Return to Part A

Mount Hood National Forest.

Chapter 4: Forest Structure and Function

The diverse topics presented in this chapter share a common objective: to characterize the structure and function of Oregon’s forests. These forests are vital habitat for a wide variety of plant and animal species, and they provide many other ecological values. The Pacific Northwest Forest Inventory and Analysis Program (PNW-FIA) data help describe plant biodiversity in Oregon’s forests, characteristics of special habitat types such as old-growth forests and riparian corridors, and status of forest components such as dead wood, tree crowns, soils, and understory vegetation.

Data in this chapter address Montréal Process criterion 1 and indicators pertaining to conservation of biological diversity, criterion 3 and indicators pertaining to maintenance of forest ecosystem health and vitality, criterion 4 and indicators pertaining to conservation and maintenance of soil and water resources, and criterion 5 and indicators pertaining to maintenance of forest contribution to global carbon cycles.

Data in this chapter also address Oregon indicator B pertaining to forest ecosystem services (carbon sequestration); indicator D pertaining to protecting, maintaining, and enhancing soil and water resources; and indicator E pertaining to the composition, diversity, and structure of forest vegetation.

Older Forests[1]

Background

Forests in later stages of successional development are an important part of the forest land matrix, contributing special habitat, aesthetics, functional resources, and ecological services not available in younger forests (Franklin et al. 1981). Older forests are not simply forests where little or no disturbance has occurred for long periods; disturbance is the norm in all forests and has helped shape old forests by creating openings and patches of older, resilient survivors.

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[1] Author: Joseph Donnegan.

The term “old” is relative; it depends on whose definition is used, the type of forest being considered, and the regional climate. Because many complex, interacting variables can be used to describe them, older forests are not easily defined. Typically, in Pacific Northwest forests, the structure, species composition, and functional attributes of older forests are attained by the age of 175 to 250 years (Franklin et al. 1981). In this section we have purposely oversimplified the definition for older forests, reporting acreage by forest type for stand ages in the 160-year-old-plus and the 200-year-old-plus categories. More complex definitions for old-growth forests often cite a minimum age of 200 years, but definitions also depend on productivity classes and forest type (Franklin et al. 1981, Old-Growth Definition Task Group 1986, Bolsinger and Waddell 1993).

Our summary uses stand age as the basis for estimates of area and age distribution. The FIA field crews estimate stand age based on the average age of predominant overstory trees, assessed by counting the tree rings on a pencil-sized sample of wood (core) extracted with an increment borer (fig. 38). It is not possible to determine the age of some trees, however, because of internal rot or because the sheer size of the tree limits the length of core that can be extracted, and some species are not cored because the core wound might make them susceptible to pathogens.

Findings

Approximately 12 percent (3.6 million acres) of forest stands across Oregon are older than 160 years; and slightly fewer than 7 percent (1.9 million acres) are older than 200 years. The vast majority of older forest is found on publicly owned land in national forests and national parks (see”Ownership” section). The Douglas-fir and ponderosa pine forest types make up the majority of the older forest acreage in Oregon. Douglas-fir stands older than 160 years account for 4.4 percent of total forest acreage, and ponderosa pine stands older than 160 years account for 1.4 percent of total forest acreage (fig. 39). The remaining combined forest types with stand ages in excess of 160 years make up less than 7 percent of total forest area.


Joseph Donnegan

Figure 38—Increment cores are extracted from trees to determine the age of dominant trees in each forested stand that is sampled by Forest Inventory and Analysis.

Western white pine leads all forest types in proportion of its acreage in older stands; 55 percent of Oregon’s white pine is older than 160 years, although the total acreage occupied by older white pine is relatively small, about 52,000 acres (fig. 40). Although Douglas-fir leads all forest types in total acreage in older stands, these stands represent only about 14 percent of the Douglas-fir forest type. That is because there is great diversity in the structure of Douglas-fir forests, with tree diameters covering a broad range of classes (fig. 41). Seedlings and saplings are the most abundant size class, although larger diameter classes are well represented.

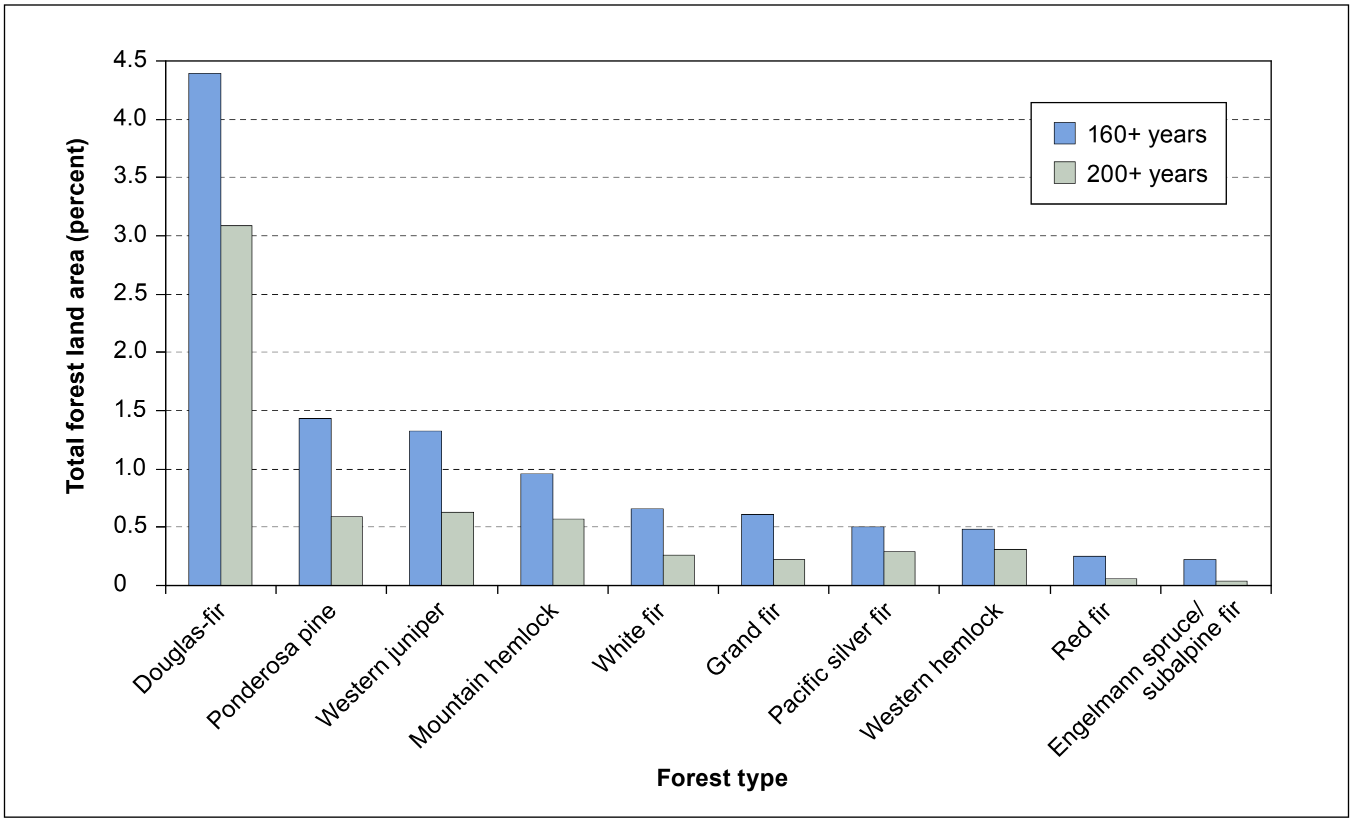

Figure 39—Percentage of total forest land area by forest type for stands 160+ and 200+ years old in Oregon, 2001–2005.

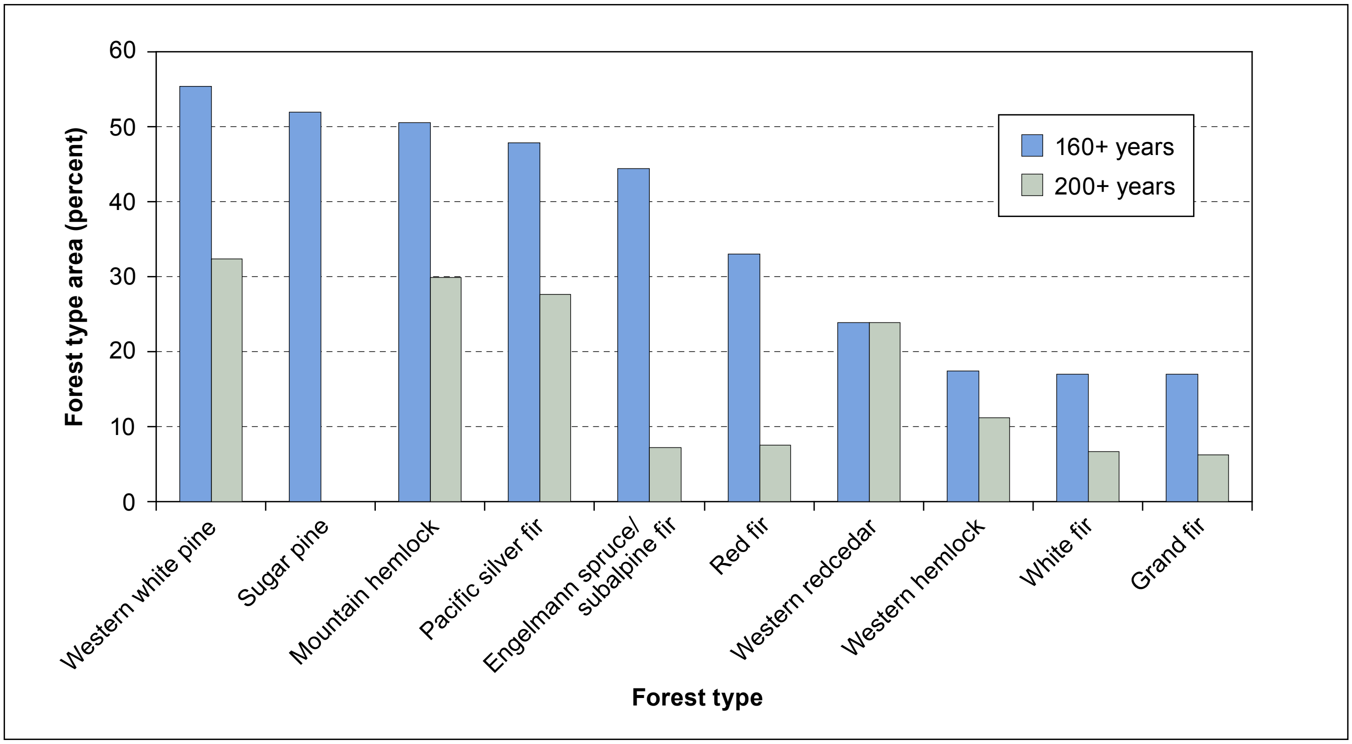

Figure 40—Percentage of area of each forest type in older forest in Oregon, 2001–2005.

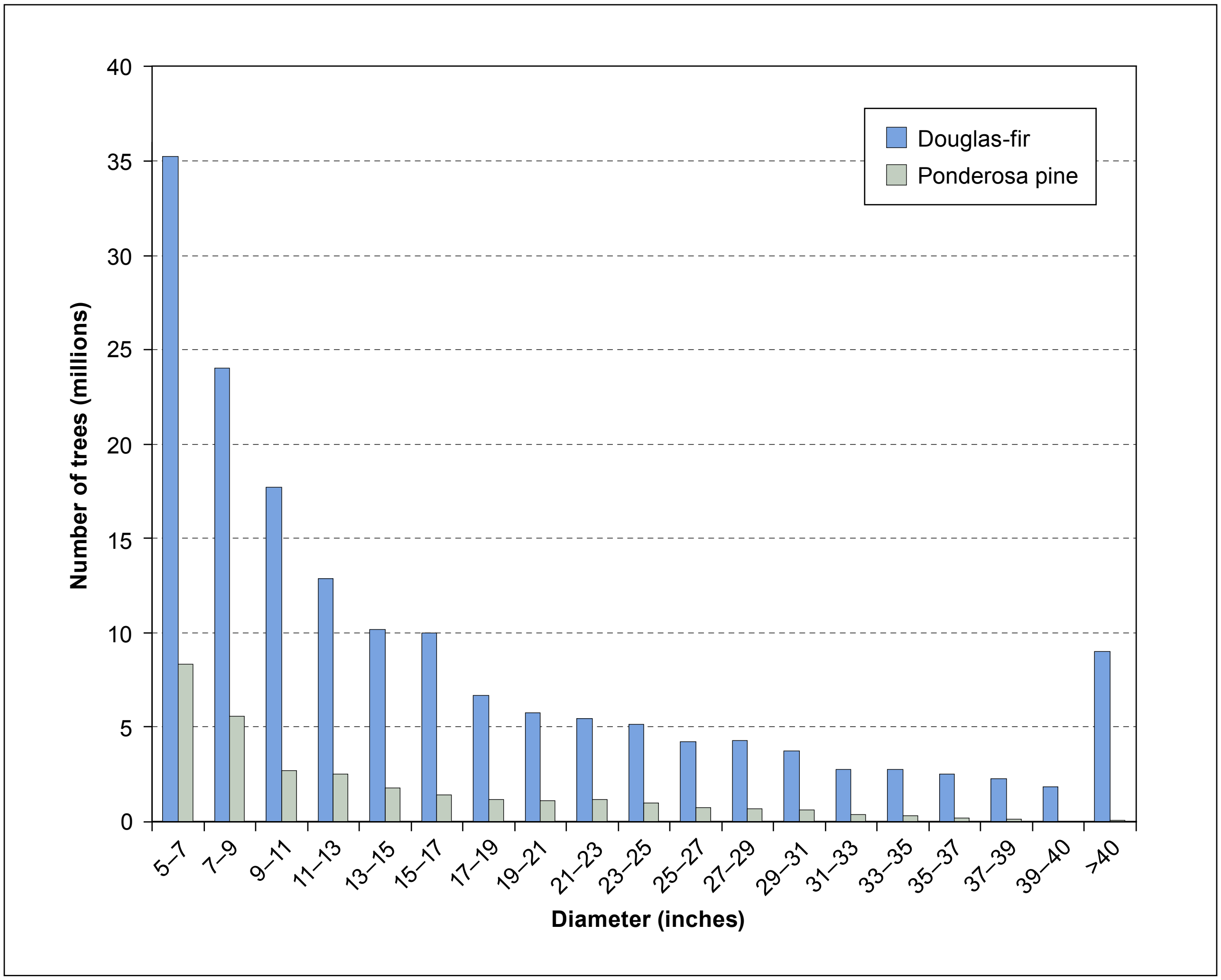

Figure 41—Number of trees by diameter class in older (≥160 years old) Douglas-fir forests on forest land in Oregon, 2001–2005.

Interpretation

Prior to the widespread logging of old forests (before the mid-1800s), these forests had been changing through time from disturbances such as fire and insect outbreaks of varying severity, recurrence intervals, and disturbance synchrony across the landscape (Winter et al. 2002). The area and distribution of older forests was highly variable through time. Estimates of the area of old-growth forest existing in the Oregon Coast Range prior to Euro-American settlement range from about 25 to 75 percent of total forest area (Booth 1991, Ripple 1994, Teensma et al. 1991, Wimberly et al. 2000). Current estimates of the extent of old-growth place it at less than half the lowest prelogging estimate. However, the proportion of older forest will increase if stands on national and state forests, established after widespread logging and stand-replacing fires during the 1930s and 1940s, continue to mature. The size diversity seen in older Douglas-fir stands (fig. 41) suggests that disturbance and regeneration will continue to play a vital role in shaping older forests.

This preliminary summary is based on approximately half the sample planned for the inventory. Additional data will add to the accuracy of our initial findings.

Lichen and Plant Biodiversity[2]

Background

Diversity of lichens and vascular plants is included among the FIA suite of forest health indicators (Gray and Azuma 2005, Jovan 2008). These organisms serve many basic and vital functions in forest ecosystems: they provide wildlife sustenance and habitat, influence stand microclimate, and contribute to nutrient dynamics. Individual species or groups of species are intimately linked to forest health. For example, invasive nonnative plants can have important economic impacts on land use, as well as ecological impacts on ecosystem function (Vitousek et al. 1996). Similarly, cyanolichens (fig. 42) are a specialized group of native lichens that fix nitrogen (N) and may make substantial contributions to forest fertility in N-limited stands of the Pacific Northwest (Antoine 2004).

The FIA crews surveyed for epiphytic (tree-dwelling) lichens on all phase 3 plots between 1998 and 2003 and recorded the abundance of each species occurring within a 0.93-acre area. Vascular plant species were recorded for a pilot study of method repeatability and data utility on 110 plots in 2000 and 2001. Plant species cover was estimated for each species on each 24-foot radius subplot and on three 3.28 square feet quadrats per subplot.

Abundance codes used in lichen community surveys are shown in the following tabulation:

Code	Abundance
1	Rare (1 to 3 thalli)[3]
2	Uncommon (4 to 10 thalli)
3	Common (>10 thalli; species occurring on less than 50 percent of all boles and branches in plot)
4	Abundant (>10 thalli; species occurring on greater than 50 percent of boles and branches in plot)


Daphne Stone

Figure 42—An oak trunk thickly coated with lungwort lichen (*Lobaria pulmonaria*), a cyanolichen.

Findings

The diversity of lichen and vascular plant communities differed widely by mapped ecological unit (ecosection) (figs. 43 and 44). A total of 182 lichen species were recorded in Oregon, a sizeable portion (88 percent) of the diversity found for the entire Pacific Northwest (Jovan 2008). In contrast, 535 vascular plant species were detected, a small portion of the 3,400 estimated to occur in all habitats in Oregon. The Willamette Valley is a prominent biodiversity hotspot that supports, on average, the highest diversity of lichens (25 species) and vascular plants (56 species) of all forested ecosections. However, species richness alone should not be considered an incontrovertible sign of good forest health; 30 percent of the plants identified to species on each plot in the Willamette were of nonnative species, and the lichen inventory contained several species indicative of N pollution (see "Air Quality" section in "Disturbance and Stressors" chapter).

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[2] Authors: Andrew Gray and Sarah Jovan.

[3] A lichen body is known as a thallus (plural = thalli).

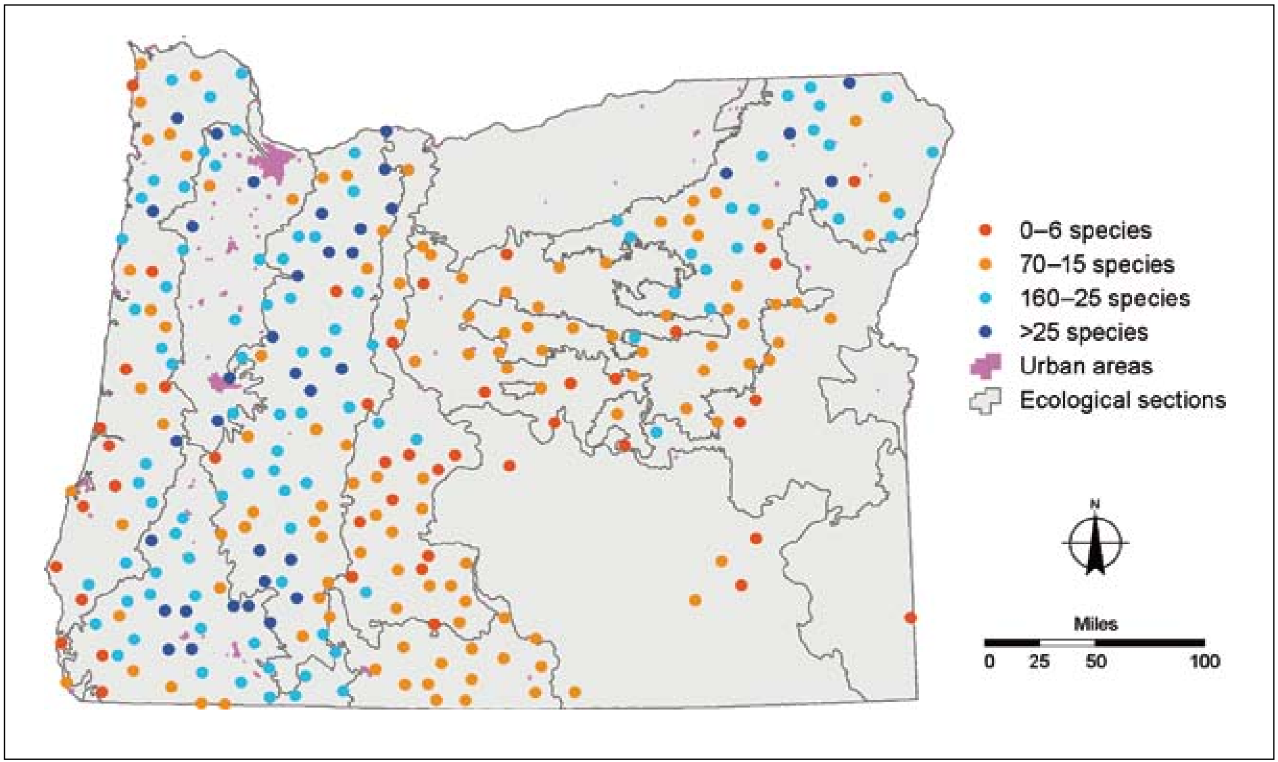

Figure 43—Lichen species richness index, Oregon forest land, 1998–2003 (ecosection geographic information system (GIS) layer: Cleland et al. 2005; Urban GIS layer: U.S. Geological Survey 2001).

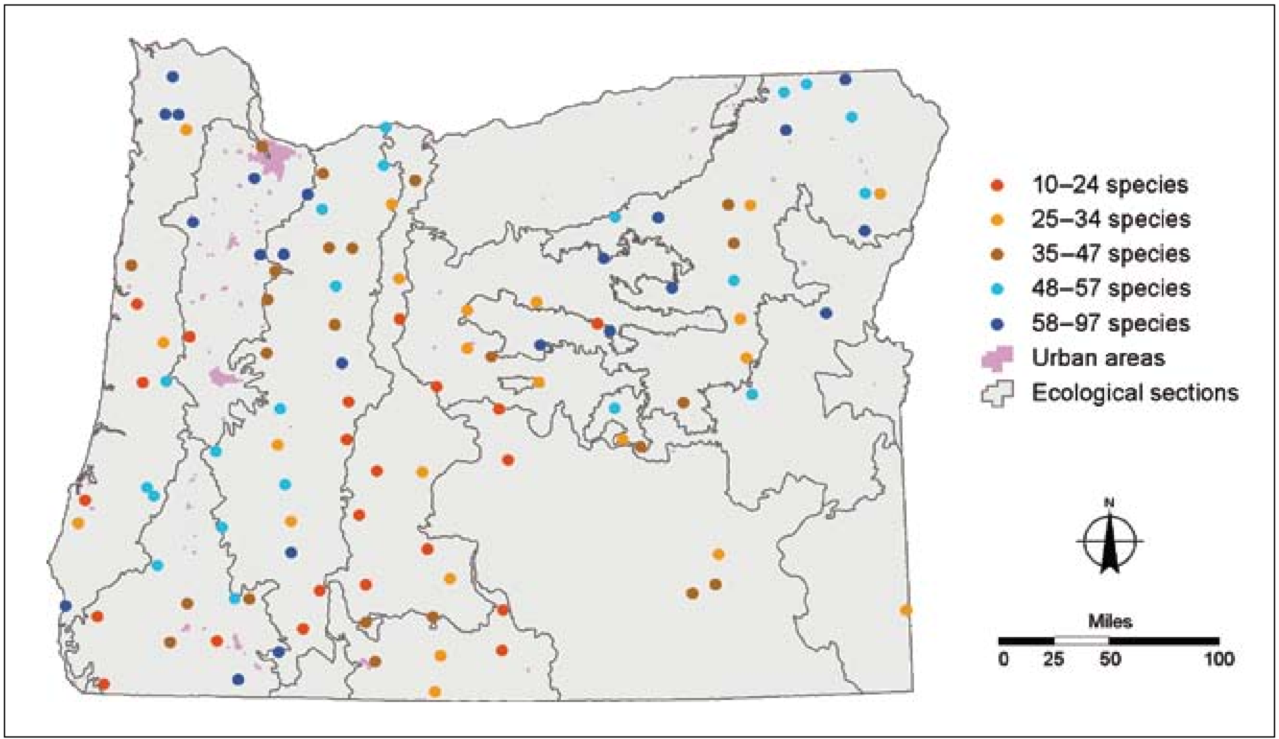

Figure 44—Vascular plant species plot-level richness index by ecoregions, Oregon forest land, 2001–2005 (ecosection geographic information system layer: Cleland et al. 2005).

The crest of the Oregon Cascades demarcates a conspicuous shift in lichen and plant communities. Generally speaking, forests on the wetter west side tend to be richer in lichen species (averaging 19 species per plot) than on the dry east side (12 species per plot). West-side sites also include a considerable variety of large N-fixing cyanolichens such as *Lobaria* and *Pseudocyphellaria* spp., owing in part to the high moisture demands of these species' physiology (fig. 42). A total of 22 nongelatinous cyanolichen species were found on the west side, but only three on the east side.

Vascular plant diversity was also relatively high across west-side ecosections, averaging 37 to 56 species per plot. The most common west-side plant species recorded were Douglas-fir, trailing blackberry, and swordfern (47, 40, and 39 out of 54 plots, respectively; fig. 45).

Sampling intensity is low across parts of the east side, notably the Northwestern Basin and Range and Owyhee Uplands (figs. 6, 43, and 44), where shrubland and grassland predominate. Lichen and plant species were especially few in these low-rainfall areas. Lowest plant diversity was recorded for the Modoc Plateau (27) and Owyhee Uplands (30). Farther to the northeast lies another biodiversity hotspot for plants; plot-level richness found for the Blue Mountains (47) was similar to that of the western Cascades (46). About 10 percent of plant species identified on each plot in this region were nonnative. The most common east-side plants encountered were common yarrow, bottlebrush squirreltail, and ponderosa pine (39, 39, and 36 out of 56 plots, respectively) (see "Scientific and Common Plant Names").

Andrew Gray

Figure 45—Trailing blackberry is one of the most common plant species in Oregon.

Interpretation

A low diversity of plants or lichens is not necessarily unnatural, nor is a high diversity inherently good. Biodiversity patterns in Oregon are driven by a multitude of factors, some human-caused (i.e., timber harvest, air quality), some natural (i.e., differences in moisture and temperature regime and herbivory pressure between east and west sides), and some of mixed origin (i.e., forest fires). As illustrated by the proportion of nonnative plants found in the species-rich Willamette Valley and Blue Mountains, implications of diversity patterns are often best analyzed in concert with other indicators that may be extracted from the vegetation and lichen data.

Our inventory of species richness tends to underestimate diversity, both because surveys are time-constrained and because the low density of plots can result in severe underestimation of the total number of species at the ecosection level. The diversity data presented here provide a baseline for temporal monitoring surveys; major shifts in diversity will be investigated as needed.

Biodiversity Tables in Appendix 2

Table 24—Index of vascular plant species richness on forest land, by ecological section, Oregon, 2005

Table 25—Index of lichen richness on forest land, by ecological section, Oregon, 1998–2001, 2003

Table 26—Summary of lichen community indicator species richness on forest land, Pacific Northwest and Oregon, 1998–2001, 2003

Dead Wood[4]

Background

Dead wood contributes to the structural complexity and biological diversity of forests throughout Oregon. In this report we define “dead wood” as snags (standing dead trees) (fig. 46) and down wood (dead woody material on the forest floor) of various dimensions and stages of decay (fig. 47). The presence of dead wood in a forest improves wildlife habitat, enhances soil fertility through nutrient cycling and moisture retention, adds to fuel loads, provides substrates for fungi and invertebrates, and serves as a defining element in old-growth forests (Harmon et al. 1986, Laudenslayer et al. 2002, Rose et al. 2001). Because of this, the dead wood resource is often analyzed from a variety of perspectives—too much can be viewed as a fire hazard and too little can be viewed as a loss of habitat.

The amount of dead wood in a forest can differ with habitat type, successional stage, species composition, management activities, and geographic location (Harmon et al. 1986, Ohmann and Waddell 2002). Here, we analyze data on snags and down wood collected by FIA crews on more than 2,600 field plots in the state. Dead wood is described in broad terms at the statewide level, with comparisons between western Oregon and eastern Oregon when relevant.

Dead trees leaning less than 45 degrees and ≥5 inches diameter at breast height (d.b.h.) were tallied as snags and measured under the same protocol as live trees. Down wood was sampled along linear transects on each plot under protocols that differed by diameter size class. Information was collected on fine woody material (FWM; pieces of wood <3 inches in diameter at the point of intersection with the transect) and on coarse woody material (CWM; branches and logs ≥3 inches in diameter at the point of intersection). Dead trees leaning more than 45 degrees were tallied as down wood. Estimates of density, volume, biomass, and carbon were developed from these data and are the basis for the analysis that follows.

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[4] Author: Karen Waddell.

Karen Waddell

Figure 46—Snags provide critical habitat and structural diversity in Oregon’s forests. Birds and other mammals use snags as roosting and foraging sites and occupy cavities for nesting and cover.

Karen Waddell

Figure 47—Dead wood accumulates on the forest floor, providing habitat, soil stability, and long-term carbon storage.

Findings

Dead wood was found in every forest type sampled in Oregon. We estimated almost 677 million tons (all references to weight refer to bone-dry tons) of dead wood biomass on forest land in the state, with about 73 percent attributable to down wood alone (CWM and FWM). Volume of snags and CWM was about 54 billion cubic feet, which is just over half the total live-tree volume recorded in Oregon. About 95 million tons of carbon are sequestered in snags, compared to 256 million tons stored in down wood (CWM = 191; FWM = 65). We estimated more than 7 billion down logs (CWM) and 500 million snags in forests statewide. Dead wood was most abundant and had the largest dimensions in western Oregon, where temperate forests have high productivity rates and produce heavy accumulations of biomass.

Assessment of dead wood attributes becomes more meaningful when expressed at the per-acre level. Statewide, biomass (also known as fuel loading) of down wood averaged 16 tons per acre and differed by forest type and diameter class (fig. 48).

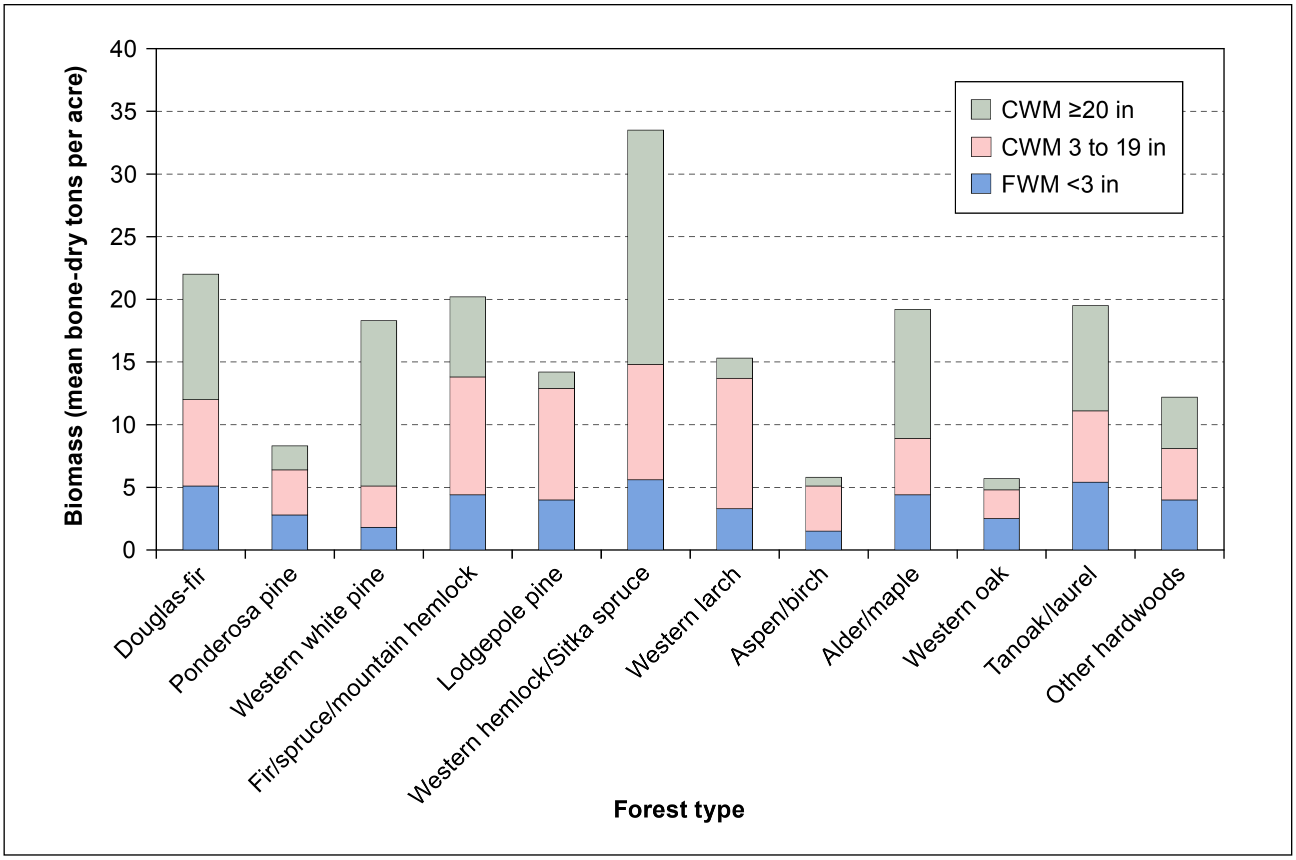

Figure 48—Mean biomass of down wood by forest type and diameter class on forest land in Oregon, 2001–2005; CWM = coarse woody material; FWM = fine woody material.

The down wood component of Oregon's total fuel load (amount of potentially combustible material) can be expressed as the average tons per acre within fuel hour-classes:

Location	1-hour class	10-hour class	100-hour class	1,000-hour class
		Mean tons/acre		
Western Oregon	0.2	1.3	3.7	17.0
Eastern Oregon	0.1	.8	2.3	7.0
Total	0.2	1.0	2.8	12.1

The range in classes from 1 to 1,000 hours corresponds to the diameters of down wood pieces as follows: 1-hour (0.1 to 0.24 inches), 10-hour (0.25 to 0.99 inches), 100-hour (1 to 2.9 inches), and 1,000-hour (≥3 inches). Each class refers to how fast dead woody material will dry and burn relative to its moisture content.

The dimensions of down logs and snags are important when evaluating ecological characteristics of the forest. Although large logs (≥20 inches diameter) represented the greatest mean volume and biomass per acre, they were present in significantly fewer numbers, with a mean of 11 logs per acre, compared to 225 logs per acre for small logs (3 to 19 inches). Western Oregon forests had five times as much biomass in large logs as those in eastern Oregon (fig. 49).

Snags represented a mean biomass of 6 tons per acre and a mean density of 19 trees per acre across the state. Almost 90 percent of the snags were <20 inches d.b.h.; only 0.3 snags per acre were >40 inches d.b.h. Softwood forest types had the most biomass and the largest proportion of large-diameter snags (>20 inches d.b.h.) (fig. 50).

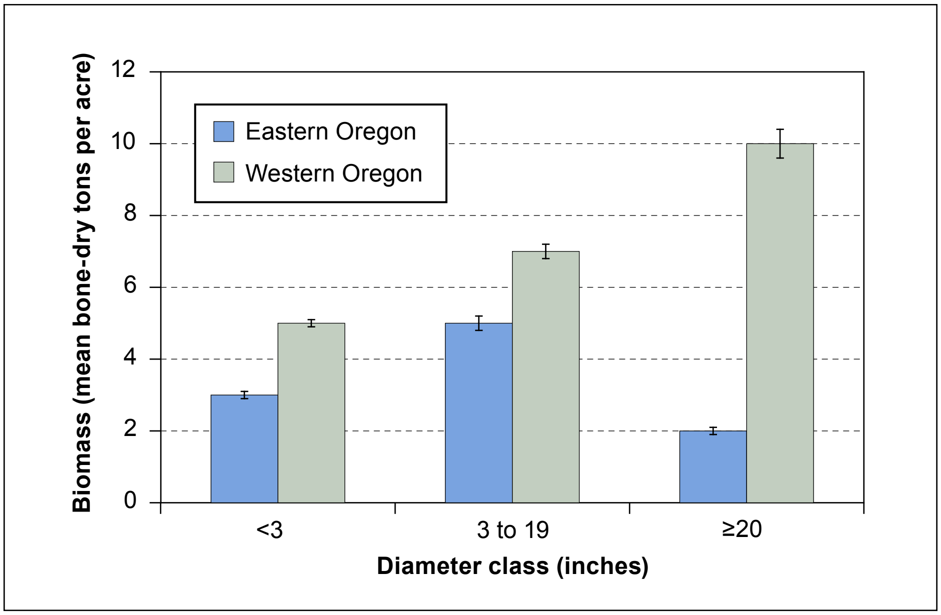

Figure 49—Mean biomass of down wood by diameter class on forest land in eastern and western Oregon, 2001–2005.

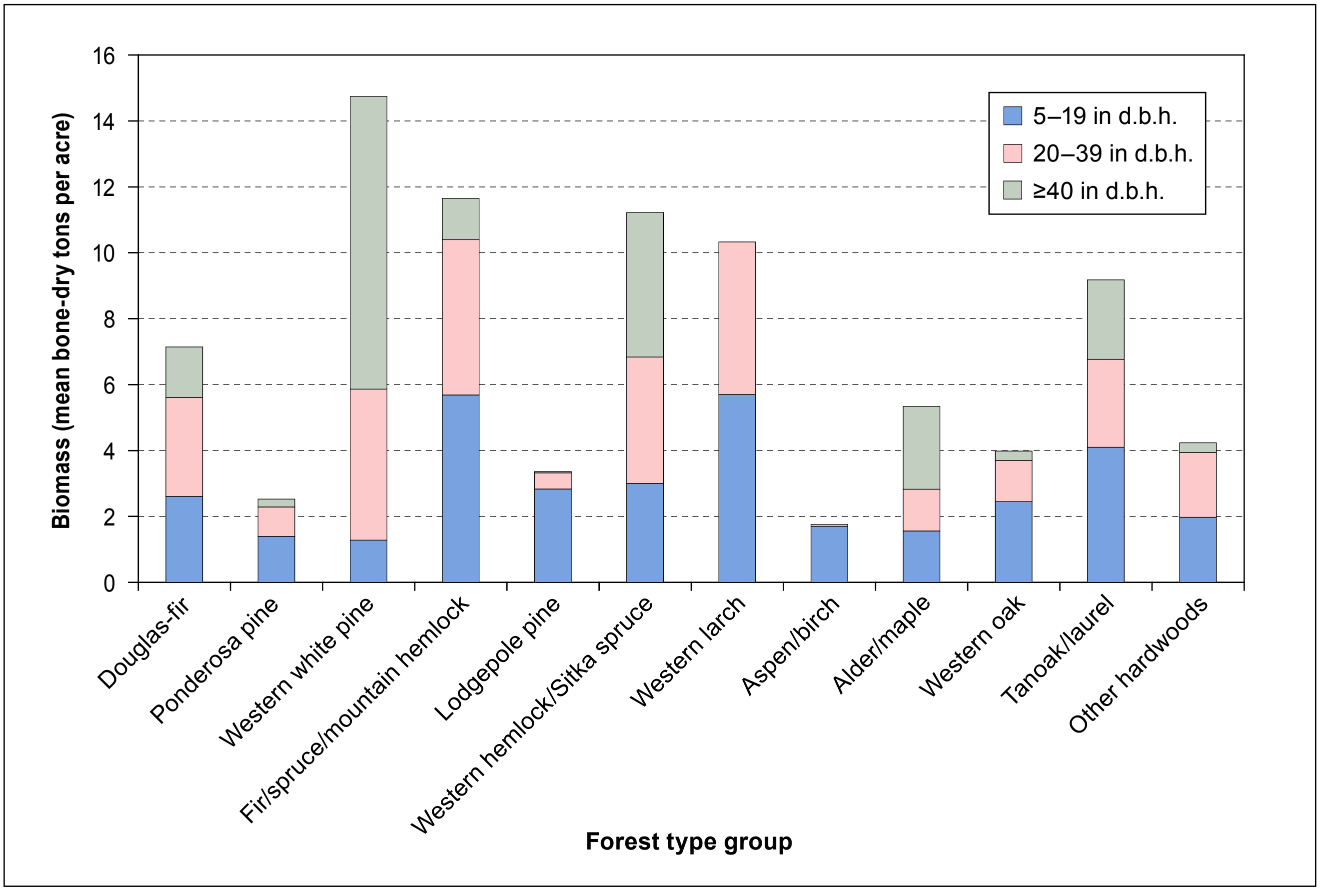

Figure 50—Mean biomass of snags by forest type and diameter class on forest land in Oregon, 2001–2005.

Although the total amount of dead wood present in a forest differs over time, the mean density of large-diameter (>20 inches) snags and down logs generally increases with stand age (fig. 51), as shown below:

	Snags		Down wood	
	Diameter classes			
Stand age in years	5 to 19 in	≥20 in	3 to 19 in	≥20 in
	Mean trees/acre		*Mean logs/acre*	
1 to 50	11.1	1.0	253.1	15.5
51 to 100	17.7	1.4	213.0	6.7
101 to 150	25.3	3.2	220.4	7.2
151 to 200	23.7	4.3	195.7	11.1
201 to 250	19.6	5.6	220.3	13.0
251 to 300	13.8	5.2	186.6	16.4
300 plus	16.2	7.0	196.1	26.9
Total	16.7	2.0	225.1	10.9

Large snags ranged from a mean of 1 tree per acre in young stands to 7 trees per acre in stands older than 300 years. In contrast, young stands appear to start out with a higher level of large down wood, which is most likely a remnant from a stand-initiating event (e.g., fire or harvest). Stands 51 to 100 years old had about half the density of large down wood that younger stands had, which increased to as many as 26.9 logs per acre in very old stands.

Interpretation

Dead wood accumulates in different patterns across the wide variety of forest types in Oregon, creating a mosaic of habitats and fuels across the landscape. Many factors influence the size, abundance, and stage of decay of dead wood. The higher fuel loading observed in western Oregon forests is likely due in part to the higher overall primary productivity rates west of the Cascades. These heavier fuel loads may suggest that forests in western Oregon represent a greater fire hazard than those on the east side, but the moist climatic conditions on the west side tend to temper the effect of large accumulations of fuels.

In general, wildlife species that use dead wood for nesting, roosting, or foraging prefer larger diameter logs and snags (>20 inches). Although we tallied dead wood in this size class throughout Oregon, the estimated density may not be sufficient for some wildlife species. For

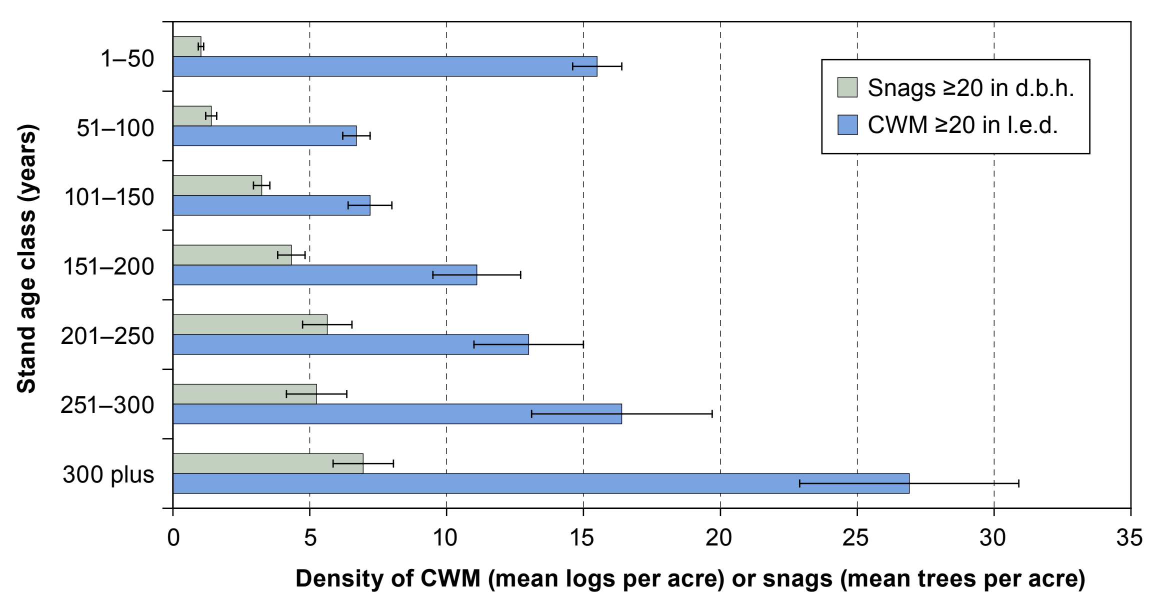

Figure 51—Mean density of large-diameter (≥20 in) coarse woody material (CWM) and snags by stand age class on forest land in Oregon, 2001–2005; d.b.h. = diameter at breast height; l.e.d. = large end diameter.

example, inventory results show a mean of almost 3 snags per acre in this size class in western Oregon and 1 per acre in eastern Oregon. This may indicate that large-diameter snags are currently uncommon in Oregon habitat and that management may be necessary to produce a greater density of large snags.

Various types of disturbance can radically change the attributes of a forest by shifting the balance of live and dead trees or FWM and CWM. Biologists and land managers may want to monitor these changes to determine whether the density, size distribution, and decay characteristics of dead wood are adequate for local management objectives, such as managing for the needs of a particular wildlife species. In addition, understanding the amount of biomass and carbon stored in dead wood will allow us to address requests pertaining to global carbon cycles.

There is a substantial amount of information about dead wood in FIA databases and summary tables that can be used for a more indepth analysis of this resource, including estimates of density, biomass, volume, and carbon for all dead wood components.

Dead Wood Tables in Appendix 2

Table 27—Estimated average biomass, volume, and density of down wood on forest land, by forest type group and diameter class, Oregon, 2001–2005

Table 28—Estimated biomass and carbon mass of down wood on forest land, by forest type group and owner, Oregon, 2001–2005.

Table 29—Estimated average biomass, volume, and density of snags on forest land, by forest type group and diameter class, Oregon, 2001–2005

Table 30—Estimated biomass and carbon mass of snags on forest land, by forest type group and owner, Oregon, 2001–2005

Riparian Forests[5]

Background

Riparian forests are forested areas adjacent to streams, lakes, and wetlands (fig. 52). Riparian forests typically make up a small portion of the total land base, but they play a very important role in maintaining the health and function of a watershed. The composition and structure of riparian forests tend to be different from those of upland forests, and thus these forests provide a unique habitat for many plant and wildlife species. Riparian forests help stabilize streambanks, reduce sediment inputs, and provide shade, nutrients, and large woody debris to the water body. Because of the critical role of riparian forests for fish and wildlife habitat and water quality, agencies have prescribed specific management rules on riparian areas, including requiring retention of certain levels of vegetation and restricting harvest and forest operations.

In this report, we examine the extent and attributes of riparian forests, defined as accessible forest land within 100 feet of a permanent water body, including rivers, streams, lakes, marshes, and bogs. Distance from each subplot center to permanent water features was estimated in the field by FIA crews.

Findings

Regional distribution of riparian forest area and volume—
On average, riparian forests cover an estimated 7.1 percent of all forest land area and hold 9.8 percent of the net volume of live trees in the state. The abundance of riparian forest differs dramatically within the state (fig. 53). In western Oregon, 10.4 percent of the total forest area is estimated to be riparian forest, whereas 3.7 percent of forest in eastern Oregon is estimated to be riparian. Riparian forests account for about 11.0 and 6.0 percent of the total net volume of the west and east sides of the state, respectively (fig. 54).

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[5] Author: Vicente Monleon.

Figure 52—Riparian forests along the Metolius River, central Oregon.

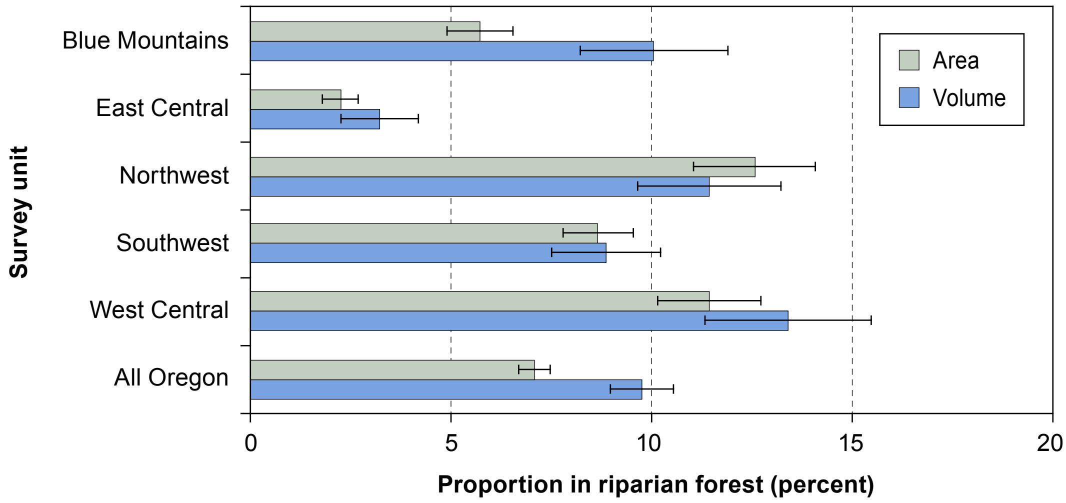

Figure 53—Riparian forest land area and net tree volume, as a percentage of forest land area and volume, by survey unit in Oregon, 2001–2005.

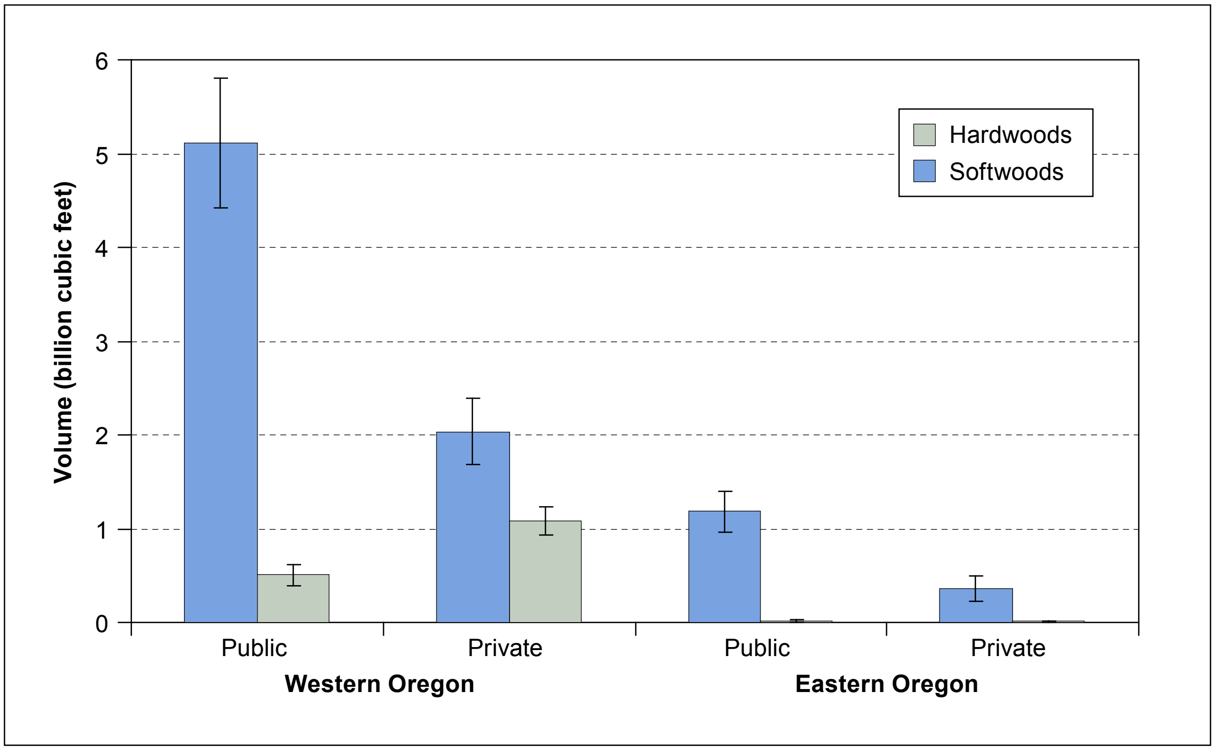

Figure 54—Net tree volume in riparian forests by region, ownership, and species group in Oregon, 2001–2005.

Across the state, riparian forests tend to hold a greater timber volume per unit area than upland forests. However, most of this difference may be attributed to eastern Oregon's drier climate, which may limit the most productive forests to areas next to streams. Below is the estimated mean net volume density of live trees in western and eastern Oregon:

	Riparian forests		Upland forests	
Region	**Volume density**	**SE**	**Volume density**	**SE**
	Cubic feet per acre			
Western Oregon	5,499	369	5,189	138
Eastern Oregon	2,750	319	1,674	55
Total	4,773	295	3,367	75

Ownership and species composition of riparian forests— In relative terms, the extent and net volume of riparian forests is greater on private than on public land. On private forest lands, 7.9 percent of the area and 13.4 percent of the timber volume is estimated to be in riparian areas, whereas on public lands, 6.6 percent of the area and 8.6 percent of the volume is estimated to be in riparian areas. This difference may result from a greater private ownership of valley bottoms and a greater proportion of private land in western Oregon, where riparian forests are more abundant.

Riparian forests account for an estimated 20.1 percent of the total net volume of hardwood species, but only 8.9 percent of the total net volume of softwood species. The difference is even greater on private lands, where 24.7 percent of the net volume of hardwood species occurs within riparian forests. Although hardwood species are more abundant on average in riparian forests than in upland forests, softwood species dominate riparian areas and account for most of the tree volume. The net timber volume of hardwood species is estimated to be 15.7 percent of the total volume in riparian forests, but only 6.4 percent of the total volume in upland forests (standard errors are 1.8 and 0.3, respectively).

Interpretation

The distribution of riparian forests follows the broad climatic patterns of the state. Riparian abundance and net volume are much greater in the moister northwestern region than in the drier eastern region. Climatic pattern may also explain some of the differences in structure and productivity between riparian and upland forests, such as the difference in volume per unit area and proportion of hardwood species. Currently, riparian forests are subject to special management regulations. Data collected by FIA may be used to examine the effectiveness and impact of those regulations at a broad scale. However, detailed information for small areas may be limited by the small sample size. Further, FIA does not collect information about stream characteristics, such as fish use, that may be important for evaluating existing regulations.

Riparian Forests Tables in Appendix 2

Table 31—Estimated area and net volume of live trees on riparian forest land, by location, Oregon, 2001–2005

Table 32—Estimated area of riparian forest land, by forest type group, owner, and location, Oregon, 2001–2005

Table 33—Estimated net volume of live trees on riparian forest land, by species group, owner, and location, Oregon, 2001–2005

Tree Crowns, Soil, and Understory Vegetation[6]

Background

This section highlights three important FIA forest health indicators, tree crowns, soil, and understory vegetation. All are ecologically important as structural components in forest ecosystems. For example, the amount and vertical layering of different plant life forms (e.g., trees, shrubs, forbs, or grasses) are key determinants of wildlife habitat, fire behavior, erosion potential, and plant competition (MacArthur and MacArthur 1961, National Research Council Committee 2000). Tree-crown density, transparency, and dieback are indicators of tree vigor, impacts from disease or other stressors, and potential for mortality (Randolph 2006). Soil structure and nutrient status contribute to the diversity and vigor of vegetation across Oregon (Franklin and Dyrness 1973). Because soil development is a slow process (Jenny 1941), protecting soil from erosion, compaction, and nutrient loss is crucial to sustaining forest products and ecosystem services.

The FIA crews visually estimated crown density, foliage transparency, and dieback on phase 3 plots across Oregon. Crown density is the percentage of the area within an outline of a full crown that contains branches, foliage, and reproductive structures when viewed from the side. Transparency is the percentage of the live foliated portion of the tree's crown with visible skylight. Crown dieback is the percentage of the foliated portion of a crown consisting of recent branch and twig mortality in the upper and outer portions of the crown (Randolph 2006).

Soils also were sampled on phase 3 plots for both physical and chemical properties (fig. 55) (O'Neill et al. 2005). Crews recorded forest floor thickness, soil texture, and indicators of erosion and soil compaction. Soil samples were sent to a laboratory and analyzed for moisture content, percentage coarse fragments, bulk density, carbon (C) and N content, pH, and the amounts of extractable phosphorus (P), sulfur (S), manganese, iron, nickel, copper, zinc, cadmium, lead, as well as exchangeable levels of sodium, potassium, magnesium, calcium, and aluminum.

Crews sampled understory vegetation on each phase 2 FIA subplot on forest land. Total cover was estimated for tree seedlings and saplings <5 inches d.b.h., shrubs, forbs, and graminoids. Total cover of all four of these life forms and of bare mineral soil also was estimated. Crews also collected information on dominant plant species; those data are presented in other sections of this report.

The full functionality of these indicators cannot be fully realized with these first 5 years of data, and so the current status of each indicator is summarized only briefly below, to establish baselines for Oregon's forests and to educate clients about the development of FIA forest health indicators. A major benefit of these indicators is that they will enable future tracking of deviations from baseline conditions.

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[6] Authors: Glenn Christensen, Joseph Donnegan, and Andrew Gray.

Joseph Donnegan

Figure 55—Forest soils are sampled with a soil coring device driven by an impact hammer.

Findings

Crown density ranged from 31 to 50 percent among species groups, with a mean of 43 percent. Mean foliage transparency was 21 percent and was greater for hardwoods than for softwoods (fig. 56). Recent crown dieback was detected in only 2.1 percent of the trees examined. Only three species groups had more than 5 percent of all trees with more than slight (i.e., 10 percent) crown dieback: western hardwoods (mostly mountain mahogany, with 21 percent of all trees having more than 10 percent dieback), other western softwoods (mostly western juniper, with 13 percent), and Engelmann and other spruces (with 6 percent).

Carbon and N in the top 7.9 inches of soil were positively correlated ($r^2 > 0.74$) with one another. Their abundance differed greatly across the state and was not significantly related to elevation, latitude, or soil moisture (figs. 57 and 58). Visual signs of soil compaction were evident on 34 percent of the plots in a variety of forests across Oregon (fig. 59). The mean compacted area for those plots was 9 percent. Bulk density was not significantly related to compaction on plots (logistic regression and chi square test), possibly because bulk density is sampled off the plot, whereas evidence of compacted trails, ruts, and other areas is visually assessed on the plot. Bare soil cover was greatest in the drier areas, particularly the south-central portion of the state.

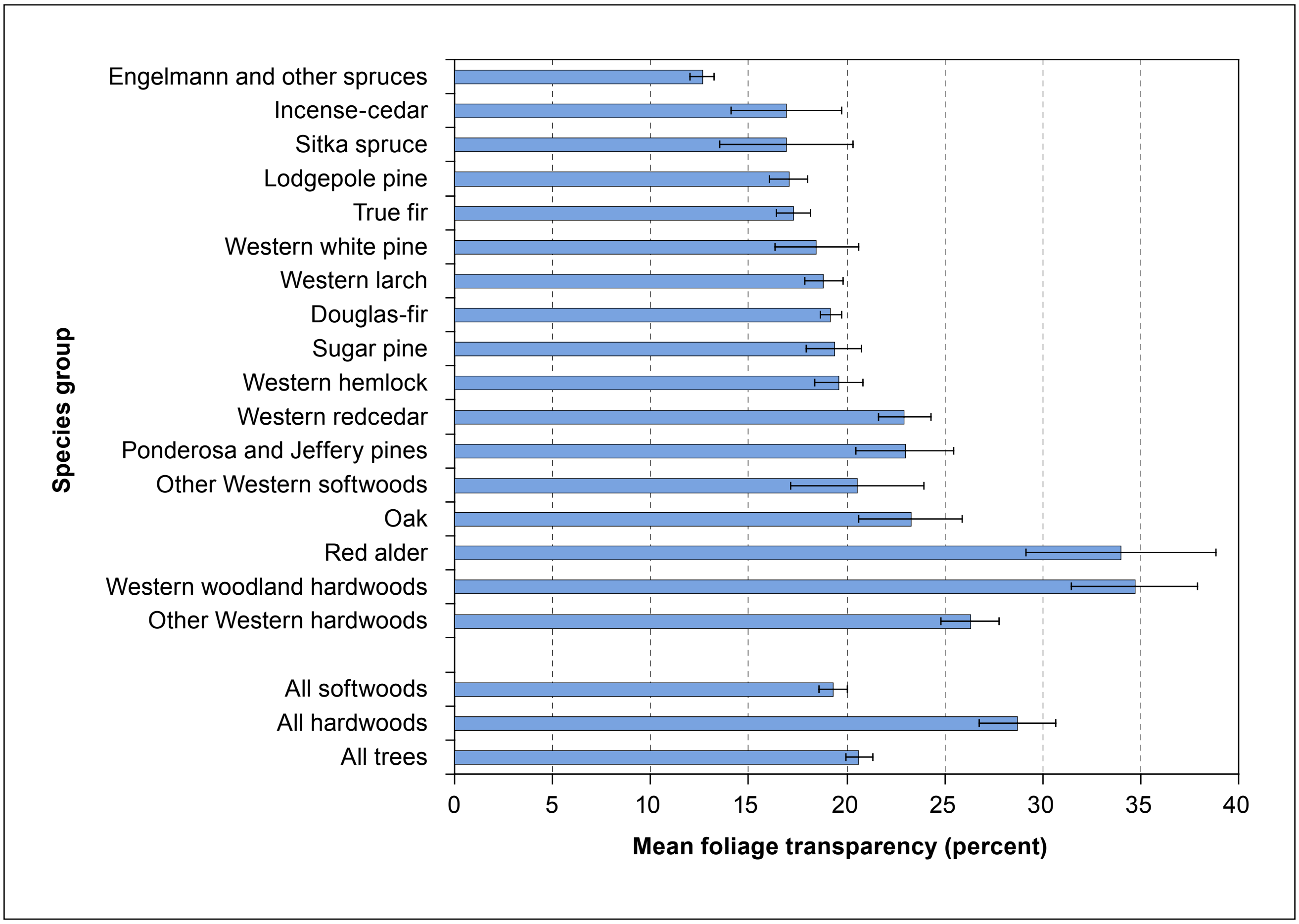


Figure 56—Mean foliage transparency by species group on forest land in Oregon, 2001–2005.

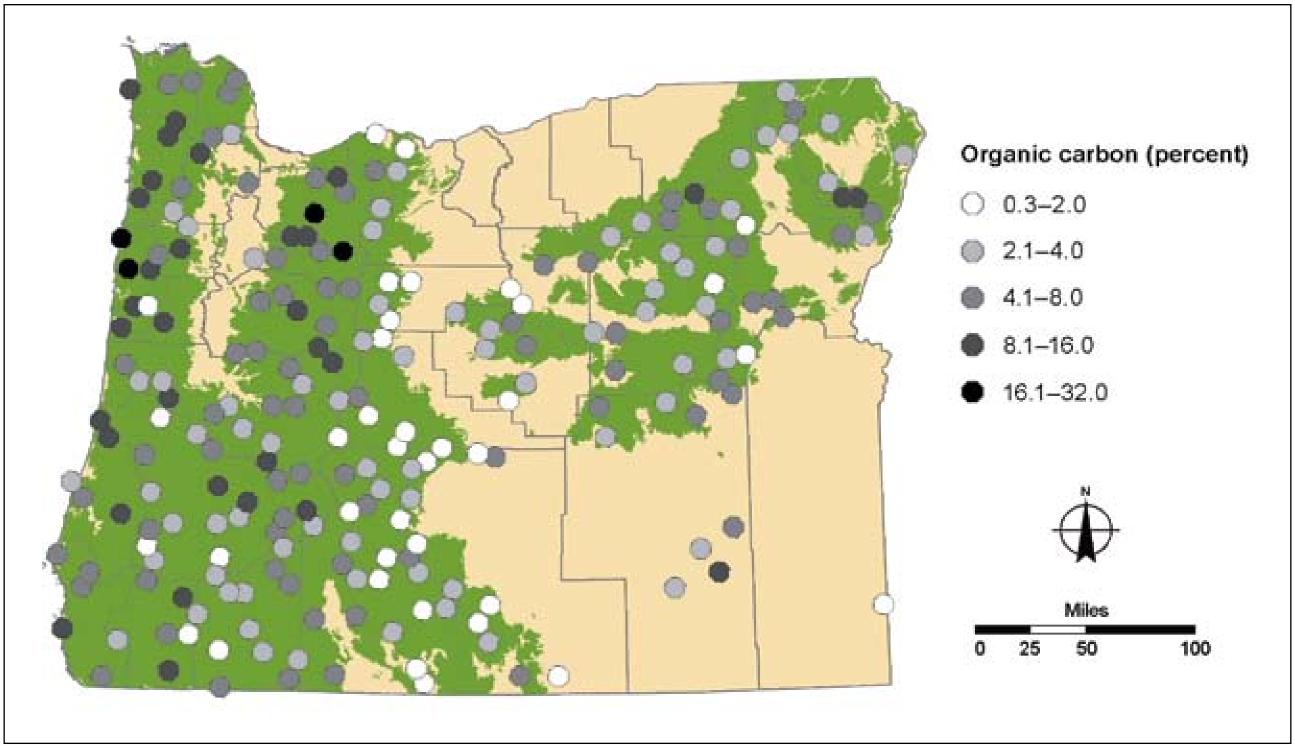


Figure 57—Distribution of soil carbon on forest land in Oregon, 2001, 2003–2005 (forest/nonforest geographic information system layer: Kagan and Caicco 1992).

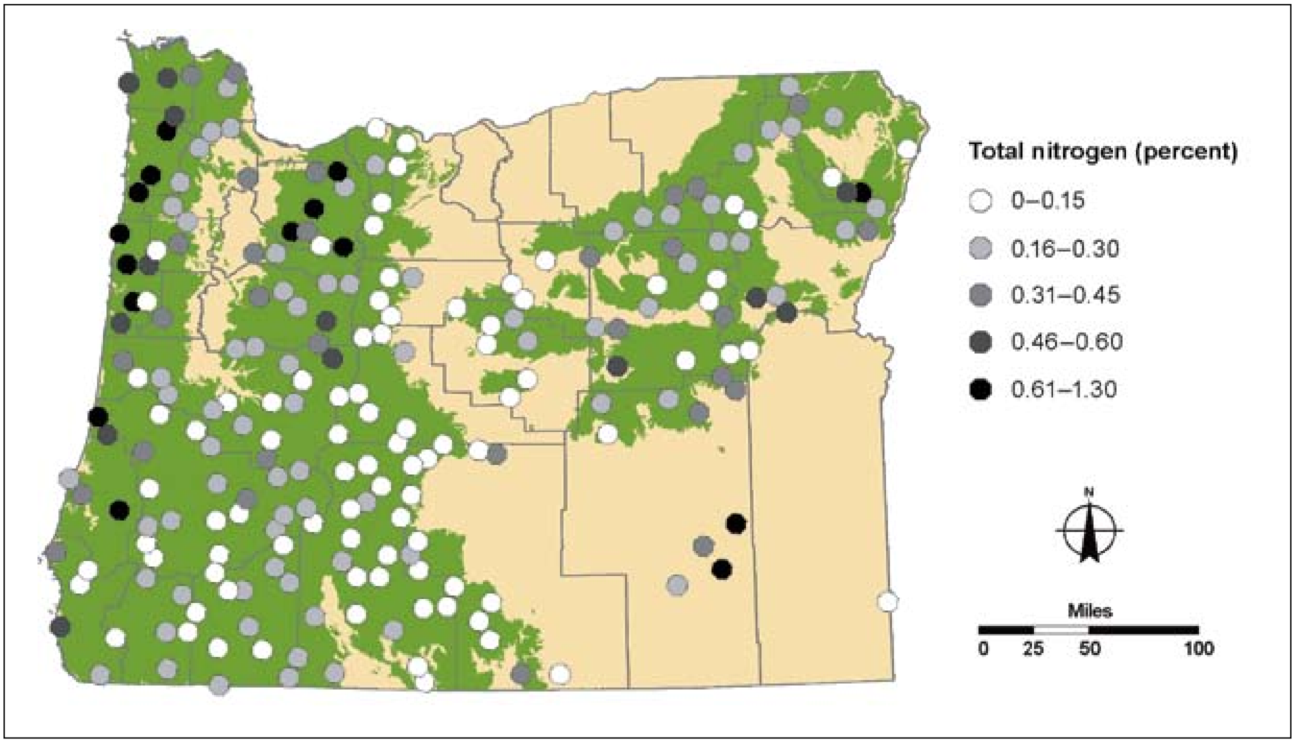


Figure 58—Distribution of soil nitrogen on forest land in Oregon, 2001, 2003–2005 (forest/nonforest geographic information system layer: Kagan and Caicco 1992).

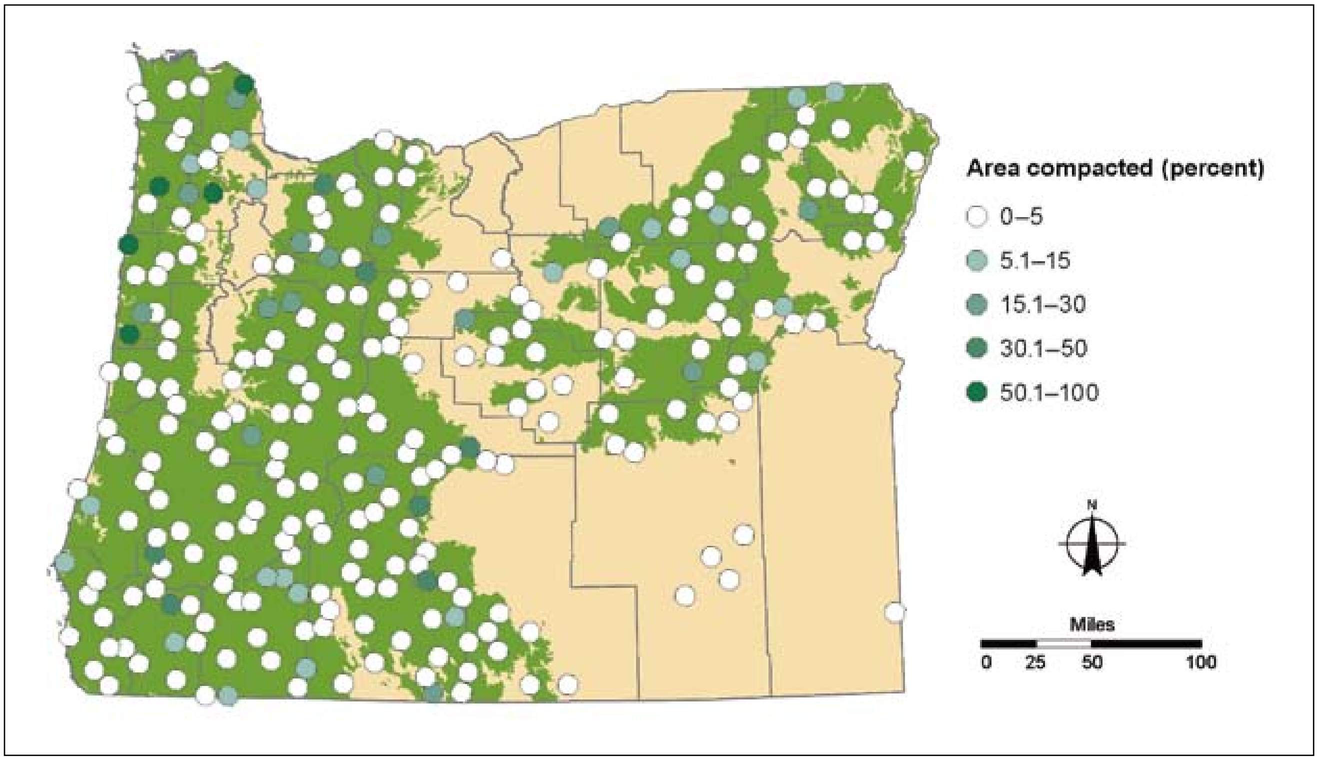


Figure 59—Evidence of compaction on forest land in Oregon, 2001, 2003–2005 (forest/nonforest geographic information system layer: Kagan and Caicco 1992).

Cover of understory vegetation in Oregon was greater in hardwood forests than in softwood forests (fig. 60). Within each type, shrub cover was highest in the higher-moisture forest type groups: elm and alder/maple, and Douglas-fir and hemlock/spruce (fig. 61). Graminoid cover was generally highest in the drier oak and pine groups. Forb cover was greatest in the hemlock and alder/maple groups. Understory cover declined initially with increasing age class (primarily owing to declines in shrub cover), but was quite similar among stands over 40 years of age (fig. 62).

Interpretation

Initial results suggest crown decline is not widespread in Oregon, with most dieback found on dry forest types in the southeastern part of the state. Future remeasurements will provide more-precise estimates of changes in crown health over time.

The abundance of C and N was correlated but highly variable across the forests of Oregon. Soils high in organic C are generally associated with higher levels of microbial activity and of key nutrients, including N, S, and P (Mengel et al. 2001). Soils in wet, cool environments tend to be high in organic C, although this pattern was not clear in the data collected to date. Soil compaction was widely dispersed. Compaction can be caused by heavy machinery, repeated use of vehicles, and trampling by humans or livestock; can inhibit plant growth by decreasing soil pore space; and can lead to increased erosion during high-precipitation events.

The amount and composition of understory vegetation differed greatly among the forest types and forest age classes of Oregon. Although all life forms were represented in all forest types to some extent, their abundance appeared to differ according to forest type. Shrubs and graminoids

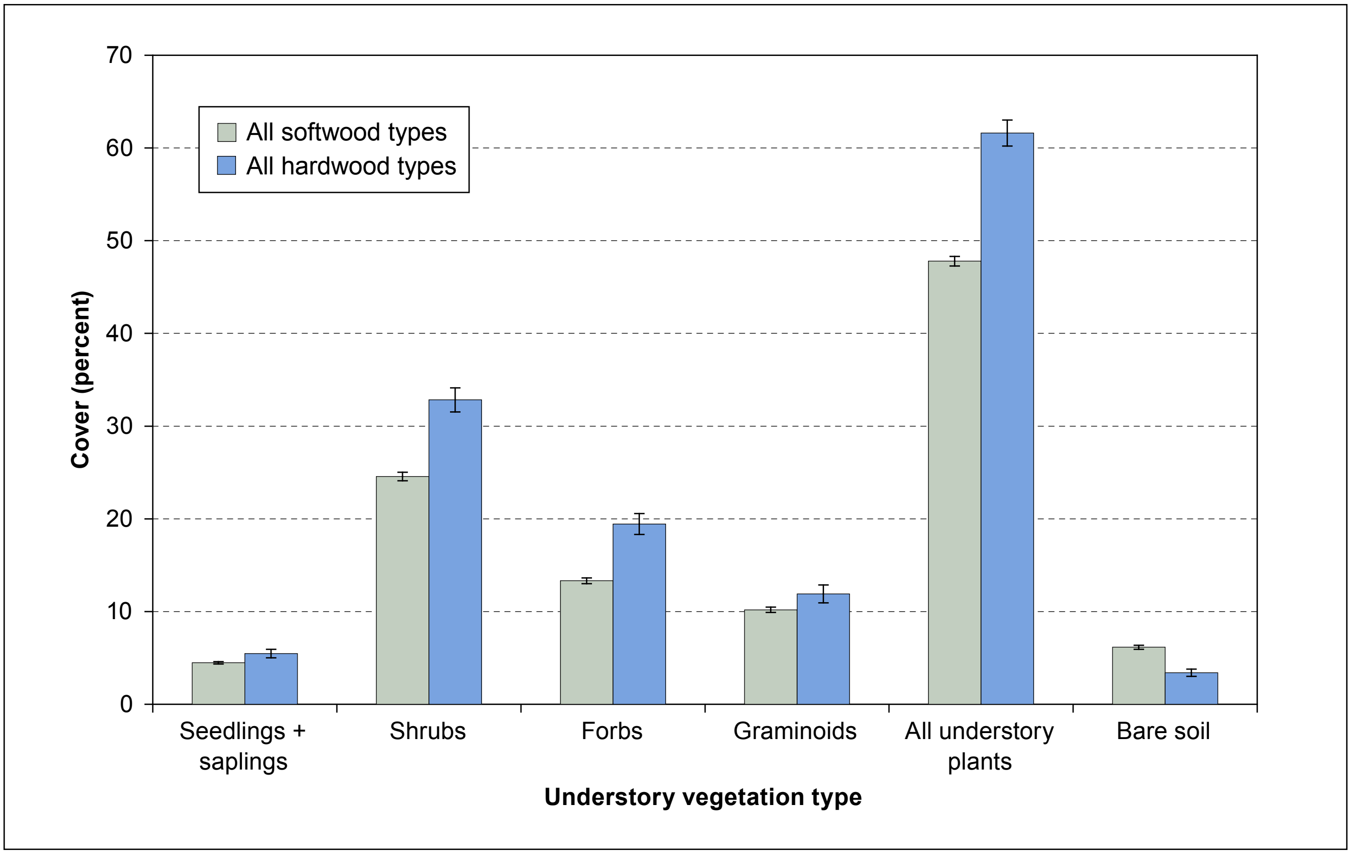


Figure 60—Cover of vegetation life forms and bare soil by hardwood or softwood forest type group on forest land in Oregon, 2001–2005.

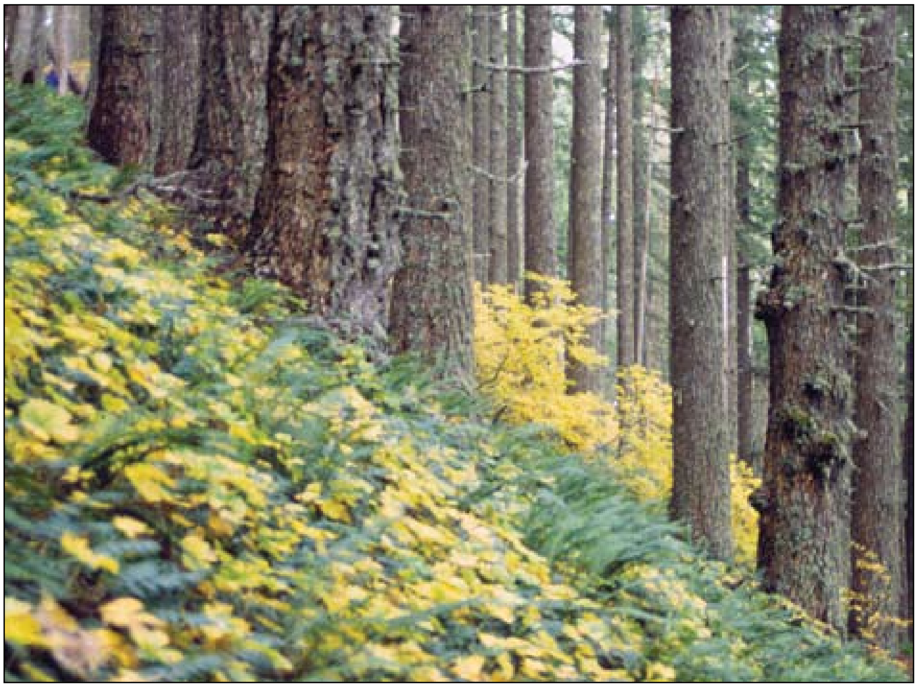


Figure 61—Dense understory cover of forbs and shrubs in a Douglas-fir forest.

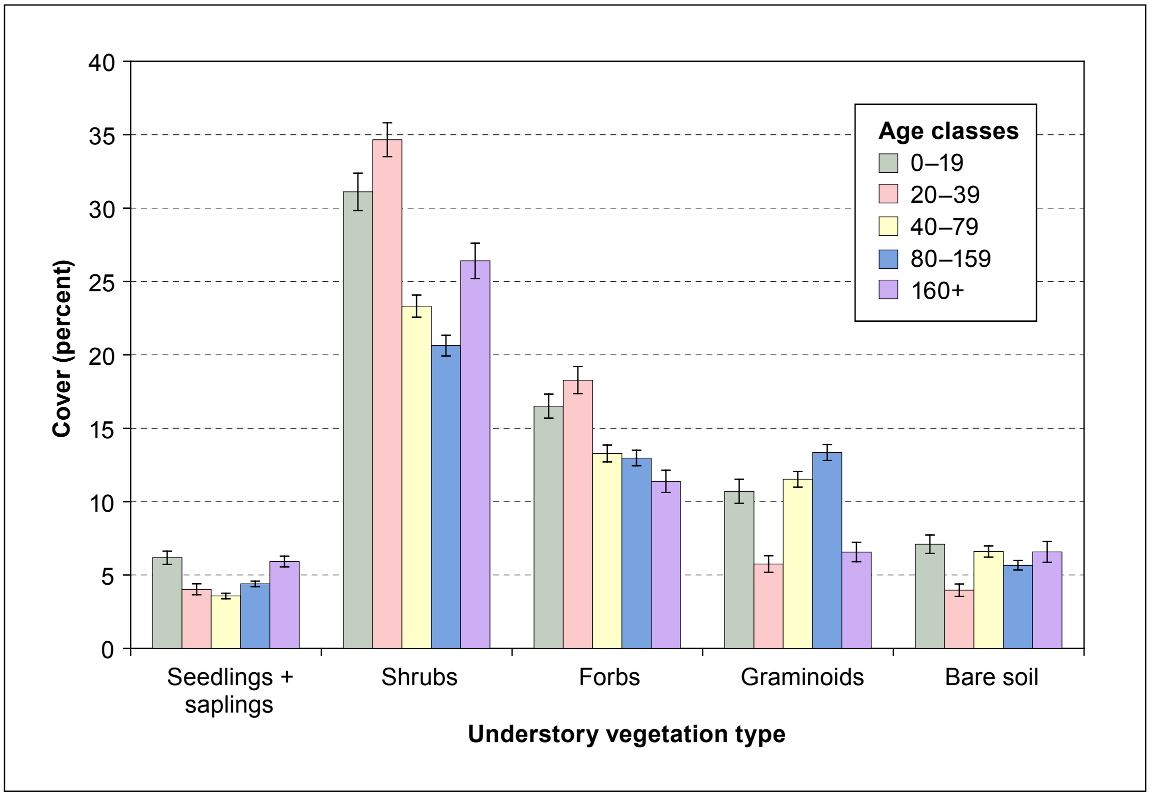


Figure 62—Cover of vegetation life forms and bare soil, by forest age class in Oregon, 2001–2005.

appeared to be particularly sensitive to the overstory tree type (softwood or hardwood) as well as moisture availability within different forest type groups. Although vegetation abundance differed with age class, the conventional wisdom that dense young forests have very low cover of understory plants does not appear to be valid across Oregon.

Crown, Soil, and Understory Vegetation Tables in Appendix 2

Table 34—Estimated mean crown density and other statistics for live trees on forest land, by species group, Oregon, 2001–2005

Table 35—Mean foliage transparency and other statistics for live trees on forest land, by species group, Oregon, 2001–2005

Table 36—Mean crown dieback and other statistics for live trees on forest land, by species group, Oregon, 2001–2005

Table 37—Properties of the forest floor layer on forest land, by forest type, Oregon, 2001, 2003–2005

Table 38—Properties of the mineral soil layer on forest land, by depth of layer and forest type, Oregon, 2001, 2003–2005

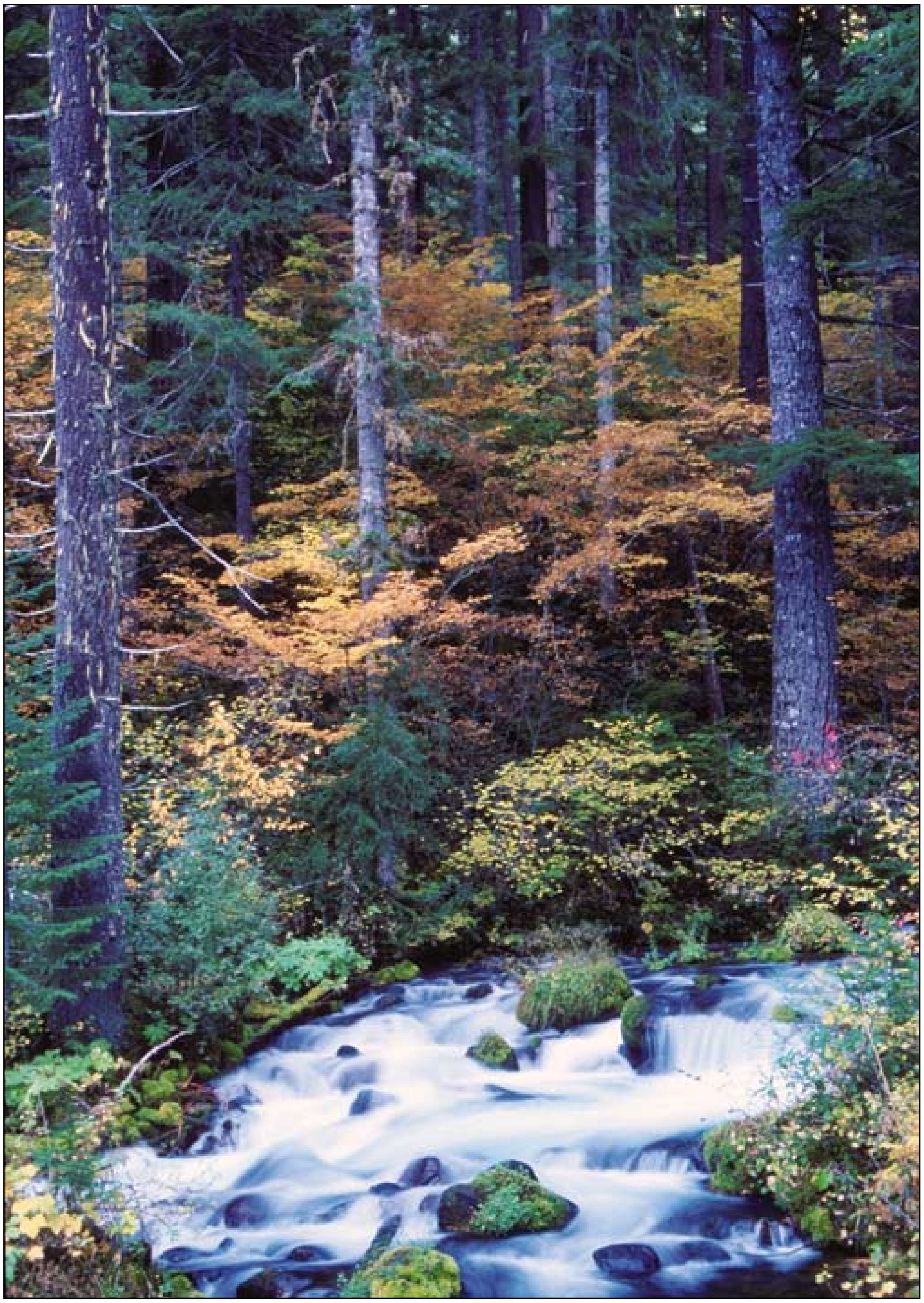
Table 39—Chemical properties of mineral soil layers on forest land, by depth of layer and forest type, Oregon, 2001, 2003–2005.

Table 40—Chemical properties (trace elements) of mineral soils on forest land, by forest type, Oregon, 2001, 2003–2005

Table 41—Compaction, bare soil, and slope properties of forest land, by forest type, Oregon, 2001, 2003–2005

Table 42—Mean cover of understory vegetation on forest land, by forest type group and life form, Oregon 2001–2005

Table 43—Mean cover of understory vegetation on forest land, by forest type class, age class, and life form, Oregon, 2001–2005



Tom Iraci

Willamette National Forest.

Chapter 5: Disturbance and Stressors

Major disturbance agents and stressors such as insects, diseases, invasive plant species, air pollution, and fire are among the most powerful influences on the structure, species composition, and ecological function of forests. We explore the influence of these agents through analysis of both Pacific Northwest Forest Inventory and Analysis (PNW-FIA) plot data and predictive risk models.

Data in this chapter address Montréal Process criterion 3 and indicators pertaining to maintenance of forest ecosystem health and vitality.

Data in this chapter also address Oregon indicator F pertaining to protecting, maintaining, and enhancing the health of Oregon's forests within a context of natural disturbance and active management.

Insects, Diseases, and Other Damaging Agents[1]

Background

Insects, diseases, and other damaging agents can have both detrimental and beneficial effects on forest ecosystems (fig. 63). The frequency and severity of damage to trees by biotic agents, such as insects or diseases, or abiotic agents, such as fire or weather, are influenced by a number of factors, ranging from the existing composition and structure of the forest to management policies and activities (Hessburg et al. 1994). Effects from damaging agents include defoliation, decay, reduced growth, increased susceptibility to other

Paul Dunham

Figure 63—Dwarf mistletoe on lodgepole pine in eastern Oregon.

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[1] Authors: Sally Campbell and David Azuma.

stressors (e.g., other insects and diseases or drought), and mortality. These impacts can affect ecosystem structure, composition, and function. Introduced insects and diseases such as balsam woolly adelgid (*Adelges piceae* (Ratzeburg)) or white pine blister rust (*Cronartium ribicola* Fisch.) often have more rapid and intense impacts than native organisms.

The PNW-FIA Program collects data on damaging agents for each measured live tree, and also maps root disease, if present, on each plot. These ground-based data complement localized ground surveys and the annual aerial survey conducted by the Oregon Department of Forestry (ODF) and the Forest Health Protection (FHP) Program of the U.S. Forest Service; the aerial survey maps defoliation and mortality observed from the low-altitude flights. The FIA plot-based sampling protocol allows estimation of acres, trees per acre, basal area, and volume affected by each agent or agent group for forest types and for individual tree species. Our information on damaging agents is most reliable for those that are common and broadly distributed; it is less reliable for unevenly distributed, less common agents such as newly established nonnative pests.

Findings

About 27 percent of live trees greater than 1 inch in diameter showed signs or symptoms of insects or diseases; damage by animals, weather, or fire; or physical defects such as a dead or missing top, crack, check, fork or crook. Fifteen percent of Douglas-fir and 32 percent of ponderosa pine had some damage recorded. Overall damage levels were higher in eastern Oregon than in western Oregon, and they were higher on public lands than on private lands. More than 15 million acres had greater than 25 percent of forest basal area affected by one or more damaging agents. The volume of live trees ≥5 inches diameter at breast height (d.b.h.) affected by one or more damaging agents was 35.1 billion cubic feet. Root disease and dwarf mistletoe, which cause significant growth loss and mortality, were recorded on 4.4 and 7.5 percent of softwoods, respectively. Of all the biotic agents recorded, these two affected the most volume and area of both softwoods and hardwoods (figs. 64 and 66). For abiotic agents, physical defects affected the most volume and area (fig. 65).

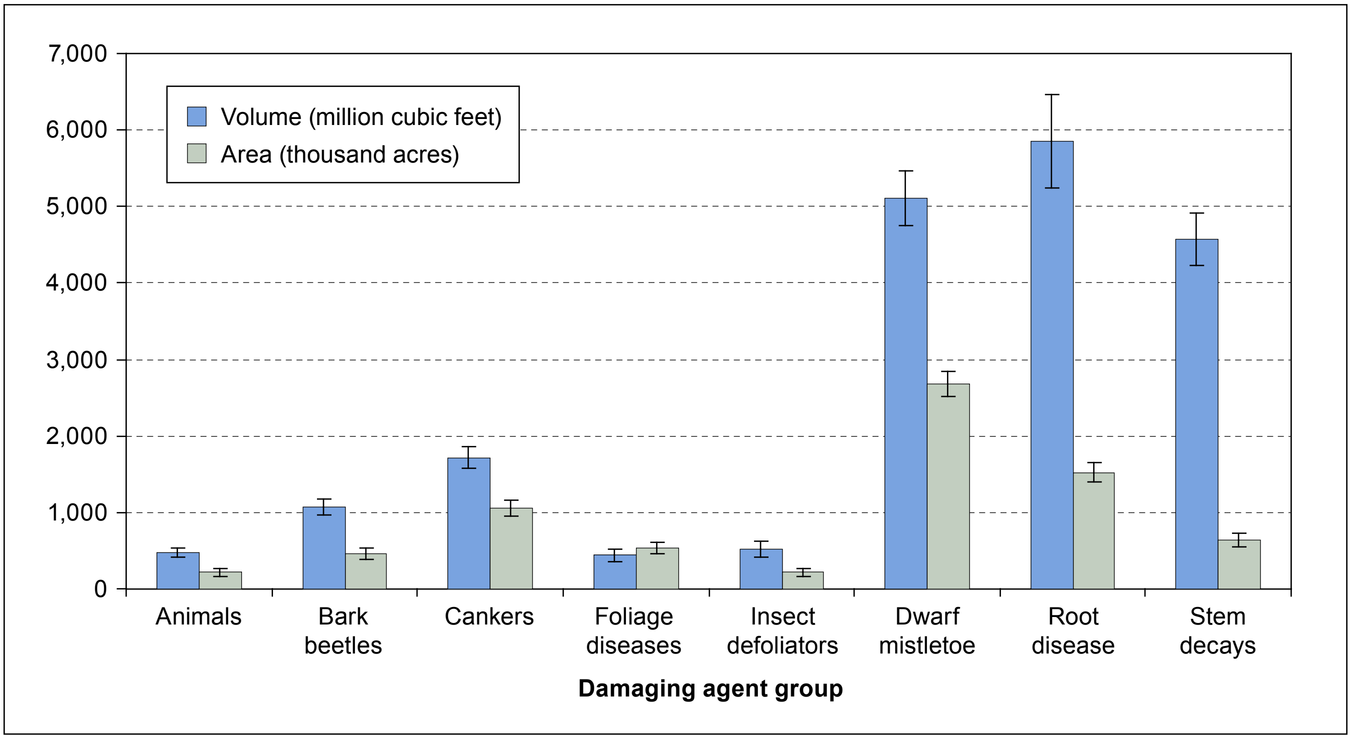

Figure 64—Area and volume of live trees affected by one or more biotic agents on forest land in Oregon, 2001–2005; acres are those with >25 percent of basal area with damage; volume is gross volume of live trees >5 inches diameter at breast height.

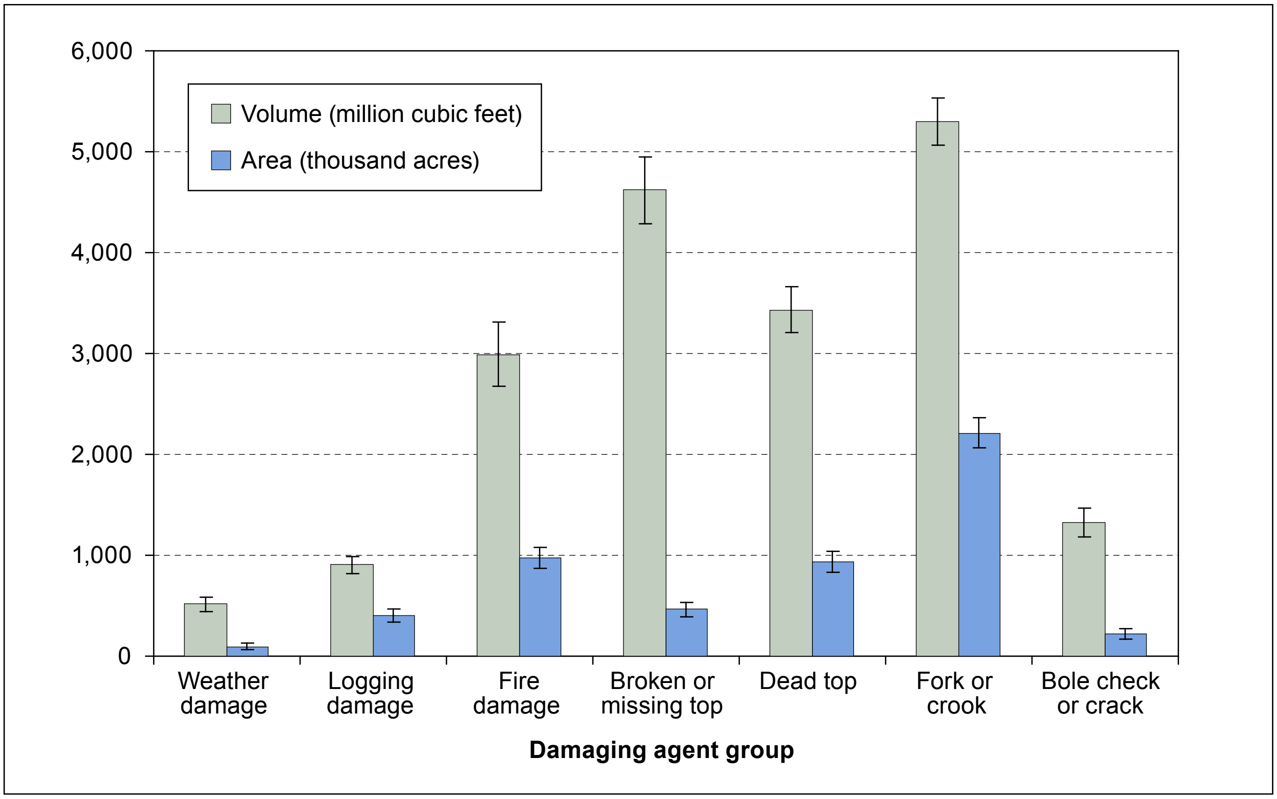

Figure 65—Area and volume of live trees affected by one or more abiotic agents on forest land in Oregon, 2001–2005; acres are those with ≥25 percent of basal area with damage; volume is gross volume of live trees ≥5 inches diameter at breast height.

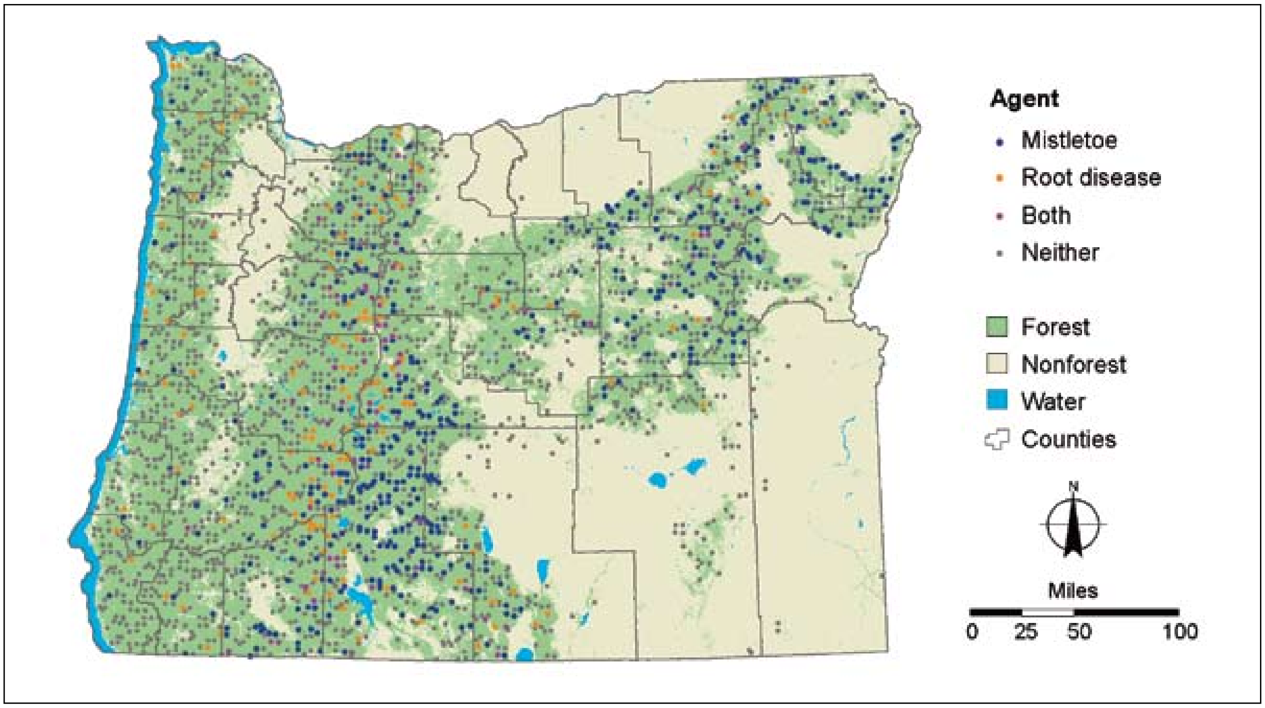

Figure 66—Root disease and dwarf mistletoe incidence on visited Forest Inventory and Analysis plots, Oregon, 2001–2005 (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008; urban/water GIS layer: Homer et al. 2004).

Compared to the previous periodic inventories (1994–2003), our findings show a smaller percentage of trees, acres, and volume affected by damaging agents:

	Periodic inventory 1994–2003[a]	Annual inventory 2001–2005
Percentage of trees >5 inches d.b.h. affected	43	29
Percentage of area with >25 percent basal area affected	64	52
Percentage of volume of trees >5 inches d.b.h. affected	49	33

[a] Dunham, P. 2007. [N.d.]. Incidence of insects, diseases, and other damaging agents on Oregon forests. Manuscript in preparation. On file with: Sally Campbell, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 620 SW Main, Suite 400, Portland, OR 97205.

Interpretation

Some of the most common biotic (living) agents of forest disturbance, such as dwarf mistletoes and stem decays, are more prevalent in unmanaged or older stands. If the current trajectory of management on federal forests continues, we would expect to see increases in these agents on national forests and other federal lands in the future; conversely, we would expect decreases or continued lower levels on private and nonfederal forests, where stands are younger and more intensively managed. Root disease, often widespread in older stands, may become more damaging in young stands that are established in infested areas. The incidence and impact of many insects and diseases are closely tied to past forest management practices that have influenced forest structure and composition (Campbell and Liegel 1996).

In the near future, the greatest insect or disease threats to Oregon's forests are likely to come from introduced organisms, and also from native species whose populations and impacts are increased by drought, high stand densities, and climate changes (Pimentel et al. 2005). Recent bark beetle epidemics in southern California and British Columbia, are attributed to a number of these factors (British Columbia Ministry of Forests 2006, Pedersen 2003, Walker et al. 2006). Although FIA underrecords bark beetles, insect defoliators, and foliage diseases owing to a number of factors,[2] results of widespread bark beetle epidemics should be observable in future FIA data on tree mortality. Annual aerial surveys can also provide excellent, timely information on insect- and disease-caused defoliation. Tracking the incidence and impact of insects, diseases, and other damaging agents over time will become particularly important as changes in climate and in human activities affect the structure and composition of Oregon's forests.

Insects, Diseases, and Other Damaging Agents Tables in Appendix 2

Table 44—Estimated number of live trees with damage on forest land, by species and type of damage, Oregon, 2001–2005

Table 45—Estimated area of forest land with more than 25 percent of the tree basal area damaged, by forest type and type of damage, Oregon, 2001–2005

Table 46—Estimated gross volume of live trees with damage on forest land, by species and type of damage, Oregon, 2001–2005

Table 47—Estimated number of live trees with damage, acres of forest land with greater than 25 percent of the basal area damaged, and gross volume of live trees with damage, by geographic region and ownership group, Oregon, 2001–2005

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[2] These agents are likely underrecorded due to FIA's difficulty in detecting (1) symptoms of bark beetle attack on live trees prior to mortality, (2) defoliation events that are not evenly distributed geographically or temporally and thus are less likely to coincide with FIA plot visits, and (3) damage occurring on upper portions of trees in dense stands.

Invasive Plants[3]

Background

Invasions of nonnative plants into new areas are having a large impact on the composition and function of natural and managed ecosystems. Invasive plants can have a large economic impact, both by changing or degrading land use and through the costs of eradication efforts, now estimated at over $35 billion per year (Pimentel et al. 2005).

Nonnative plant invasions competitively exclude desired species, alter disturbance regimes, and are a primary cause of extinction of native species (D'Antonio and Vitousek 1992, Mooney and Hobbs 2000, Vitousek et al. 1996). Despite their importance, there is little comprehensive information about the extent and impact of invasive species. Most of the emphasis given invasive plants is in the context of local eradication efforts. Comprehensive numbers are not available to describe the magnitude of the problem, which plants are having the most impact, and where these plants are found.

The FIA phase 3 vegetation inventory (Gray and Azuma 2005, Schulz 2003), conducted on a trial basis for several years now, provides a useful source of information on plant composition. In 2000 and 2001, 110 plots were sampled in Oregon with this protocol. Botanists visited plots during mid-summer and recorded all species found or collected samples for later identification. Because the definition of "invasive" can be quite subjective, all species that were listed as nonnative to the United States (USDA Natural Resources Conservation Service 2000) were selected for analysis. Vegetation data collected on the phase 2 (standard inventory) plots were also analyzed by selecting records of nonnative species that were readily identifiable by most crews (i.e., common shrubs or common and distinctive herbs).

Findings

Sixty-nine percent of the plots across Oregon's forest land had at least one nonnative species growing on them. The percentage was highest in some of the eastern Oregon ecosections (e.g., 100 percent of plots in the Blue Mountain foothills) and lowest in the Coast Range (about 47 percent of plots) (fig. 67). Invasive plants were pervasive on forest land

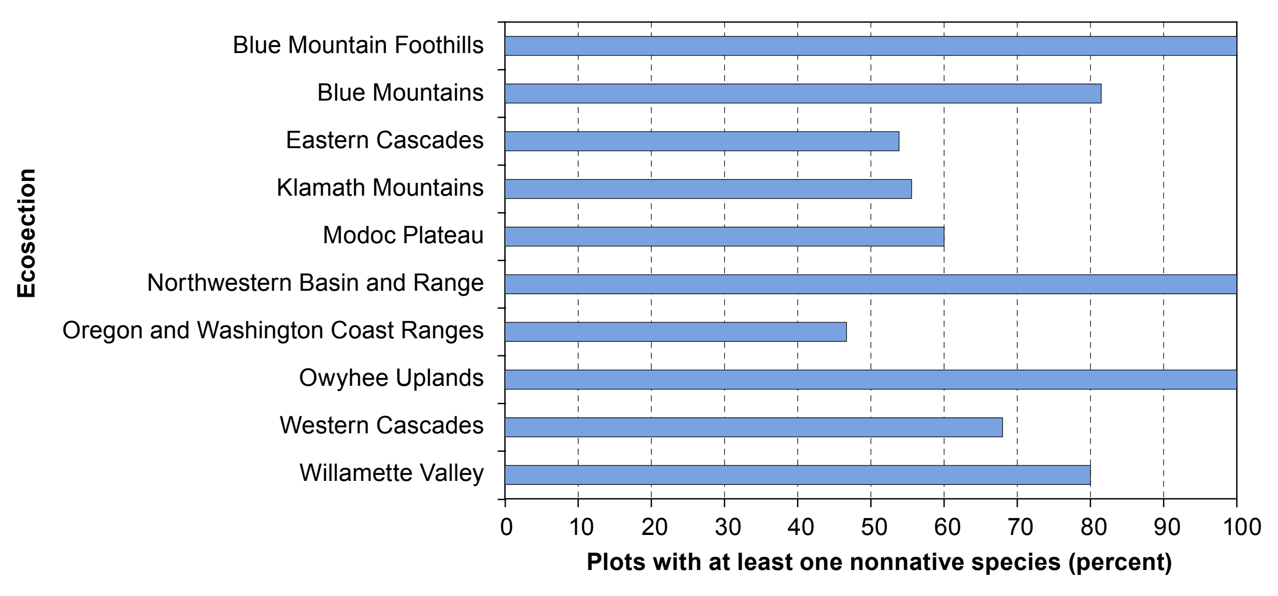

Figure 67—Percentage of plots with at least one nonnative species present by ecosection on forest land in Oregon, 2001–2005.

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[3] Author: Andrew Gray.

in the Willamette Valley ecosection, with a surprisingly high mean of 11 nonnative species covering 42 percent of the plot area. The percentage of nonnative species decreased with increasing stand size class (fig. 68). The basic metric proposed by the Heinz Center (2002) for national reporting of the impact of nonnative plants simply sums the cover of nonnative plants and divides by the cover of all plants. For Oregon, this calculation indicates that 6.2 percent of all plant cover on forest land consists of nonnative plants (standard error = 1.2 percent).

The most common invasive plant found on phase 3 plots in western Oregon was Himalaya blackberry (fig. 69), and the most common in eastern Oregon was cheatgrass (see “Scientific and Common Plant Names”). These and some other nonnative species are readily identifiable through long field seasons, so the vegetation records on phase 2 plots provide an estimate of overall abundance on forest land. The area covered by each species on each plot was extrapolated to all forest land with standard inventory statistics. These data suggest that Himalaya blackberry covered 149,000 acres and cheatgrass covered 196,000 acres of forest land in Oregon.

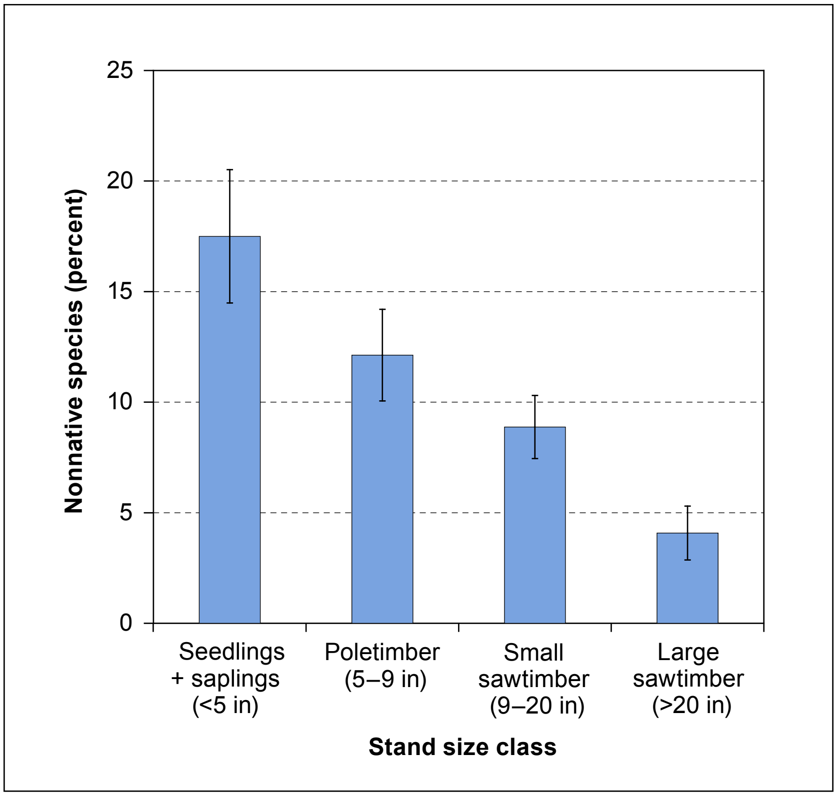

Figure 68—Mean percentage of species on a plot that were nonnative by stand size class on forest land in Oregon, 2001–2005.


Andrew Gray

Figure 69—Himalaya blackberry, the most common invasive plant in forests of western Oregon.

Interpretation

Nonnative invasive plant species already are well established in Oregon's forested lands, making up a significant proportion of the species and plant cover present. Current trends suggest that their importance will increase. For example, species like English holly and false brome (see "Scientific and Common Plant Names") have been rapidly increasing in abundance in western Oregon. Most species tend to be associated with young, recently disturbed stands (Gray 2005), although the two species mentioned above are good examples of those well suited to shady, undisturbed forests. Although FIA's Phase 3 vegetation inventory provides sufficient comprehensive information on species composition to inform national indicators, the plot density is too low to assess distribution of individual species. The FIA phase 2 sample does provide that information for species that are readily identifiable, and potentially for others of specific interest if crews are given dedicated identification training.

Invasive Plants Tables in Appendix 2

Table 24—Index of vascular plant species richness on forest land, by ecological section, Oregon, 2005

Table 48—Estimated area of forest land covered by selected nonnative vascular plant species and number of sample plots, by life form and species, Oregon, 2001–2005

Air Quality[4]

Air quality in many of Oregon's forests is fair to excellent, better than in many other parts of the country. Still, evidence of degraded air quality has been detected in some forests of the Columbia Gorge National Scenic Area (Fenn et al. 2007) and the Willamette Valley, and in those near major urban areas such as Portland and Medford (Eilers et al. 1994, Geiser and Neitlich 2007). Air quality effects on vegetation depend on many factors; among the most important are plant life stage, species, pollutants, site conditions, and degree of exposure. Effects commonly culminate in declines in stand productivity and shifts in community composition when sensitive individuals are damaged or killed. Changes can cascade through the ecosystem, especially if the affected species provide sustenance or habitat for wildlife or other important ecosystem services.

The FIA Program monitors two phase 3 indicators for air quality: (1) injury to ozone (O_3)-sensitive plants (fig. 70), and (2) the composition of epiphytic (i.e., tree-dwelling) lichen communities (fig. 71). Instruments that directly measure air pollutants are sparsely distributed in Oregon's forests (DEQ 2005). Thus, air quality monitoring with indicator species is indispensable, allowing for a spatially comprehensive assessment of risks to forest health across the landscape.

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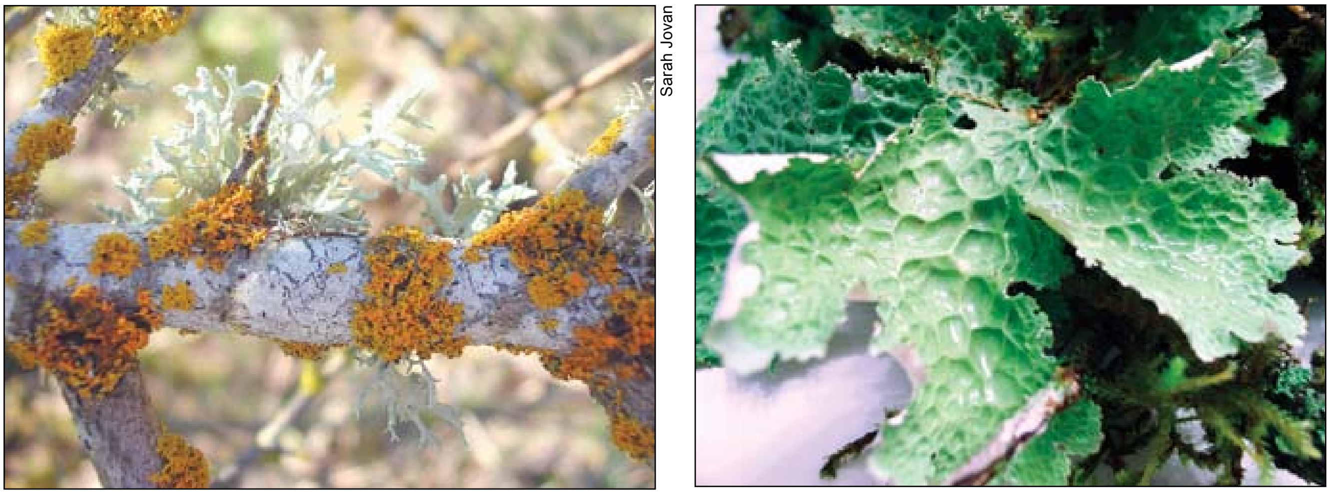
[4] Authors: Sarah Jovan and Sally Campbell.

Sally Campbell

Figure 70—Ozone injury (chlorotic mottle) on Jeffrey pine needles, Columbia Gorge biosite.



Sarah Jovan

Eric Straley

Figure 71—Lichens are well known for their high sensitivity to air quality. Bright orange *Xanthoria polycarpa* (left) is a common indicator of nitrogen pollution in Oregon. *Lobaria oregana* (right) is a typical indicator of clean air.

Ozone Injury Background

Tropospheric (ground-level) O_3 is highly toxic to plants and is considered an important ecological threat to Oregon's forest resources (Eilers et al. 1994). For the FIA O_3 indicator, three or more plant species known for their O_3 susceptibility (bioindicators) are scored for foliar injury at each O_3 plot (biosite). Injury data are combined into a biosite index that is used to predict local potential for O_3 damage (Coulston et al. 2003). Using geospatial interpolation of biosite indices averaged over a number of years, we can predict relative risk to susceptible forest vegetation across a broader geographic area and identify areas where O_3 is more likely to cause injury (Coulston et al. 2003). The FIA biosite network is the only statewide O_3 detection program that uses bioindicators to monitor O_3 impacts to forest vegetation.

Ozone Injury Findings

In contrast to widespread O_3 injury detected on California biosites, no O_3 injury was found on Oregon biosites visited between 2000 and 2005 (fig. 72). This finding is consistent with low measurements from ambient O_3 sampling networks (fig. 73) (DEQ 2005, Eilers et al. 1994). However, at one Washington biosite in the Columbia Gorge about 100 miles east of Portland, planted Jeffrey pine has shown injury 5 of the last 6 years, indicating that phytotoxic O_3 levels are present (Campbell et al. 2007). An assessment of risk using the geospatial interpolation method mentioned above shows very low or no risk to Oregon's forests from O_3.

Ozone Injury Interpretation

All of Oregon's air basins currently meet the national standards for O_3, although projected population increases are expected to result in higher pollutant emissions (DEQ 2005). It is hoped that continued efforts and innovations to abate vehicular and industrial emissions will sustain low O_3 levels. Because the entire biosite network is fully resampled each year, the FIA O_3 indicator will allow us to easily track temporal and geographic fluctuations in O_3 injury.

Lichen Community Background

For the lichen community indicator, surveyors determine the abundance and diversity of epiphytic lichens on phase 3 plots. The FIA Program uses these data for monitoring air quality as well as forest biodiversity (see "Lichen and Plant Biodiversity" section in "Forest Structure and Function" chapter) and climate change (Jovan 2008). With the help of multivariate models, FIA lichen data are used to score air quality at each plot. Two models are used to monitor Oregon's forests: one each for the west and east

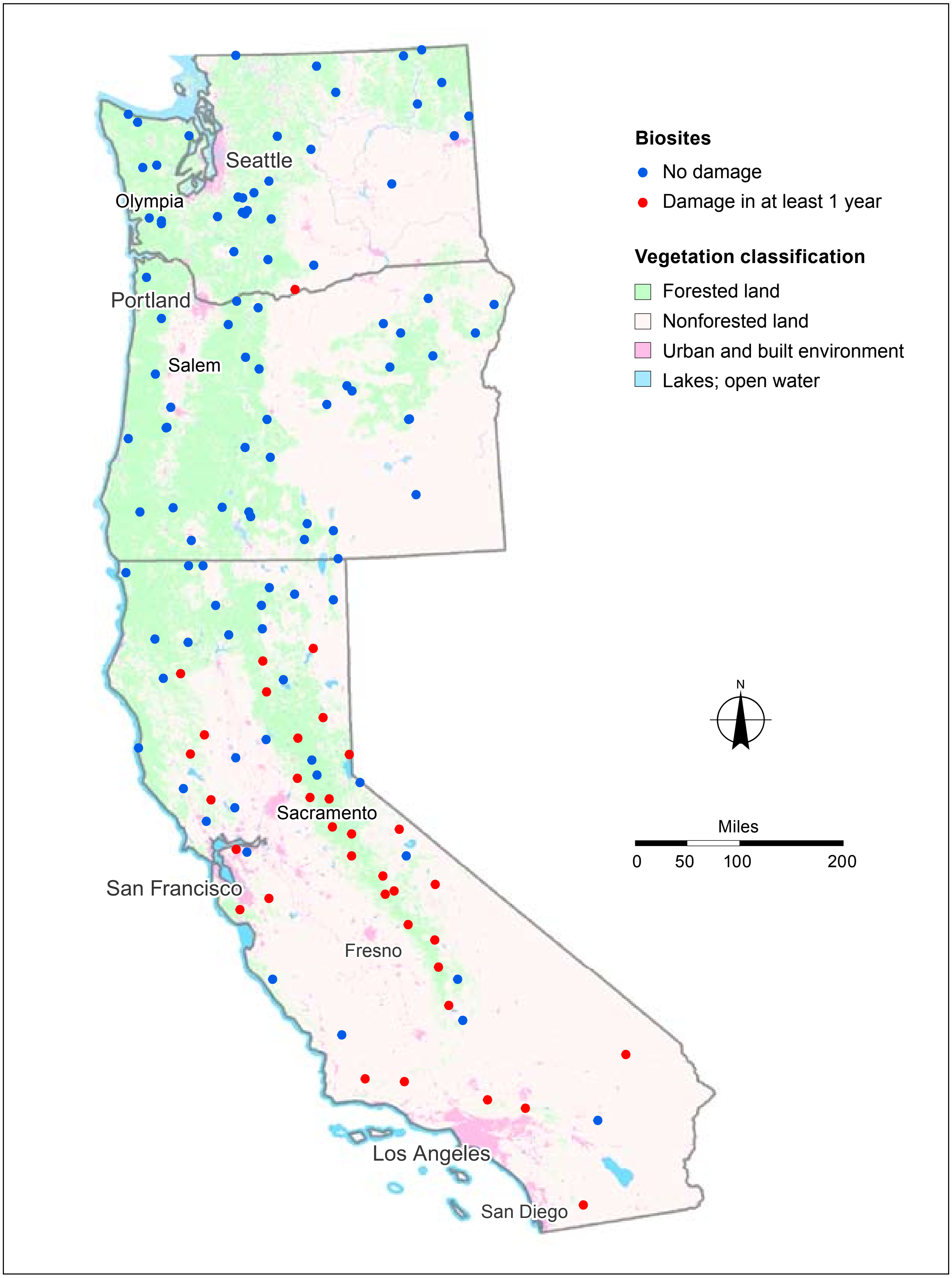


Figure 72—Forest Inventory and Analysis ozone biosites and injury status for forests in Washington, Oregon, and California, 2000–2005 (forest/nonforest geographic information system (GIS) layer: Blackard et al. 2008; urban/water GIS layer: Homer et al. 2004).

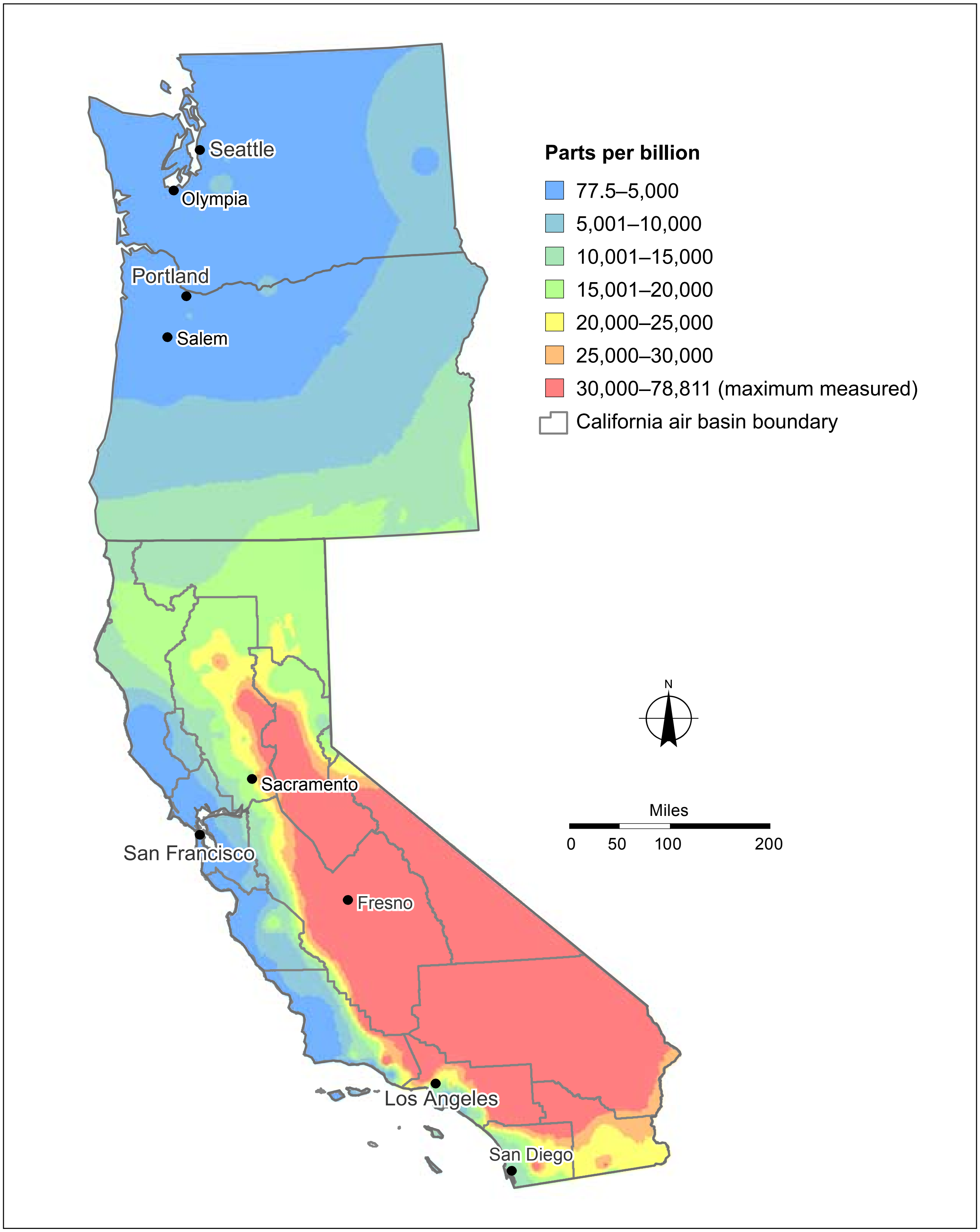


Figure 73—Average ozone exposure in Washington, Oregon, and California, based on cumulative hourly ozone concentrations exceeding 60 parts per billion (SUM60) June 1 to August 31, 8am to 8pm, 2001 to 2005 average (SUM60 ozone data: U.S. Environmental Protection Agency 2006).

sides of the Cascades. The west-side model, as reported here, was developed by Geiser and Neitlich (2007) in collaboration with FIA and the Forest Service's PNW Region, Air Resource Program.

Low air pollution scores suggest lower levels of pollutants and vice-versa. Geiser and Neitlich (2007) made their assessment by (1) examining the distribution of lichen indicator species across plots, (2) laboratory analysis of nitrogen (N) and sulfur (S) accumulation in collected lichens, (3) correlations of scores to pollutant measurements collected at a subset of plots, and (4) land use patterns. Air quality scores are used to delineate six air quality zones, best, good, fair, degraded, poor, and worst.

Lichen Community Findings

Results from 5 years of surveys (1998–2001 and 2003) provide strong evidence that N pollution is having a heavy impact on some west-side forests. Diverse assemblages of pollution-sensitive lichens characterized low-scoring plots, and species that indicate high N levels, known as nitrophytes (fig. 71), were relatively abundant at high-scoring plots (fig. 74). The presence of these lichen communities suggests that the Willamette Valley, much of which is in agricultural or urban land use, is part of a major N hotspot that extends into foothill forests of the Coast and Cascade ranges.

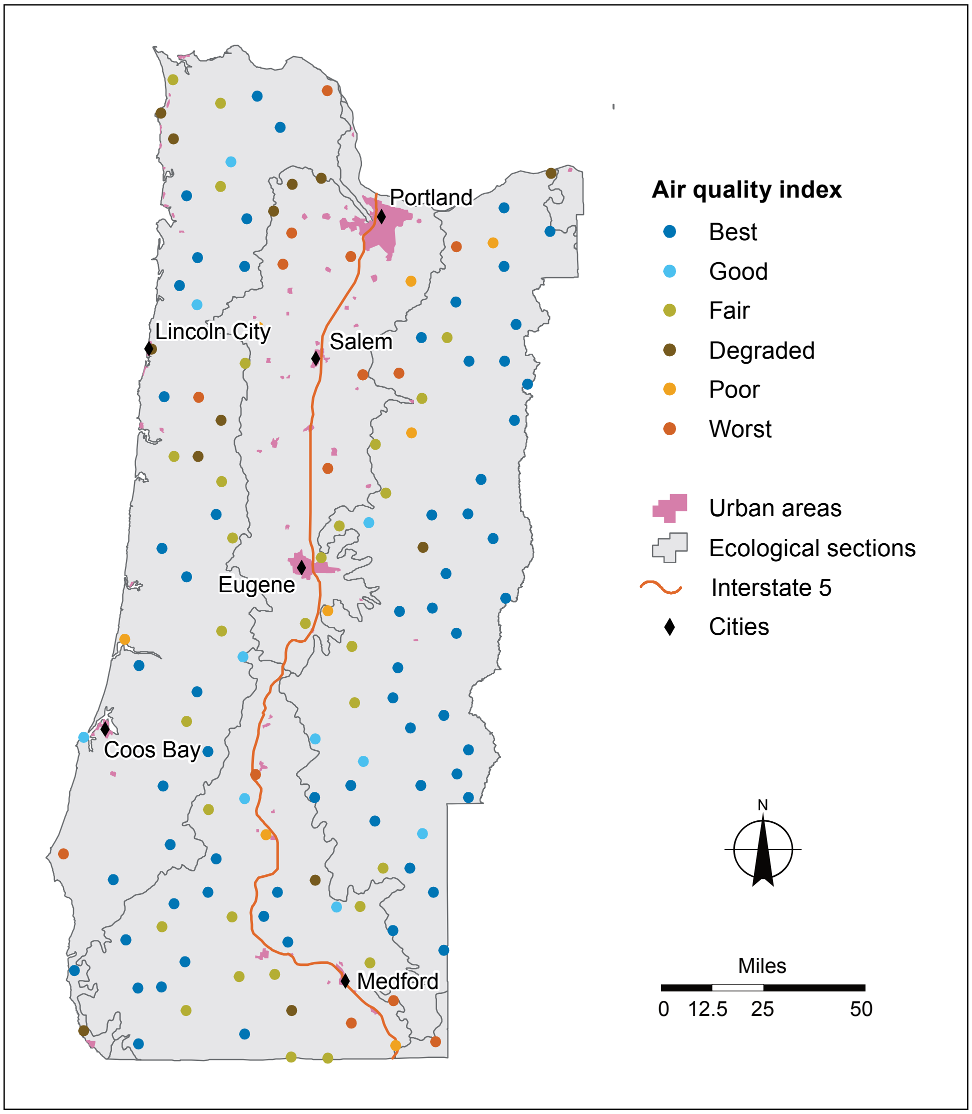


Figure 74—Air quality scores (Geiser and Neitlich 2007) on forest land plots in western Oregon, 1998–2001, 2003 (ecosection geographic information system (GIS) layer: Cleland et al. 2005, urban GIS layer: U.S. Geological Survey 2001).

A deterioration in air quality owing to N was also detected on both the Oregon and Washington sides of the Columbia River Gorge, a phenomenon well-documented by Fenn et al. (2007). Poor-scoring sites south of the Willamette Valley tend to lie near the Interstate-5 corridor. Otherwise, air quality at most sites in the Western Cascades, Klamath Mountains, and Coast Range is rated as "fair," "good," or "best."

Lichen Community Interpretation

Beyond degrading air quality, the ecological and economic impacts of excessive N pose an increasing concern for terrestrial and aquatic ecosystems in the Pacific Northwest. In addition to promoting a nitrophytic lichen flora, N pollution can cause accelerated accumulation of fuels, soil acidification, shifts in plant communities, and a decline in mycorrhizal fungi (Fenn et al. 2003). Remeasurement of lichen communities beginning in 2009 will allow FIA to track changes in N as well as the proliferation of other ecologically harmful pollutants. More elaborate discussion of lichens and Oregon's air quality may be found in Geiser and Neitlich (2007) and Jovan (2008), and at the Forest Service PNW Region lichen-air quality Web page: http://www.fs.fed.us/r6/aq/lichen/.

Air Quality Tables in Appendix 2

Table 49—Summary of Forest Inventory and Analysis plots sampled for lichen community, air quality index information, western Pacific Northwest and western Oregon, 1998–2001, 2003

Table 50—Summary of Forest Inventory and Analysis plots sampled for lichen community, climate index information, western Pacific Northwest and western Oregon, 1998–2001, 2003

Table 51—Ozone injury summary information from ozone biomonitoring plots, by year, Oregon, 2000–2005

Crown Fire Hazard[5]

Background

Reduction of wildfire hazard has emerged as a priority issue in Oregon, where fuel treatments are proposed on an unprecedented scale. Characterization of fire hazard typically focuses on crown fire potential—the tendency of a forest stand to experience crown rather than surface fire—because crown fires are typically stand-replacing events and often are regarded as highly destructive (fig. 75). Before an effective fuel treatment program can be developed, it is essential to know initial hazard levels and identify where hazard reduction is most technically, economically, and socially feasible (see, for example, Barbour et al. 2008; Vogt et al. 2005). The FIA inventory provides an unprecedented opportunity to assess the extent of crown fire hazard across all land ownerships, ecosection groups[6] and forest types. Examining these statistics on a proportional basis, by forest type and geographic distribution, provides key insights into factors associated with high crown fire hazard.

All plots with forest[7] were simulated with the Forest Vegetation Simulator (FVS) and its Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003) to calculate indices of crown fire potential and fire type under severe fire weather. Each inventory plot was assigned to the appropriate FVS variant by geographic information system (GIS) overlay with the FVS variant map (USDA Forest Service 2007a). Other than the tree height, canopy bulk density, and canopy base height crown fuel parameters, which were

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[5] Authors: Jeremy Fried and Glenn Christensen.

[6] Ecosection groupings (see fig. 5 in "Introduction"): Coast/West Cascades—Oregon Coast Range and Western Cascades; Southwest/Eastern Cascades—Southern Cascades, Eastern Cascades, and Klamath Mountains; Eastern Oregon—Palouse Prairie, Norwestern Basin and Range, Owyhee Uplands, Snake River Basalts and Basins, Blue Mountain Foothills, Columbia Basin, and Blue Mountains.

[7] FVS-FFE was applied to all conditions classified as forested on the ground. Though classified as forested, sometimes by field crews considering areas of the condition outside of the plot footprint, some conditions contained few or no trees on the plot, such that stand attributes the model uses to estimate crown fire potential (for example, canopy bulk density, height to canopy base) cannot be calculated reliably. FFE assumes that sparsely forested conditions have a surface fire regime, which may or may not be true depending on stand structure in the remainder of the condition (outside the plot footprint).

Don Gedney

Don Gedney

Figure 75—Stands within the Biscuit Fire in southwest Oregon experienced a variety of fire regimes, including mixed-severity with both surface and crown fire (top) and severe crown fire with 100-percent tree mortality (bottom).

derived from the tree-level data collected by FIA, fuel (e.g., surface fuel model) and weather (e.g., windspeed 20 feet above the ground) parameters were assigned default values.[8] Fire type was modeled using FFE as one of four classes (see tabulation below), and results were analyzed and mapped.[9]

Fire type	**Fire characteristics**
Surface	Only surface fuels on the forest floor burn.
Conditional	Existing crown fire will continue as a crown surface fire, but if canopy gaps interrupt its spread, it will convert to a surface fire and not reinitiate as a crown fire.
Passive	Some crowns will burn as individual trees, or groups of trees "torch," with fire climbing from the surface via ladders of dead branches and lesser vegetation.
Active	Fire moves through the tree crowns and reinitiates as a crown fire if canopy gaps interrupt its progress.

Findings

Patterns for the crown fire potential indices and fire type were similar, so for simplicity, only the fire type results are reported here. Under the modeled weather conditions, fire would likely occur as a surface fire on 59 percent of the forest statewide. Passive crown fire would likely occur on 31 percent of the forest, and active crown fire would be expected on only 9 percent. However, there is substantial regional variation—for example, active crown fires would be expected on about 5 percent of forests in the Southwest/Eastern Cascades ecosection group, and on about 15 percent of those in the Coast/West Cascades ecosection group (fig. 76). It is difficult to predict how these differences in potential hazard translate to events on the ground, because incidence of severe fire weather also differs among these regions.

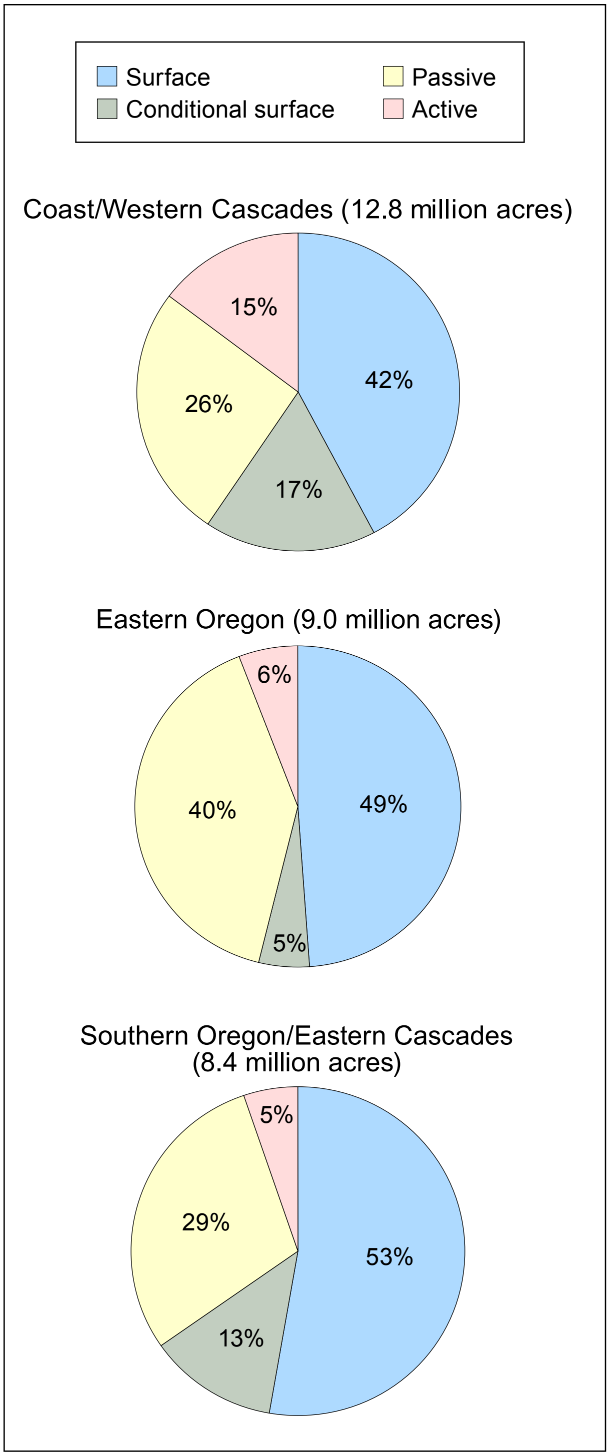

Figure 76—Percentage of forest land in each modeled fire type category by ecosection group in Oregon, 2001–2005.

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[8] Surface fuels were determined via lookup tables based on forest type. For the fire weather scenario, FFE default parameters were used such that 20-foot windspeed was set at 20 miles per hour, temperature at 70 degrees F; 1, 10, 100, and 1000 hour fuel moisture at 4, 4, 5, and 10 percent, respectively; duff fuel moisture at 15 percent, and live fuel moisture at 70 percent.

[9] To better visualize the geographic distribution of fire regimes, local kriging interpolation was performed on the ordinal variable, fire type, as if it were a ratio (continuous) variable. This produces a surface of crown fire potential from the plot data, with values ranging from 1 (surface fire) to 4 (active crown fire).

Moreover, incidence of crown fire appears to differ by forest type. Among the four most prevalent coniferous forest type groups, Douglas-fir and fir/spruce/hemlock have the highest incidence of active crown fire, and ponderosa pine and lodgepole pine the lowest (fig. 77). This is probably because Douglas-fir and fir/spruce/hemlock forests have denser canopies and are more likely to contain ladder fuels. However, passive crown fire is more common than active crown fire in all four forest type groups, and does not appear to differ much among forest types. Fire regime also appears to differ by ownership (fig. 78), with state-owned lands predicted to have the highest percentage of forests in which surface fire would be expected (76 percent in surface or conditional surface) and other federal lands having the lowest (49 percent). Such differences could be due to differences in management, but may also be traced to differences in age class structure, forest type, and stand history.

The geographic distribution of likely fire type consistently indicates a concentration of elevated crown fire potential in forests of the Western Cascades. Other patterns are difficult to decipher, although the substantial area of likely surface fire regimes in southwest Oregon could reflect the sizeable component of evergreen hardwoods there (which moderate crown fire potential as represented in the models) (fig. 79). Research into these patterns, their significance, and the lessons that can be learned from them is underway.

Interpretation

These data paint a different picture of fire hazard and fuel treatment opportunity than do certain commonly used maps of fire regime condition class (Hardy et al. 1999; Schmidt et al. 2002). These maps depict most of the area in at least some ecosection groups (notably Southwest/East Cascades)

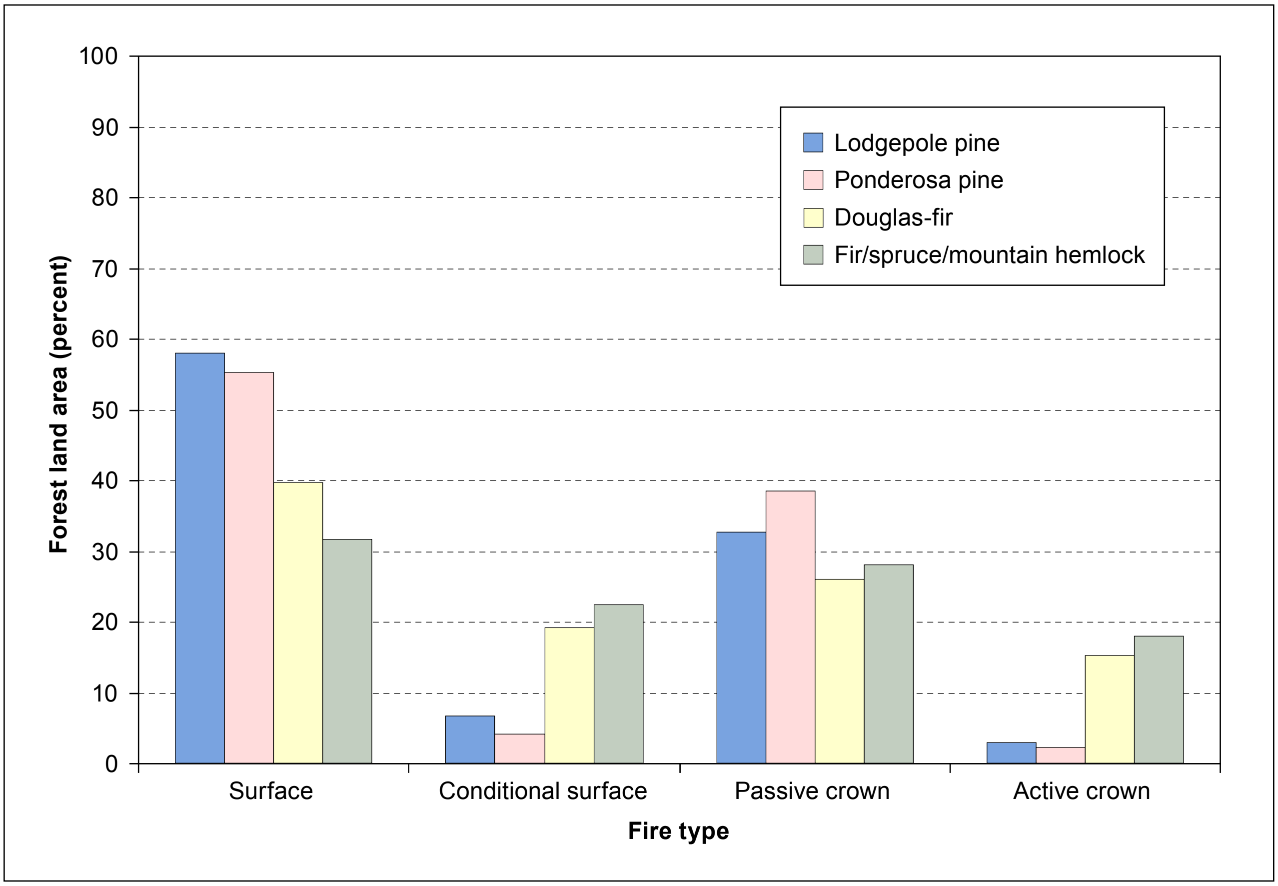

Figure 77—Percentage of forest land in each of the four most prevalent coniferous forest type groups in each modeled fire type class in Oregon, 2001–2005.

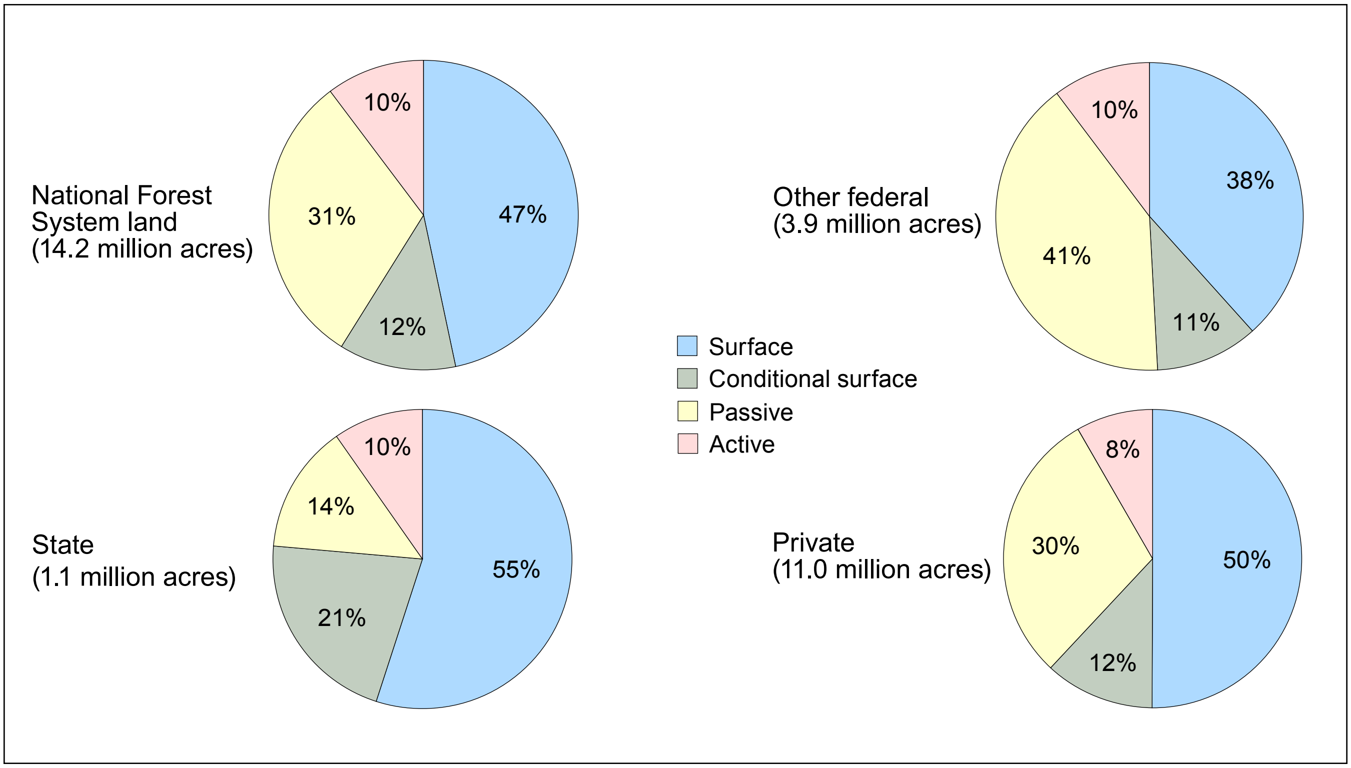

Figure 78—Percentage of forest land in each modeled fire type category by ownership group in Oregon, 2001–2005.

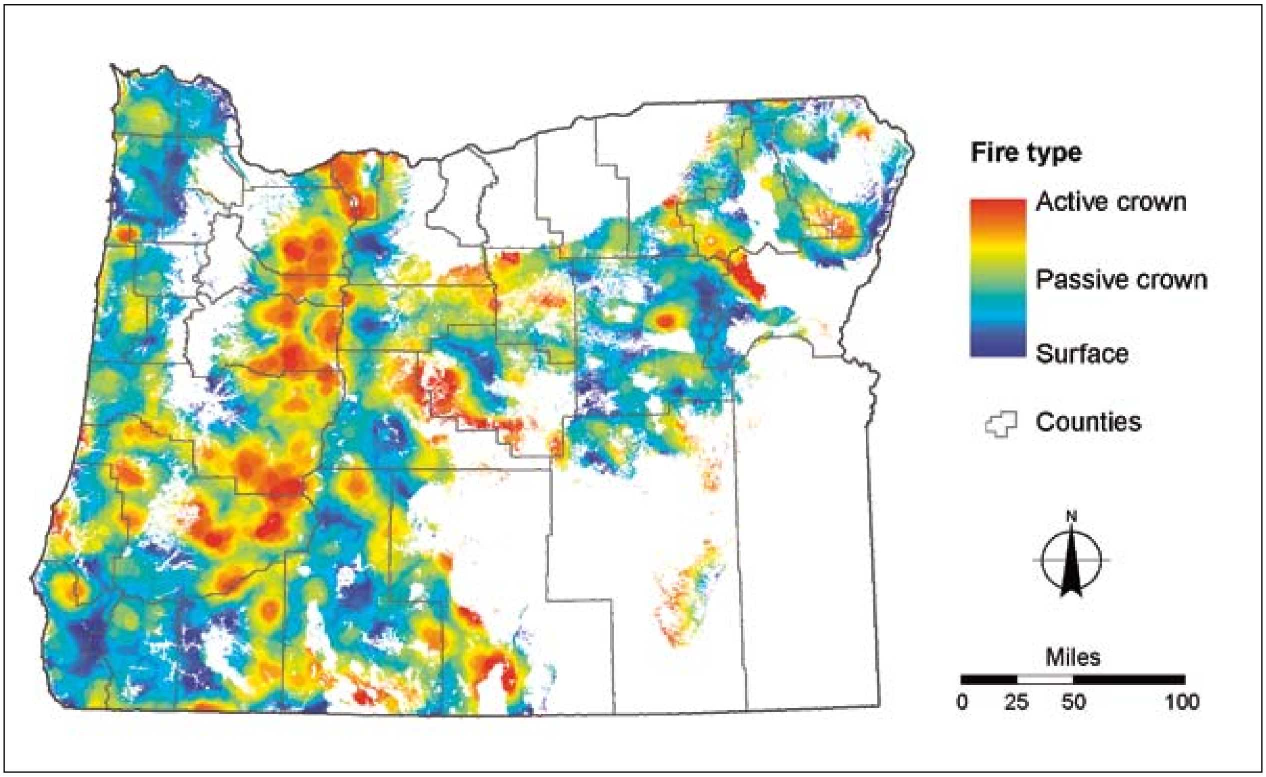

Figure 79—Predicted likely fire type in forested areas using kriging as a modeling method.

as having significantly departed from historical fire regimes and, by implication, as being in urgent need of intervention to reduce fire hazard. Under the fire weather assumed for this analysis, less than half the forested lands are predicted to develop crown fires, and an even smaller fraction, 5 to 15 percent, can be expected to develop active crown fire. Although crown-fire potential models such as FFE have yet to be rigorously validated against behavior of actual fires, many fire managers regard them as suitable for "ballpark" predictions of what is likely to occur.

These results have implications both for the scope of fuel treatment programs and for the challenges that firefighters will face. In the context of firefighting, building a fire line that disrupts the continuity of surface fuels can be effective in stopping fire spread in areas prone to surface fires. In areas where crown fire, if it occurs, is likely to be passive, trees will torch individually, and most trees may die. On those more limited areas where active crown fire is likely to occur, a far more labor- and time-intensive job of linebuilding to remove standing trees would be required for fire containment efforts to be successful.

From the standpoint of implementing fuel treatments, these results suggest that only a fraction of the forested landscape is likely to benefit from fuel treatment if the objective is to reduce crown fire hazard. Given that spatial analyses of fuel treatments has demonstrated that treating a small percentage of the landscape can reduce landscape-scale fire hazard significantly and sometimes cost-effectively (Finney 2001), these results suggest that the fuels management challenge may be more tractable than has been assumed.

Fire Incidence[10]

Background

All forest types in Oregon have the potential to experience crown or surface fire, although fire incidence differs considerably by region and forest type. State and federal agencies estimate the size of all wildland fires and some prescribed fires, map the perimeters of larger fires, and calculate statistics on fire incidence for the lands for which they have protection responsibility. Agencies' fire incidence reports seldom specify the vegetation type that was burned, and in addition, different agencies use different reporting thresholds. Therefore, reliable and consistent estimates of annual burned area across all ownership classes are lacking. The FIA field crews record evidence of surface and crown fire that occurred since the previous plot visit (usually 5 to 10 years) (fig. 80), making it possible to estimate both the average forest area burned per year and the average percentage of forest burned per year.

Findings

We estimate that over the decade 1995–2004, more than 155,000 acres of forest burned statewide per year (range 49,000 to 575,000). No clear trends in area burned were observed. This average represents 0.51 percent of total forest land in Oregon, but year-to-year variability was considerable (fig. 81), ranging from 1.90 percent of forest area burned in 2002 to zero percent in 2004. Regional variability also was high; the average annual percentage of burned forest ranged from 0.11 percent in the Coast/West Cascades ecosection group to 0.95 percent in the Southwest/East Cascades ecosection group[11] (fig. 6).

The following tabulation shows the mean and standard error for the percentage of Oregon forest land area burned, by region from 1995 to 2004:

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[10] Authors: Jeremy Fried and Glenn Christensen.

[11] Ecosection groupings (see Ecosection level map in "Introduction"): Coast/West Cascades—Oregon Coast Range and Western Cascades; Southwest/Eastern Cascades—Southern Cascades, Eastern Cascades, and Klamath Mountains; Eastern Oregon—Palouse Prairie, Northwestern Basin and Range, Owyhee Uplands, Snake River Basalts and Basins, Blue Mountain Foothills, Columbia Basin, and Blue Mountains.

Figure 80—Evidence of fire recorded by field crews can be the result of prescribed burns, as shown here, or naturally caused fires.

Region	**Percent**	**Standard error**
Coast/West Cascades	0.11	0.04
Southwest/Eastern Cascades	.95	.14
Eastern Oregon	.68	.10
All areas	.51	.05

The estimate of 155,000 acres per year of burned forest compares favorably with data derived from databases of fire incidents for all agencies maintained by the Bureau of Land Management. Calculations from these data put the 10-year average burned area in Oregon for this period at just under 274,000.[12] These and other interagency fire databases are concerned with causes of the fire and the ownership of the acres burned, not the vegetation within the fires, and thus much of the area accounted for by these statistics is covered in flammable vegetation not classified as forest. Because FIA does not collect a complete ground-based sample of nonforest lands, it is not possible to estimate directly from FIA plot data the area burned in nonforest vegetation types.

Caveats

Because fire is a relatively rare event, the number of plots where recent fire is observed is small, and therefore, standard errors on estimates of area burned are large. Generating estimates for subsets of the forest land base (e.g., ownership classes, particular forest types) is impractical

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[12] Fitzpatrick, M. 2007. Personal communication. Predictive Services Support Staff, NW Coordination Center, Bureau of Land Management, 333 Southwest First Ave., Portland, OR 97204.

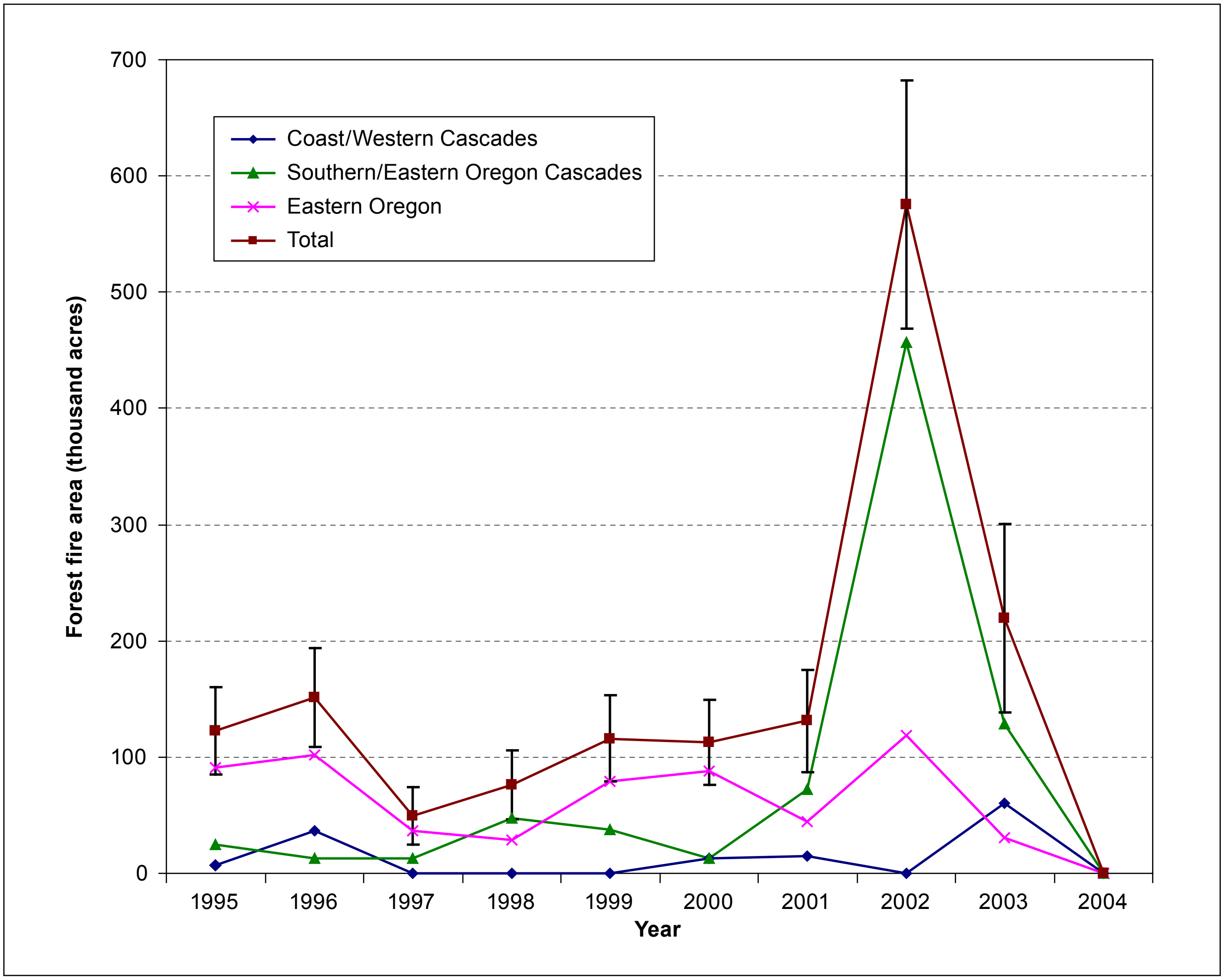

Figure 81—Area of forest fire by ecosection group on forest land in Oregon, 1995–2003.

because of the small sample, inconsistent differentiation of fire type (e.g., surface vs. crown) and origin (e.g., prescribed vs. wildfire), and because field crews did not usually have the training to assess a severity level. For those reasons, all acres observed to have been burned were pooled for this analysis.

However, we have no reason to believe that these estimates are any less accurate than those based on available agency databases. Most fire incident databases have numerous fire reports that do not have information on the area burned, some have large discrepancies between reported sizes and the geographic information system (GIS)-calculated area, and they differ in the size thresholds of fires included. They also generally do not track acres by vegetation type, making it impossible to analyze burned area by forest type. These common problems suggest that users who rely on such databases may unknowingly under- or overestimate actual area burned.

Interpretation

The high year-to-year variability in wildfire incidence and extent makes it impossible to assess whether there is an increasing trend in forest area burned over the past 10 years. Even so, increased media attention to wildfires and a perception among land managers of the need for managing wildland fuels more actively may be generating the impression that the area burned is increasing.

We lack landscape-scale historical or paleoecological data to compare with today's average annual rate of 0.51 percent of forest land burned. Thus we cannot determine whether this rate represents a departure from historical rates. It is also likely that the distribution of acres burned among severity classes and forest types is changing with climatic fluctuations, but our inventory is not designed to detect such changes efficiently.

Fire Incidence Tables in Appendix 2

Table 52—Total acres of forest land with a forest fire incident, by year and ecosection group, Oregon, 1995–2004

The Biscuit Fire[13]

The 2002 Oregon fire season was one of the worst in recorded history. Total fire perimeters encompassed over 900,000 acres, including almost 500,000 in the Biscuit Fire alone (fig. 82). Statewide suppression costs exceeded $150 million. In the aftermath of the Biscuit Fire, a debate continues about salvage logging, artificial regeneration, and riparian issues in the Biscuit area. Divergent conclusions offered by Sessions et al. (2003 and 2004) and Donato et al. (2006) highlight the arguments for and against salvage logging and artificial regeneration.

David Azuma

Figure 82—Burned-over stand, Biscuit Fire 2002.

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[13] Author: David Azuma.

Additional work by Reeves et al. (2006) discussed the impacts of postfire logging in riparian areas.

To assess forest type areas and wood volumes associated with different burn severities within the Biscuit Fire, Azuma et al. (2004a) overlaid FIA data from the late 1990s onto a burn-severity map developed by the multiagency postfire Burn Area Emergency Rehabilitation (BAER) program (Parsons and Orlemann 2002). We looked particularly at the relationships among burn severity, site productivity, forest type, and size class over the sample area, which consisted of both wilderness and nonreserved land.

In general, we found that most of the sampled area (63 percent) had experienced burns of low or very low severity, that less-productive areas had experienced the most severe burns, and that stands of big trees (both hardwood and softwood types) had burned less severely than stands of smaller trees.

Nearly 70 percent of the sampled area was classified as softwood forest types. These areas were dominated by Douglas-fir, which occurred on more than 44 percent of the area and accounted for 71 percent of the prefire board feet volume across all forest types. Douglas-fir forest types burned less severely than most other softwood forest types, with less than 35 percent of the area classified as high or moderate burn severity.

More than three-quarters (76 percent) of the area of very large trees (>20 inches d.b.h.) of both hardwood and softwood forest types burned at low or very low severity. Fifty-five percent of the softwood area and 82 percent of the hardwood area burned at low or very low severity. More than 94 percent of the tanoak area burned at low or very low severity.

Sites that mostly experienced highly or moderately severe fire tended to be of lower site productivity and had lower stand volumes, more brush, and less large-diameter woody debris before the fire compared to areas of higher productivity. Almost 45 percent of the sampled area was classified as low productivity, suggesting that artificial regeneration in these areas would be expensive and achieve limited success.

To validate the Azuma et al. (2004a) work, FIA conducted a postfire remeasurement of 180 plots within the Biscuit Fire perimeter. Initial results confirm the prior FIA overlay and severity ratings from the BAER map. When completed, this study will link pre- and postfire stand conditions, fire weather, fire severity, recovery, and fire impacts.

The PNW-FIA Program has also implemented the pre- and postfire assessment protocol for other large fires in connection with the 2003 McNally and 2006 Day Fires in California and the 2003 B&B Fire in central Oregon. This effort is building a unique research database covering a wide range of forest types, prefire stand structures, and fire severities that will prove useful in addressing the links among prefire stand conditions, severity, and postfire impacts.

FIA BioSum[14]

Background

Land managers who are contemplating the implementation of legislation like the Healthy Forests Restoration Act of 2002 understand that mechanical fuel treatments have the potential to produce large quantities of wood that is unmerchantable as sawtimber. Conventional wisdom suggests that effective treatments require the removal of large numbers of small stems at considerable cost, and that this harvested material has little or no value.

One widely considered approach to this perceived problem is to develop forest bioenergy production facilities that simultaneously generate renewable energy and increase employment opportunities in rural areas. Scientists at PNW-FIA developed an analytical system, FIA BioSum (Forest Inventory and Analysis Biomass Summarization), to guide investors seeking to exploit such opportunities and land managers seeking to attract such investment. This system can evaluate a multitude of fuel treatment prescriptions and assess their economic feasibility in terms of modeled harvest yields and costs, haul costs, and product values, and it also can model the achieved reduction in fire hazard.

The FIA BioSum system integrates data and simulation programs, using linked spatial and relational databases, into a geographically explicit analytical framework for summarizing potential biomass production from fuel treatments (Daugherty and Fried 2007; Fried 2003; Fried et al. 2003, 2005; Fried and Christensen 2004). The system relies on publicly available data (for example, inventory plots and GIS layers representing roads, existing wood-processing facilities, and land ownership) and off-the-shelf computer simulators. The simulators apply stand prescriptions, assess fire hazard, and evaluate fuel treatment costs via joint optimization of treatments and processing facility siting. The system requires many assumptions about acres eligible for treatment, logging and haul costs, product prices, and fuel-treatment prescription options. Some of these inputs must be developed in consultation with local experts in fire, fuels, silviculture, and logging.

Findings

The FIA BioSum system was applied to a 28-million-acre, mostly forested landscape spanning four ecosections in central and southern Oregon and northern California (fig. 83). As shown below, when the model is set to maximize net revenue, FIA BioSum suggests this area can produce $5.9 to $8.9 billion in net revenue through the treatment of 2.8 to 8.1 million acres, depending on how the problem is constrained. About 61 million to 124 million green tons of woody biomass would be recovered for power generation, sufficient to operate a network of bioenergy plants with a combined capacity of 496 to 1009 megawatts over a 10-year period. In these scenarios, estimated production potential for merchantable wood products ranges from 8.3 to 12.4 billion cubic feet, almost all from the harvest of trees larger than 12 inches d.b.h. (the threshold size determined by modeling for effectiveness in reducing crown fire hazard). Results of the modeling depend on the level of treatment effectiveness required and on whether all eligible acres are treated (which would entail subsidy on some acres) or only those that contribute profit to the enterprise. See the tabulation on page 82.

We evaluated a range of power-generating capacities and conversion efficiencies to assess the tradeoffs of building lower versus higher capacity plants; these included increased hauling costs for transporting wood chips longer distances to reach a higher capacity plant. Results suggest that unless small-capacity (<15 mW) facilities achieve efficiencies near to those of large capacity facilities (at least 90 percent of the efficiency of big plants), they do not represent a viable alternative

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[14] Authors: Jeremy Fried and Glenn Christensen.

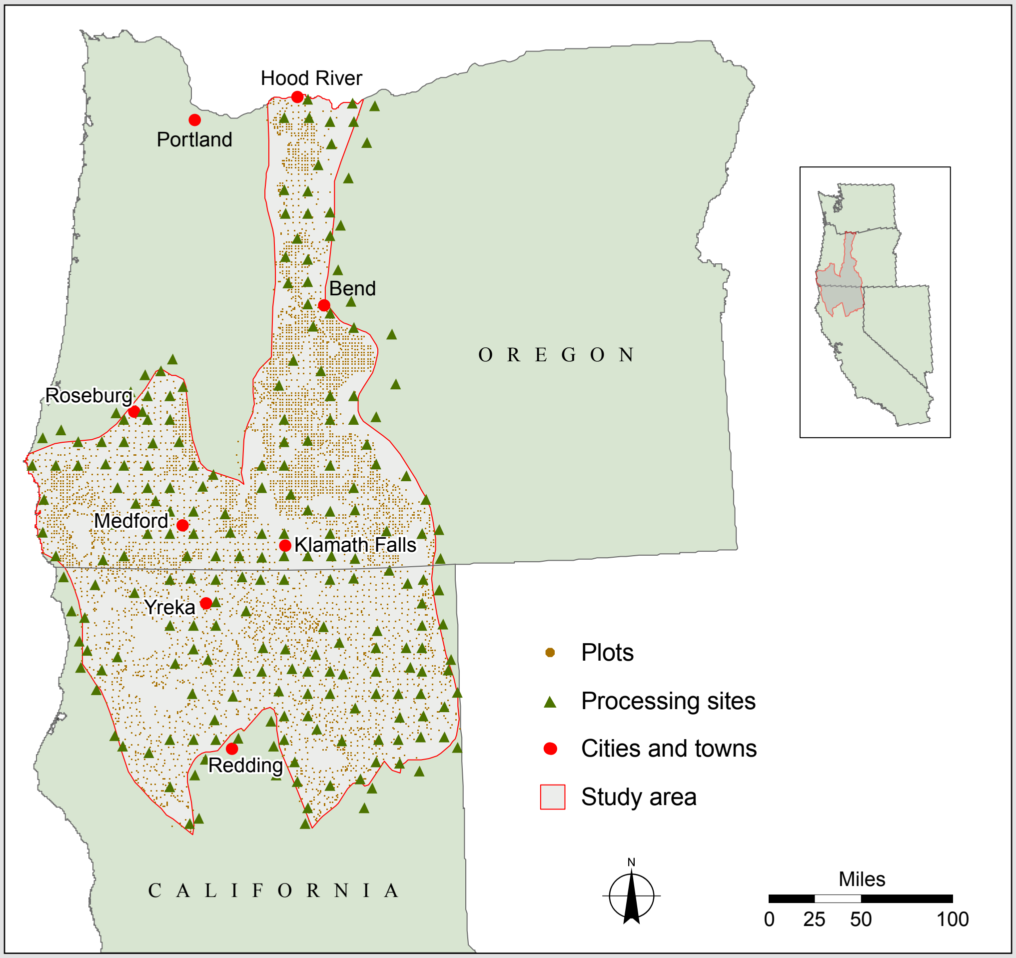

Figure 83—Oregon/California BioSum study area showing locations of inventory plots, sites evaluated as potential power-generating facilities, and major cities.

	Scenario			
	1	2	3	4
Constraint on acres treated [a]	Any	All	Any	All
Constraint on effectiveness [b]	Moderate/high	Moderate/high	High	High
Net revenue (billion dollars)	8.94	6.65	7.15	5.88
Merchantable net revenue (billion dollars) [c]	7.71	4.74	6.24	4.61
Biomass net revenue (billion dollars) [c]	1.23	1.92	0.91	1.27
Merchantable volume (billion ft^3)	10.93	12.41	8.35	9.22
Delivered biomass (million green tons)	81.21	123.87	60.92	84.40
Area treated (million acres)	4.49	8.12	2.84	4.05
Highly effective area treated (million acres)	2.53	3.21	2.84	4.05
Number of facilities	31	47	23	30
Bioenergy capacity (megawatts)	661	1009	496	688

[a] "Any" allows the model to select optimal number of acres to treat; "all" requires treatment of all acres that meet effectiveness constraint.

[b] Effectiveness refers to the set of effectiveness criteria applied. Moderate effectiveness requires a modeled improvement in resistance to active crown fire; high effectiveness requires modeled improvement in resistance to both active and passive crown fire. These criteria limit the number of acres considered in analysis; under the high constraint, only high-effectiveness acres are eligible for treatment.

[c] On-site treatment costs are only deducted from merchantable gross revenue. Biomass net revenue equals delivered value net of haul costs.

given the large amount of biomass removed. The locations selected by the optimization model as the best places to build bioenergy facilities were comparatively insensitive to capacity constraints. Locations that were selected when minimum electrical generation capacity was set high were a subset of those selected when the minimum capacity constraint was set low, lending support to the idea that some places in the forested landscape are inherently well-suited for bioenergy facilities under a variety of potential wood supply and energy pricing scenarios by virtue of their location on the transportation network relative to where fuel treatments would occur.

The FIA BioSum framework provides a statistically representative foundation for assessing the opportunities to use "waste" from fuel treatments to expand capacity for generating bioenergy (fig. 84). However, results of these optimizations should not be the only basis for a decision to develop a fuel-treatment program. Decisionmakers will also need to factor in the nonmarket benefits and costs of fuel reduction, the various resource goals among landowners and management agencies that are unrelated to fuel, and the reluctance of investors to commit capital without a reasonable expectation of sufficient fuel supply. Nevertheless, FIA BioSum does provide a starting point and a tool for further analysis.

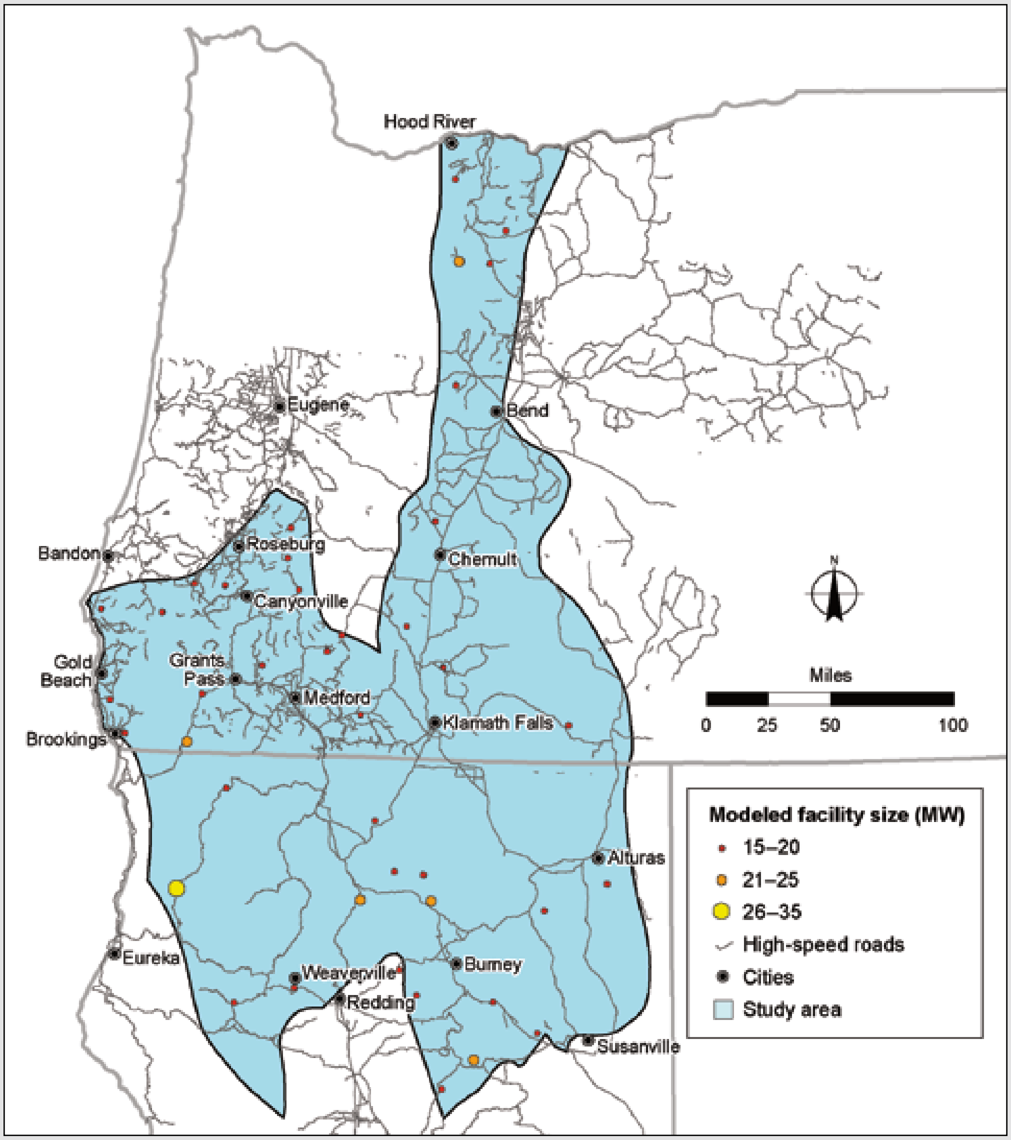

Figure 84—Model-recommended locations for forest bioenergy production facilities, with minimum 5-megawatt (MW) capacity, and high-speed road network.

Go to Part C