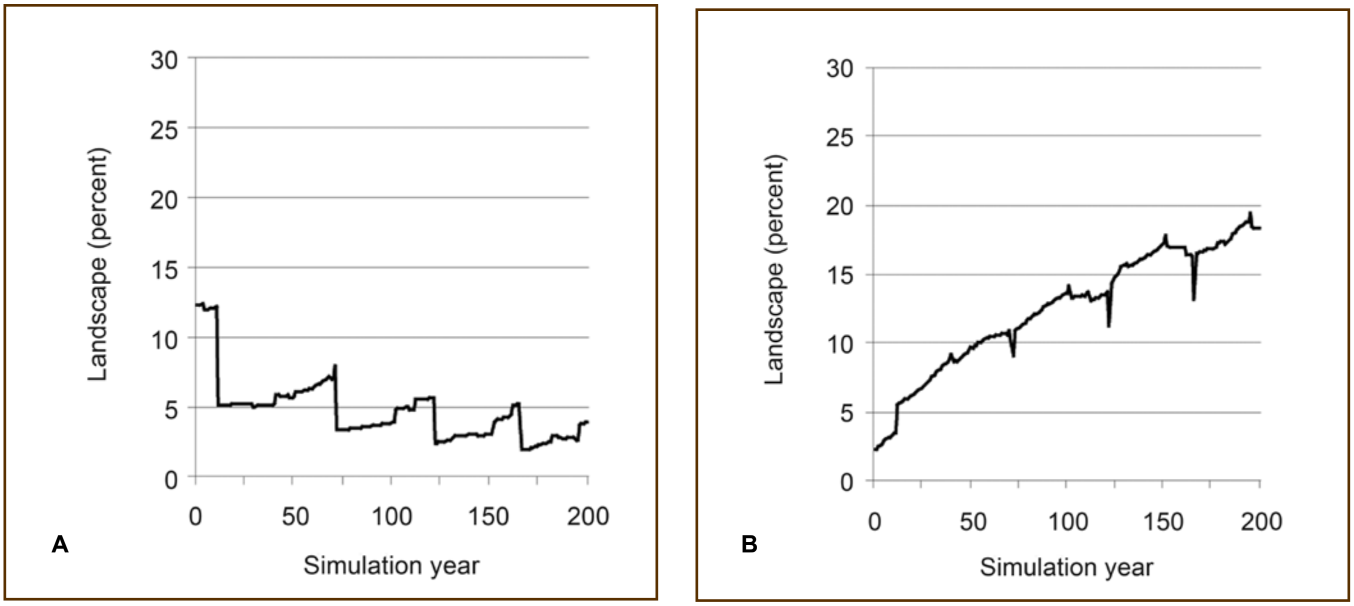

Figure 10—One randomly selected example simulation run showing amounts of multi- and single-story large- and very-large-tree forests under scenario 2 in the Five Buttes area, central Oregon, U.S.A.

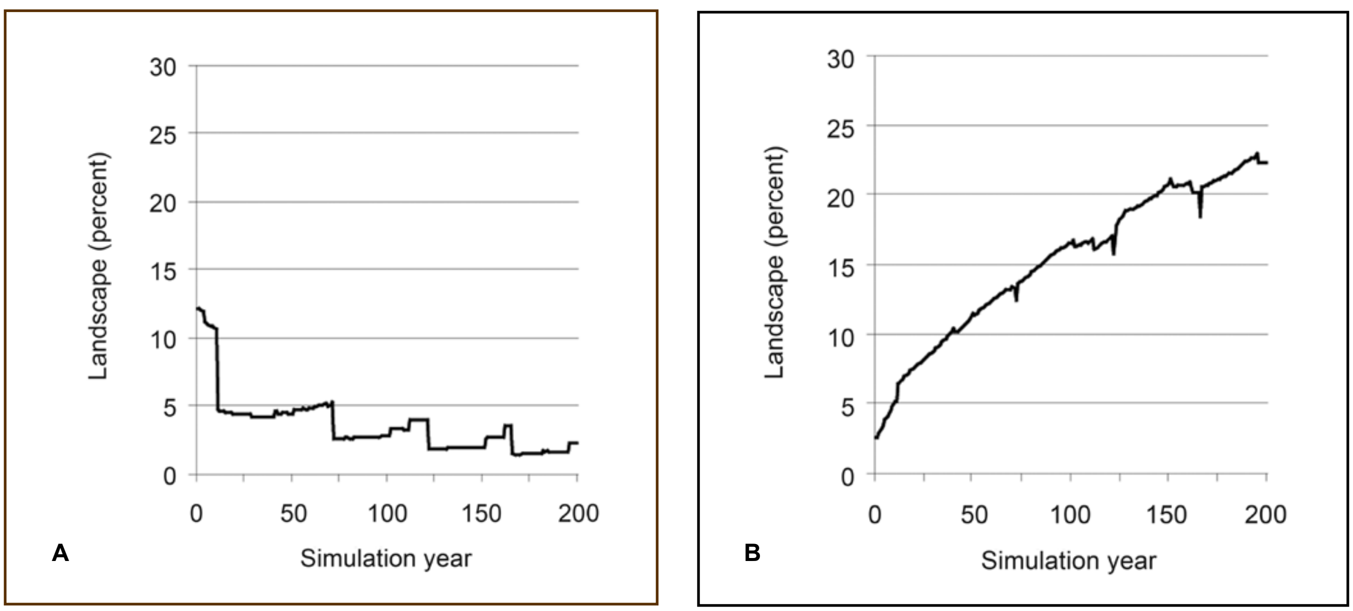

Figure 11—Variation in amounts of multistory large- and very-large-tree forests under Scenario 3 in the Five Buttes area, central Oregon, U.S.A.

very-large-tree forests increased steadily to an average of about 22 percent of the landscape area with relatively narrow variation. Large- and very-large-tree multistory forests steadily declined from current conditions to less than 6 percent of the landscape area by the end of the simulations. Our interpretation, based on our modeling assumptions, was that single-story large- and very-large-tree forests were relatively stable and might be sustained at high abundance for many decades in much of the study area given fuel and thinning treatments, as others have suggested for similar environments (e.g., Agee 2003, Hann and others 1997, Hessburg and Agee 2003). In addition, managing to increase multistory large- and very-large-tree forests in this landscape might not succeed, and future variation might produce very small amounts even with management designed to increase them.

In fact, none of the individual simulation runs that make up the 30 Monte Carlo set for multistory large- and very-large-tree forests under scenarios 2 or 3 looked anything like the mean trend (Figures 10a, 10b, 11a, 11b). In these examples, multistory large- and very-large-tree forests experience occasional crashes during a sequence of years with abundant high-severity wildfire or insect outbreaks. Simulated patterns, however, suggest that multistory large-tree forests may be subject to boom-and-bust abundance in the study area. Single-story large-tree forests also experienced occasional sharp drops, but to a lesser degree, and recovery was quicker. Judging from patterns in individual simulations and variation in many simulations, single-story large- and very-large-tree forest structures were the most stable older forest structure in general Federal forests in the study area.

Conclusions

Our model results may indicate some interesting landscape hypotheses in this and similar areas:

1. Fuel treatments in WUI may shift wildfire behavior as fires burn in grass, shrubs, and open forests, but not reduce overall wildfire probability. However, shift in behavior could be important because wildfires in grass, shrub, and open forest fuels are easier to control than those in closed, dense forests.
2. Efforts to increase multistory, dense forest habitats in these drier environments for particular wildlife habitats may prove difficult because increased wildfire and insect outbreak probabilities might offset gains from silvicultural manipulation. In our simulations, multistory large-tree forests didn't exceed about 15 percent of the landscape on average, and amounts declined from current conditions. Most individual model runs in our Monte Carlo set experienced boom and bust conditions such that this forest type occasionally crashed to less than 5 percent of the landscape area.
3. Scenario 3, which moved Federal general forests toward historical conditions, generated the most stable landscape conditions, but individual simulations still produced occasional sharp declines in large-tree forests because of severe wildfire years or insect outbreaks.

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. Calibration of annual wildfire year and insect outbreak sequences with historical drought and other climatic influences with empirical data from other sources (e.g., dendroclimatology) is an area where future model improvements could be made. Stand treatment prescriptions we used need to be tested in the field to determine whether desired outcomes are achieved. In addition, processes in the future 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 undetected logical error in our models, (4) climate change may alter fire, insects/disease, and other disturbances, and (5) management direction may change.

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