Chapter 3: Simulating Fire Hazard Across Landscapes Through Time: Integrating State-and-Transition Models With the Fuel Characteristic Classification System

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Chapter Summary

Information on the effects of management activities such as fuel reduction treatments and of processes such as vegetation growth and disturbance on fire hazard can help land managers prioritize treatments across a landscape to best meet management goals. State-and-transition models (STMs) allow landscape-scale simulations that incorporate effects of succession, management, and disturbance on vegetation composition and structure. State-and-transition models have been used for many different types of landscape-scale assessments. However, STMs do not currently assess fuels and fire hazard for different vegetation state classes.

We integrated STMs with a software application called the Fuel Characteristic Classification System (FCCS) to enable assessment of fuel properties and fire hazard with succession, disturbance, and management across landscapes over time. We created FCCS fuel beds from inventory plots for each vegetation state class in STMs covering forests and woodlands in Arizona, New Mexico, Oregon, and Washington. We used FCCS to analyze each fuel bed for its potential fire behavior, and we linked results to STM simulation output to assess potential changes in fire hazard with management and natural disturbance regimes over time.

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The analysis across the four-state study area resulted in thousands of fuel beds that cover a broad range of fuel conditions, and the links between these fuel beds and STMs can be used to help develop successful fuel treatment regimes in fire-prone forests. We present a Washington East Cascades (WEC) case study that illustrates potential application of this work. We analyzed potential future fire hazard under fire-suppression-only and resilience scenarios for the WEC region. We found that crown fire potential was reduced under the resilience scenario; area of high crown fire potential was reduced by 13 percent by 2056. However, patterns in surface fire potential were obscured by variation in surface fuel characteristics within a vegetation state class. The fuels analysis in the WEC gives land managers information they need to prioritize areas for fuel treatments and help them to determine what types of activities will result in the greatest reduction in crown fire potential.

Introduction

Twentieth-century fire suppression policies have led to fuel accumulations and greater risk of high-severity fire in many dry forest types of western North America that were historically characterized by relatively high frequency and low- to moderate-severity fire regimes (Allen et al. 2002, Brown et al. 2004, Covington 2003, Hessburg et al. 2005). Fire area burned has increased in the Western United States over the past few decades (Westerling et al. 2006), and this trend is expected to continue with warmer and drier conditions associated with climate change (Littell et al. 2010, McKenzie et al. 2004). Climate change may also lead to fires becoming more difficult to control because of more frequent extreme burning conditions (Fried et al. 2004). To reduce stem densities and fire intensity and support suppression efforts, vegetation management treatments are often implemented in areas characterized by historically low- to moderate-severity fire regimes (Graham et al. 2004, Peterson et al. 2005). However, the effectiveness of these treatments varies by treatment type and treatment intensity within managed forest stands and by treatment type, intensity, and arrangement across landscapes (Finney et al. 2007, Johnson et al. 2011, Prichard et al. 2010a, Schmidt et al. 2008), making it difficult for managers to choose what type of treatments to conduct and where to prioritize treatments on a landscape.

Fire hazard, or the potential fire behavior for a fuel type (Hardy 2003), concerns fire and land managers because it gives an indication of the potential fireline intensity, flame lengths, crown fire activity, resistance to control, and potential physical and biological effects of fire in a given area of vegetation. Fire hazard also reflects the only element of fire behavior that can be affected by management—fuels. Information on the effects of management activities and forest succession and disturbances on fire hazard can help land managers prioritize vegetation management treatments on a landscape to meet management objectives.

State-and-transition models (STMs), which subsume vegetation dynamics into state classes (boxes) and transitions (arrows), are tools that provide landscape-scale information on the effects of management, forest growth and development, and natural disturbance on vegetation composition and structure (chapter 2). Thus, STMs can provide information that is useful to managers in prioritizing treatments across a landscape. The STMs have been used for many types of landscape-scale assessments that incorporate potential effects of management on vegetation composition and structure over time (e.g., Arbaugh et al. 2000; Forbis et al. 2006; Hemstrom et al. 2001, 2007; Merzenich et al. 2003; Merzenich and Frid 2005; Ryan et al. 2006; Weisz et al. 2009). However, STMs do not currently allow direct assessment of fuels and fire hazard for different vegetation state classes.

The Fuel Characteristic Classification System (FCCS) is a software application that allows users to analyze fuel properties and fire potential of wildland and managed vegetation.

The Fuel Characteristic Classification System (FCCS) (McKenzie et al. 2007; Ottmar et al. 2007; Riccardi et al. 2007a, 2007b; Sandberg et al. 2007a, 2007b; Schaaf et al. 2007) is a software application that allows users to analyze fuel properties and fire potential of wildland and managed vegetation. The FCCS analysis involves development of fuel beds (detailed descriptions of all burnable biomass, from the litter layer to the canopy), and the software evaluates those fuel beds for fire behavior potential (the intrinsic physical capacity of a fuel bed to support fire) (Sandberg et al. 2007a, 2007b). The FCCS is a flexible tool that allows fuel bed development and analysis for any relatively homogeneous unit. Providing an alternative to the categorization of fuel characteristics into standard fuel models (e.g., Scott and Burgan 2005), FCCS allows development of detailed fuel beds and analysis for any chosen unit of land. The flexibility and detailed analysis that characterize FCCS allowed us to integrate FCCS with STMs to enable assessment of fuel properties and fire hazard with succession, disturbance, and management across landscapes over time.

To integrate FCCS with STMs, we used inventory plot data to construct FCCS fuel beds that represent each vegetation state class in STMs covering forested and woodland ecosystems in Arizona, New Mexico, Oregon, and Washington. We then analyzed the potential fire behavior for each fuel bed and linked the results to STM simulation output to assess potential changes in fire hazard with management and natural disturbance regimes over time.

This project was conducted as a part of the Integrated Landscape Assessment Project (ILAP), which involved the examination of current and potential future dynamics of broad-scale, multiownership landscapes by integrating and evaluating information about current and future vegetation and related resources (see chapter 1 for further detail on the ILAP project). Linking our fuel bed analysis with output from the ILAP STM modeling effort (chapter 2) allowed us to address a number of research and management questions, including, (1) How do different forest management scenarios affect fuel conditions and fire hazard across a given landscape? and (2) To what extent can fuel treatment programs reduce fire hazard?

This chapter describes methods used to integrate STMs with FCCS in the four-state study areas and illustrates results of our process with a case study in the Washington East Cascades (WEC) modeling zone. We chose to use a case study to illustrate results because results are more clearly displayed and conceptualized at the scale of a region than at the scale of the four-state study area. We chose eastern Washington as a case study area for two main reasons: (1) the fire and fuels management questions on which ILAP was focused (see chapter 1) are highly relevant in this region; and (2) ILAP researchers worked with a land management collaborative in the WEC to get user input on models, output, and management scenarios. Thus, the vegetation models and management scenarios for WEC are likely to be used by land managers to answer management questions.

Methods

We integrated fuels information into STMs covering forest and woodland vegetation types in the states of Arizona, New Mexico, Oregon, and Washington (fig. 3.1). The integration of fuels information in STMs for the study area involved five main steps:

- Select field-measured inventory plots from existing data sets to represent each state class, or vegetation structure and cover combination, in STMs. Inventory plots were selected from the U.S. Department of Agriculture Forest Service (USDA FS) Forest Inventory and Analysis (FIA) program (USDA FS 2012) and Current Vegetation Survey (CVS) program data sets.
- Construct FCCS fuel beds (descriptions of burnable biomass extending from the forest floor to the canopy) for each plot.
- Use FCCS to analyze fuel beds for fire hazard (e.g., crown fire potential).
- Summarize fire potentials for all fuel beds representing each state class in STMs.
- Link summarized fuel beds and associated fire hazard to results of STM simulations.

Each of these steps is described in further detail below.

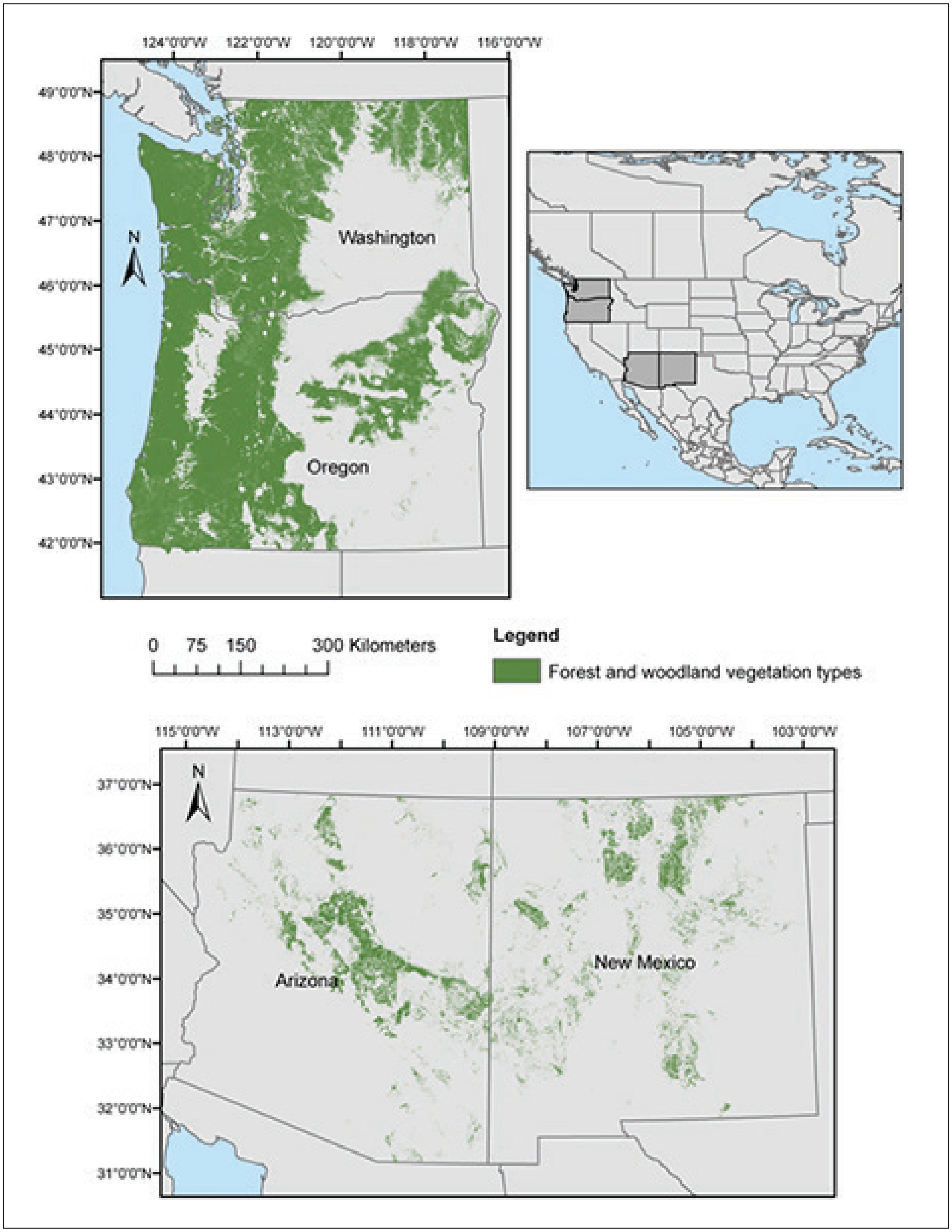

Figure 3.1—Area covered by forest and woodland vegetation types in the four-state study area.

Plot Selection and Classification Into State-and-Transition Model State Classes

Inventory plots were selected to represent combinations of vegetation cover and structure within each STM.

State-and-transition models—

Inventory plots were selected to represent combinations of vegetation cover and structure within each STM. These combinations of vegetation cover and structure, called STM state classes, represent a subset of vegetative conditions found within the broader landscape. The STMs are represented by boxes (vegetation state classes) and arrows (transitions between state classes). Transitions between state classes are either deterministic (occurring with time, e.g., succession) or probabilistic (with a given probability of occurring at each time step, e.g., disturbance or management). The STM runs incorporate Monte Carlo simulations and track both the state of the landscape over time and the occurrence of transitions. The STMs were developed in the Vegetation Dynamics Development Tool (VDDT) framework (ESSA Technologies Ltd. 2007) and run using the Path Landscape Model platform (Apex Resource Management Solutions 2012; Daniel and Frid 2012). The VDDT and Path simulate vegetation dynamics by dividing the landscape into state classes, assigning probabilities to transitions between state classes, and simulating the state of the landscape over time using Monte Carlo methods (see chapter 2 for more detailed information on STMs).

The ILAP STM modeling effort (chapter 2) encompassed all lands in Arizona, New Mexico, Oregon, and Washington. For modeling purposes, Oregon and Washington (OR/WA hereafter) were divided into 12 modeling zones, and Arizona and New Mexico (AZ/NM hereafter) were divided into six zones (see maps in chapter 2). These modeling zones represent Omernik ecoregions (Omernik 1987), with boundaries modified to coincide with hydrologic unit code 5 watershed boundaries (USGS and USDA NRCS 2011). One STM was built for every potential vegetation type (e.g., fig. 3.2) resulting in 7 to 22 models in each modeling zone. Potential vegetation type maps were downloaded from Ecoshare (http://ecoshare.info/). Each STM was characterized by 5 to 60 state classes.

Inventory plot data—

We used inventory plot data from the FIA and CVS programs to develop FCCS fuel beds for forested and woodland STM state classes. We limited our analysis to forests and woodlands (canopy cover >10 percent) because insufficient inventory plot data were available to characterize arid lands with canopy cover <10 percent. We used the most recent or comprehensive inventory plot data sets available for each state (the comprehensive CVS data set for OR/WA, and the most recent FIA data sets for AZ (annual) and NM (periodic)). Only the forested portions of CVS inventory plots were used in our analysis in OR/WA because our goal was to characterize

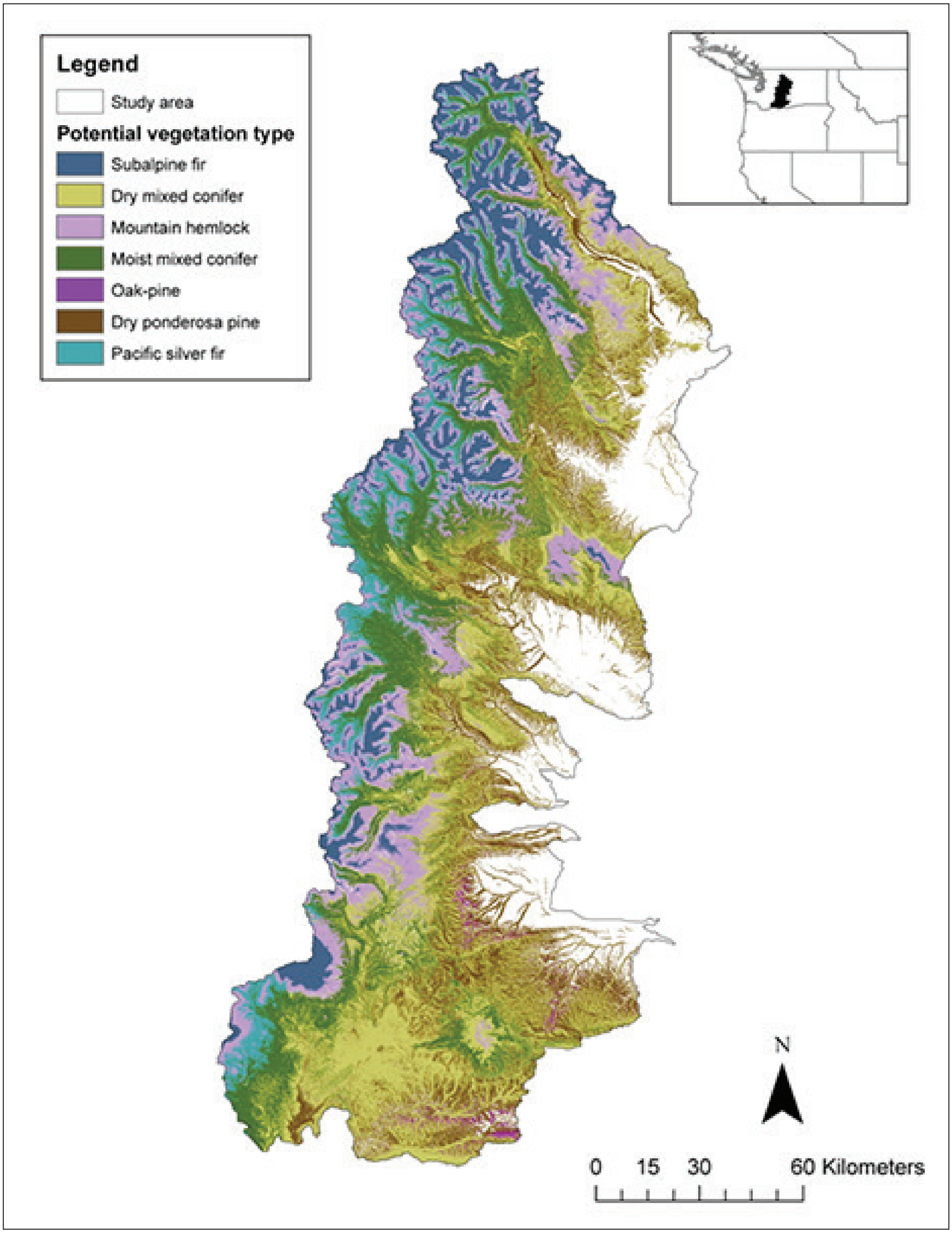

Figure 3.2—Potential vegetation types in the Washington East Cascades modeling zone. One state-and-transition model was built for each potential vegetation type.

fuel conditions in forested ecosystems and information was available at that scale for OR/WA. Owing to the unavailability of data at the forested condition level in AZ/NM, we used the entire FIA plot database in our analysis for AZ/NM.

Inventory plot classification—

The process used to select inventory plots to represent each state class in the STMs differed somewhat between AZ/NM and OR/WA. For AZ/NM, plots were first classified to one potential vegetation type, corresponding to one STM, by experts using plant association information associated with each plot. Once a plot was classified to a potential vegetation type, it was assigned a specific STM vegetation state class based on size class of the dominant cohort (defined by basal area), percentage canopy cover, number of canopy layers (1 or >1), and in some cases (i.e., aspen cover types) forest type importance value (Horn 1975). The rule-set for classification was vegetation type-specific. Owing to the relatively low number of FIA inventory plots for AZ/NM, inventory plots were used to represent state classes without regard for the geographic location of the plot. For example, an inventory plot from southwestern Arizona, classified into the dry pine vegetation type, could be used to represent a state class in the dry pine vegetation type in northeastern New Mexico. We classified a total of 1,734 inventory plots into 62 forest state classes and 1,870 inventory plots into 49 woodland state classes (state classes were consistent across modeling zones in AZ/NM).

Owing to a greater sample size, we further geographically constrained which inventory plots could be used to represent a given potential vegetation type in OR/WA. For each modeling zone in OR/WA, we considered all inventory plots within ECOMAP sections (Cleland et al. 2007) that fell within the modeling zone. For example, if four ECOMAP sections fell within a modeling zone boundary, we would consider all plots within those four ECOMAP sections, and not just the plots within the modeling zone boundary (see fig. 3.3 for illustration). We used plant association information (ecoclass codes from Hall 1998) for each plot to determine which plots to include in the analysis for each modeling zone. If plant association for a plot was determined to not occur in a modeling zone, the plot was dropped from the analysis for that region. Each plot was used only once (to represent a single state class within an STM) within a modeling zone, but plots could be used in more than one modeling zone because ECOMAP sections typically overlapped with multiple zones. Because one to five subplots were aggregated to represent a plot, it was possible for individual subplots to represent different potential vegetation types. When this occurred, the majority type (covering >60 percent of analysis area) was assigned to the plot.

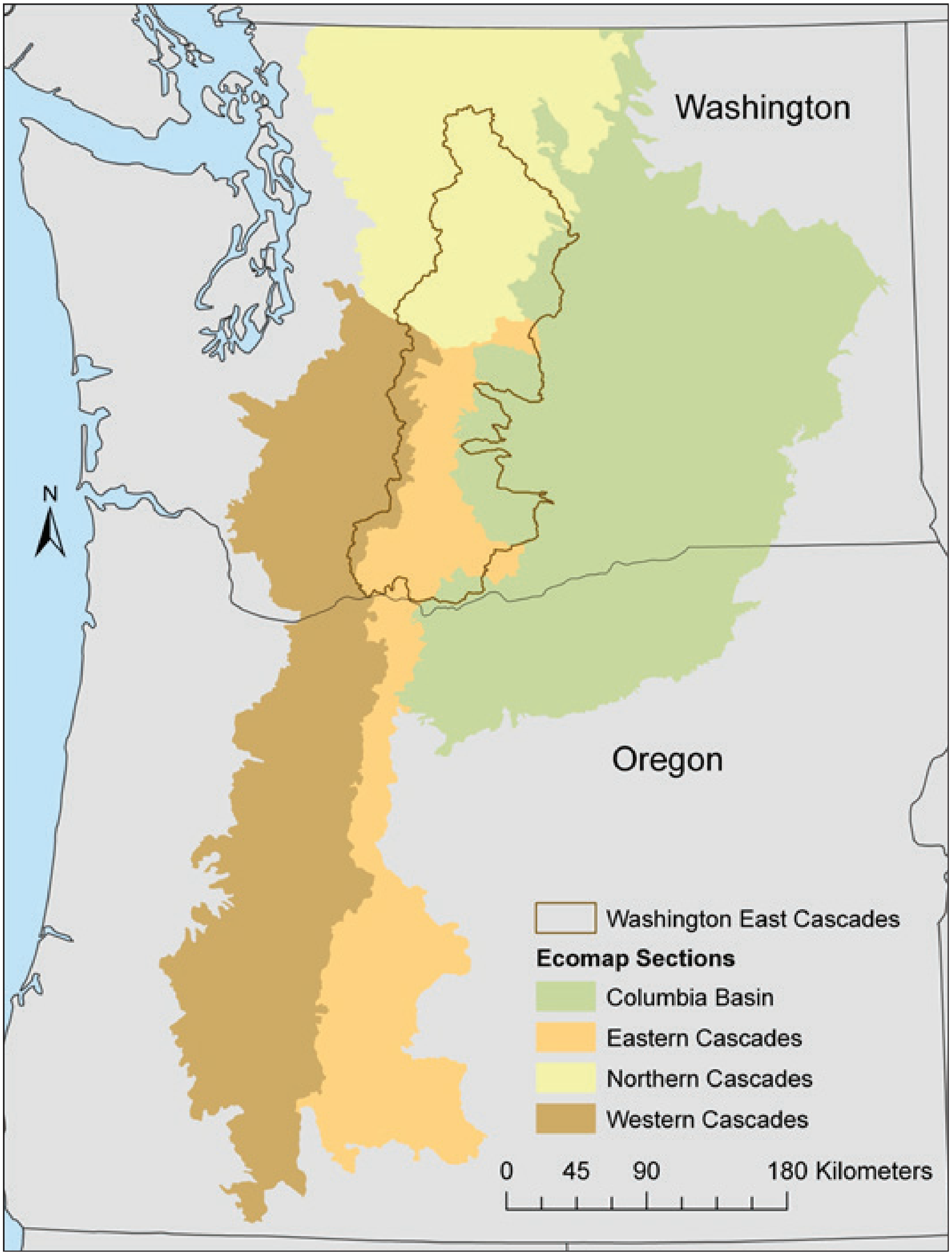

Figure 3.3—Ecomap sections in the Washington East Cascades (WEC) modeling zone. We used Ecomap sections to determine which inventory plots to use to represent vegetation state classes in state-and-transition models. For each modeling zone in Oregon and Washington, we considered all plots within Ecomap sections that were intersected by the modeling zone boundary. In this example, the analysis for the WEC modeling zone included all inventory plots that fell within the Columbia Basin, Eastern Cascades, Northern Cascades, and Western Cascades Ecomap sections.

In OR/WA, plots determined to be representative of each potential vegetation type were put into STM-specific cover categories based on forest type importance values as calculated by the Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) team (www.fsl.orst.edu/lemma/splash.php). Plots were then classified into structure categories based on calculated quadratic mean diameter (0 cm diameter at breast height (DBH) = grass/forb; <13 cm DBH = seedling/sapling; 13 to 25 cm DBH = pole; 25 to 38 cm DBH = small; 38 to 51 cm DBH = medium; 51 to 76 cm DBH = large; >76 cm DBH = giant), percentage canopy cover (<10 percent = grass/forb; 10 to 40 percent = low; 40 to 60 percent = medium; >60 percent = high), and number of canopy layers (1 = single or >1 = multiple) (these variables were also calculated by the LEMMA team). However, because a broader suite of conditions exist on a landscape than are modeled, many plots were reclassified to fit into one of the STM boxes. Our reclassification rules allowed plots with the same species cover, canopy cover, and canopy layers to either shift up or down one diameter size class. For example, a plot in the 25- to 38-cm DBH category could be reclassified into a state class in the 13- to 25-cm or 38- to 51-cm DBH category. Despite this potential reclassification by diameter, some plots still did not fit into any of the state classes included in the model, and these plots were dropped from the analysis. We classified a total of 10,581 inventory plots into 3,716 state classes in OR/WA (see table 3.1 for a modeling zone-specific list of number of state classes and number of inventory plots classified into state classes; see table 3.2 for a list of specific state classes and number of plot classified into each state class for the WEC modeling zone).

We classified a total of 10,581 inventory plots into 3,716 state classes in Oregon and Washington.

Once our classification of inventory plots into STM potential vegetation types and state classes was complete, we found some STM state classes had no representative plots (e.g., see table 3.2). In those cases, we chose plots with characteristics similar to the missing state class to represent the state class. We first selected plots from the size class above or below the missing state class (within potential vegetation and cover type). If there were no plots in the size classes above or below that of the missing state class, we selected plots with the same structural attributes in a similar potential vegetation type or species cover. If representative plots were still not found, we considered plots with a different number of layers but otherwise identical attributes to that of the missing state class. For example, in multiple zones, many medium canopy closure, single-storied state classes had no representative plots in the large and medium size classes. In such cases, we used plots with medium canopy closure and multiple layers within the same vegetation type, cover

Table 3.1—Number of state classes (combinations of vegetation cover and structure; excluding development state classes) that characterized state-and-transition models for each modeling zone in Oregon and Washington, and number of inventory plots classified into state classes in each zone[a]

Modeling zone	Number of state classes	Number of inventory plots classified into state classes
Oregon Blue Mountains	330	2,301
Oregon Coast Range	368	824
Oregon East Cascades	491	1,675
Oregon Southeast	134	321
Oregon Southwest	342	854
Oregon West Cascades	421	1,075
Washington Columbia Basin	477	1,117
Washington Coast Range	229	821
Washington East Cascades	207	3,000
Washington North Cascades	228	875
Washington Northeast	253	519
Washington West Cascades	236	1,008

[a] Total number of inventory plots classified into state classes was 10,581. Plots were used only once within a modeling zone but could be used in more than one modeling zone.

type and size class to represent the missing state class. Best judgment was used in the remaining cases. If no suitable plots were found to represent a state class, we did not include that state class in our analysis.

Although it is likely that some of the inventory plots used in our analysis were actively managed or experienced natural disturbance not long before the measurements were taken, we were not able to account for the management and disturbance history of the inventory plots in our analysis. Thus, one type of STM state class that was not covered by inventory data was postdisturbance state classes, which were included in all OR/WA STMs (but generally not in AZ/NM STMs). For the postdisturbance state classes in OR/WA, we used a set of expert-developed post-wildfire fuel beds from similar vegetation types (R. Ottmar, Central Oregon and Okanogan-Wenatchee Fuel Succession Pathways, http://www.fs.fed.us/pnw/fera/fccs/applications/oakwen.shtml) to represent the postdisturbance state classes (see table 3.3 for an example list of postdisturbance state classes and representative fuel beds for the WEC).

Table 3.2—State classes (combinations of vegetation cover and structure) included in state-and-transition models for the Washington East Cascades modeling zone (excluding postdisturbance state classes; see table 3.4), and number of inventory plots classified into and corresponding fuel beds built for each state class

Potential vegetation type	Cover type[a]	Size class[b]	Canopy density	Canopy layers	Number of fuel beds
Dry mixed conifer	Douglas-fir/ grand fir	Grass/forb	NA	NA	0
		Seedling/ sapling	Low	NA	1
		Pole	Low	Single	7
			Medium	Single	4
		Small	Low	Single	6
				Multiple	5
			Medium	Single	0
				Multiple	23
			High	Single	19
				Multiple	34
		Medium	Low	Single	10
				Multiple	7
			Medium	Single	0
				Multiple	25
			High	Single	0
				Multiple	46
		Large	Low	Single	13
				Multiple	9
			Medium	Single	0
				Multiple	61
			High	Single	0
				Multiple	94
		Giant	Low	Single	6
				Multiple	6
	Ponderosa pine	Grass/forb	NA	NA	50
		Seedling/ sapling	Low	NA	8
		Pole	Low	Single	9
			Medium	Single	1
		Small	Low	Single	10
				Multiple	4
			Medium	Single	2
				Multiple	7
		Medium	Low	Single	9
				Multiple	4
			Medium	Single	0
				Multiple	17
		Large	Low	Single	12
				Multiple	7
			Medium	Single	0
				Multiple	7
		Giant	Low	Single	2
				Multiple	5

Table 3.2—State classes (combinations of vegetation cover and structure) included in state-and-transition models for the Washington East Cascades modeling zone (excluding postdisturbance state classes; see table 3.4), and number of inventory plots classified into and corresponding fuel beds built for each state class (continued)

Potential vegetation type	Cover type[a]	Size class[b]	Canopy density	Canopy layers	Number of fuel beds
Dry pine	Ponderosa pine	Grass/forb	NA	NA	72
		Seedling/ sapling	Low	NA	6
		Pole	Low	Single	33
			Medium	Single	25
		Small	Low	Single	39
				Multiple	41
			Medium	Single	3
				Multiple	61
		Medium	Low	Single	58
				Multiple	58
			Medium	Single	6
				Multiple	46
		Large	Low	Single	75
				Multiple	60
			Medium	Single	0
				Multiple	40
		Giant	Low	Single	21
				Multiple	8
Moist mixed conifer	Grand fir	Grass/forb	NA	NA	0
		Seedling/ sapling	Low	NA	10
		Pole	Low	Single	10
			Medium	Single	14
			High	Single	27
		Small	Low	Single	11
				Multiple	0
			Medium	Single	0
				Multiple	14
			High	Single	0
				Multiple	66
		Medium	Low	Single	8
				Multiple	3
			Medium	Single	1
				Multiple	27
			High	Single	0
				Multiple	108
		Large	Low	Single	2
				Multiple	8
			Medium	Single	0
				Multiple	45
			High	Single	1
				Multiple	173
		Giant	Low	Single	1
				Multiple	1

Table 3.2—State classes (combinations of vegetation cover and structure) included in state-and-transition models for the Washington East Cascades modeling zone (excluding postdisturbance state classes; see table 3.4), and number of inventory plots classified into and corresponding fuel beds built for each state class (continued)

Potential vegetation type	Cover type[a]	Size class[b]	Canopy density	Canopy layers	Number of fuel beds
			Medium	Single	0
				Multiple	11
			High	Single	0
				Multiple	81
	Ponderosa pine	Grass/forb	NA	NA	23
		Seedling/sapling	Low	NA	9
		Pole	Low	Single	19
			Medium	Single	7
			High	Single	2
		Small	Low	Single	5
				Multiple	3
			Medium	Single	2
				Multiple	11
			High	Single	0
				Multiple	9
		Medium	Low	Single	5
				Multiple	4
			Medium	Single	0
				Multiple	7
			High	Single	0
				Multiple	10
		Large	Low	Single	6
				Multiple	2
			Medium	Single	0
				Multiple	14
			High	Single	0
				Multiple	9
		Giant	Low	Single	2
				Multiple	0
			Medium	Single	0
				Multiple	1
			High	Single	0
				Multiple	3
Mountain hemlock	Lodgepole pine	Grass/forb	NA	NA	0
		Seedling/sapling	Low	NA	0
		Pole	Low	Single	11
			Medium	Single	20
			High	Single	28
		Small	Low	Single	5
			Medium	Single	0
			High	Single	0
	Mountain hemlock	Grass/forb	NA	NA	23

Table 3.2—State classes (combinations of vegetation cover and structure) included in state-and-transition models for the Washington East Cascades modeling zone (excluding postdisturbance state classes; see table 3.4), and number of inventory plots classified into and corresponding fuel beds built for each state class (continued)

Potential vegetation type	Cover type[a]	Size class[b]	Canopy density	Canopy layers	Number of fuel beds
		Seedling/ sapling	Low	NA	9
		Pole	Low	Single	16
			Medium	Single	3
		Small	Low	Single	5
			Medium	Single	1
				Multiple	10
		Medium	Low	Single	5
			Medium	Single	0
				Multiple	22
			High	Multiple	378
		Large	Low	Single	4
			Medium	Single	1
				Multiple	14
Oak/pine	Grass/shrub	Open shrub	Low	NA	1
	Oregon white oak/ponderosa pine	Pole	Low	Single	2
			Medium	Single	0
		Small	Low	Single	4
			Medium	Multiple	0
		Medium	Low	Single	0
			Medium	Multiple	0
Pacific silver fir	Pacific silver fir mix	Grass/forb	NA	NA	11
		Seedling/ sapling	Low	NA	22
		Pole	High	Single	28
		Small	Medium	Single	18
			High	Single	0
		Medium	Medium	Single	0
			High	Single	1
				Multiple	113
		Large	Medium	Single	0
			High	Multiple	158
		Giant	Medium	Single	0
			High	Multiple	117
Subalpine parkland	Subalpine fir	Grass/forb	NA	NA	5
		Seedling/ sapling	Low	NA	2
		Pole	Medium	Single	5
		Small	Medium	Single	1
		Medium	Medium	Single	0

NA = not applicable.
[a] Cover type was determined for each plot using calculated forest type importance value.
[b] Size class was determined using quadratic mean diameter (0 = grass/forb; <13 cm DBH = seedling/sapling; 13 to 25 cm DBH = pole; 25 to 38 cm DBH = small; 38 to 51 cm DBH = medium; 51 to 76 cm DBH = large; >76 cm DBH = giant). Plots with canopy density of <10 percent were classified as grass/forb, while plots with canopy density of 10 to 40 percent were classified as low, 40 to 60 percent medium, and >60 percent high.

Table 3.3—Postdisturbance state classes in state-and-transition models for the Washington East Cascades modeling zone, and brief descriptions of expert-based postdisturbance fuel beds used to represent the postdisturbance state classes[a]

Potential vegetation type	Cover type	Tree size class	Representative fuel bed description
Dry mixed conifer	Douglas-fir/grand fir	Grass/forb	Douglas-fir, ponderosa pine, grand fir (dry site) (post-wildfire)
		Seedling/sapling	Douglas-fir, ponderosa pine, grand fir (dry site) (post-wildfire)
		Pole	Douglas-fir, ponderosa pine, grand fir (dry site) (post-wildfire)
		Small	Douglas-fir, ponderosa pine, grand fir (dry site) (post-wildfire)
		Medium	Douglas-fir, ponderosa pine, grand fir (dry site) (post-wildfire)
		Large	Douglas-fir, ponderosa pine, grand fir (dry site) (post-wildfire)
	Ponderosa pine	Grass/forb	Ponderosa pine (post-wildfire)
		Seedling/sapling	Ponderosa pine (post-wildfire)
		Pole	Ponderosa pine (post-wildfire)
		Small	Ponderosa pine (post-wildfire)
		Medium	Ponderosa pine (post-wildfire)
		Large	Ponderosa pine (post-wildfire)
		Giant	Ponderosa pine (post-wildfire)
Dry pine	Ponderosa pine	Grass/forb	Ponderosa pine (post-wildfire)
		Seedling/sapling	Ponderosa pine (post-wildfire)
		Pole	Ponderosa pine (post-wildfire)
		Small	Ponderosa pine (post-wildfire)
		Medium	Ponderosa pine (post-wildfire)
		Large	Ponderosa pine (post-wildfire)
		Giant	Ponderosa pine (post-wildfire)
Moist mixed conifer	Grand fir	Grass/forb	Douglas-fir, grand fir (post-wildfire)
		Seedling/sapling	Douglas-fir, grand fir (post-wildfire)
		Pole	Douglas-fir, grand fir (post-wildfire)
		Small	Douglas-fir, grand fir (post-wildfire)
		Medium	Douglas-fir, grand fir (post-wildfire)
		Large	Douglas-fir, grand fir (post-wildfire)

Table 3.3—Postdisturbance state classes in state-and-transition models for the Washington East Cascades modeling zone, and brief descriptions of expert-based postdisturbance fuel beds used to represent the postdisturbance state classes[a] (continued)

Potential vegetation type	Cover type	Tree size class	Representative fuel bed description
	Ponderosa pine	Grass/forb	Ponderosa pine, Douglas-fir, western larch (post-wildfire)
		Seedling/sapling	Ponderosa pine, Douglas-fir, western larch (post-wildfire)
		Pole	Ponderosa pine, Douglas-fir, western larch (post-wildfire)
		Small	Ponderosa pine, Douglas-fir, western larch (post-wildfire)
		Medium	Ponderosa pine, Douglas-fir, western larch (post-wildfire)
		Large	Ponderosa pine, Douglas-fir, western larch (post-wildfire)
		Giant	Ponderosa pine, Douglas-fir, western larch (post-wildfire)
Mountain hemlock	Lodgepole pine	Grass/forb	Lodgepole pine (post-wildfire)
		Seedling/sapling	Lodgepole pine (post-wildfire)
	Mountain hemlock	Grass/forb	Mountain hemlock
		Seedling/sapling	Mountain hemlock
Pacific silver fir	Pacific silver fir mix	Grass/forb	Western hemlock, Pacific silver fir, mountain hemlock (post-wildfire)
		Seedling/sapling	Western hemlock, Pacific silver fir, mountain hemlock (post-wildfire)
		Small	Western hemlock, Pacific silver fir, mountain hemlock (post-wildfire)
		Medium	Western hemlock, Pacific silver fir, mountain hemlock (post-wildfire)
		Large	Western hemlock, Pacific silver fir, mountain hemlock (post-wildfire)
		Giant	Western hemlock, Pacific silver fir, mountain hemlock (post-wildfire)

[a] All representative fuel beds for the Washington East Cascades were from the Okanogan-Wenatchee Fuel Succession Pathways project (http://www.fs.fed.us/pnw/fera/fccs/applications/oakwen.shtml).

Building Fuel Beds

We used inventory plot data to calculate the variables to build one or more FCCS fuel beds for each STM state class.

The FCCS defines a fuel bed as the inherent physical characteristics of fuels that contribute to fire behavior and effects (Riccardi et al. 2007a). The FCCS fuel beds are stratified into six strata that represent every fuel element that has the potential to combust, including canopy, shrubs, nonwoody fuels, woody fuels, litter, lichen, moss, and ground fuels (fig. 3.4). We used inventory plot data to calculate the variables to build one or more FCCS fuel beds for each STM state class (fuel bed variables listed in table 3.4). We chose to construct one fuel bed for each inventory plot and used one to many plots to represent each state class, rather than statistically summarizing data from multiple inventory plots to construct a single composite fuel bed for each state class, because we wanted to use real world fuels assemblages to represent the state classes instead of creating a composite fuel bed that may not exist under natural conditions.

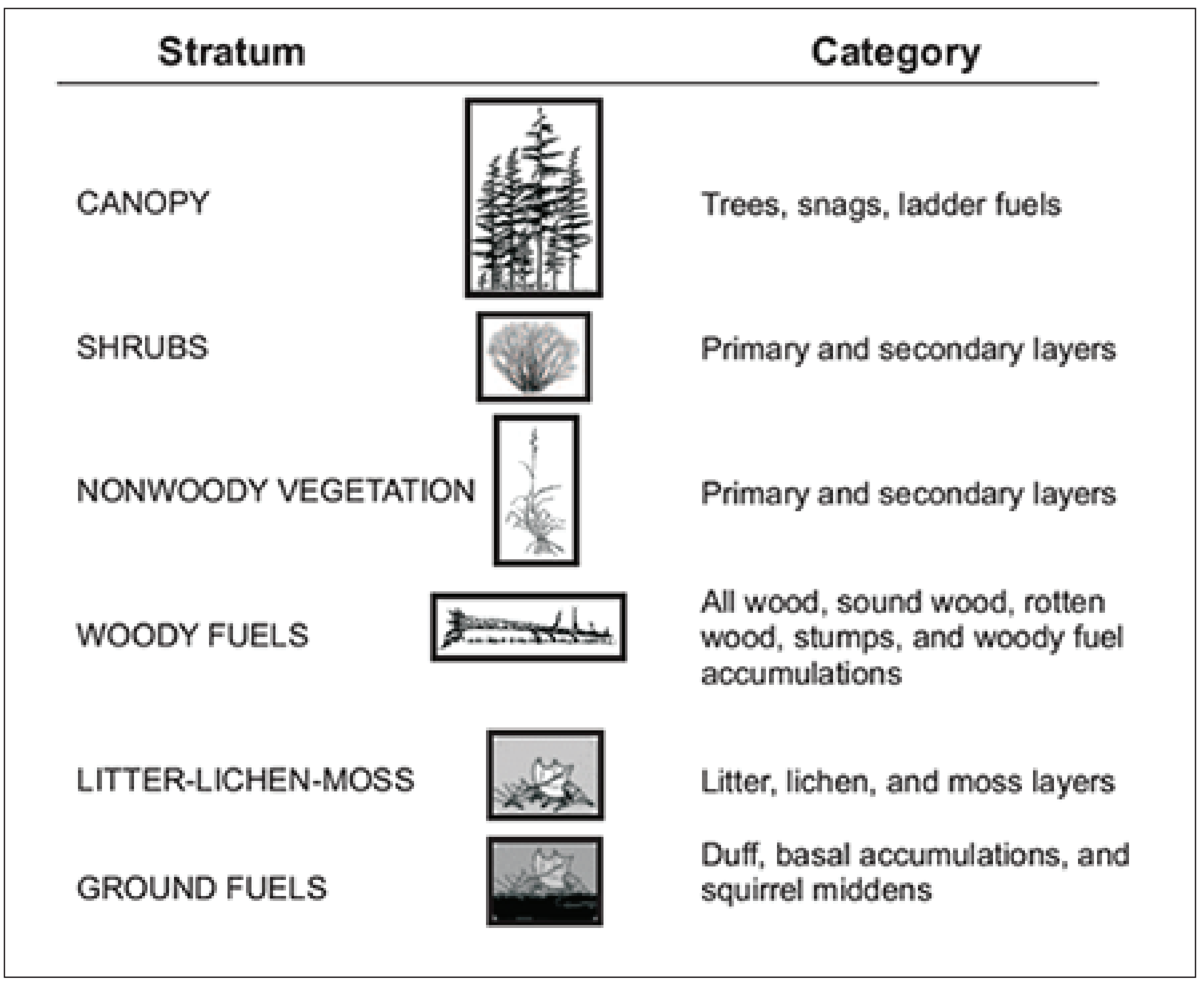

Figure 3.4—Strata and categories of vegetation information included in Fuel Characteristic Classification System (FCCS) fuel beds. We summarized FCCS fuel bed attributes for each state class (vegetation cover and structure combinations) in state-and-transition models of vegetation growth and dynamics. (Figure from Ottmar et al. 2007.)

Table 3.4—Fuel Characteristic Classification System fuel bed variables used in the calculation of physical characteristics and properties of wildland fuels[a]

Fuel strata	Category	Subcategory	Variable
Canopy	Total canopy		Percentage cover
	Trees	Overstory	Percentage cover
		Midstory	Height (m)
		Understory	Height to live crown (m)
			Density (number of stems/ha)
			Diameter at breast height (cm)
			Species and relative cover (%)
	Snags	Class 1 with foliage	Density (number of stems/ha)
		Class 1 without foliage	Diameter (cm)
		Class 2	Height (m)
		Class 3	Species and relative cover (%)
	Ladder fuels	Arboreal lichens	Minimum height (m)
	`	and moss	
		Climbing ferns and	Maximum height (m)
		other epiphytes	Is there vertical continuity
		Dead branches	sufficient to carry fire
		Leaning snags	between the canopy and
		Stringy or fuzzy bark	lower fuel strata?
		Tree regeneration	(yes/no)
		Vines–liana	
Shrub	Primary layer		Percentage cover
	Secondary layer		Height (m)
			Percentage live
			Species and relative cover (%)
	Needle drape		Is needle drape on shrubs
			sufficient to affect fire behavior?
			(yes/no)
Nonwoody fuels	Primary layer		Percentage cover
	Secondary layer		Height (m)
			Percentage live
			Loading (tons/ha)
			Species and relative cover (%)
Woody fuels	All woody		Total percentage cover
			Depth (m)
	Sound wood	All sound wood	For >7.6 cm sound wood—
		Size classes—	Species and relative cover (%)
		<0.6 cm, >0.6 to	For size classes—
		2.5 cm, >2.5 to	Loading (Mg/ha)
		7.6 cm, >7.6 to	
		22.9 cm, >22.9 to	
		50.8 cm, >50.8 cm	
	Rotten wood	All rotten wood	For all rotten wood—
		Size classes—	Species and relative cover (%)
		>7.6 to 22.9 cm,	For size classes—
		>22.9 to 50.8 cm,	Loading (Mg/ha)
		>50.8 cm	

Table 3.4—Fuel Characteristic Classification System fuel bed variables used in the calculation of physical characteristics and properties of wildland fuels[a] (continued)

Fuel strata	Category	Subcategory	Variable
	Stumps	Sound	Density (number of stumps/ha)
		Rotten	Diameter (cm)
		Lightered-pitchy	Height (m)
			Species and relative cover (%)
	Woody fuel accumulation	Piles	Width (m)
		Jackpots	Length (m)
		Windrows	Height (m)
			Density (number of accumulations/ha)
Litter-lichen-moss	Litter	Arrangement— Fluffy, normal, perched	For overall litter— Depth (cm)
		Type— Short needle pine, long needle pine, other conifer, broadleaf deciduous, broadleaf evergreen, palm frond, grass	Percentage cover For each litter type— Relative cover (%)
	Lichen	None	Depth (cm)
	Moss	Type— Spaghnum, other moss	Percentage cover Depth (cm)
Ground fuels	Duff	Percentage rotten wood	For percentage rotten wood— Percentage cover
		Upper layer— Partially decomposed dead moss and litter, partially decomposed sphagnum moss and sedge	For duff layers— Depth (cm) Percentage cover
		Lower layer— Fully decomposed dead moss and litter, fully decomposed sphagnum moss and sedge	
	Squirrel middens	None	Depth (cm) Radius (m) Density (number of middens/ha)
	Basal accumulations	Type— Bark slough, branches, broadleaf deciduous, broadleaf evergreen, grass, needle litter, palm fronds	Depth (cm) Radius (m) Percentage of trees affected

[a] Adapted from Prichard et al. 2010b.

Inventory data did not include all of the potential inputs for FCCS, including information on ladder fuels, needle drape, fine (0 to 7.6 cm) woody fuel depth, woody fuel accumulations (piles, jackpots, windthrows), stumps, litter, lichens, moss, and ground fuels (duff, squirrel middens, and basal accumulations). With the exception of fine woody fuel depth, missing variables were not required by FCCS to calculate fire potentials for a fuel bed and were omitted. Fine woody fuel depth was estimated for each fuel bed as described below. Owing to a lack of inventory plot information that would indicate otherwise, we also assumed 100 percent of the shrub and nonwoody cover was live and assumed that only a primary shrub and nonwoody layer was present.

Fine woody fuel depth was estimated from formulas developed for the Forest Vegetation Simulator Fire and Fuels Extension (Reinhardt and Crookston 2003; see addendum). Formulas used fuel loading variables for which we had information (e.g., 10-hour fuels (diameter 0.64 to 2.54 cm), and 100-hour fuels (diameter 2.5 to 7.6 cm). The exception was 1-hour (diameter <0.64 cm) fuel loading information, which was estimated by matching inventory plots to timber-understory and timber-litter fire behavior fuel models in Scott and Burgan (2005) based on 10-hour, 100-hour, live herb, and live woody fuel loads, and using the 1-hour fuel load value from the matching fire behavior fuel model.

In some cases, categories for variables in FCCS did not match those of our information sources, so we had to reclassify accordingly. For example, FCCS requires information on snag decay class and uses a four-category system, including class 1 with foliage, class 1 without foliage, class 2, and class 3. The FIA (annual) and CVS programs use a five-class system and do not collect information on snag foliage. Therefore, based on the descriptions for both classification systems (Cline et al. 1980 for FIA/CVS classification, Prichard et al. 2010b for FCCS classification), we cross-walked the categories between the two systems (FIA/CVS class 1 with FCCS class 1 without foliage, FIA/CVS class 2 with FCCS class 2, and FIA/CVS class 3–5 with FCCS class 3). Similarly, FCCS differentiates between two categories of down wood (sound and rotten). The FIA protocol similarly differentiates between sound and rotten down wood. However, with CVS protocols, down wood was put into one of three decay classes. Therefore, based on the description of the CVS classification system in the metadata for the database, we classified decay classes 1 and 2 in the FCCS sound category and decay class 3 in the FCCS rotten category.

Inventory data were used to calculate many of the variables needed for FCCS. For example, percentage cover of fine woody fuels was calculated from inventory plot data using equations described in Woodall and Monleon (2009). Also, total canopy cover and average height of overstory, midstory, and understory canopy layers were calculated using equations from the Forest Vegetation Simulator (Crookston and Stage 1999).

Calculated variables from inventory plot data were used to build 10,581 fuel beds in OR/WA and 3,604 fuel beds for AZ/NM. These fuel beds were analyzed in FCCS as described below.

We used FCCS to analyze fire hazard of fuel beds constructed from inventory plot data.

Fire Hazard Analysis

We used FCCS to analyze fire hazard of fuel beds constructed from inventory plot data. Based on fuel characteristics, FCCS calculates fire potentials, including surface fire behavior potential (Sandberg et al. 2007a, 2007b), crown fire potential (Schaaf et al. 2007), and available fuel potential (Sandberg et al. 2007a), which rate the intrinsic physical capacity of a fuel bed to support surface fire, crown fire, and consume and smolder fuels, respectively (Ottmar et al. 2007). The FCCS fire potentials are indexed values, scaled between 0 and 9, and are based on default environmental conditions (6.4 km/h for midflame windspeed, and 0, 30, and 60 percent moisture content for the dead, herbaceous, and live moisture contents, respectively) (Sandberg et al. 2007a, 2007b). With user inputs of fuel moisture and windspeed values, FCCS also calculates surface fire behavior outputs including reaction intensity (kJ/m^2), rate of spread (m/s), and flame length (m) (Sandberg 2007b).

To calculate surface fire behavior outputs from FCCS fuel beds, we used fuel moisture and windspeed values that are typical during extreme fire weather in dry forest types (Agee and Lolley 2006, Ager et al. 2010; fuel moistures of 3 percent for 1-hour fuels, 4 percent for 10-hour fuels, 6 percent for 100-hour fuels, 7 percent for 1000-hour fuels (diameter 7.6 to 20.3 cm), 31 percent for nonwoody fuels, 90 percent for shrub and crown fuels, and 20 percent for duff, and a midflame windspeed value of 36 km/h). We did not account for topography within inventory plots (slope was set at zero for FCCS analysis) because we were using inventory plots to represent a general condition (an STM state class) with no defined topography. Increased slope leads to increased fireline intensity and surface fire rate of spread (Rothermel 1983), and thus setting slope at zero for FCCS analysis resulted in lower estimates of surface fire behavior potentials than those that would have resulted if slope were increased.

Summarizing Fuel Bed Information and Linking to State-and-Transition Model Output

We associated calculated FCCS fire behavior and fire potential variables for fuel beds with the appropriate STM state class. Because each STM state class could have multiple fuel beds to represent it, we calculated a mean and standard error for all fire behavior and potential variables for each state class. Once we had calculated means for fuel bed variables for each STM state class, we linked the mean fuel bed information to STM simulation output for each modeling zone to look at trends in fuels and fire potential over time. For spatial displays, we took the area-weighted average of each variable for each modeling stratum (a combination of watershed, potential vegetation type, and ownership-management; see chapter 2). Geodatabases used in this analysis are available at www.WesternLandscapeExplorer.com.

The STMs were run under a fire-suppression-only (FSO) scenario in all modeling zones in both OR/WA and AZ/NM. The FSO scenario was characterized by current levels of fire suppression (i.e., current fire frequency based on a 25-year Monitoring Trends in Burn Severity record for the study area; Eidenshink et al. 2007; see chapter 2 for further detail) but no other land management actions. For the WECs, Oregon East Cascades, Oregon Blue Mountains, and Washington Northeast modeling zones in OR/WA, STMs were also run under a resilience scenario, developed by ILAP to reflect management activities that could be undertaken to increase resilience of dry forests on the east side of the Cascades in Oregon and Washington. Thus, under the resilience scenario, management treatments were focused in the dry forest types, including oak-pine, dry pine, and dry mixed-conifer vegetation types. Prescribed fire was conducted on USDA FS and U.S. Department of the Interior Bureau of Land Management (USDI BLM) lands, excluding federally protected lands such as wilderness, with 1 to 4 percent of the available landscape treated with prescribed fire annually. Thinning from below was also conducted in dry forest types on USDA FS and USDI BLM lands, with annual area treated ranging from 0.005 to 5 percent of high- and medium-density stands and 0.25 to 1 percent of low density stands. On state and tribal lands, thinning from below was conducted on 1.25 to 5 percent of medium and dense forests, while on private industrial lands, 10 percent of available land was treated annually. Planting was conducted across ownerships and management allocations on 2.5 to 20 percent of available lands. Salvage logging was conducted on 5 to 20 percent of available federal lands and 12.5 to 50 percent of available state and tribal lands. See chapter 2 and www.WesternLandscapeExplorer.com for more detail on how scenarios were run.

Results

We built over 14,000 fuel beds characterizing approximately 3,800 vegetation conditions (state classes) in forests and woodlands of Arizona, New Mexico, Oregon, and Washington. A database with complete lists of inventory plots classified into each STM state class, and fuel bed input and output data is located at www.WesternLandscapeExplorer.com. Example fuel bed output for state classes in the WEC is shown in table 3.5, and results for the WEC are discussed further below.

Table 3.5—Mean flame length and crown fire potential (unit-less index) for state classes in the Washington East Cascades state-and-transition models[a]

Potential vegetation type	Cover type	Size class	Canopy density	Canopy layers	Flame length	Crown fire potential
					Meters	
Dry mixed conifer	Douglas-fir/ grand fir	Grass/forb	NA	NA	6.7	2.1
		Postdisturbance	Low	NA	8.2	1.8
		Seedling/sapling	Low	NA	1.3	1.9
		Pole	Low	Single	0.1	1.5
			Medium	Single	0.4	2.4
		Small	Low	Single	0.5	1.3
				Multiple	0.1	1.1
			Medium	Single	0.4	2.4
				Multiple	0.4	2.2
			High	Single	0.5	3.2
				Multiple	0.4	2.8
		Medium	Low	Single	0.4	1.4
				Multiple	0.4	1.3
			Medium	Single	0.4	2.3
				Multiple	0.4	2.3
			High	Single	0.5	3.2
				Multiple	0.6	3.1
		Large	Low	Single	0.7	1.7
				Multiple	0.5	1.6
			Medium	Single	0.6	2.6
				Multiple	0.6	2.6
			High	Single	0.9	3.5
				Multiple	0.4	3.2
		Giant	Low	Single	0.5	1.1
				Multiple	0.5	1.4
	Ponderosa pine	Grass/forb	NA	NA	0.7	0.4
		Postdisturbance	Low	Single	3.4	1.6
		Seedling/sapling	Low	NA	1.1	3.2
		Pole	Low	Single	0.7	1.8
			Medium	Single	1.3	4.0
		Small	Low	Single	0.7	1.8
				Multiple	0.4	1.1
			Medium	Single	0.7	2.8
				Multiple	0.4	2.0
		Medium	Low	Single	0.5	1.5
				Multiple	0.7	1.9
			Medium	Single	0.5	2.1
				Multiple	0.5	2.1
		Large	Low	Single	0.6	1.2
				Multiple	0.4	1.2
			Medium	Single	0.8	2.7
				Multiple	0.8	2.7
		Giant	Low	Single	0.2	0.5
				Multiple	0.5	1.3

Table 3.5—Mean flame length and crown fire potential (unit-less index) for state classes in the Washington East Cascades state-and-transition models[a] (continued)

Potential vegetation type	Cover type	Size class	Canopy density	Canopy layers	Flame length	Crown fire potential
Dry pine	Ponderosa pine	Grass/forb	NA	NA	0.6	0.9
		Postdisturbance	Low	Single	3.4	1.6
		Seedling/sapling	Low	NA	0.4	1.8
		Pole	Low	Single	0.4	1.8
			Medium	Single	0.4	2.2
		Small	Low	Single	0.5	1.6
				Multiple	0.4	1.4
			Medium	Single	0.3	1.6
				Multiple	0.5	2.3
		Medium	Low	Single	0.4	1.3
				Multiple	0.4	1.5
			Medium	Single	0.2	1.3
				Multiple	0.3	2.1
		Large	Low	Single	0.5	1.4
				Multiple	0.3	1.4
			Medium	Single	0.2	1.3
				Multiple	0.4	2.5
		Giant	Low	Single	0.4	1.4
				Multiple	0.4	1.6
Moist mixed conifer	Grand fir	Grass/forb	NA	NA	2.0	2.1
		Postdisturbance	Low	Single	2.4	2.3
		Seedling/sapling	Low	NA	0.4	2.5
		Pole	Low	Single	0.6	2.3
			Medium	Single	0.9	3.3
			High	Single	0.7	3.5
		Small	Low	Single	1.0	2.5
				Multiple	0.2	2.0
			Medium	Single	0.7	2.1
				Multiple	0.4	2.4
			High	Single	0.7	3.5
				Multiple	0.6	3.8
		Medium	Low	Single	0.3	1.4
				Multiple	0.2	2.0
			Medium	Single	0.7	2.1
				Multiple	0.5	2.8
			High	Single	0.9	3.5
				Multiple	0.5	3.5
		Large	Low	Single	1.1	1.4
				Multiple	0.6	1.4
			Medium	Single	0.6	2.8
				Multiple	0.6	2.8
			High	Single	0.9	3.5
				Multiple	0.5	3.7
		Giant	Low	Single	1.0	2.6
				Multiple	0.8	2.6

Table 3.5—Mean flame length and crown fire potential (unit-less index) for state classes in the Washington East Cascades state-and-transition models[a] (continued)

Potential vegetation type	Cover type	Size class	Canopy density	Canopy layers	Flame length	Crown fire potential
			Medium	Single	0.7	2.7
				Multiple	0.7	2.7
			High	Single	0.7	3.5
				Multiple	0.7	3.5
	Ponderosa pine	Grass/forb	NA	NA	0.7	0.6
		Postdisturbance	NA	NA	0.8	1.9
		Seedling/sapling	Low	NA	1.1	2.4
		Pole	Low	Single	0.8	2.5
			Medium	Single	0.5	2.7
			High	Single	0.1	3.7
		Small	Low	Single	1.0	2.4
				Multiple	1.2	2.1
			Medium	Single	1.0	2.7
				Multiple	0.7	2.4
			High	Single	0.2	2.9
				Multiple	0.2	2.9
		Medium	Low	Single	0.5	1.7
				Multiple	0.7	2.3
			Medium	Single	1.0	2.7
				Multiple	0.1	2.6
			High	Single	0.2	2.9
				Multiple	0.2	3.3
		Large	Low	Single	0.7	1.6
				Multiple	0.5	2.2
			Medium	Single	1.2	3.3
				Multiple	1.2	3.3
			High	Single	0.9	3.5
				Multiple	0.6	3.6
		Giant	Low	Single	0.5	0.9
				Multiple	0.5	2.2
			Medium	Single	1.2	3.3
				Multiple	0.5	1.8
			High	Single	0.9	3.5
				Multiple	0.5	2.4
Mountain hemlock	Lodgepole pine	Grass/forb	NA	NA	1.8	4.0
		Postdisturbance	NA	NA	1.8	4.0
		Seedling/sapling	Low	NA	0.1	1.0
		Pole	Low	Single	0.1	1.0
			Medium	Single	0.3	2.4
			High	Single	0.4	3.1
		Small	Low	Single	0.4	1.4
			Medium	Single	0.3	2.4
			High	Single	0.4	3.1

Table 3.5—Mean flame length and crown fire potential (unit-less index) for state classes in the Washington East Cascades state-and-transition models[a] (continued)

Potential vegetation type	Cover type	Size class	Canopy density	Canopy layers	Flame length	Crown fire potential
	Mountain hemlock	Grass/forb	NA	NA	0.5	0.6
		Postdisturbance	NA	NA	10.6	3.9
		Seedling/sapling	Low	NA	0.4	2.2
		Pole	Low	Single	0.7	2.0
			Medium	Single	0.8	3.4
		Small	Low	Single	0.4	1.7
			Medium	Single	0.8	4.1
				Multiple	0.4	2.5
		Medium	Low	Single	0.4	1.2
			Medium	Single	0.5	2.8
				Multiple	0.5	2.8
			High	Multiple	0.4	4.2
		Large	Low	Single	0.4	1.6
			Medium	Single	1.4	3.7
				Multiple	0.5	3.1
Oak/pine	Grass shrub	Open shrub	Low	NA	0.9	1.5
	Oregon white oak/ ponderosa pine	Pole	Low	Single	0.9	3.1
			Medium	Single	0.9	3.1
		Small	Low	Single	0.2	0.7
			Medium	Multiple	0.2	0.7
		Medium	Low	Single	0.2	0.7
			Medium	Multiple	0.2	0.7
Pacific silver fir	Pacific silver fir mix	Grass/forb	NA	NA	0.8	1.1
		Postdisturbance	NA	NA	5.8	3.5
		Seedling/sapling	Low	NA	0.7	2.7
		Pole	High	Single	0.4	3.7
		Small	Medium	Single	0.6	3.1
			High	Single	0.4	3.7
		Medium	Medium	Single	0.6	3.1
			High	Single	0.6	2.7
				Multiple	0.3	3.7
		Large	Medium	Single	0.6	2.6
			High	Multiple	0.4	3.8
		Giant	Medium	Single	0.6	2.6
			High	Multiple	0.6	4.0
Subalpine parkland	Subalpine fir	Seedling/sapling	Low	NA	0.4	2.5
		Pole	Medium	Single	0.5	2.9
		Small	Medium	Single	0.1	3.4
		Medium	Medium	Single	0.1	3.4
		Grass/forb	NA	NA	0.1	0.8

NA = not applicable.

[a] Inventory plots were classified into each state class, fuel beds were built from inventory plot data, and fuel beds were analyzed for potential fire behavior in the Fuel Characteristic Classification System. Each state class is represented by at least one inventory plot, and thus values represent the means for fuel beds classified into each state class.

Washington East Cascades Case Study

For the WEC modeling zone (figs. 3.2 and 3.3), we focused on two indicators of fire hazard: crown fire potential and flame length. Crown fire potential gives an indication of the potential for fire to spread into, and propagate through, the canopy of forests and woodlands. The FCCS crown fire potential index is based on whether the energy supplied by a surface fuel bed layer is sufficient to ignite and sustain fire spread in the canopy. Flame length, or the distance from the ground at the leading edge of the flame to the tip of the flame, is an indicator of surface fuels and potential surface fire behavior and can be interpreted to determine wildfire suppression strategies (Andrews and Rothermel 1982).

Crown fire potential—

Although the crown fire potential index was >7 (on a scale of 0 to 9) for some individual fuel beds in the WEC, the mean crown fire potential index for any state class in the WEC did not exceed 4.2 (table 3.5). To examine crown fire potential results in the region on a relative scale, we classified the state classes into low, moderate, and high crown fire potential categories by ordering the data based on crown fire potential and separating it into thirds. Although we cannot associate these categories with specific information on potential crown fire intensity and resulting mortality, we can assume that the sites in the high crown fire potential category would have a high likelihood of experiencing stand-replacing fire, while those in the low category would have a relatively low likelihood of experiencing stand-replacement fire.

For both the entire landscape and in the dry forest types (dry mixed conifer and dry ponderosa pine) crown fire potential increased over time under the FSO scenario but decreased over time under the resilience scenario.

For both the entire landscape and in the dry forest types (dry mixed conifer and dry ponderosa pine) crown fire potential increased over time under the FSO scenario but decreased over time under the resilience scenario (figs. 3.5 and 3.6). For the entire landscape under the FSO scenario, area in the high crown fire potential category increased by 61 163 ha (from 977 549 ha in 2007 to 1 038 711 ha in 2056), but under the resilience scenario, area in the high crown fire potential category decreased by 110 341 ha (from 966 336 ha in 2007 to 855 995 ha in 2056; fig. 3.5). In addition, in 2056, area in the low crown fire potential category was lower under the FSO scenario compared to the resilience scenario (141 936 ha versus 279 843; fig. 3.5).

In the dry mixed conifer and dry ponderosa pine types, which are the vegetation types in which fuel treatments such as thinning and prescribed fire are focused in the WEC, crown fire potential increased over time under the FSO scenario, with increases in area in the high crown fire potential category (from 211 087 ha in 2007 to 281 094 ha in 2056) and moderate crown fire potential category (from 132 484 ha in 2007 to 173 130 ha in 2056) and a decrease in area in the low crown fire potential category (from 228 247 ha in 2007 to 117 586 ha in 2056; fig. 3.6). Crown

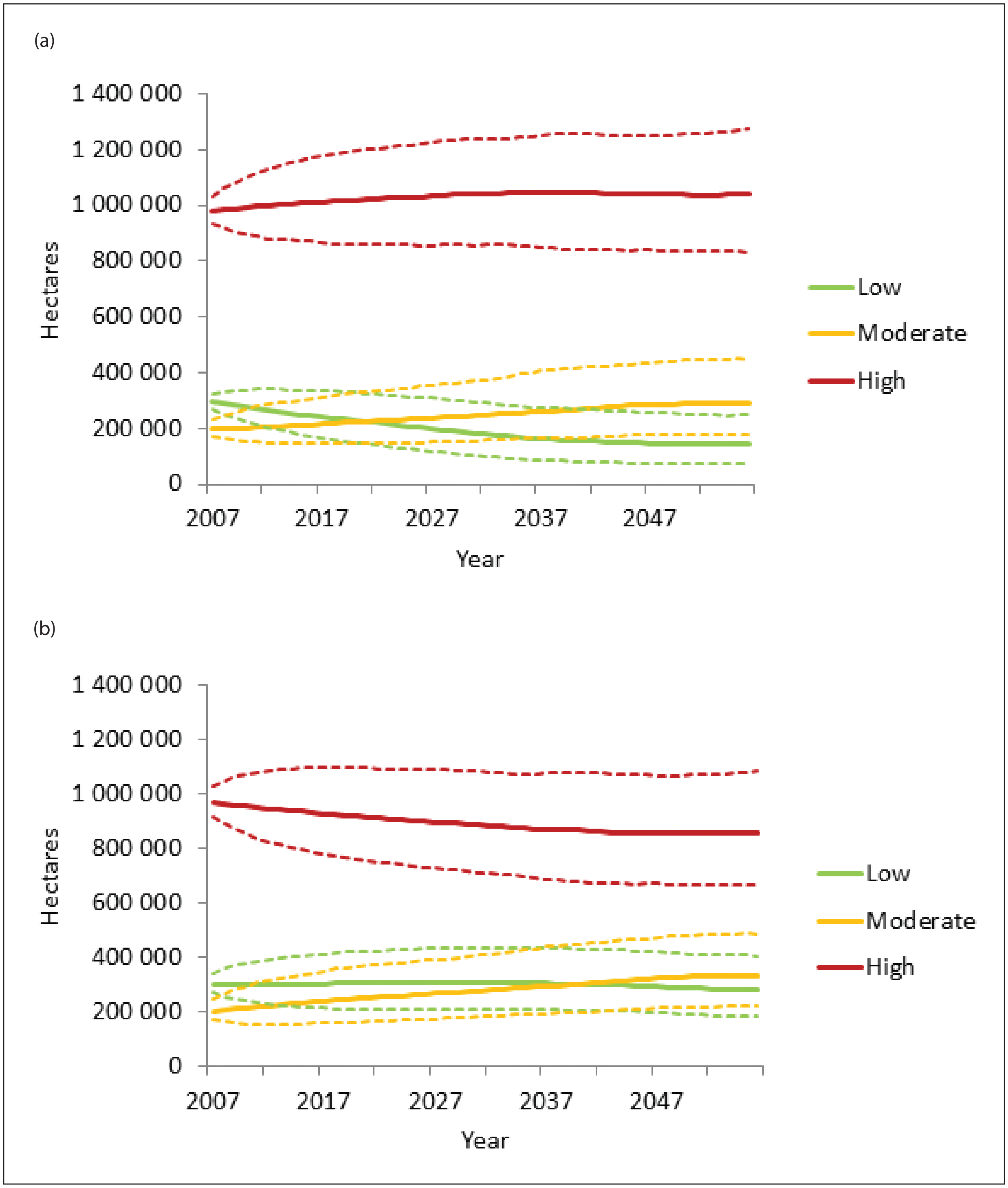

Figure 3.5—Area of the Washington East Cascades landscape in low, moderate, and high crown fire potential categories under (a) fire suppression only, and (b) resilience scenarios, as simulated by state-and-transition models. Dashed lines represent minimum and maximum area in each category across Monte Carlo simulations. Crown fire potential was assessed for model state classes by using inventory plots to represent each state class, building fuel beds with the inventory plot data, and analyzing the fuel beds in the Fuel Characteristic Classification System.

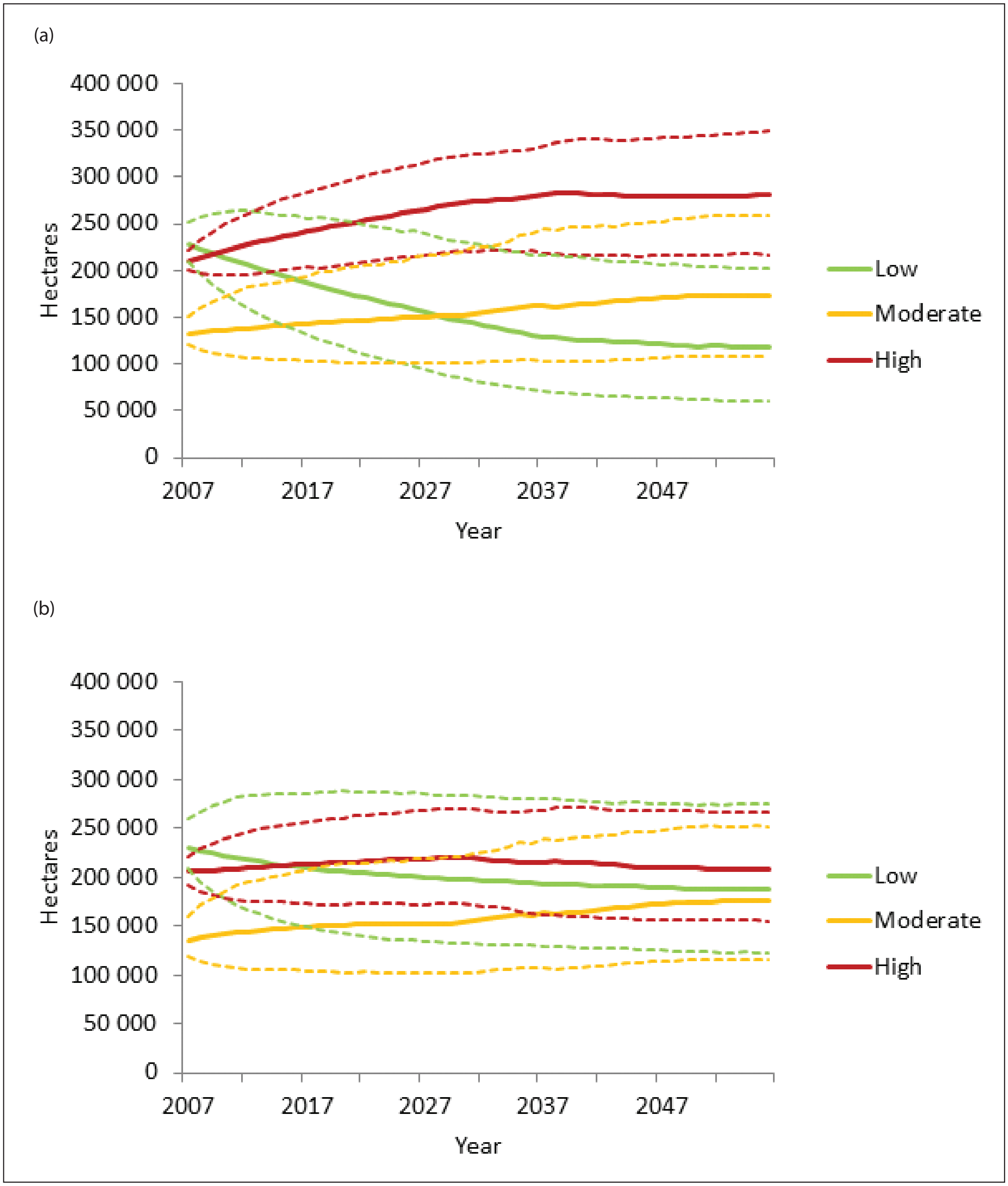

Figure 3.6—Area of the dry mixed conifer and dry pine potential vegetation types in low, moderate, and high crown fire potential categories under (a) fire suppression only, and (b) resilience scenarios, as simulated by state-and-transition models for the Washington East Cascades landscape. Dashed lines represent minimum and maximum area in each category across Monte Carlo simulations.

fire potential also increased over time under the resilience scenario, but not to the same degree as under the FSO scenario. Under the resilience scenario, area in the high crown fire potential category remained relatively constant (206 309 ha in 2007 versus 208 377 ha in 2056), while area in the moderate category increased (from 134 950 ha in 2007 to 175 384 ha in 2056), and area in the low category decreased (from 230 552 ha in 2007 to 188 055 ha in 2056; fig. 3.6).

These patterns were also apparent when results were examined spatially (fig. 3.7). Although crown fire potential was not substantially reduced compared to current conditions in the resilience scenario, crown fire potential was lower under the resilience scenario than under the FSO scenario by 2056, particularly in the lower elevation dry forest types where fuel treatments are focused (generally the southeastern and eastern portions of the study area; see dry pine, dry mixed-conifer, and moist mixed-conifer potential vegetation types in fig. 3.2).

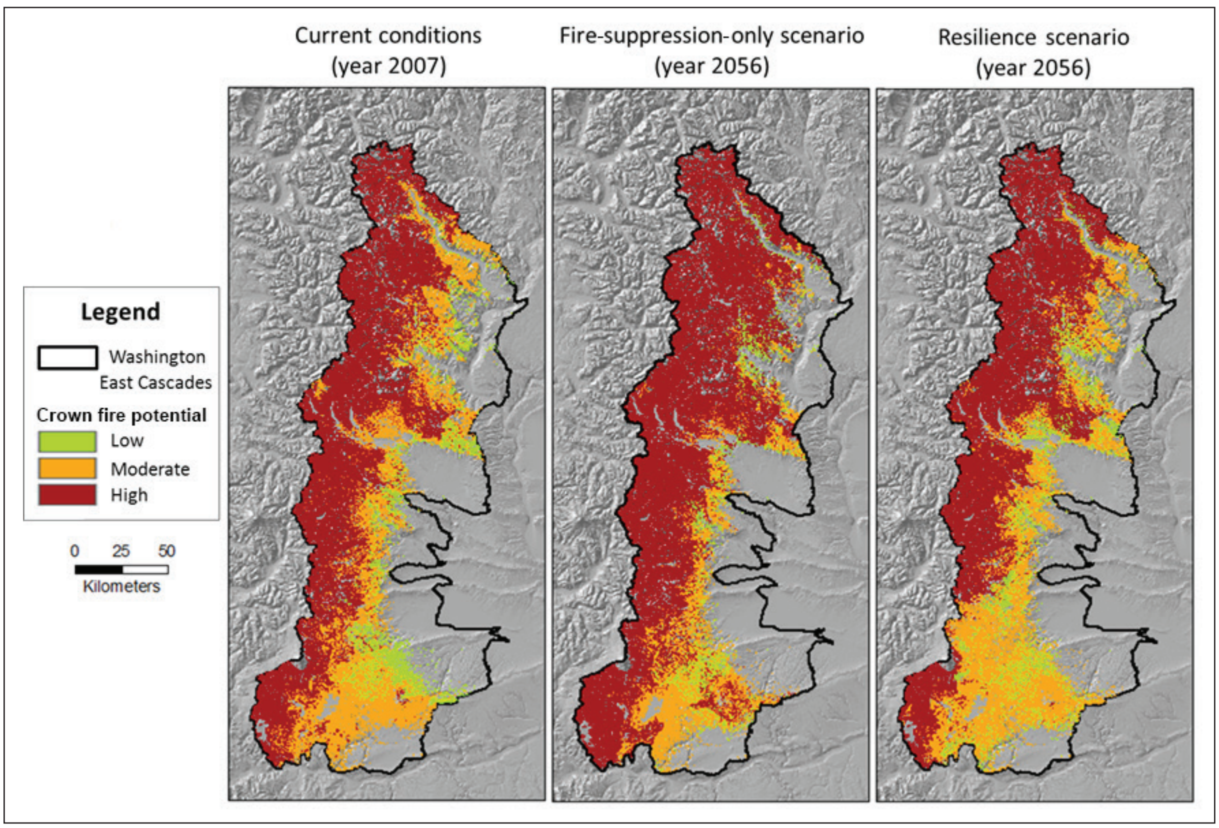

Figure 3.7—Crown fire potential for the Washington East Cascades region for current conditions (2007; left panel), simulated 2056 conditions under a fire-suppression-only (FSO) scenario (center panel), and simulated 2056 conditions under a resilience scenario (right panel). Crown fire potential was assessed for state-and-transition model state classes by using inventory plots to represent each state class, building fuel beds with the inventory plot data, and analyzing the fuel beds in the Fuel Characteristic Classification System. The FSO scenario was characterized by current levels of fire suppression (i.e., current fire frequency based on a 25-year Monitoring Trends in Burn Severity record for the study area) but no other land management actions. The resilience scenario was characterized by light to moderate levels of thinning and some prescribed fire in dry forest types. The area-weighted average for crown fire potential index was calculated for each modeling stratum (potential vegetation type, ownership, and land allocation within a watershed), and each modeling stratum was categorized into the low, moderate, and high crown fire potential category for the spatial display.

Flame length—

Patterns in potential flame length did not differ substantially between the FSO and resilience scenarios in the WEC. Under both scenarios, there was an increase in potential flame length over time, with a decrease in area in the low flame length category (<1.2 m), and slight increases in the area in the higher flame length categories (fig. 3.8). These patterns were similar between all lands (fig. 3.8) and the dry forest types (not shown).

Discussion

Management Applications

Our integrated FCCS-STM approach can give land managers information they need to determine the types, extent, and locations of management activities that will result in the greatest reduction in crown fire potential. Acquiring this information is a critical step in the development of successful fuel treatment regimes in fire-prone forests. Fire hazard information can be used alone or in conjunction with other types of information, such as wildlife habitat and economic potential, to prioritize areas for fuel treatments or other types of management activities. Analyses integrating fuels data with data on wildlife habitat, economic potential, and community economics are forthcoming products of ILAP.

The thousands of fuel beds developed for this work cover a broad range of fuel conditions in both OR/WA and AZ/NM. The link between these fuel beds and specific forest and woodland compositional and structural conditions has potential for other types of applications other than fire hazard analysis. For example, fuel beds generated from this work are being used in USDA FS Region 3 (AZ/NM) to assess potential emissions from wildfire using a software program that is complementary to FCCS, called CONSUME (Prichard et al. 2005). In addition, inventory data summaries could be used to assess wildlife habitat suitability in different STM state classes.

Results of the integrated FCCS-STM simulations in the WEC region indicated that a management regime characterized by targeted fuel treatments in dry forest types can lead to lower crown fire potential than a FSO management regime.

Washington East Cascades Case Study

Results of the integrated FCCS-STM simulations in the WEC region indicated that a management regime characterized by targeted fuel treatments in dry forest types can lead to lower crown fire potential than a FSO management regime. High crown fire potential is associated with stand-replacing fire events. Avoiding stand-replacement fire events and maintaining substantial live basal area is often a goal of vegetation management treatments (Agee and Skinner 2005), and our results suggest that the resilience scenario tested in this study would be successful in reducing the likelihood of stand-replacement fire events in dry forests compared to an FSO scenario.

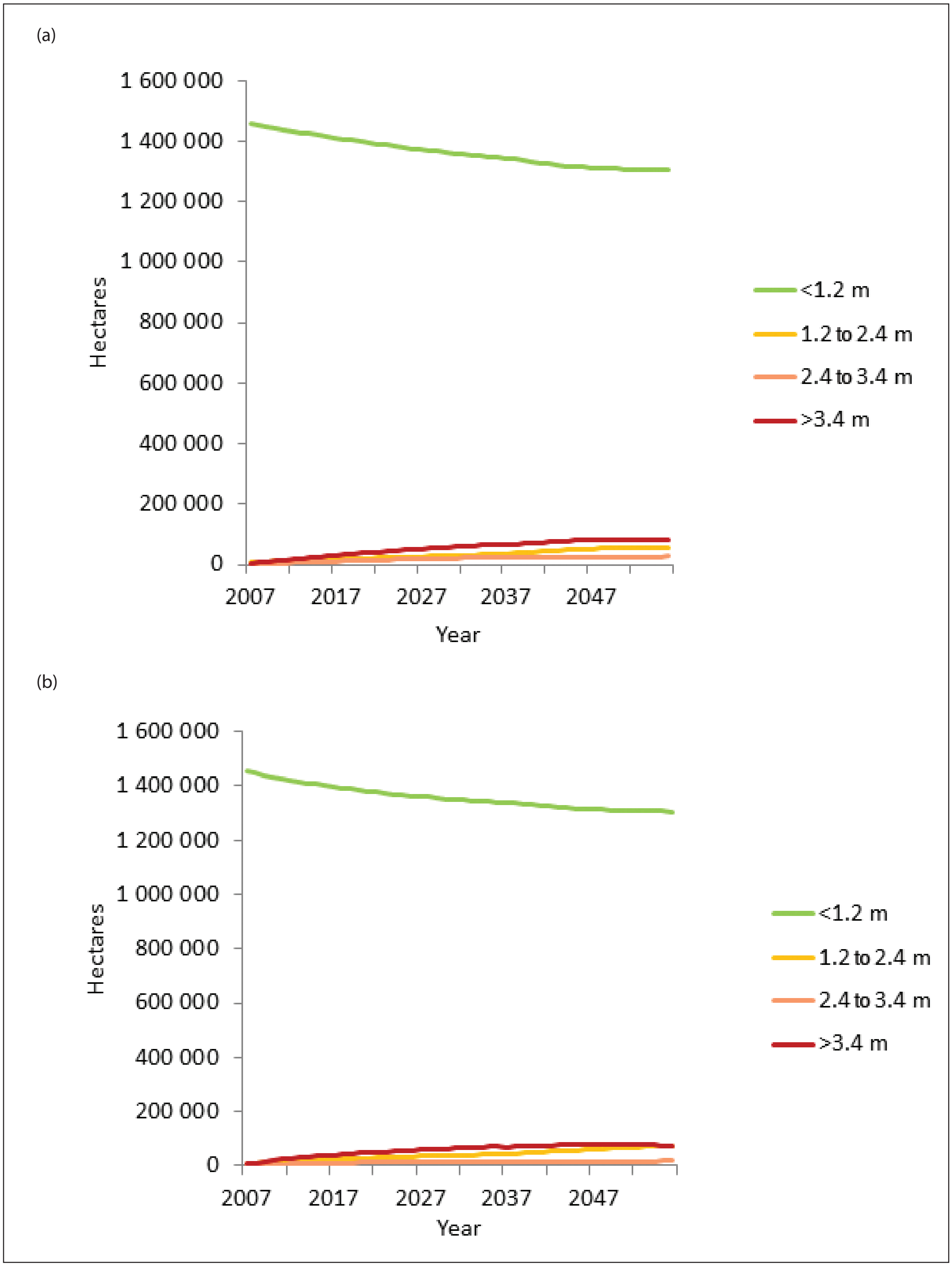

Figure 3.8—Area of the Washington East Cascades landscape in four flame length categories under (A) fire suppression only, and (B) resilience scenarios, as simulated by state-and-transition models. Each flame length category reflects thresholds in ease of fire suppression (Andrews and Rothermel 1982).

Although crown fire potential was reduced under the resilience scenario compared to the FSO scenario in the WEC, resilience activities did not decrease potential flame length in the study area. These results illustrate that forest thinning to reduce tree density, which was the focus of the resilience scenario evaluated in this study, does not necessarily reduce surface fuels and surface fire hazard, which is reflected in flame length (Agee and Skinner 2005). Instead of reducing surface fire hazard, thinning activities can increase surface fuel levels and surface fire intensity (Johnson et al. 2007, Raymond and Peterson 2005), and thus surface fuel treatments are essential to reduce surface fire hazard after thinning treatments (Agee and Skinner 2005).

The flame length results also illustrate a limitation to our approach. Although flame length potential did vary substantially among individual inventory plots used to represent the STM state classes (with flame lengths up to 10 m), mean flame lengths were much less variable (with most below 1.2 m). The state classes in STMs represent a general condition and are based primarily on forest and woodland overstory structure, whereas flame lengths are based largely on surface fuels. In addition, we could not account for the management and disturbance history of inventory plots used to develop fuel beds. Thus, representative plots for each state class had variable surface fuel levels, and this variation obscured patterns when surface fuel variables such as potential flame length were averaged by state class.

Future Improvements and Research Needs

There are several ways this analysis could be improved for future applications. First, although we used the most comprehensive inventory plot data set available in OR/WA (CVS), this data set only covered national forests in the two states. Thus, expanding the analysis to use more recent FIA annual data would help us to cover a broader range of vegetation/fuels conditions than what exists on national forests. We also discovered that inventory plot data for arid lands with sufficient detail for fuel bed characterization are lacking, particularly in Oregon and Washington. Further field-based data will be needed to integrate fuels information with arid lands STMs in the four states. We were also lacking information on postdisturbance fuel conditions, and thus more field-based data on postdisturbance conditions for different vegetation types and structural conditions would improve the estimates of fire hazard for postdisturbance state classes. Finally, to more accurately capture effects of management and disturbance on surface fuels and potential surface fire hazard, our approach would need to be modified. One way to do this would be to differentiate state classes based on surface fuel properties (e.g., include a ponderosa pine, large size class, open canopy, single layer, low surface fuels, and a ponderosa pine, large size class, open canopy, single layer, high surface fuels state class), and incorporate surface fuel characteristics in the plot classification process. Another way would be to do a post-hoc analysis of effects of specific treatments on surface fuel properties using the Forest Vegetation Simulator (Dixon 2003), and use estimates of area affected by those treatments to determine effects on surface fire hazard.

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