USDA United States Department of Agriculture

Oregon's Forest Resources, 2006–2015: Ten-Year Forest Inventory and Analysis Report

Forest Service

Pacific Northwest Research Station

General Technical Report PNW-GTR-971

October 2018

Technical Editors

Marin Palmer and **Glenn Christensen** are foresters and **Olaf Kuegler** is a statistician, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 620 SW Main Street, Suite 400, Portland, OR 97205.

Contributing Authors

John Chase is a geographic information system/remote sensing specialist, **Jeremy Fried** is a research forester, **Sarah Jovan** is a research ecologist, and **Katherine Mercer** is a forestry technician, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 620 SW Main Street, Suite 400, Portland, OR 97205. **Andrew Gray** is a research ecologist and **David M. Bell** is a research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331. **Sara Loreno** is a natural resource data scientist, Ecotrust, 721 NW 9th Avenue #200, Portland, OR 97209. **Todd Morgan** is director of the Bureau of Business and Economic Research, University of Montana, Gallagher Business Building, 32 Campus Drive, Missoula, MT 59812.

Cover photo: The Imnaha River canyon with Douglas-fir and grand fir trees in foreground, Wallowa County, Oregon, 2017. Photo by J. Sprovkin.

Oregon's Forest Resources, 2006–2015: Ten-Year Forest Inventory and Analysis Report

Marin Palmer, Glenn Christensen, and Olaf Kuegler,
Technical Editors

Contributing authors: John Chase, Jeremy Fried, Sarah Jovan, Katherine Mercer, Andrew Gray, David M. Bell, Sara Loreno, and Todd Morgan

U.S. Department of Agriculture
Forest Service
Pacific Northwest Research Station
Portland, Oregon
General Technical Report PNW-GTR-971
October 2018

Abstract

Palmer, Marin; Kuegler, Olaf; Christensen, Glenn, tech. eds. 2018. Oregon's forest resources, 2006–2015: Ten-year Forest Inventory and Analysis report. Gen. Tech. Rep. PNW-GTR-971. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 54 p.

Oregon has 30 million forested acres that cover roughly half the state's land area. The Forest Inventory and Analysis (FIA) program reports on the status and trends of Oregon's forest resources, producing comprehensive updates every 5 years. This report provides detailed estimates of forest area, tree species composition and distribution, volume, biomass, carbon, standing dead trees and down wood, and understory vegetation on forest land for the state of Oregon based on the annual FIA forest land inventory through 2015. It also includes the first estimates of annual growth, mortality, and removals on forest land available from remeasured annual inventory plots, representing 50 percent of the full 10-year cycle. The FIA program collected inventory data on 9,439 forested plots during the 2006–2015 measurement cycle. Oregon has more than 10 billion live trees on forest land that collectively represent nearly 107 billion ft^3 of net volume or nearly 1 billion Mg of carbon. Three-fourths of this forest volume occurs on the moist west side of the state. Douglas-fir, Oregon's state tree, represents the majority of Oregon's softwood lumber production. More than one-third of the forested area and more than one-half of forest volume occurs in stands dominated by Douglas-fir trees.

Keywords: Biomass, carbon, dead wood, FIA, forest change, Forest Inventory and Analysis, forest land, inventory, timber volume, timberland, Oregon.

Summary

Key Forest Inventory and Analysis (FIA) Statistics, Oregon, 2006–2015

- Number of forested plots measured by the FIA program (2006–2015): 9,439
- Estimated total forest area: 29.7 million ac
- Estimated number of live trees: 10.3 billion
- Estimated net live tree volume: 106.9 billion ft^3
- Estimated aboveground net live biomass: 2.2 billion tons
- Estimated aboveground net live carbon: 975.6 million Mg

Contents

Background

What Is Forest Inventory and Analysis?

The Forest Inventory and Analysis (FIA) program of the U.S. Forest Service was created in 1928 to provide comprehensive information on the nation's forest resources necessary for economic and forest management planning. Forest inventories were conducted periodically in each state until the Agricultural Research, Extension, and Education Reform Act of 1998 (the Farm Bill) mandated a nationally consistent methodology in which a portion of all plots in each state were measured each year. States in the Pacific Northwest Forest Inventory and Analysis (PNW-FIA) unit are on a 10-year measurement cycle.

How Does FIA Define a Forest?

The FIA collects data only in forested areas; therefore, the definition used for forest land affects the estimates produced in each inventory year. The FIA program defines a forest as currently or formerly (within 30 years) at least 10 percent canopy cover of trees of any size and not currently developed for nonforest use. Forests must be at least 1 ac in size where a minimum width of 120 ft is maintained. Prior to 2013, the FIA program used stocking tables to define forest based on a minimum of 10-percent stocking rather than canopy cover. This procedural change affects a small percentage of sampled plots, and estimates of forest land area-change between 2001–2005 and 2011–2015 have been adjusted to consistently use the current definition. The PNW-FIA collected information on forested lands using both definitions to allow calibration between estimates.

What are the differences between timberland, other forest land, and reserved forest land? —

- Timberland: Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)
- Reserved forest land: Land permanently reserved from wood products utilization through statute or administrative designation. Examples include national forest wilderness areas and national parks and monuments.
- Other forest land not capable of producing 20 ft^3 of wood per acre per year, often occurring on sites with poor soils.

What Is in This Report?

This report presents a summary of Oregon's forest resources, highlighting key forest characteristics estimated from inventory field plots sampled across the state over the 10-year period from 2006 through 2015. It also includes the first set of remeasurement data from the FIA annual inventory of Oregon (plots measured for the second time between 2011 and 2015). Estimates presented here are an update to prior estimates reported in Donnegan et al. 2008 and Bansal et al. 2017 and are based on field measurements of 9,439 forested plots, of which 4,594 have now been remeasured and can be used to assess change in forest conditions (fig. 1). We present estimates of current forest area, ownership, composition, volume, and distribution, as well as information on growth, mortality, and removals. We also provide information on forest health via occurrence of forest pathogens and stands affected by fires, and we include information on understory vegetation and down woody debris in Oregon's forests.

J. Sprovkin

Figure 1—Field crews measured 9,439 forested plots in Oregon from 2006 to 2015. Working in an area burned by the 2015 Canyon Creek Complex Fire, Malheur National Forest.

An extensive set of 125 summary data tables accompanies this report and can be downloaded from the Web at https://www.fs.usda.gov/pnw/pubs/pnw_gtr971-supplement.pdf. These tables provide estimates of forest area, number of trees, volume, biomass, carbon, forest change, National Forest System (NFS) summaries, down wood, understory vegetation, tree damages, and timber-products output for the state. A complete list of online tables is available at the end of this report.

Where Can I Find Additional Information?

Donnegan et al. (2008) and Bansal et al. (2017) provided detailed information on annual inventory methods and definitions as well as prior periodic inventories implemented in Oregon. The PNW-FIA website (https://www.fs.fed.us/pnw/rma/) has most of the data used in this report accessible through the PNW-FIADB (Forest Inventory and Analysis Database) application (requires Microsoft Access[1]) that contains both national core data and regional variables collected only by the PNW-FIA unit. This site has up-to-date reports and statistics for each state in the PNW-FIA unit and field guides that include PNW-FIA regional variables.

The main Web page for FIA is at https://www.fia.fs.fed.us/. Links lead to resources such as publications or data and tools. EVALIDator and DATIM are the primary estimation tools that allow users to generate custom summaries from the most recent data in FIADB. Definitions of tables and fields are available in the FIADB user manual (O'Connell et al. 2017), and core FIA field guides contain details on how each data item was collected. A glossary of FIA terms can be found at https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp.

Forest Resources

Importance of Oregon's Forests

Forests provide many ecosystem services and benefits to society, including timber production, carbon storage, water regulation, aesthetic amenities, recreation, and wildlife (Binder et al. 2017, Boyd and Banzhaf 2007). Oregon forests provide each of these benefits, and forest lands across the state are managed in different ways to balance these and other priorities. The iconic temperate rainforests in the Pacific Northwest contain some of the oldest and tallest trees in the country and store more aboveground biomass than most other forest ecosystems worldwide (Keith et al. 2009). Forest products are an important component of Oregon's rural economy. Many Oregonians experience their state's forests through the lens of recreation, whether at sites as popular as Crater Lake or in remote wilderness areas. As Oregon's population continues to grow, so will the importance of the state's forests in providing ecosystem services.

Forest Area and Composition

Oregon contains diverse and productive forest lands that cover almost half the state (fig. 2). The current forested area estimate of 29,656,200 ac (table 1) is remarkably similar to the state's initial forest inventory estimate of 29,661,000 ac in 1942, although exact forest land definitions differed across inventories, and some forested area has been lost in

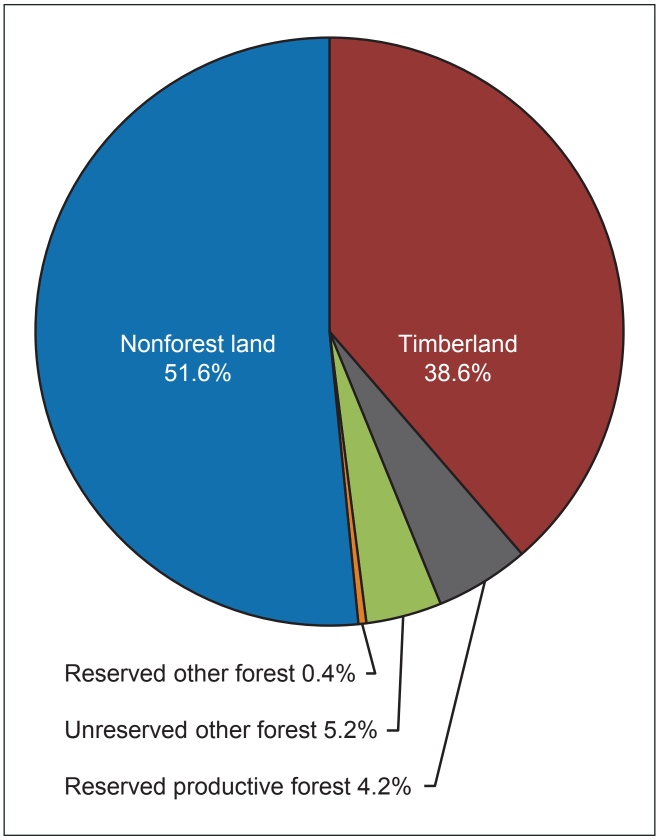


Figure 2—Forest Inventory and Analysis area classification by land class category, Oregon, 2006–2015.

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1—Area of forest land, by ownership and land status, Oregon 2006–2015

	Land status													
	Unreserved forests						Reserved forests							
	Timberland		Other forest		Total		Productive		Other forest		Total		All forest land	
Ownership	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
	Thousand acres													
USDA Forest Service:														
National forest	11,091.6	54.6	539.2	29.7	11,630.8	50.7	2,248.2	52.3	199.2	33.2	2,447.4	46.5	14,078.2	48.0
National grasslands	—	—	14.9	5.2	14.9	5.2	—	—	—	—	—	—	14.9	5.2
Total	11,091.6	54.6	554.1	29.9	11,645.7	50.7	2,248.2	52.3	199.2	33.2	2,447.4	46.5	14,093.1	48.1
Other federal government:														
Bureau of Land Management	2,248.2	56.8	1,200.5	73.1	3,448.7	84.0	80.0	21.4	44.6	16.7	124.6	27.1	3,573.3	81.6
Department of Defense or Energy	0.1	0.1	—	—	0.1	0.1	—	—	—	—	—	—	0.1	0.1
National Park Service	—	—	—	—	—	—	147.5	28.6	12.9	9.1	160.4	29.7	160.4	29.7
U.S. Fish and Wildlife Service	—	—	—	—	—	—	11.3	8.3	5.3	6.0	16.6	10.2	16.6	10.2
Other federal	6.1	6.2	—	—	6.1	6.2	8.9	6.8	—	—	8.9	6.8	14.9	9.2
Total	2,254.4	57.1	1,200.5	73.1	3,454.9	84.2	247.7	36.4	62.7	19.8	310.4	41.0	3,765.3	77.7
State and local government:														
Local	129.0	27.2	41.7	14.9	170.7	31.4	16.6	10.4	—	—	16.6	10.4	187.2	33.1
State	821.7	36.2	76.6	20.8	898.3	40.5	37.0	14.7	6.4	5.2	43.4	15.4	941.7	40.3
Total	950.7	41.5	118.2	25.6	1,069.0	47.8	53.6	17.9	6.4	5.2	60.0	18.5	1,129.0	47.4
Corporate private	6,218.8	129.5	268.3	38.9	6,487.1	133.0	—	—	—	—	—	—	6,487.1	133.0
Noncorporate private:														
Nongovernmental conservation or natural resource organizations	216.1	35.5	—	—	216.1	35.5	—	—	—	—	—	—	216.1	35.5
Unincorporated partnerships, associations, or clubs	4.5	4.6	11.8	8.4	16.3	9.6	—	—	—	—	—	—	16.3	9.6
Native American	402.4	48.5	77.4	21.8	479.7	52.9	—	—	—	—	—	—	479.7	52.9
Individual	2,527.5	106.2	942.0	70.7	3,469.6	123.5	—	—	—	—	—	—	3,469.6	123.5
Total	3,150.5	115.7	1,031.2	74.0	4,181.7	132.3	—	—	—	—	—	—	4,181.7	132.3
All private	9,369.3	112.1	1,299.5	82.5	10,668.8	118.6	—	—	—	—	—	—	10,668.8	118.6
All owners	23,666.0	130.7	3,172.3	116.6	26,838.3	147.4	2,549.5	66.2	268.3	39.0	2,817.8	64.6	29,656.2	140.7

Note: Totals may be off because of rounding; data subject to sampling error; SE = standard error; — = less than 50 acres was estimated.

recent decades owing to land use change (Lettman et al. 2016). Timberland area estimates (the unreserved, productive component of forest land) have been more dynamic over the past eight decades owing to differing timber stocking definitions and reserved classifications at each inventory date, but productive timberland area in the state remains around 24 million ac (fig. 3).

Conifers (softwoods) dominate the state's forest cover as more than 85 percent of the total forest area, while hardwoods comprise 11 percent, and 4 percent is currently nonstocked (forested areas that currently lack 10-percent tree cover, typically on account of recent fire or harvest). Douglas-fir (10,942,600 ac) and ponderosa pine (5,169,300 ac) are the two predominant forest types with 37 and 17 percent of the state's forest area, respectively (fig. 4). Forest area is evenly distributed on the east and west sides of the state, with 49 percent of Oregon's forested land east of the Cascade Crest. Western Oregon's forests are mainly composed of Douglas-fir forest types with some hemlock/Sitka spruce, alder/maple, and other hardwoods that thrive in the moist maritime climate. Eastern Oregon forests are mainly drier climate types; ponderosa pine forest types dominate, with elements of western juniper and lodgepole pine. Fir/spruce/mountain hemlock forests grow at higher elevations along the Cascade crest (fig. 5).

Pacific Northwest forests contain a broad range of stands that are unique in their age and size, reflecting both young, intensively managed productive timber stands and intact old-growth forests and stands in large-diameter classes. While 54 percent of Oregon's forests are between 1 and 80 years old, 8 percent (more than 2 million ac) are greater than 200 years old (fig. 6). Douglas-fir stands tend to be younger than other common softwood species, and the same is true for alder/maple forest types compared to other

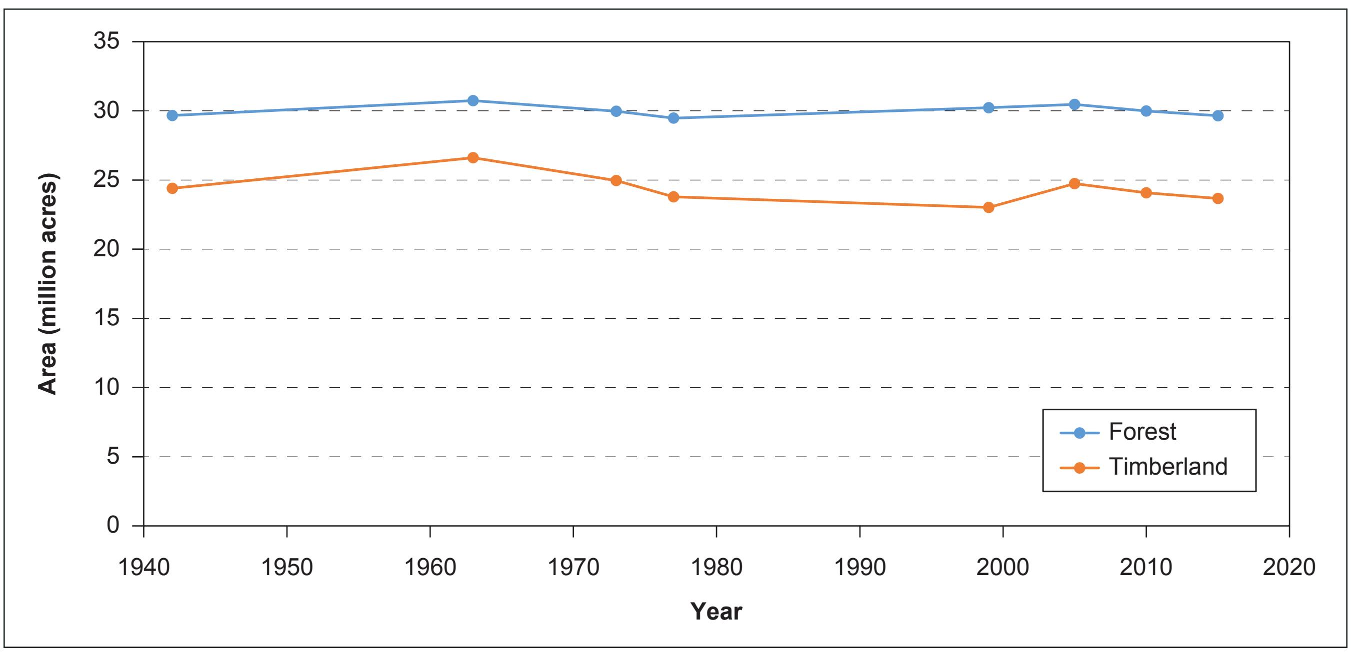


Figure 3—Area of forest land and timberland (thousand acres) by inventory year in Oregon, 1942–2015. Note: estimates from 2000 to 2015 are based on the annual inventory design and protocols, while prior estimates were based on periodic inventories which used different designs and methods (Bassett and Choate 1974, Campbell et al. 2004, Farrenkopf 1982, Gedney 1982, Metcalf 1965, Moravets et al. 1942). Differences shown here represent a combination of real change, wilderness designations that placed timberland into reserved status, and protocol differences over time such as the use of stockability factors during periodic inventories.

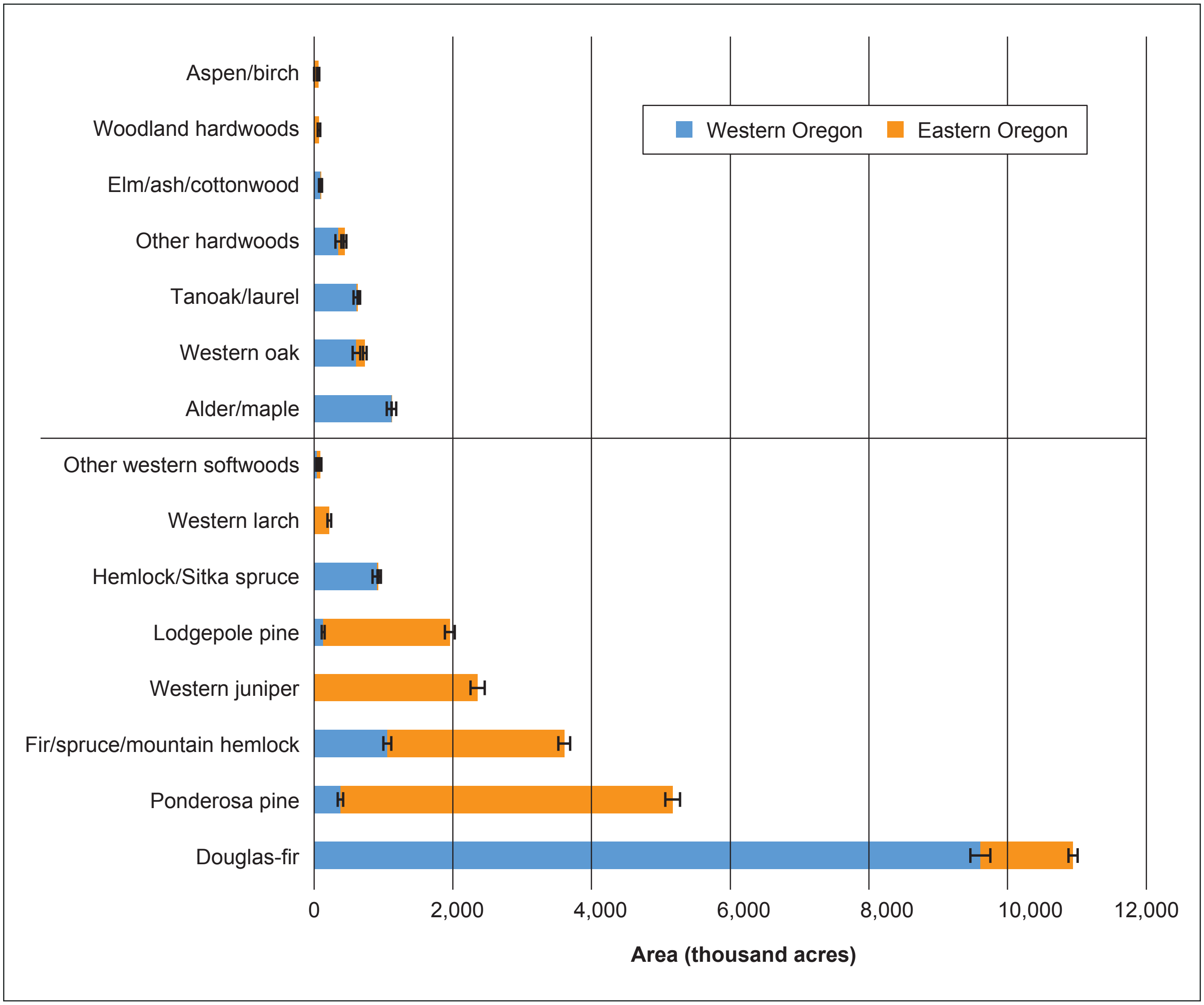


Figure 4—Area of softwood and hardwood forest type groups in eastern and western Oregon, 2015.

hardwoods (fig. 7). Differences in age and diameter distributions among species reflect a combination of ecology, natural disturbances, and forest management (fig. 8).

Oregon is home to more than 10.2 billion live trees on forest land, or an average of 347 trees per forested acre Douglas-fir is the most numerous species, with nearly one-quarter (24 percent) of all trees in the state. Other top species groups include lodgepole pine, true firs, and ponderosa and Jeffrey pines. Tree numbers are more evenly distributed in the smaller diameter classes, while among large-diameter trees (greater than 30 in diameter at breast height [d.b.h.]), Douglas-fir dominates (fig. 9).

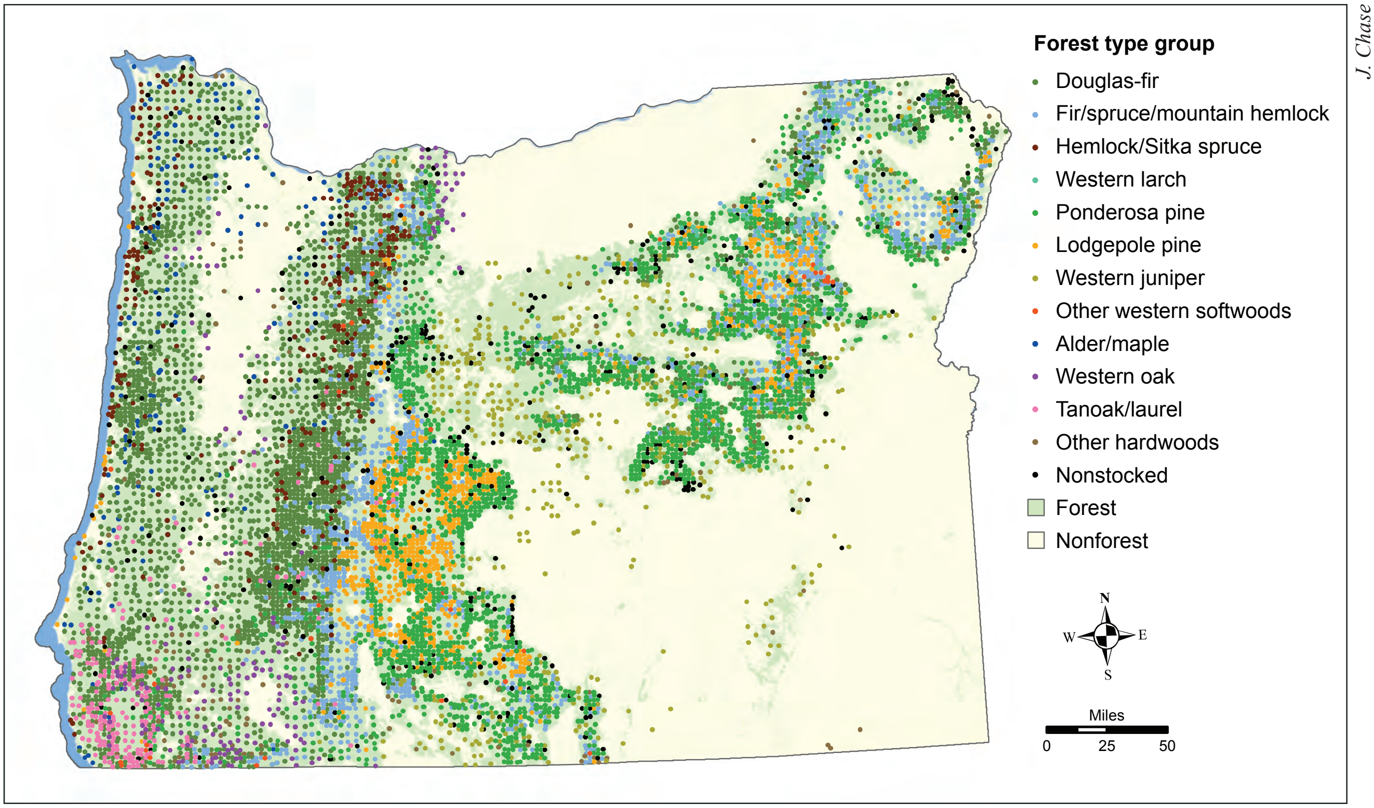


Figure 5—Distribution of forest type groups based on field observations at Forest Inventory and Analysis sample sites, Oregon, 2006–2015 (forest/nonforest geographic information system layer: Blackard et al. 2008; Oregon boundary polygons: Oregon Bureau of Land Management, Oregon/Washington State Office).

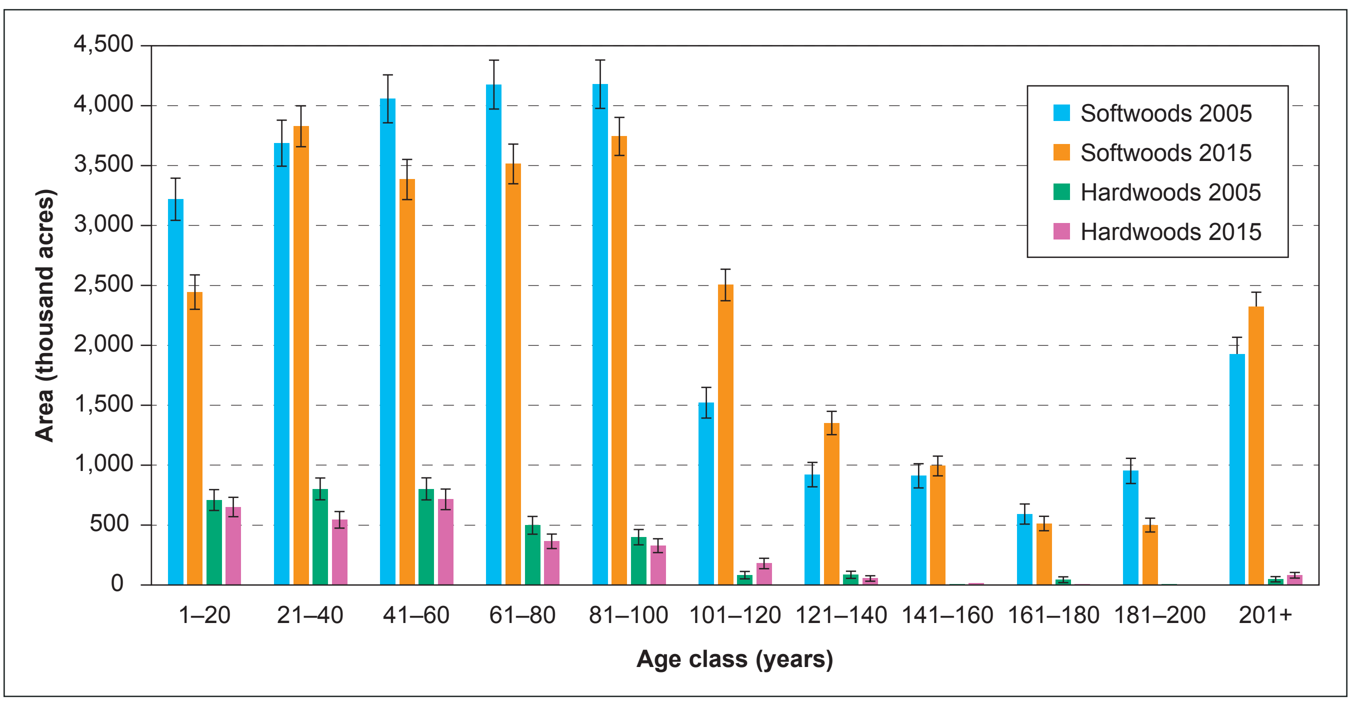


Figure 6—Stand age distribution for softwoods and hardwoods in Oregon, 2005 and 2015. To ensure that the estimates are comparable, the 2015 estimates include only plots that were remeasured in 2011–2015. Therefore, they differ from the 2006–2015 estimates discussed elsewhere in this report.

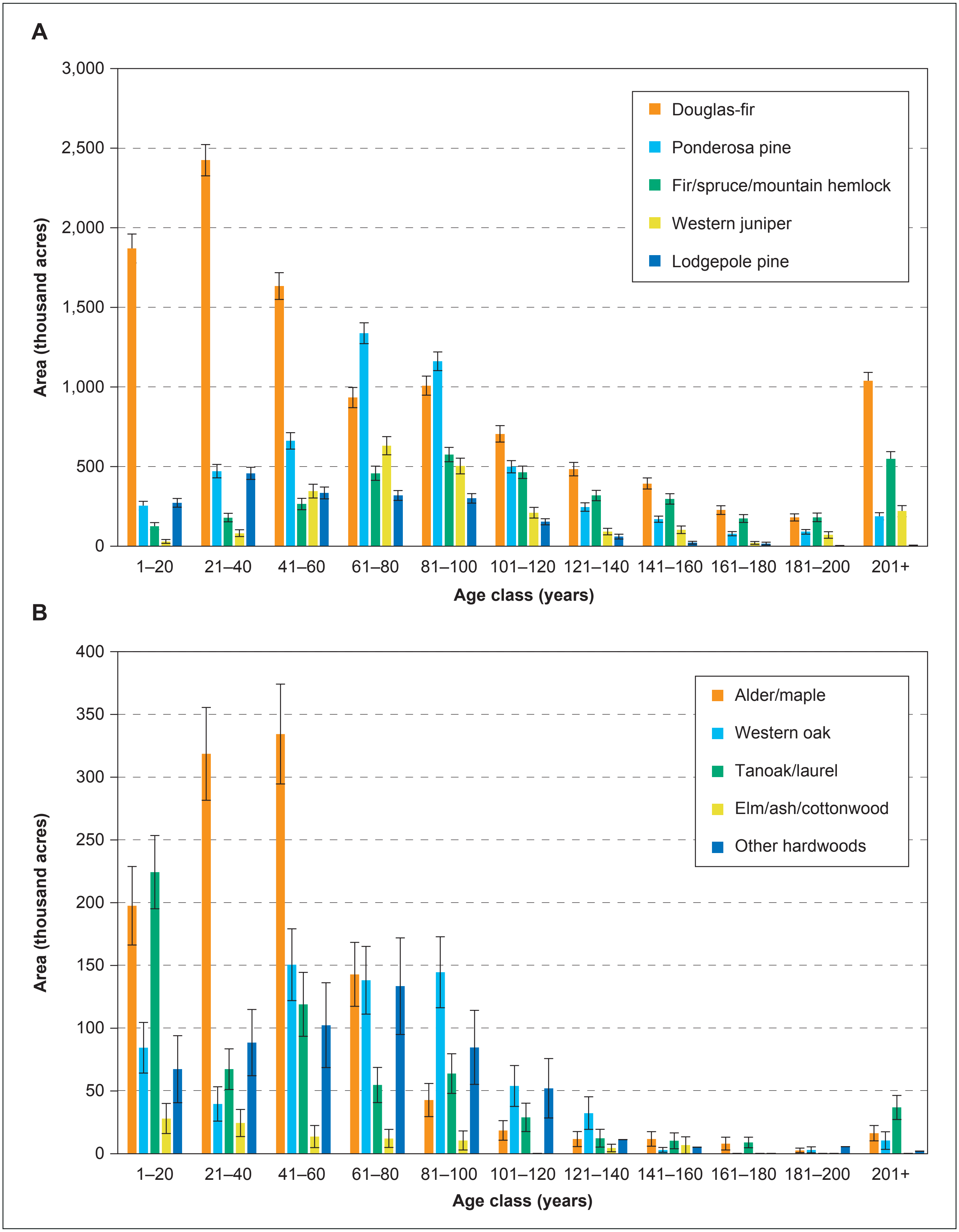


Figure 7—Stand age distributions of the most common (A) softwood and (B) hardwood species in Oregon, 2006–2015.

B. Borden

J. Sprovkin

Figure 8—Species stand ages are influenced by life histories, disturbance, and management. (A) Douglas-fir is typically long lived, but often harvested on 50-year-or-shorter rotations, while (B) lodgepole pine frequently experiences mortality caused by insects and disease in densely stocked stands.

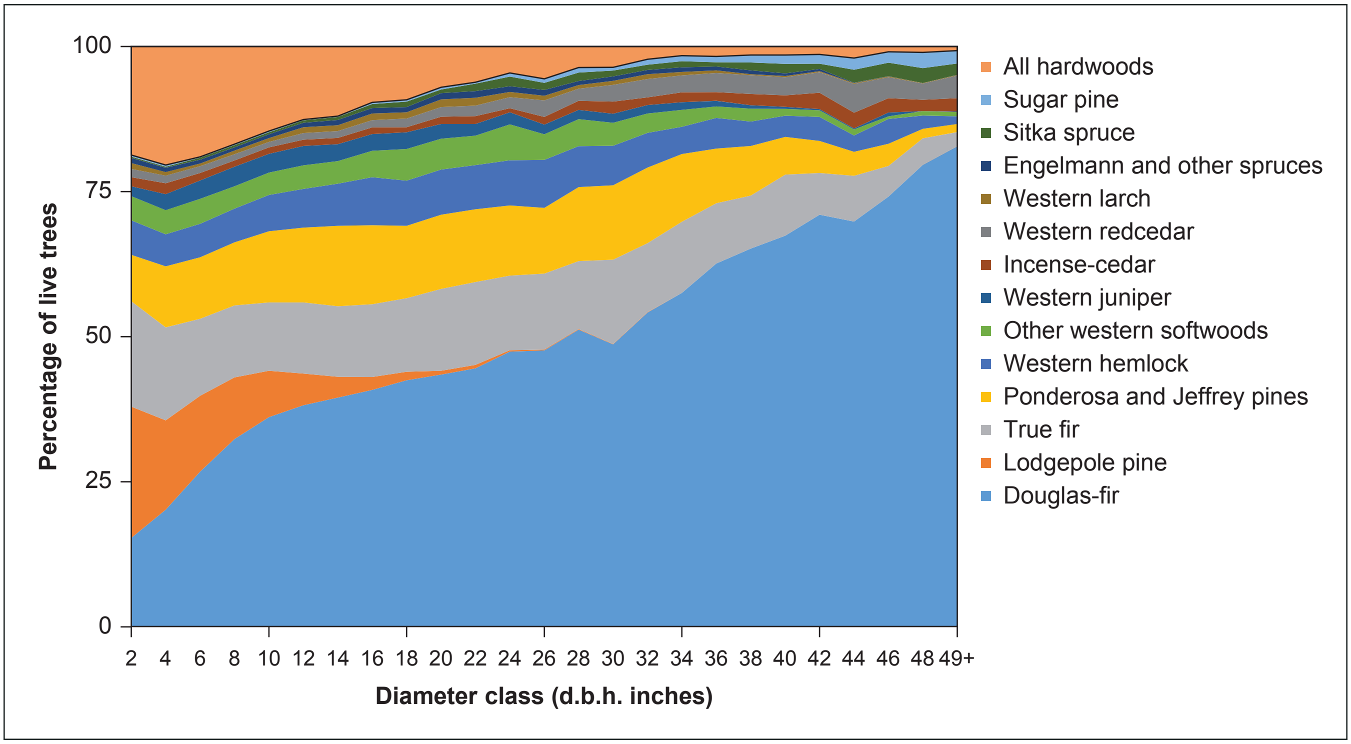


Figure 9—Proportional species composition on forest land by diameter class, Oregon, 2006–2015. Value shown on the horizontal axis represents the midpoint of the 2-inch diameter class, i.e., 6 inches refers to trees with diameter of 5 to 6.9 inches. D.b.h. = diameter at breast height.

Forest Ownership

Oregon's forest lands are owned and managed by a variety of public and private entities. Thirty-six percent of forest land is under private ownership, of which 88 percent is considered productive timberland. Sixty-one percent of private forest land is owned by corporations, while 39 percent is noncorporate, mainly owned by American Indian tribes and individuals (4 and 33 percent, respectively). Privately owned forest lands tend to be at lower elevation sites and in higher productivity classes. Both ownership and site characteristics affect management; Oregon's private forest lands tend to be managed more intensively than public lands (fig. 10), so they hold just 24 percent of the standing volume despite covering 36 percent of the forest land base.

Almost 19 million ac of Oregon forest lands are under public management; 48 percent are managed by the National Forest System (NFS) and an additional 13 percent are under other federal management. State and local governments manage 4 percent of Oregon's forest lands. Publicly owned forests tend to be at higher elevations and on average are on less productive sites, but these forests contain a range of characteristics and productivity classes. Fifteen percent of public forests are reserved (removed by statute from management for timber production), while 75 percent are classified as productive timberland.

Ownership trends differ east and west of the Cascade crest (fig. 11). Western Oregon has a larger share of private corporate and state forest lands, while almost 60 percent of eastern Oregon's forests are NFS managed. Eight percent of western Oregon forests are reserved and 88 percent are timberland, while eastern Oregon forests are 11 percent reserved and 71 percent timberland. Although statewide ownership estimates have changed slightly since the 2010 inventory, Oregon's forest ownership groups have remained mostly stable during this time period (fig. 12).

Figure 10—Private land in Lane County, Oregon, demonstrating active timber management.

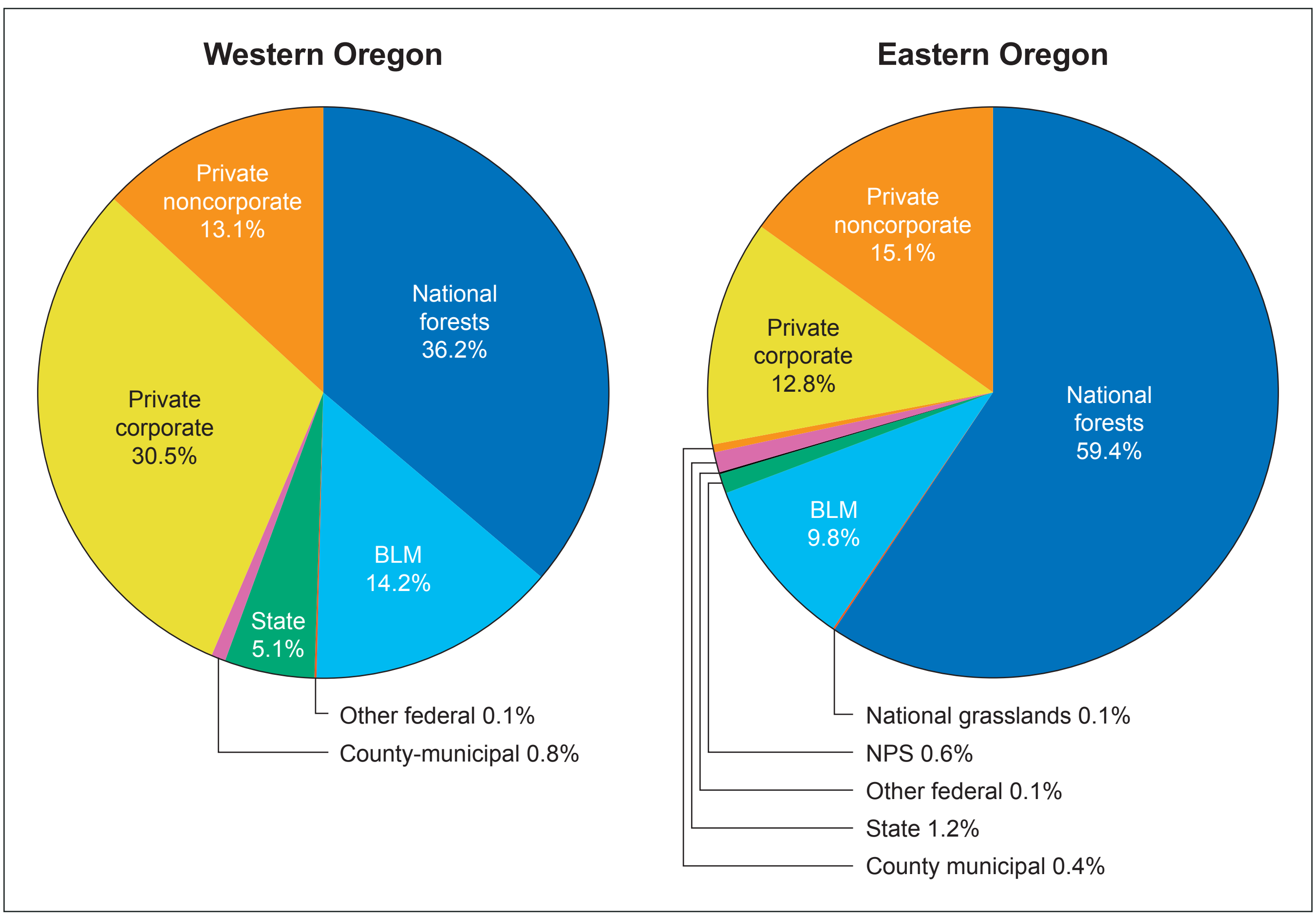


Figure 11—Percentage of forest land by owner group in western and eastern Oregon, 2006–2015. BLM = Bureau of Land Management, NPS = National Park Service.

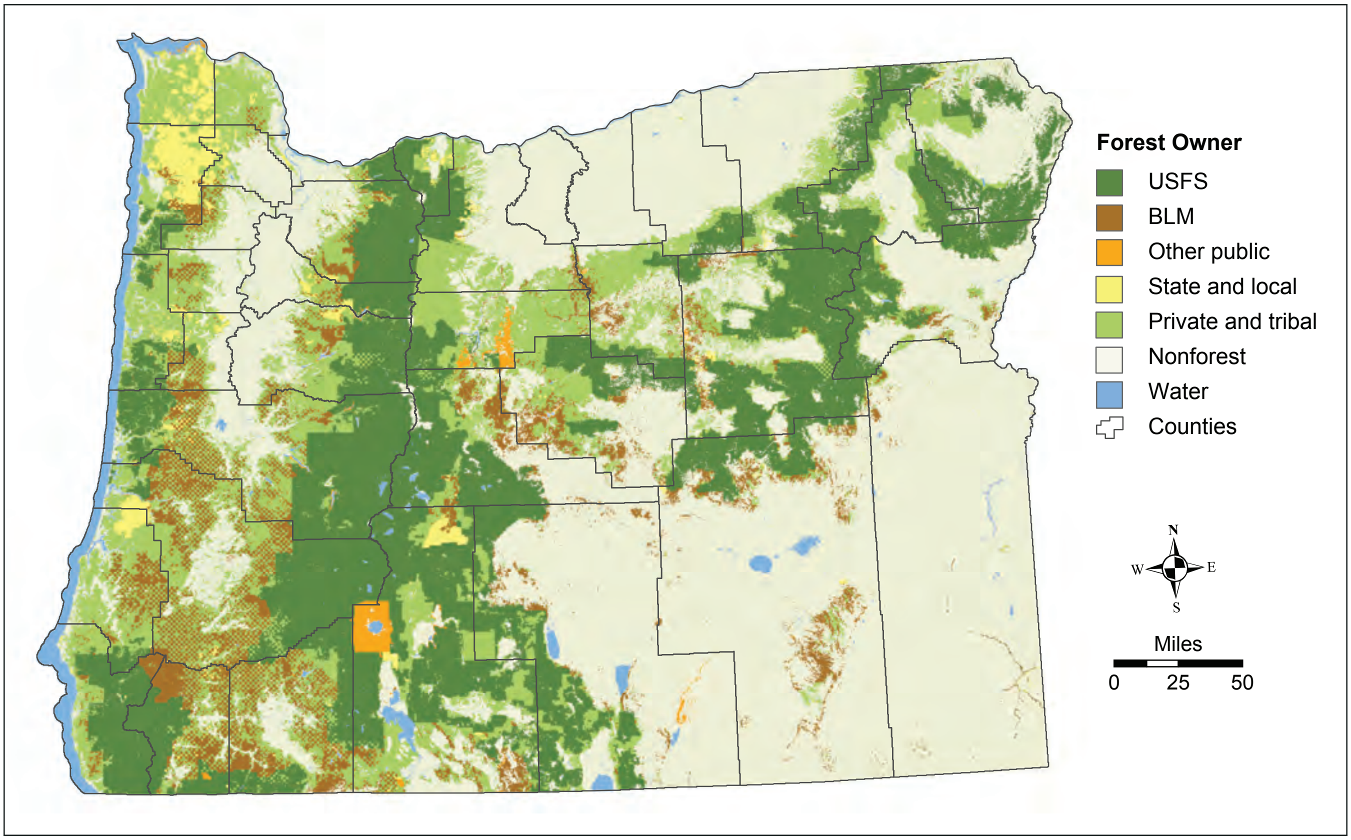


Figure 12—Oregon forest ownership categories (Oregon boundary and ownership polygons: Bureau of Land Management, Oregon/Washington State Office [BLM]). USFS = U.S. Forest Service.

Forest Volume

Forest volume is a critical variable that facilitates accurate estimates of change in standing timber availability, growth and mortality, biomass and carbon mass accumulation, and as input to fuel and habitat models. The FIA volume estimates are typically calculated by species, using measurements of a tree's diameter and height (Woodall et al. 2011).

Oregon's forests contain almost 107 billion ft^3 of live tree volume, slightly more than the 101 billion ft^3 estimated in 2005 (fig. 13). Fifty-five percent of current volume is located on NFS lands. The vast majority (85 percent) of volume resides in productive timberlands, while 15 percent is in reserved areas (table 2). Douglas-fir dominates with 58 percent of total live tree volume and more than 5 billion ft^3 resides in Douglas-fir trees greater than 49 inches d.b.h. (fig. 14). Volume per acre provides an indication of the potential productivity of a site, but is highly dependent on relative density with young stands typically carrying less volume per acre than mature stands. Oregon averages 3,604 ft^3 of live tree wood volume per forested acre. Hemlock/Sitka spruce forest types carry the most standing volume per acre, while lodgepole pine and woodland species such as western juniper carry far less (fig. 15).

Forest Biomass and Carbon Storage

Oregon forests contain 2.2 billion tons of aboveground live tree biomass. The National Forest System has the largest biomass share, with 55 percent of forest biomass, while 25 percent is held on private ownerships. The moist west side of the state contains the majority (75 percent) of forest biomass, mainly in coniferous (softwood) species, which make up 91 percent of biomass statewide. More than 57 percent of Oregon's biomass is in stands dominated by Douglas-fir, while the fir/spruce/mountain hemlock forest-type group is in second place at 14 percent.

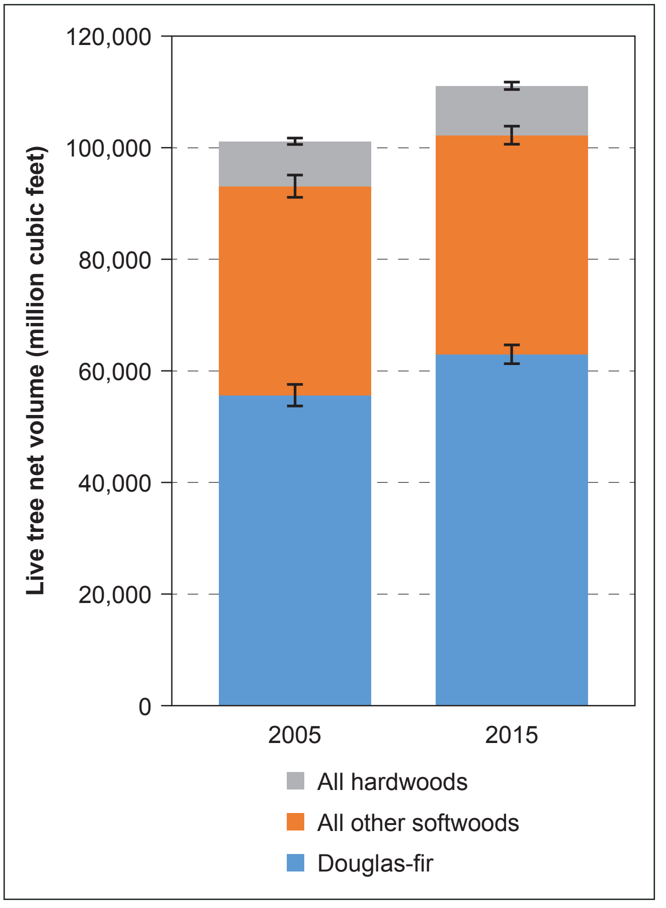


Figure 13—Live tree net volume of softwoods and hardwoods in Oregon, 2005 and 2015. To ensure that the estimates are comparable, the 2015 estimates include only plots that were remeasured in 2011–2015. Therefore, they differ from the 2006–2015 estimates discussed elsewhere in this report.

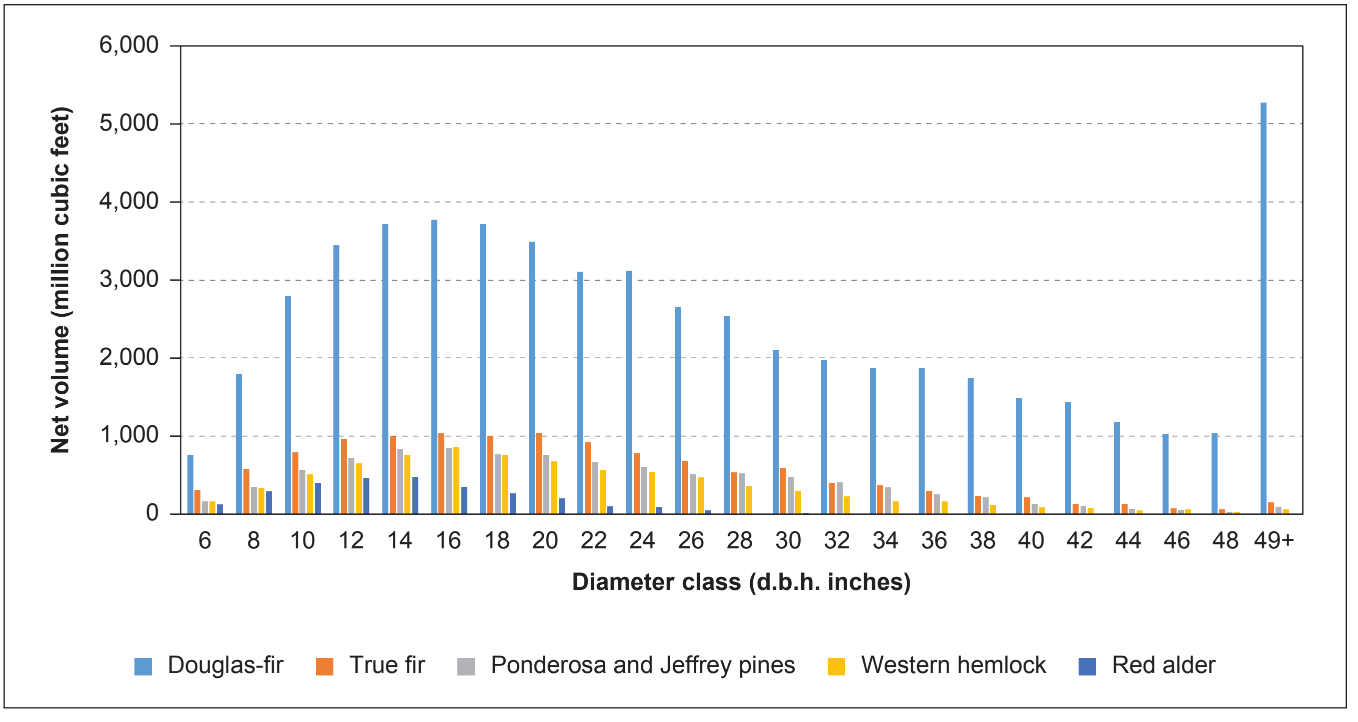


Figure 14—Diameter class distribution of live tree net volume on forest land, top five species groups, Oregon, 2006–2015. d.b.h. = diameter at breast height.

Table 2—Net volume of live trees[a] on forest land, by ownership and land status, Oregon 2006–2015

	Land status													
	Unreserved forests						Reserved forests							
	Timberland		Other forest		Total		Productive		Other forest		Total		All forest land	
Ownership	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
	Million cubic feet													
USDA Forest Service:														
National forest	46,351.6	538.9	559.5	61.7	46,911.2	534.6	11,885.5	517.4	371.5	106.4	12,257.0	507.0	59,168.2	656.1
National grasslands	—	—	1.5	0.8	1.5	0.8	—	—	—	—	—	—	1.5	0.8
Total	46,351.6	538.9	561.0	61.7	46,912.6	534.6	11,885.5	517.4	371.5	106.4	12,257.0	507.0	59,169.7	656.1
Other federal government:														
Bureau of Land Management	14,914.5	538.0	383.1	50.5	15,297.6	536.2	510.4	165.7	14.0	7.2	524.4	165.8	15,821.9	527.3
National Park Service	—	—	—	—	—	—	726.8	156.5	78.5	64.8	805.3	168.8	805.3	168.8
Other federal	7.8	8.0	—	—	7.8	8.0	37.5	30.1	—	—	37.5	30.1	45.3	31.1
Total	14,922.3	538.1	383.1	50.5	15,305.3	536.2	1,289.2	225.0	94.0	65.2	1,383.3	233.4	16,688.6	515.3
State and local government:														
Local	383.4	113.1	13.4	7.1	396.8	113.4	131.3	90.1	—	—	131.3	90.1	528.1	144.5
State	4,476.7	284.2	38.5	22.0	4,515.2	284.9	363.4	175.7	23.8	30.8	387.2	177.8	4,902.4	305.0
Total	4,860.1	294.9	51.9	23.1	4,912.0	295.6	494.7	197.2	23.8	30.8	518.5	199.0	5,430.5	316.3
Corporate private	16,172.2	589.0	218.0	76.1	16,390.2	592.8	—	—	—	—	—	—	16,390.2	592.8
Noncorporate private:														
Nongovernmental conservation or natural resource organizations	600.5	151.6	—	—	600.5	151.6	—	—	—	—	—	—	600.5	151.6
Unincorporated partnerships, associations, clubs	13.5	13.8	0.3	0.3	13.8	13.8	—	—	—	—	—	—	13.8	13.8
Native American	1,172.7	208.8	40.3	20.6	1,212.9	209.6	—	—	—	—	—	—	1,212.9	209.6
Individual	6,867.3	411.8	494.6	59.0	7,361.8	414.0	—	—	—	—	—	—	7,361.8	414.0
Total	8,653.9	469.9	535.2	62.3	9,189.1	471.6	—	—	—	—	—	—	9,189.1	471.6
All private	24,826.1	625.3	753.1	97.8	25,579.3	626.1	—	—	—	—	—	—	25,579.3	626.1
All owners	90,960.2	1,001.4	1,749.1	128.2	92,709.3	998.4	13,669.5	597.7	489.3	128.6	14,158.8	592.6	106,868.0	1,058.9

Note: Totals may be off because of rounding; data subject to sampling error; SE = standard error; — = less than 50,000 cubic feet was estimated.
[a] Includes all live trees ≥= 5 inches in diameter at breast height, consisting of growing stock, rough cull, and rotten cull tree classes.

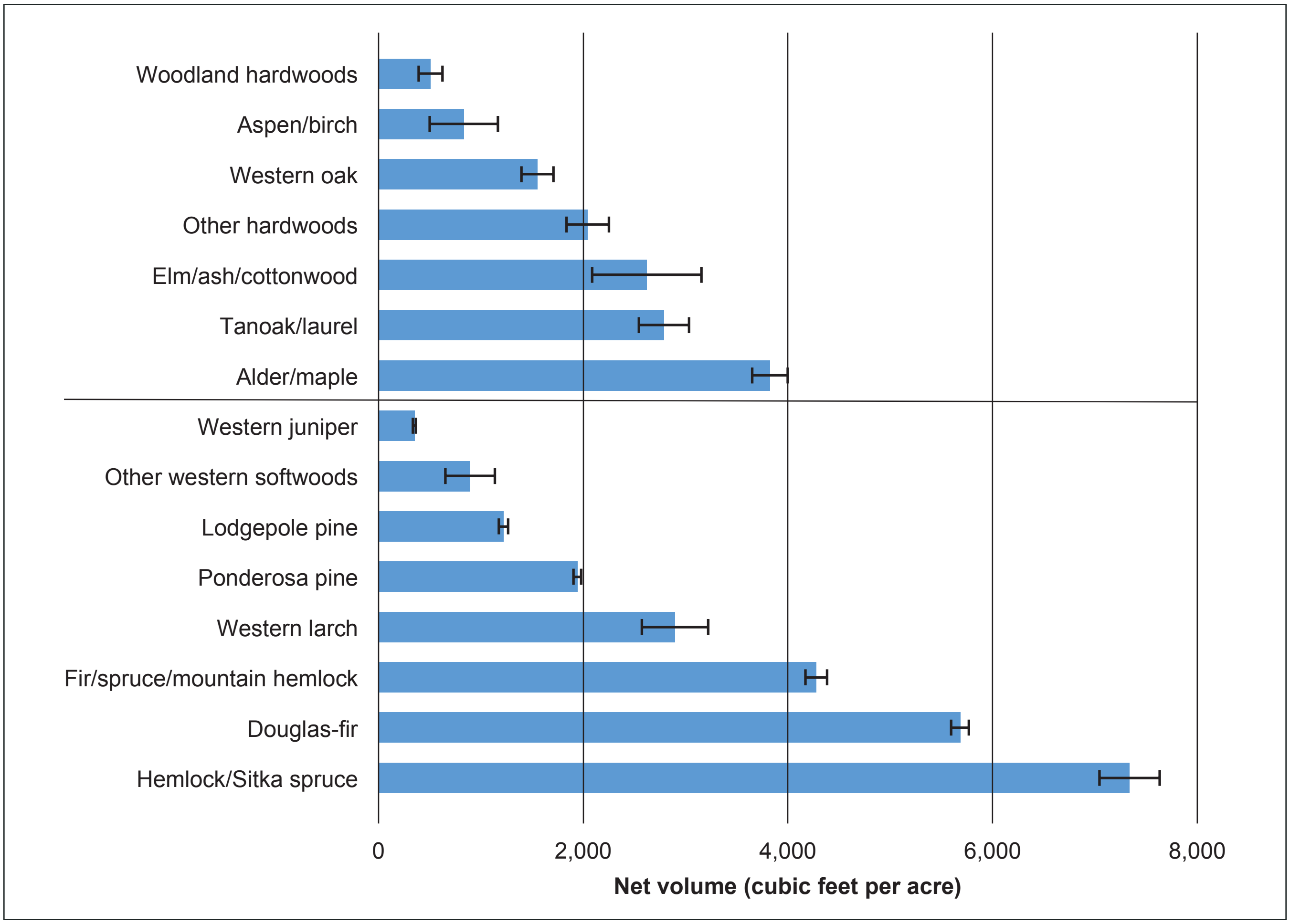


Figure 15—Average net live tree volume per acre on forest land by forest type group, Oregon, 2006–2015.

Change in carbon mass is proportional to the change in biomass, and is a basic measure of productivity that can be used to determine forest carbon stocks and the flux of carbon into and out of atmospheric carbon pools. In Oregon, 976 million Mg of aboveground carbon[2] is stored in live trees (table 3); note: metric units are used for carbon mass to remain consistent with accepted accounting practices). The Pacific Northwest is known for its old-growth forests; and large-diameter trees, while less numerous than small-diameter trees, store a large fraction of the carbon. Trees >25 inches d.b.h. stored more than 36 percent of the aboveground carbon (fig. 16). Forest carbon density is concentrated on the west side of the Cascades with Multnomah, Lane, Clackamas, and Benton Counties having the highest aboveground live tree carbon per hectare (fig. 17). The Douglas-fir species group has the highest total carbon storage (501 million Mg), with true firs in a distant second place (110 million Mg); however, sugar pines and Sitka spruce store the most aboveground carbon per live tree (on average, 301 and 242 kg of carbon per tree, respectively).

Two important components of aboveground forest biomass and carbon storage are standing dead trees (snags) and down wood. These components are key to any comprehensive inventory of forest carbon pools. Oregon has 102 million Mg of carbon in standing dead trees (table 4) and 156 million Mg of carbon in down wood. The total amount of carbon mass and its distribution among the aboveground pools varies as stands age (fig. 18). Snag biomass is lowest on private ownerships, averaging 4 tons per ac, while there are 11 and 9 tons per ac in standing dead trees on NFS and

[2] Metric units are used for carbon mass to remain consistent with accepted accounting practices.

Table 3—Aboveground carbon mass[a] of live trees[b] on forest land, by ownership and land status, Oregon 2006–2015

	Land status													
	Unreserved forests						Reserved forests							
	Timberland		Other forest		Total		Productive		Other forest		Total		All forest land	
Ownership	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
	Thousand megagrams													
USDA Forest Service:														
National forest	421,561.6	4,693.8	5,837.5	602.0	427,399.1	4,648.7	106,006.5	4,442.2	3,696.2	989.2	109,702.6	4,337.7	537,101.7	5,616.4
National grasslands	—	—	21.5	9.8	21.5	9.8	—	—	—	—	—	—	21.5	9.8
Total	421,561.6	4,693.8	5,858.9	602.1	427,420.6	4,648.7	106,006.5	4,442.2	3,696.2	989.2	109,702.6	4,337.7	537,123.2	5,616.4
Other federal government:														
Bureau of Land Management	133,714.7	4,632.5	5,109.8	636.9	138,824.6	4,614.4	4,639.5	1,469.8	239.1	134.8	4,878.6	1,475.6	143,703.2	4,521.2
National Park Service	—	—	—	—	—	—	6,671.2	1,435.8	747.4	615.4	7,418.6	1,556.9	7,418.6	1,556.9
U.S. Fish and Wildlife Service	—	—	—	—	—	—	249.1	183.9	21.3	25.4	270.4	185.7	270.4	185.7
Other federal	112.5	115.1	—	—	112.5	115.1	315.2	241.4	—	—	315.2	241.4	427.8	267.4
Total	133,827.3	4,634.0	5,109.8	636.9	138,937.1	4,615.9	11,875.1	2,029.7	1,007.8	630.5	12,882.9	2,115.8	151,820.0	4,390.7
State and local government:														
Local	3,477.9	989.5	153.9	77.8	3,631.9	993.6	1,022.6	705.1	—	—	1,022.6	705.1	4,654.5	1,215.3
State	38,491.4	2,391.5	457.3	242.7	38,948.7	2,401.5	2,774.2	1,326.9	268.0	312.3	3,042.2	1,357.0	41,990.9	2,509.3
Total	41,969.4	2,495.5	611.2	254.8	42,580.6	2,506.6	3,796.8	1,500.3	268.0	312.3	4,064.7	1,526.9	46,645.3	2,610.4
Corporate private	150,701.3	5,148.1	2,506.6	854.4	153,207.8	5,204.4	—	—	—	—	—	—	153,207.8	5,204.4
Noncorporate private:														
Nongovernmental conservation or natural resource organizations	5,584.1	1,353.5	—	—	5,584.1	1,353.5	—	—	—	—	—	—	5,584.1	1,353.5
Unincorporated partnerships, associations, clubs	123.0	125.4	3.9	3.1	126.9	125.5	—	—	—	—	—	—	126.9	125.5
Native American	10,452.1	1,778.4	464.5	225.1	10,916.7	1,790.0	—	—	—	—	—	—	10,916.7	1,790.0
Individual	63,851.6	3,665.3	6,275.3	698.1	70,126.9	3,704.3	—	—	—	—	—	—	70,126.9	3,704.3
Total	80,010.8	4,143.8	6,743.8	731.1	86,754.6	4,175.6	—	—	—	—	—	—	86,754.6	4,175.6
All private	230,712.0	5,400.5	9,250.4	1,119.4	239,962.4	5,424.9	—	—	—	—	—	—	239,962.4	5,424.9
All owners	828,070.3	8,627.0	20,830.4	1,443.6	848,900.7	8,604.7	121,678.4	5,109.1	4,971.9	1,213.9	126,650.2	5,061.9	975,550.9	9,033.8

Note: Totals may be off because of rounding; data subject to sampling error; SE = standard error; — = less than 50 megagrams was estimated.

[a] Total aboveground carbon mass of the tree from ground to tip; includes stem wood, bark, and branches; calculated by applying a factor of 0.5 to aboveground biomass estimated from regional biomass equations, and converting to metric units. Convert megagrams of carbon to tons of biomass by multiplying by 2.204586. The result will be approximate because of rounding.

[b] Includes all live trees >= 1 inches in diameter at breast height, consisting of growing stock, rough cull, and rotten cull tree classes.

Figure 16—Large trees with diameters greater than 25 inches such as this Douglas-fir in Linn County store 36 percent of the aboveground carbon in Oregon's forests.

J. Chase

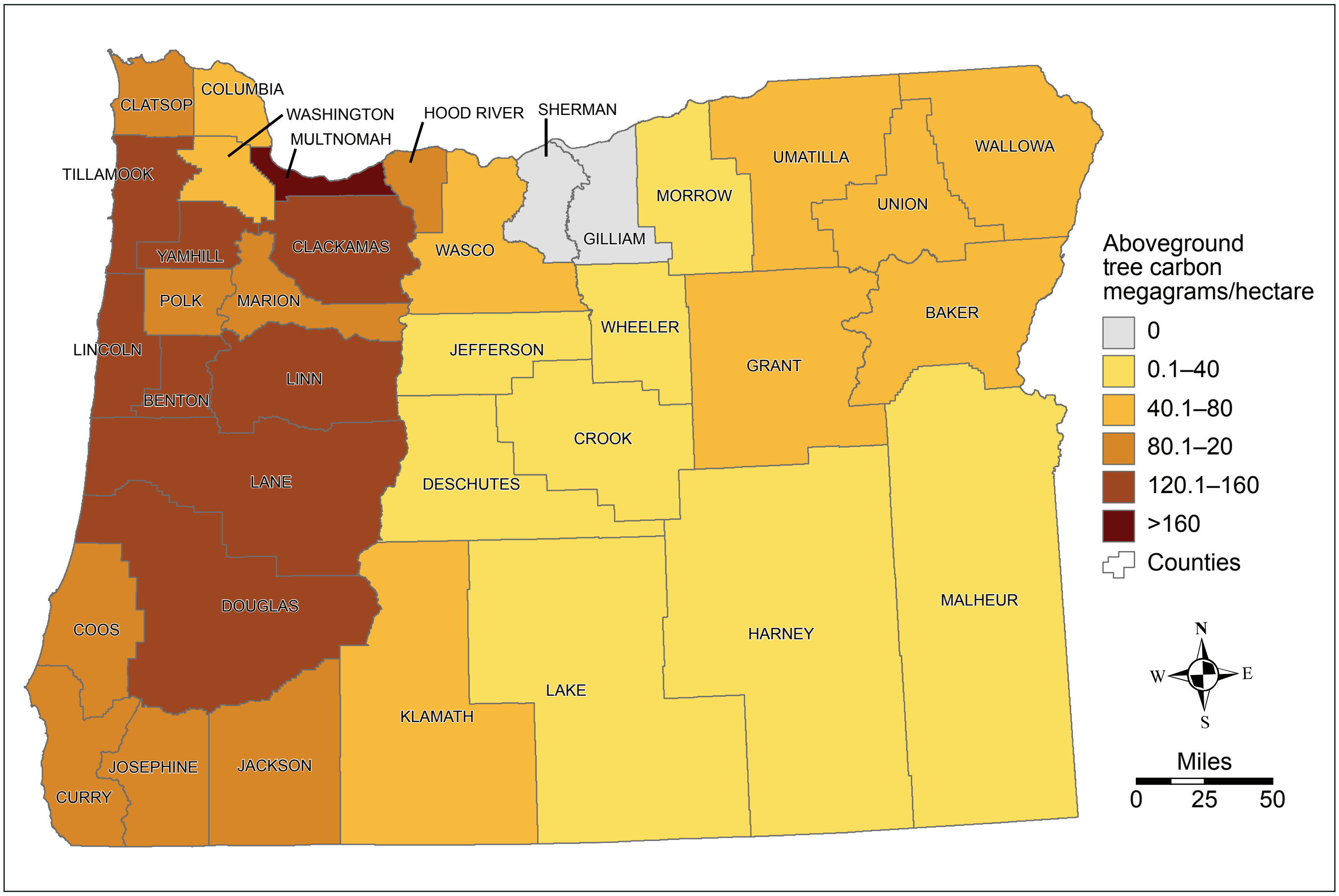


Figure 17—Average aboveground live tree carbon (tons per acre) by county, Oregon, 2006–2015 (Oregon boundary polygons: Oregon Bureau of Land Management, Oregon/Washington State Office).

Figure 18—Average aboveground carbon mass per hectare on forest land, by stand age class, Oregon, 2006–2015.

Table 4—Aboveground carbon mass[a] of dead trees[b] on forest land, by ownership and land status, Oregon 2006–2015

	Land status													
	Unreserved forests						Reserved forests							
	Timberland		Other forest		Total		Productive		Other forest		Total		All forest land	
Ownership	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
	Thousand megagrams													
USDA Forest Service:														
National forest	51,433.9	1,188.7	1,249.0	182.0	52,682.9	1,192.9	20,972.8	1,201.0	1,084.1	289.1	22,056.9	1,180.6	74,739.8	1,614.4
National grasslands	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	51,433.9	1,188.7	1,249.0	182.0	52,682.9	1,192.9	20,972.8	1,201.0	1,084.1	289.1	22,056.9	1,180.6	74,739.8	1,614.4
Other federal government:														
Bureau of Land Management	9,737.3	758.9	487.3	115.0	10,224.6	765.7	446.3	231.1	16.8	11.2	463.1	231.3	10,687.7	783.2
National Park Service	—	—	—	—	—	—	1,049.9	265.2	124.5	94.8	1,174.5	279.9	1,174.5	279.9
U.S. Fish and Wildlife Service	—	—	—	—	—	—	0.6	0.5	—	—	0.6	0.5	0.6	0.5
Other federal	7.0	7.2	—	—	7.0	7.2	37.8	36.3	—	—	37.8	36.3	44.8	37.0
Total	9,744.3	758.9	487.3	115.0	10,231.6	765.8	1,534.7	348.2	141.4	95.4	1,676.0	359.2	11,907.6	797.7
State and local government:														
Local	282.7	102.3	—	—	282.7	102.3	28.5	21.3	—	—	28.5	21.3	311.1	104.4
State	3,049.3	377.2	25.4	21.2	3,074.7	377.8	225.4	125.0	2.2	3.1	227.6	125.0	3,302.3	386.3
Total	3,331.9	386.5	25.4	21.2	3,357.4	387.0	253.9	126.8	2.2	3.1	256.1	126.8	3,613.4	394.1
Corporate private	7,341.1	495.3	123.6	47.6	7,464.8	497.1	—	—	—	—	—	—	7,464.8	497.1
Noncorporate private:														
Nongovernmental conservation or natural resource organizations	429.1	120.6	—	—	429.1	120.6	—	—	—	—	—	—	429.1	120.6
Unincorporated partnerships, associations, clubs	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Native American	1,380.6	339.0	184.5	89.7	1,565.1	350.0	—	—	—	—	—	—	1,565.1	350.0
Individual	2,457.0	216.2	242.3	58.0	2,699.3	223.2	—	—	—	—	—	—	2,699.3	223.2
Total	4,266.7	412.8	426.8	106.1	4,693.5	424.5	—	—	—	—	—	—	4,693.5	424.5
All private	11,607.8	613.2	550.5	116.3	12,158.3	620.8	—	—	—	—	—	—	12,158.3	620.8
All owners	76,118.0	1,578.5	2,312.2	245.6	78,430.1	1,588.0	22,761.3	1,256.8	1,227.7	304.5	23,989.0	1,240.5	102,419.1	1,938.5

Note: Totals may be off because of rounding; data subject to sampling error; SE = standard error; — = less than 50 megagrams was estimated.

[a] Total aboveground carbon mass of the tree from ground to tip; includes stem wood, bark, and branches; calculated by applying a factor of 0.5 to aboveground biomass estimated from regional biomass equations, and converting to metric units. Convert megagrams of carbon to tons of biomass by multiplying by 2.204586. The result will be approximate because of rounding.

[b] Includes all dead trees ≥= 5 inches in diameter at breast height; smaller dead trees were not measured in this inventory.

other federal lands, respectively. Biomass of down wood can be highly variable, but on average it is highest on state and local government lands (17 tons per acre) and lowest on private noncorporate ownerships (6 tons per acre).

The FIA also calculates carbon storage using the component ratio method (CRM) (Heath et al. 2009, O'Connell et al. 2017), which estimates belowground carbon and divides the aboveground tree carbon into distinct components. Live trees and saplings make up more than 70 percent of the total woody carbon; within this component, 82 percent is in boles, 14 percent is in tops and branches, and 4 percent is in stumps (fig. 19).

Forest Productivity

Timber Resources and Forest Productivity

Forest products are an important element of Oregon's economy, especially in rural areas. In 2015, 3.8 billion board feet (BBF) Scribner were harvested from Oregon forests, with the vast majority (76 percent) coming from private and American Indian tribal lands (ODF 2016). Harvest totals reached a historic low in 2009 during the height of the economic recession, but since 2011 have rebounded to levels similar to those seen during the 1990s. Total sales of primary wood products were $7.1 billion in 2013 (Simmons et al. 2016). Oregon has long been the top state for softwood lumber, producing 5.2 BBF, 17 percent of the United States total, in 2015 (OFRI 2017). Although employment in the forestry sector has decreased significantly since 1990, wood products manufacturing still employed 22,500 Oregonians in 2015 and is expected to continue a slow post-recession growth (Rooney 2016). Total forestry sector employment in Oregon is around 61,000 (OFRI 2017).

Growing-stock or sawtimber volumes on timberland are one measure of the current stock of standing timber for a region, and trends over time have been used to ensure sustained yield. However, because management objectives differ widely among landowners and timber harvests are driven by market factors in addition to supply, timberland volume alone is not a direct measure of timber availability or future harvest levels. Growing-stock volume on timberland is currently 90.9 billion ft^3. This estimate is difficult to compare to early periodic inventories owing to different definitions of timberland and commercial timber included at each measurement, but in general, growing-stock volume decreased

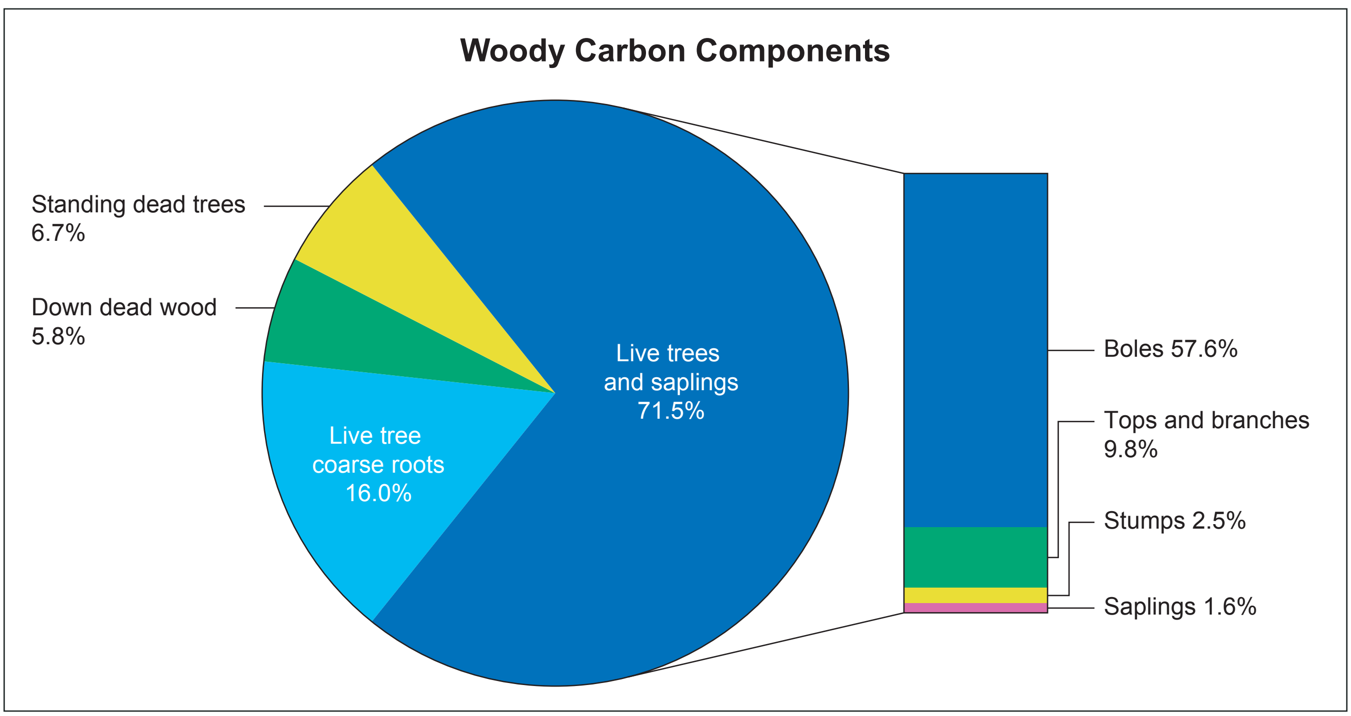


Figure 19—Distribution of woody tree carbon components on forest land, Oregon, 2006–2015. Live tree carbon is subdivided into saplings (at least 1 but less than 5 inches diameter at breast height [d.b.h.]) and trees (at least 5 inches d.b.h.).

during the era of intensive timber harvesting between the first inventory in the 1930s and the 1980s and has since been on a steady increase as harvest rates have slowed (fig. 20).

Oregon's timberlands currently hold 80.6 billion ft^3 or 394.1 BBF Scribner of live sawtimber trees. Sawtimber trees include only the sound portion of commercial species meeting minimum sawlog size. The five highest volume species groups include Douglas-fir (58 percent of sawtimber volume), ponderosa and Jeffery pines (11 percent), true firs (10 percent), western hemlock (8 percent), and red alder (2 percent) (fig. 21). Over three-fourths of Oregon sawtimber volume is west of the Cascade Crest. Counties with the highest sawtimber volume on a per-acre basis are concentrated in northwest Oregon, ranging between 25,000 and 30,000 board feet Scribner per acre. The average sawtimber tree volume per acre of timberland is 16,653 board feet Scribner per acre statewide. However, this varies significantly among owner groups, with an average of 9,252 board feet Scribner per acre on private lands and more than 30,000 board feet Scribner per acre on non-NFS federal lands (fig. 22).

Another indicator of a forest stand's potential productivity is mean annual increment at culmination, referred to by the FIA as the site productivity class (Hanson et al. 2003). In Oregon, 41 percent of forest land area is classified as low productivity (capable of producing 20 to 84 ft^3 ac^{-1} yr^{-1}), 35 percent is medium productivity (85 to 1654 ft^3 ac^{-1} yr^{-1}), 12 percent is high productivity (at least 165 ft^3 ac^{-1} yr^{-1}), and the remaining 12 percent is classified as nonproductive other forest land incapable of producing at least 20 ft^3 ac^{-1} yr^{-1}. On average, western Oregon encompasses medium productivity sites, whereas eastern Oregon has lower productivity sites. Lane and Douglas Counties contain the most forested area classified as high productivity, with 675,105 and 491,843 ac, respectively (fig. 23). The majority of highly productive stands falls outside of reserved areas, and most of the highly productive sites occur west of the Cascade crest (fig. 24). Hemlock/Sitka spruce forest types tend to grow on the most productive sites, followed by Douglas-fir, while dry-site forest types such as ponderosa and lodgepole pines thrive on low-productivity sites (fig. 25).

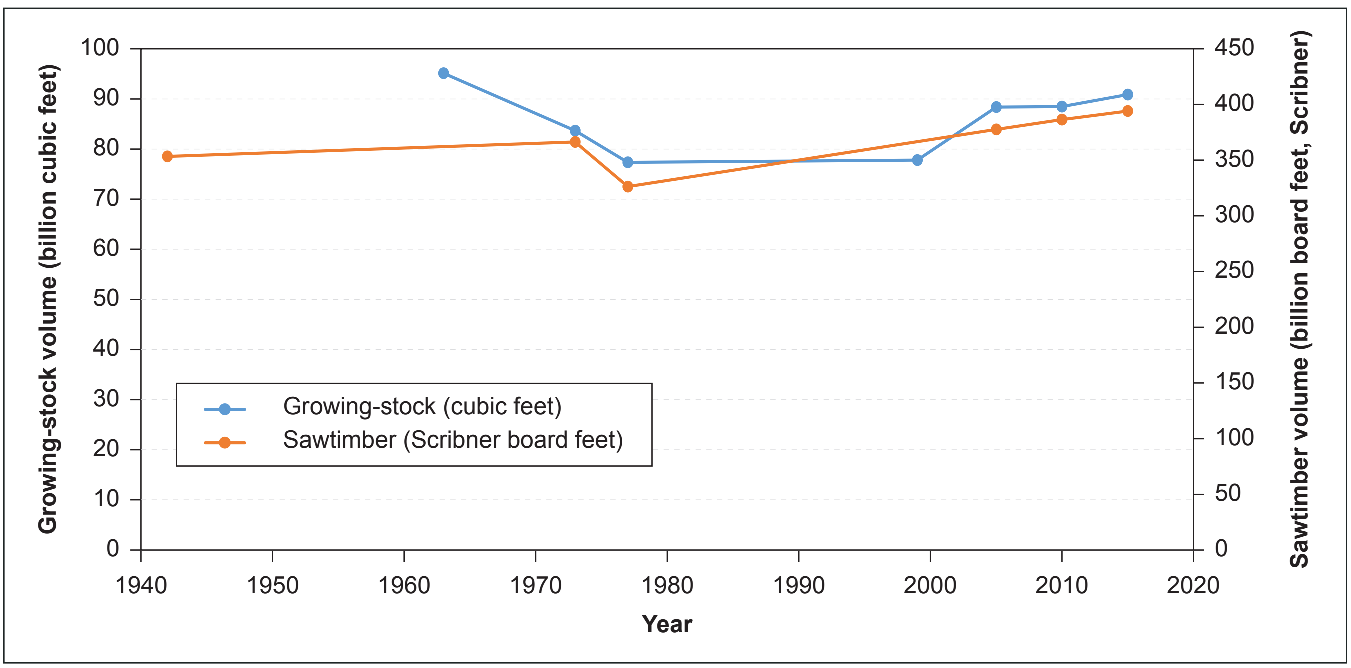


Figure 20—Growing-stock (billion cubic feet) and sawtimber (billion board feet, Scribner) volumes on unreserved timberland by inventory year in Oregon, 1942–2015. Note: the 2000–2015 estimates from are based on the annual inventory design and protocols, while prior estimates were based on periodic inventories, which used different designs and methods (Bassett and Choate 1974, Campbell et al. 2004, Farrenkopf 1982, Gedney 1982, Metcalf 1965, Moravets et al. 1942). Not all inventory years reported each estimate (growing-stock or Scribner sawtimber). Differences shown here represent a combination of real change and protocol differences over time such as use of stockability factors during periodic inventories and updated volume equations.

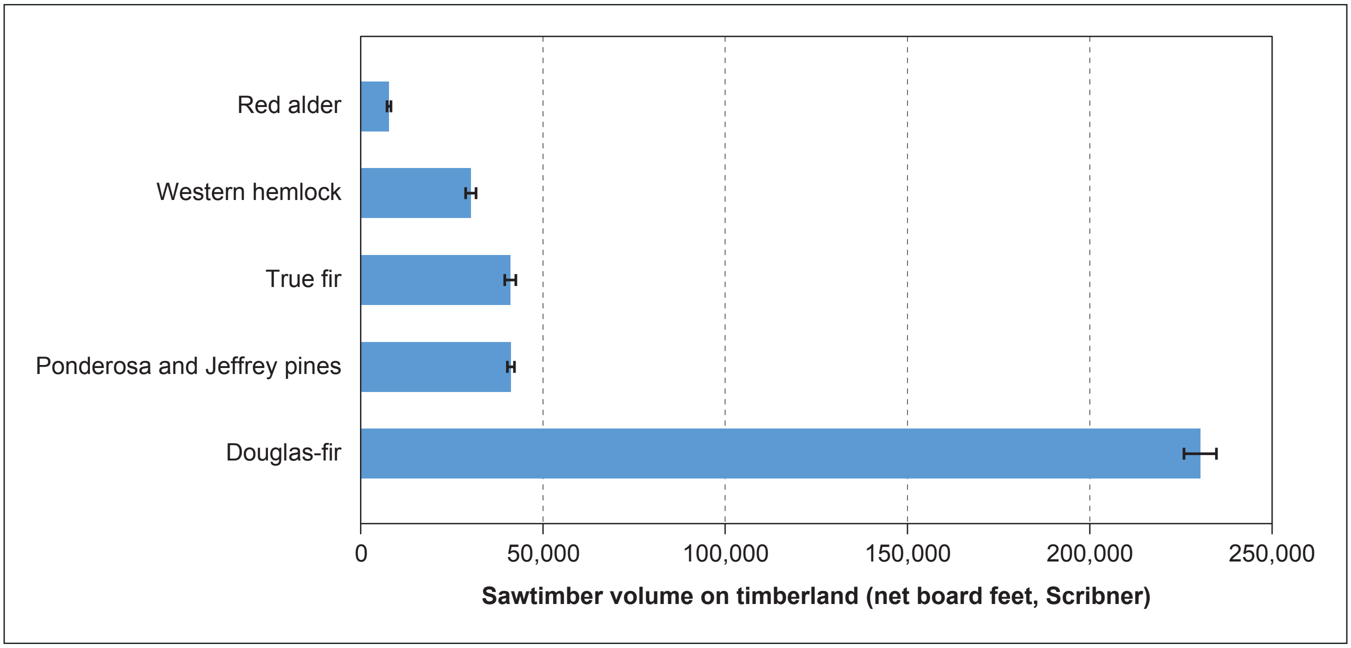


Figure 21—Scribner board-foot volume found on timberland by species group (five highest-volume species groups), Oregon, 2006–2015.

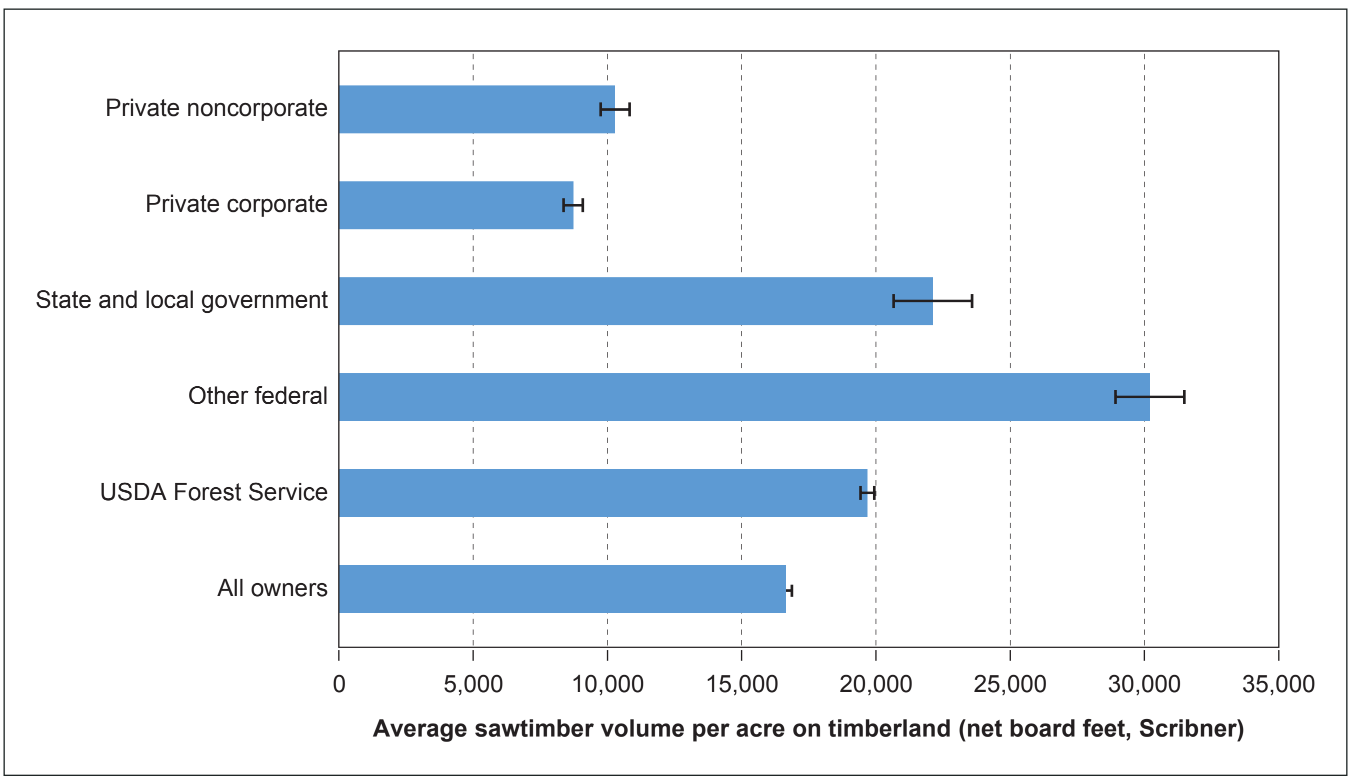
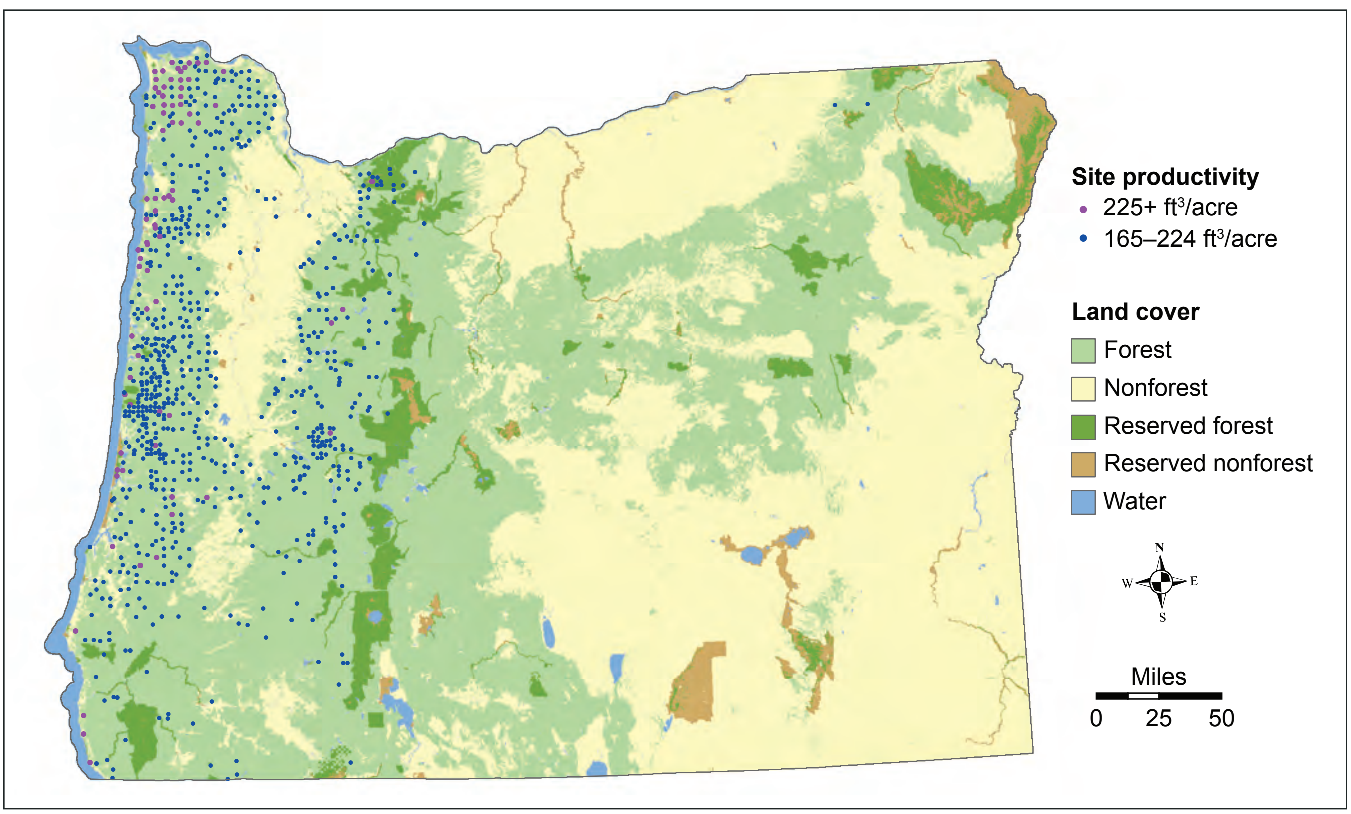


Figure 22—Average sawtimber tree volume per acre of timberland by ownership group (net board feet, Scribner), Oregon, 2006–2015.

M. Palmer

Figure 23—Northwest Oregon boasts the highest annual growth rates, such as this Douglas-fir stand in Clatsop County, where average annual gross growth is 197 ft^3 ac^{-1} yr^{-1}.



J. Chase

Figure 24—Forest Inventory and Analysis plots on highly productive sites, Oregon, 2006–2015. Seventy-six plots were classified as capable of at least 225 ft^3/ac and 730 plots capable of 165 to 224 ft^3/ac annual growth (forest/nonforest geographic information system layer: Blackard et al. 2008; Oregon boundary polygons: Oregon BLM).

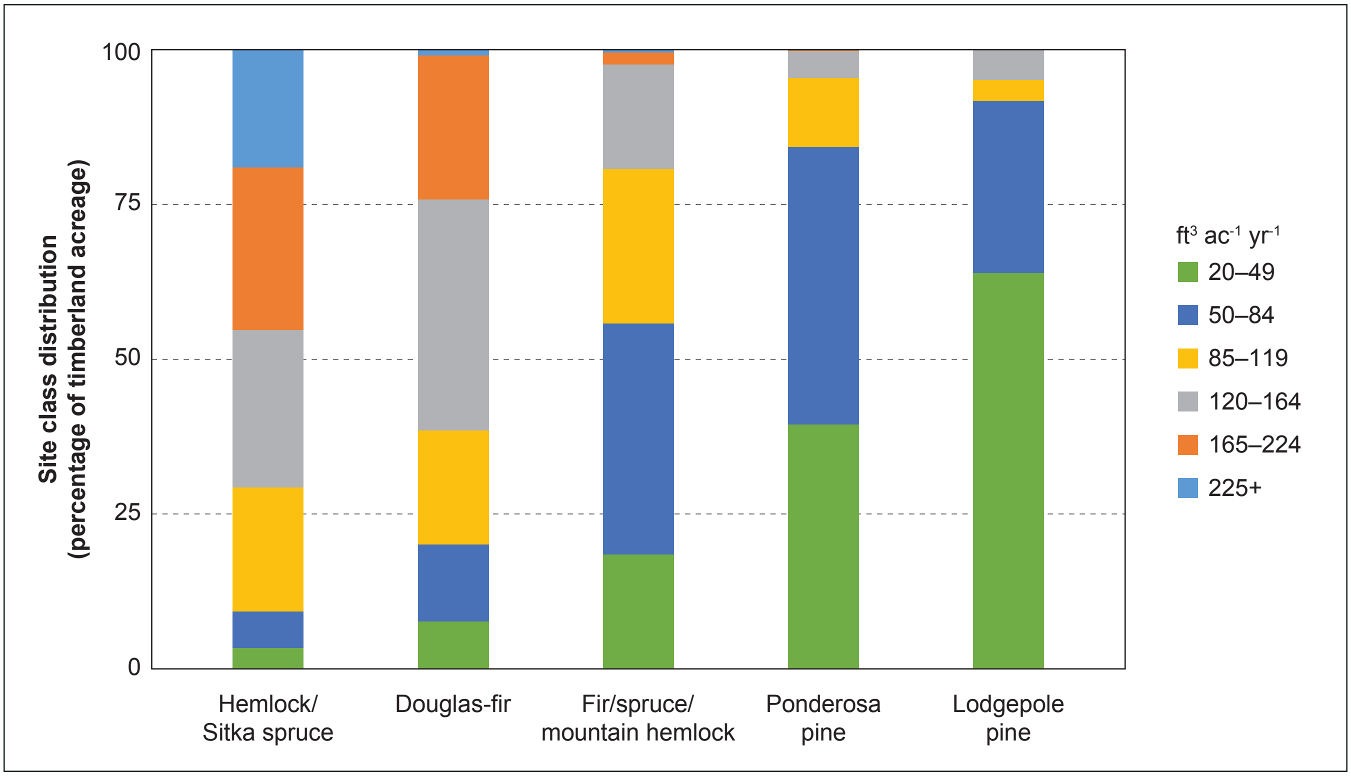


Figure 25—Timberland site class distribution for major forest type groups, Oregon, 2006–2015.

Average Annual Growth, Removals, and Mortality

One unique aspect of the FIA sampling design is the broad network of field plots across all forest land ownerships. Because the same plots and trees are measured each 10-year cycle, the FIA is able to provide a detailed accounting of forest growth, removals, and mortality (GRM). GRM estimates represent average annual rates over the entire measurement cycle, and the GRM estimates in this report include 4,594 forested plots initially installed in 2001–2005 and remeasured in 2011–2015, 50 percent of the Oregon FIA grid. As the second cycle is completed through 2020, the estimates reported here are not expected to change much, but their precision will improve.

Annual gross growth in Oregon averaged 95 ft^3 ac^{-1} yr^{-1} statewide and was threefold higher in western Oregon than eastern Oregon (fig. 26). Net change (defined as gross growth minus mortality and harvest removals) was positive for each ownership group, meaning that Oregon's forests are adding tree volume each year (table 5). Statewide, net change in volume was 35 ft^3 ac^{-1} yr^{-1} or a total addition to net volume of 1.0 billion ft^3 yr^{-1} (fig. 27, table 6). On both sides of the state, mortality rates are highest on NFS lands (34 ft^3 ac^{-1} yr^{-1}) and harvest removals are highest on corporate private land (105 ft^3 ac^{-1} yr^{-1}), which compares to statewide mortality and removal averages of 24 and 37 ft^3 ac^{-1} yr^{-1}, respectively.

Mortality rates (ratios of average annual mortality to original standing net volume) give an estimate of the tree volume lost each year to a variety of natural agents such as fire, insects, disease, weather, or competition. The average annual mortality rate in Oregon, in terms of tree volume, is 0.7 percent. Lodgepole pine and red alder have the highest mortality rates at 2.4 and 1.7 percent, respectively (fig. 28). Lodgepole pine is frequently attacked by mountain pine beetle (*Dendroctonus ponderosae*) and other insects; more than 60 percent of lodgepole pine tree mortality was attributed to insects. The most frequent causes of death noted for red alder were windthrow and suppression/competition. The mortality rate for a given species can be an indicator of forest health, but is also highly dependent of each species' life history or average stand age. Net growth is a better indicator of whether growth is offsetting mortality losses.

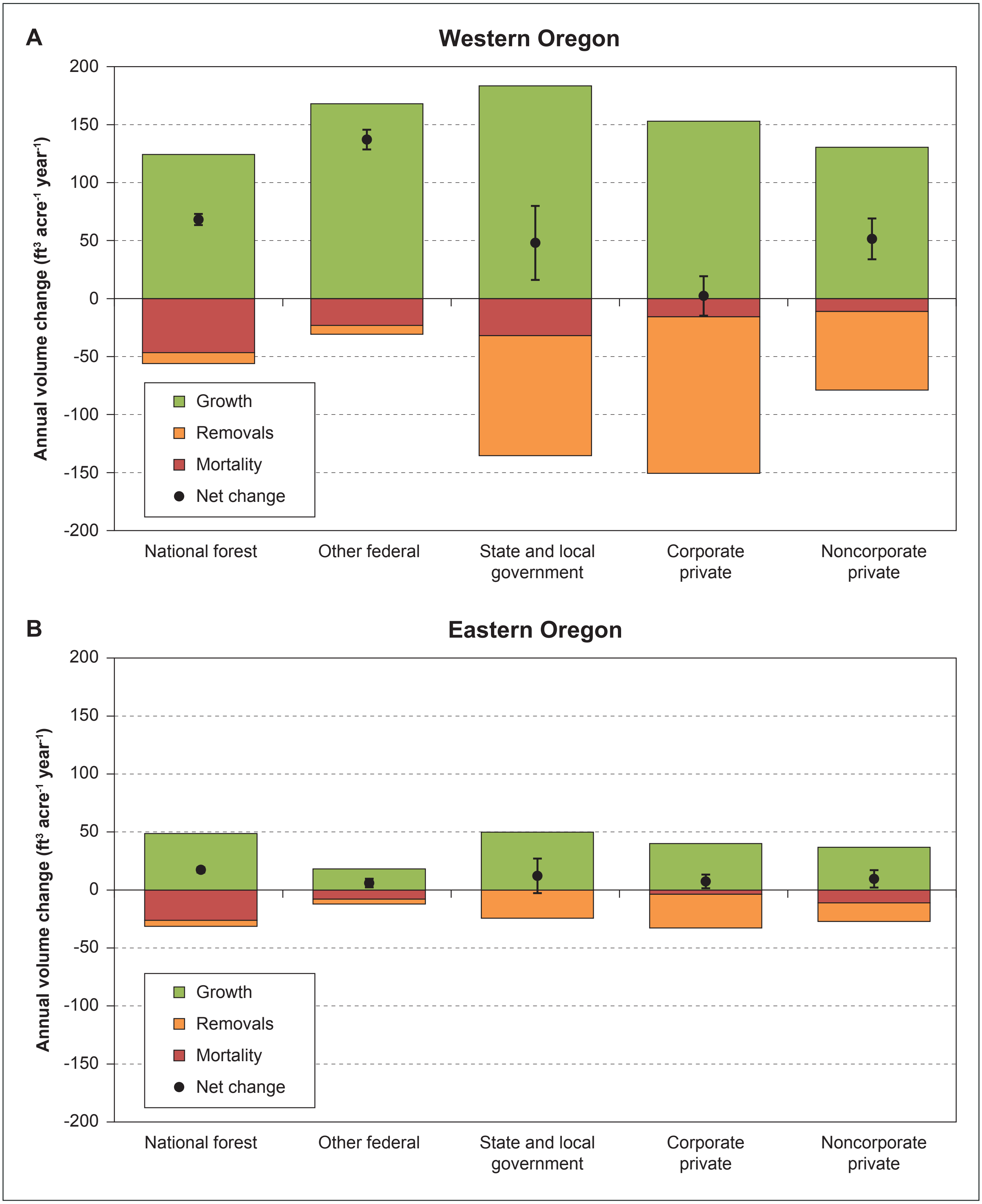


Figure 26—Average annual change in volume (cubic feet per acre per year) of growth, mortality, and removals between 2001–2005 and 2011–2015 by ownership group in (A) western Oregon and (B) eastern Oregon.

Table 5—Average annual volume (cubic feet per acre) growth, removals, and mortality on forest land by ownership group, Oregon 2001–2005 and 2011–2015

	Ownership group													
							Private							
	National forest		Other federal		State and local government		Corporate		Noncorporate		Total private		All owners	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Cubic feet per acre per year													
All Oregon:														
Growth	78.3	1.3	106.9	5.2	156.4	10.2	120.5	4.6	82.5	4.9	107.6	3.4	95.4	1.5
Mortality	34.1	1.7	16.9	2.2	28.1	6.4	12.1	1.6	11.0	1.8	11.7	1.2	23.7	1.0
Removals	6.9	0.8	6.3	2.2	87.6	22.1	104.6	10.5	41.4	8.4	83.2	7.4	37.3	2.8
Net change	37.2	2.3	83.7	5.7	40.8	25.7	3.8	12.2	30.1	9.5	12.7	8.7	34.5	3.5
Eastern Oregon:														
Growth	48.7	1.0	18.1	3.3	49.8	11.2	40.1	2.6	36.8	3.2	38.5	2.0	42.6	0.9
Mortality	26.1	2.0	7.9	2.7	13.2	7.0	3.6	0.9	11.0	3.1	7.1	1.6	18.8	1.3
Removals	5.3	0.6	4.2	1.6	24.3	14.6	29.1	5.6	16.2	6.3	22.9	4.2	10.3	1.2
Net change	17.3	2.2	6.0	3.7	12.2	14.9	7.4	5.9	9.6	7.5	8.4	4.7	13.6	1.9
Western Oregon:														
Growth	124.3	2.8	167.9	7.5	183.4	10.6	153.0	6.0	130.4	8.1	147.1	4.8	144.1	2.7
Mortality	46.6	3.2	23.1	3.2	31.9	7.8	15.6	2.2	11.1	1.8	14.4	1.7	28.2	1.5
Removals	9.5	1.8	7.7	3.5	103.6	27.5	135.1	14.5	67.8	15.6	117.6	11.4	62.1	5.3
Net change	68.2	4.8	137.1	8.5	48.0	31.9	2.3	17.0	51.5	17.6	15.1	13.4	53.8	6.5

Net growth, in forestry terms, is defined as the gross growth minus mortality losses. All species groups in Oregon exhibit positive net growth. Sugar pine and lodgepole pine have negligible annual net growth rates of 0.1 and 0.2 percent, respectively, while the five highest volume species groups in the state are all adding volume at rates between 1.5 and 2.6 percent annually. Sitka spruce represents less than 1 percent of total tree volume yet has the highest annual net growth rate, more than 2.8 percent, compared to an average net growth rate for all species groups in Oregon of 2.2 percent (fig. 29).

The vast majority (80 percent or 889 million ft^3 annually) of harvest removals in Oregon occur on private forest land. National Forest System, state, and local ownerships each make up an additional 9 percent of annual harvest removals. Sixty-six percent of tree volume removed from forest land is Douglas-fir, which is the state's most valuable timber species, while western hemlock comes in second place with just 11 percent of the removed volume (fig. 30).

The net growth-to-removals ratio is an indicator of sustained yield, where >1 ratios indicate that more tree volume is growing than is being harvested but <1 ratios show that the available resource is being depleted. The desirable net growth-to-removals ratio depends on the land management objective; in areas being managed for timber production a ~1 ratio may be a management goal. In Oregon, the average net growth-to-removals ratio is 1.93, meaning that each year Oregon's forest lands add almost twice as much tree volume as is removed, after accounting for mortality losses. Two tree species are declining in terms of volume: sugar pine (0.15) and lodgepole pine (0.29). Both of these species have very minimal harvest removals but high mortality rates. Both state and federal agencies support programs to aid in the removal of western juniper, which has expanded well beyond its historical range and can degrade rangelands normally dominated by big sagebrush. Despite removal activities on both public and private lands, western juniper has a net growth-to-removals ratio of 1.49.

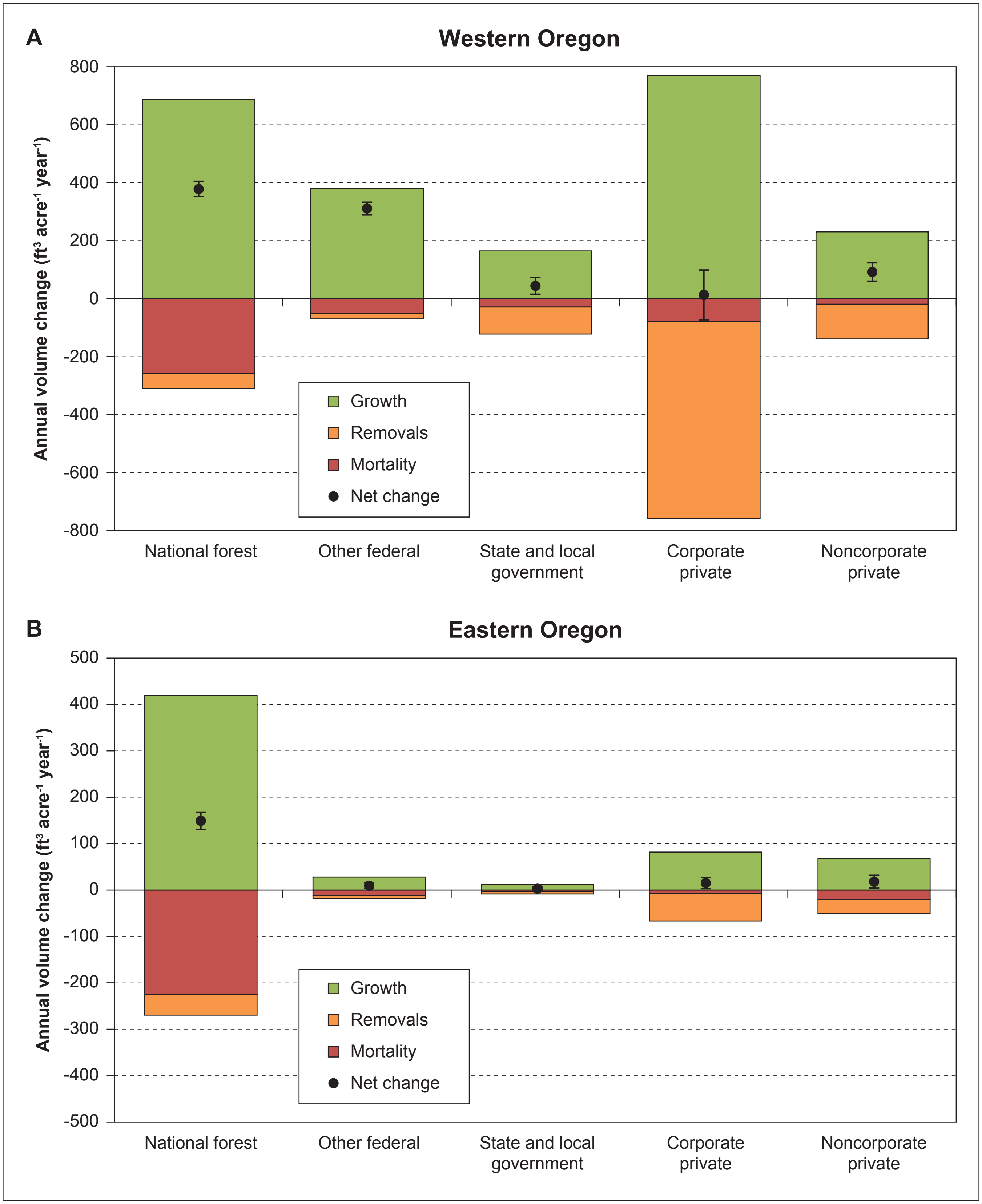


Figure 27—Average annual change in volume (cubic feet per year) of growth, mortality, and removals between 2001–2005 and 2011–2015 by ownership group in (A) western Oregon and (B) eastern Oregon.

Table 6—Average annual volume (cubic feet) growth, removals, and mortality on forest land by ownership group, Oregon 2001–2005 and 2011–2015

	Ownership group													
							Private							
	National forest		Other federal		State and local government		Corporate		Noncorporate		Total private		All owners	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Thousand cubic feet per year													
All Oregon:														
Growth	1,106,703	17,849	407,823	19,002	175,971	12,394	851,459	38,338	298,019	22,633	1,149,478	37,779	2,839,975	46,135
Mortality	482,458	24,519	64,450	8,343	31,615	7,329	85,658	11,620	39,815	6,833	125,473	13,173	703,996	29,927
Removals	97,817	11,169	23,954	8,225	98,504	24,732	739,014	75,133	149,578	31,060	888,592	78,911	1,108,866	83,308
Net change	526,429	32,266	319,419	21,424	45,852	29,057	26,787	86,457	108,626	34,659	135,413	93,096	1,027,113	104,728
Eastern Oregon:														
Growth	419,081	9,317	28,031	5,592	11,330	3,313	81,522	7,596	68,063	7,824	149,585	10,247	608,027	15,180
Mortality	224,744	17,219	12,249	4,357	3,005	1,709	7,359	1,889	20,315	5,978	27,674	6,205	267,672	18,892
Removals	45,229	5,229	6,473	2,544	5,540	3,564	59,182	12,093	29,947	11,925	89,129	16,810	146,370	18,130
Net change	149,108	18,705	9,310	5,836	2,784	3,362	14,982	12,096	17,800	13,917	32,782	18,370	193,984	27,078
Western Oregon:														
Growth	687,623	16,216	379,791	20,013	164,641	12,592	769,937	38,743	229,957	21,980	999,893	39,479	2,231,948	47,727
Mortality	257,714	17,960	52,201	7,409	28,610	7,166	78,299	11,495	19,500	3,404	97,799	11,816	436,324	23,803
Removals	52,588	9,883	17,481	7,826	92,963	24,474	679,832	74,796	119,631	28,753	799,463	78,134	962,496	82,325
Net change	377,320	26,407	310,109	21,389	43,068	28,947	11,806	85,694	90,826	31,717	102,631	91,324	833,129	101,461

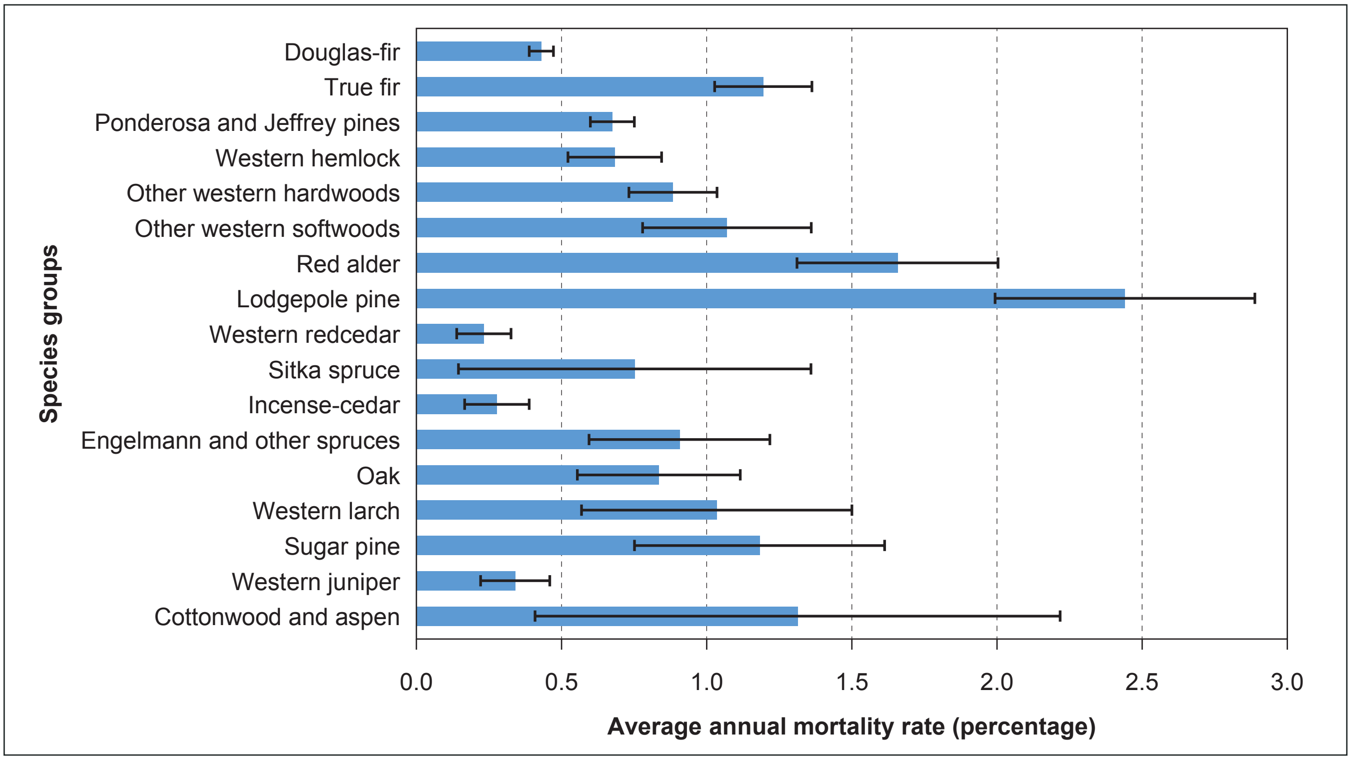


Figure 28—Average annual mortality rates (percent) for species groups on forest land, Oregon, 2015. Species groups are shown ordered by total net standing volume; average annual mortality rate for all species is 0.7 percent.

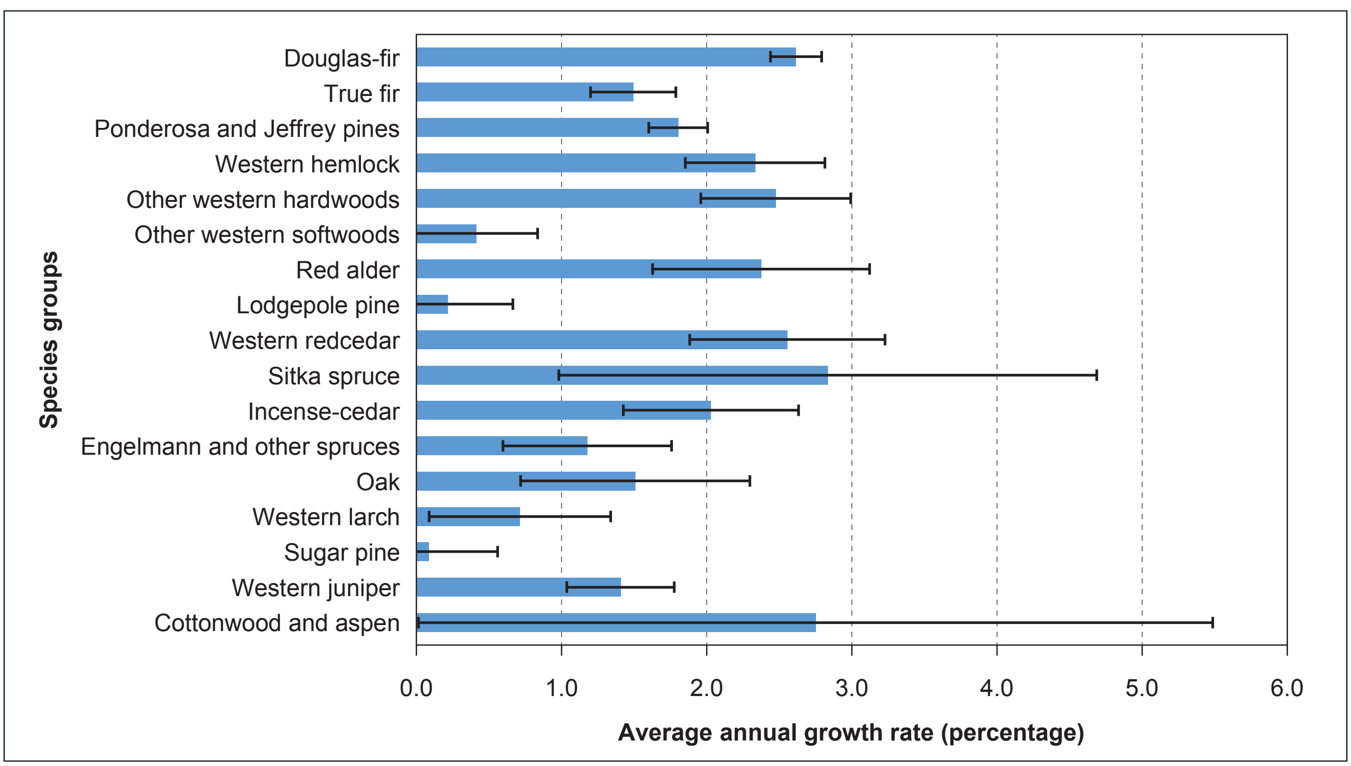


Figure 29—Average annual net growth rates (percent) by species group for all live trees on forest land, Oregon, 2015. Species groups are shown ordered by total net standing volume.

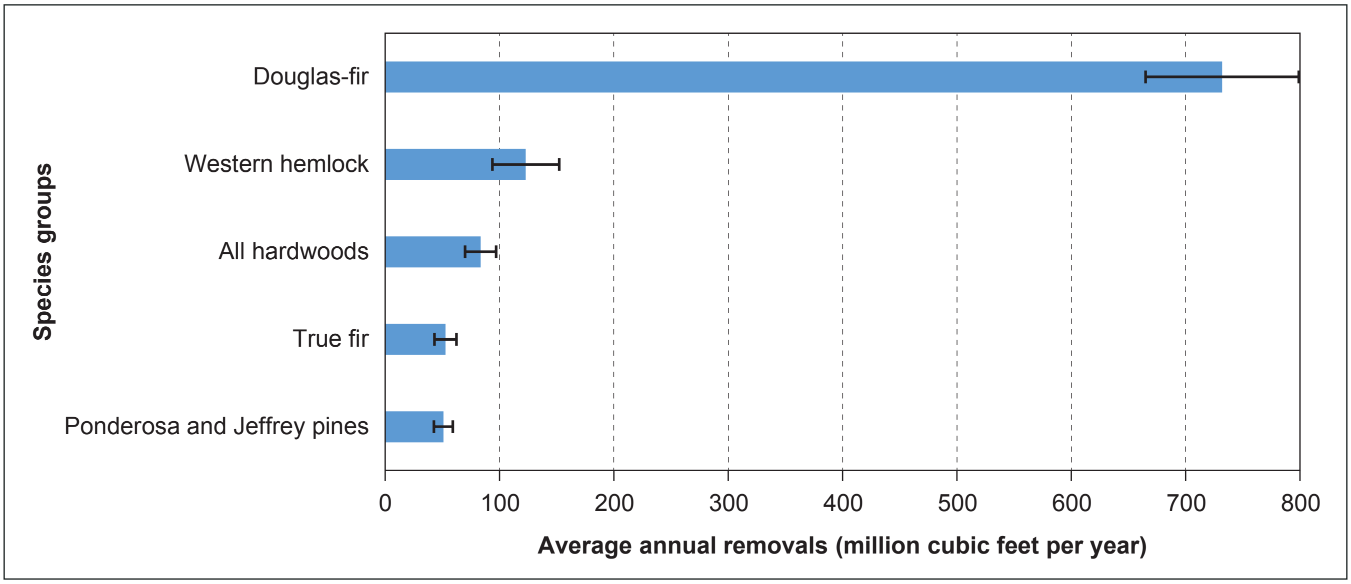


Figure 30—Average annual removals (tree harvest and forest to nonforest diversion) for selected species groups on forest land, Oregon, 2015.

Research Application: Evaluating the Feasibility of Accelerating Forest Restoration in the Blue Mountains Region[3]

Accelerating the pace and scale of forest restoration has been of keen interest to state and federal agencies in the Blue Mountains region of eastern Oregon (FAC 2012, USDA FS 2013), an area encompassing 3 million ac of unreserved forest land (fig. 31). In a partnership with the Oregon Department of Forestry, we modelled the effectiveness of restoration treatments over a 40-year period, estimating potential net revenues (revenue from sales of wood, less operations and transportation costs). We applied the BioSum modeling framework (Fried et al. 2017), which relies on Forest Inventory and Analysis (FIA) plot data as a representative sample of current forest fire hazard levels, then simulated 34 different silvicultural treatments with the Forest Vegetation Simulator. Our goal was to understand how the choice of restoration treatment affects economic costs across the landscape, and consequently, the proportion of the landscape for which forest restoration can be accomplished.

To evaluate current fire hazard and to assess the effectiveness of silvicultural sequences in reducing fire hazard over time, we computed a hazard score (0–4) for each stand as it currently exists and at 10-year intervals over 40-year trajectories associated with each of up to 34 simulated silvicultural treatments. Methods are defined in Loreno et al. (2015) and Jain et al. (2012). Treatments that reduce a stand's mean hazard score compared to no treatment are deemed effective, and the treatment that reduces hazard score the most is assumed "best" for that stand. Treatment and haul costs and revenues from wood production determine the economic feasibility of each silvicultural sequence.

When best silvicultural sequences are implemented, hazard is initially reduced to a considerable extent (Loreno et al. 2015), though hazard score is reduced to zero on only about half of the area (fig. 32). As ladder fuels and stand density rebound, hazard reduction benefits gradually fade, so the immediate effect is perhaps not the best policy driver. For that reason and because stands are most ready to receive treatment at different times, depending on their stage of development, we chose to base effectiveness on the 40-year mean hazard score.

[3] Authors: Jeremy Fried and Sara Loreno.

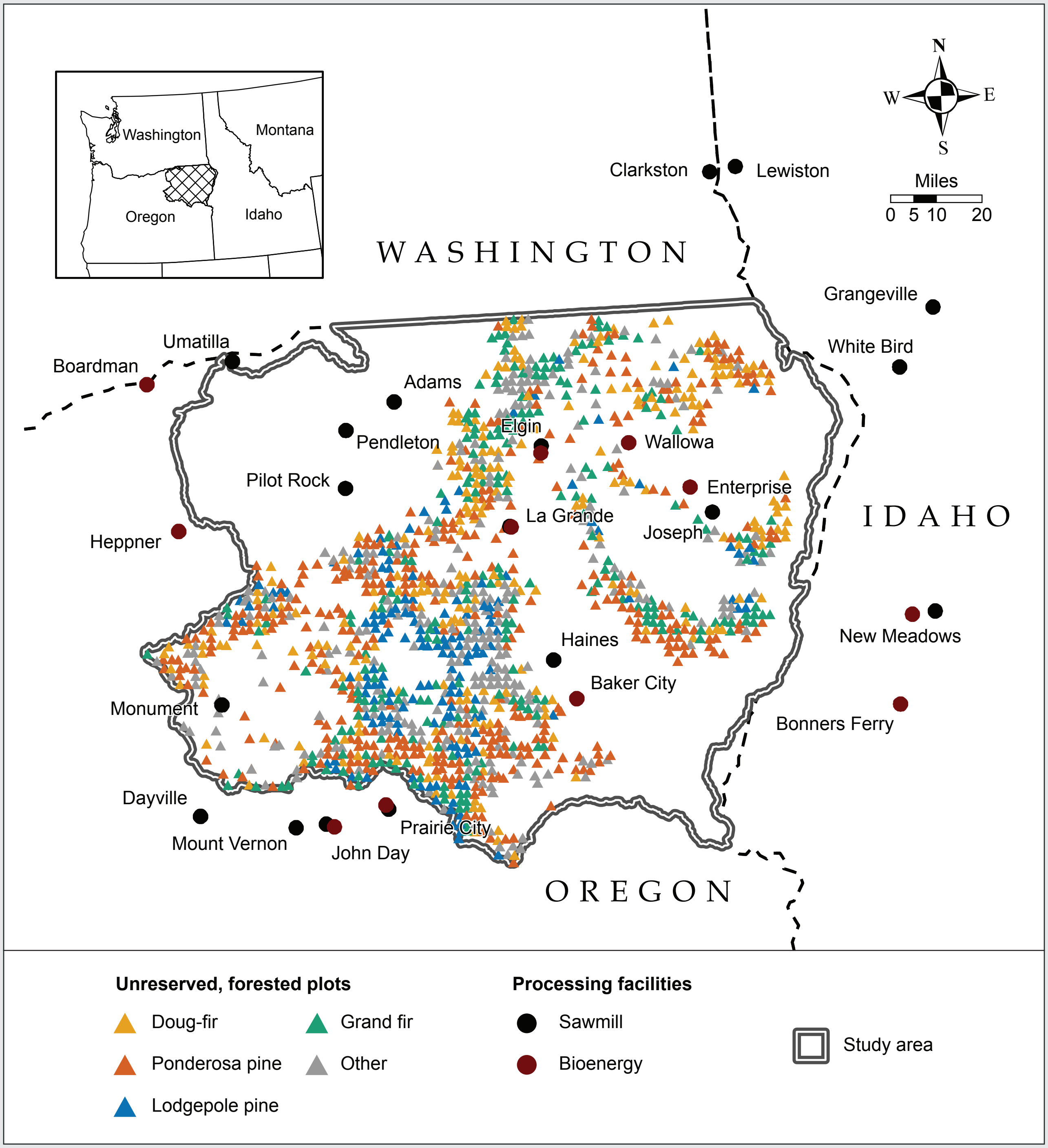


Figure 31—Location of study plots and processing facilities within the Blue Mountain region.

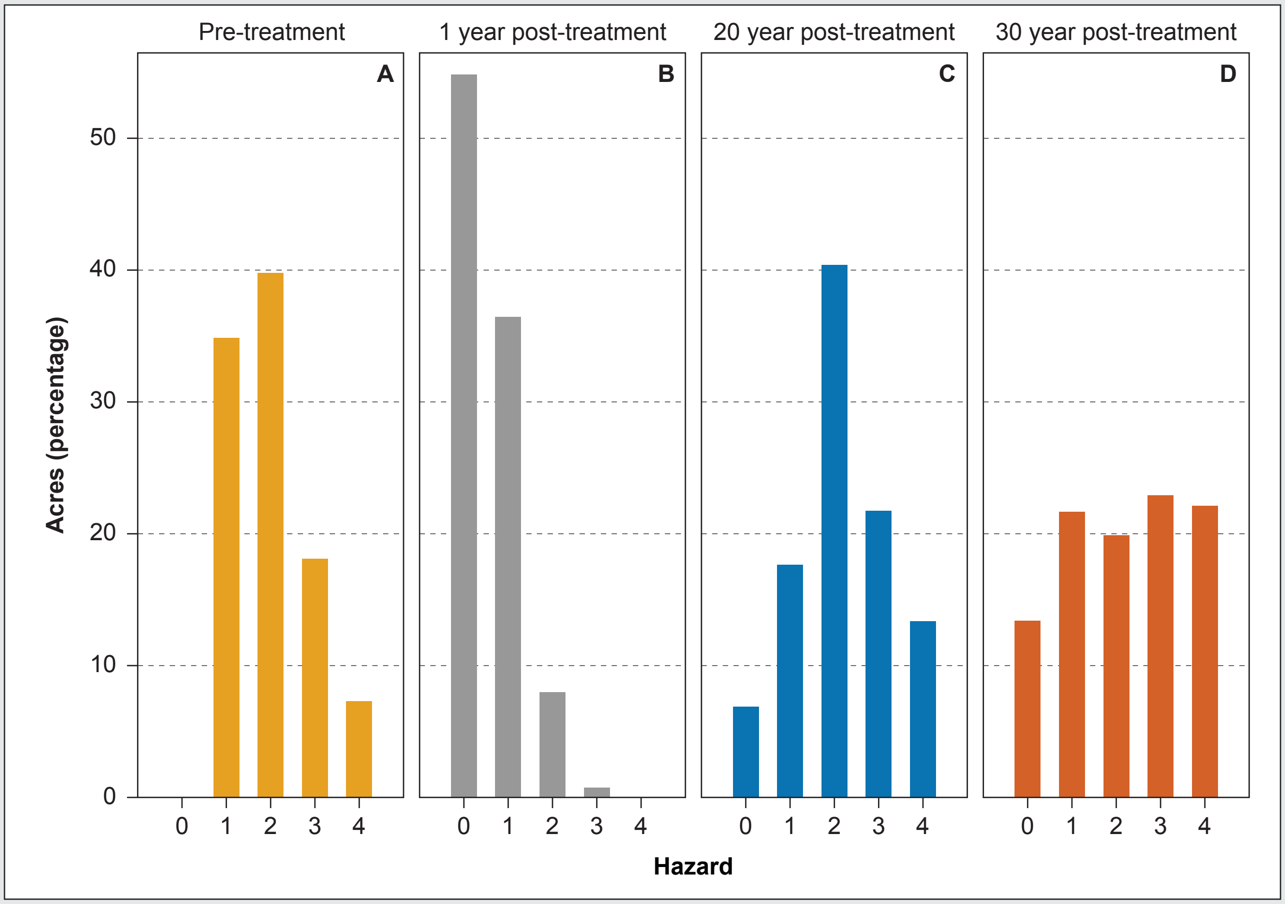


Figure 32—Distribution of area by hazard score for stands in which a treatment sequence could begin today with immediate effect. (A) Before the first treatment in the sequence, (B) 1 year later, (C) 20 years later, and (D) 30 years later. Note that hazard distribution reflects the retreatment of some of these stands at year 20 or 30, as specified by the most effective silvicultural sequence for those stands.

Only 15 percent of the Blue Mountains forest area is hazard free, and the percentage of forest at hazard scores 1–4 is currently 28, 26, 18, and 13 percent, respectively. If cost were not a consideration, at least one of the silvicultural sequences we modeled would be effective on 54 percent of private and 67 percent of NFS area with current hazard scores between 1 and 4. If revenues must cover treatment costs, the effective areas would decrease to 43 and 55 percent, respectively. Although this analysis does not account for planning and administrative costs, it is clear that most forests in the region can realize at least some improvement in fire resistance if a broad spectrum of treatments are available from which to choose, without requiring significant subsidy. Constraining treatment choices, however, reduces the share of the forest that can benefit. For example, if a diameter cap of 30 inches is replaced with a 21-inch limit on the maximum tree size that can be harvested, the effectively treatable area drops to 36 percent overall (on both private and NFS ownerships), and if proportional thinning (across all diameter classes) is removed as an option, leaving only thin-from-below treatments as alternatives to select from, it drops to 32 percent. While thin-from-below treatments are, on average, slightly more effective than proportional thins (average improvement in a 40-year mean hazard score of

0.675 versus 0.579 points), net revenue is much greater with a proportional thin owing to the harvest of more merchantable wood (fig. 33). Net revenue is also substantially greater, on average, with larger upper limits on the size of trees that may be removed. Either shifting from thin-from-below to a proportional thin or relaxing the diameter cap from 21 to 30 inches moves the average net revenue from a negative to a positive value of more than $700 per acre. The pace of restoration could be accelerated by moving forward now with the treatment of stands where net revenue is positive as little or no subsidy would be required. If net revenues from these acres can be retained and redirected to subsidize other priority acres where treatment costs exceed revenues, this could also present an opportunity to increase the scale of forest restoration.

A fully implemented fuel treatment program in the Blue Mountains region has the potential to produce substantial quantities of merchantable and energy wood as well as a net revenue (table 7) that could be important to the rural communities where this work would be conducted (table 5). Area treated annually increases as more acres attain treatment readiness and other acres treated in the first two decades become eligible for retreatment. Yield and net revenue likely decline over time owing to the availability of fewer high-value (e.g., larger) trees at the retreatment opportunity such that the self-pay requirement cannot be met, suggesting that subsidies may become more important in the future if hazard reduction is to be maintained on acres where this is a priority.

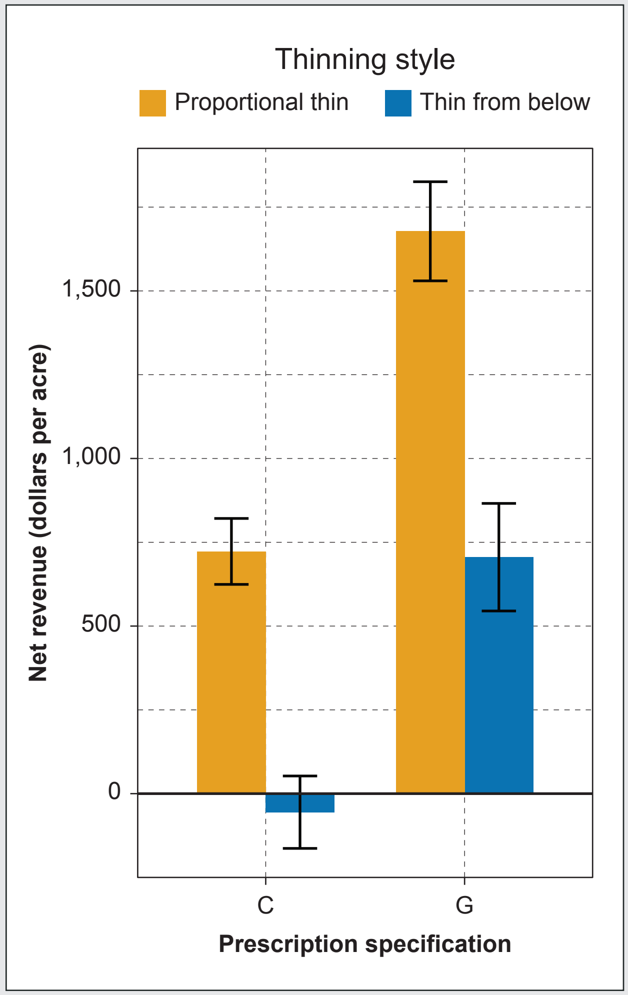


Figure 33—Mean net revenue for thin-from-below and proportional thin versions of two prescriptions, one with an upper limit of 21 inches on the diameter of trees eligible for removal and one with a 30-inch limit; both prescriptions thin all trees greater than 5 inches diameter at breast height to a residual basal area of 75 ft^2/ ac using ground-based mechanical whole-tree harvest, rely on prescribed fire to reduce surface fuels, and are repeated in any decade (after skipping one decade) in which basal area exceeds 110 ft^2/ac.

Table 7: Average annual estimates for the four decade planning horizon in the Blue Mountains region.

Time Period	Area Treated	Energy Wood Yield	Merchantable Wood Yield	Net Revenue
	Acres	- - - - - - - *Million cubic feet*	- - - - - - -	*Dollars*
Years 1-20	39,440	40,855	88,568	$81,965,000
Years 21-40	50,434	35,460	64,980	$25,099,000

Note: wood yield is classified as merchantable (delivered to facilities) or non-merchantable (delivered to bioenergy generators) based on species or size. Net revenue equals sales of wood minus treatment and transportation costs.

The BioSum framework used for this analysis is now available for anyone to use for analysis in five western states: California, Oregon, Washington, Idaho, and Montana. It facilitates prospective analysis of all kinds of scenarios involving alternative forest futures using the FIA plot data as a test bed. Software, documentation, articles describing its use, and sample data can be obtained at http://www.biosum.info.

Literature Cited

Federal Forest Advisory Committee [FFAC] 2012. National forest health restoration: an economic assessment of forest restoration on Oregon's eastside national forests. Prepared for: Governor John Kitzhaber and Oregon's Legislative Leaders. Portland, OR: Portland State University Northwest Economic Research Center. 94 p. https://www.pdx.edu/nerc/sites/www.pdx.edu.nerc/files/Forest%20Restoration%20Final%20Report_0.pdf. (24 May 2018).

Fried, J.S.; Potts, L.D.; Loreno, S.M.; Christensen, G.; Barbour, J.R. 2017. Inventory based landscape-scale simulation of management effectiveness and economic feasibility with BioSum. Journal of Forestry. 115: 249–257.

Jain, T.J.; Battaglia, M.A.; Han, H.S.; Graham, R.T.; Keyes, C.R.; Fried, J.S.; Sandquist. J.E. 2012. A comprehensive guide to fuel management practices for dry mixed conifer forests in the northwestern United States. Gen. Tech. Rep. RMRS-GTR-292. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 331 p. https://www.fs.usda.gov/treesearch/pubs/42150. (24 May 2018).

Loreno, S.; Fried, J.S.; Yost, A. 2015. Applying management modeling to assess the feasibility of accelerating landscape restoration on federal forests in eastern Oregon. In: Stanton, S.M.; Christensen, G.A., comps. Pushing boundaries: new directions in inventory techniques and applications: Forest Inventory and Analysis (FIA) symposium 2015. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 260–265. https://www.fs.usda.gov/treesearch/pubs/50355. (24 May 2018).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2013. Accelerated restoration. Portland, OR: Pacific Northwest Region. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5423599.pdfhttps://www.fs.usda.gov/detail/r6/landmanagement/resourcemanagement/?cid=stelprdb5423597. (19 December 2017).

Wildlife Habitat

Standing dead trees (snags) and down dead wood provide key habitat components for forest wildlife in addition to their roles in carbon storage and nutrient cycling (fig. 34). Dead wood forest components are used by a variety of bird, mammal, and amphibian species for nesting, roosting, foraging, hibernating, and thermal cover (Rose et al. 2001). While local patterns and locations of dead wood structures are important in identifying species-specific habitat, broad-scale estimates of dead wood provided by the FIA are useful in comparisons within or across forest types or disturbance histories.

There are 571 million standing dead trees in Oregon, 37 percent occurring on Douglas-fir forest types. This amounts to 19 snags per acre on average, with >25 snags per acre in stands older than 100 years. The amount of snags and down wood varies considerably by ownership, with the vast majority of snag biomass (165 million tons) and highest density of total snags (27 per acre) occurring on NFS lands and the lowest snag densities (11 per acre) on private lands (figs. 35 and 36).

The amount and distribution of down wood is highly variable among sites, often dictated by recent management and natural disturbances; however, broad-scale trends are evident. Expressed as volume, Oregon forests average 1,580 ft^3 of down wood per acre, 11 percent less than Donnegan et al.'s (2008) estimate for 2001–2005 of 1,779 ft^3/ac. There are on average 11.6 tons of down wood per acre, with almost twice as much on the moist west side of the state (fig. 37). Down-wood density is highly variable among forest type groups, ranging from more than 26 tons per acre on fir/spruce/mountain hemlock sites to just 1.4 tons per acre on western juniper forest types.

Figure 34—Large coarse woody debris pieces serve important roles in wildlife habitat and nutrient cycling on forest lands.

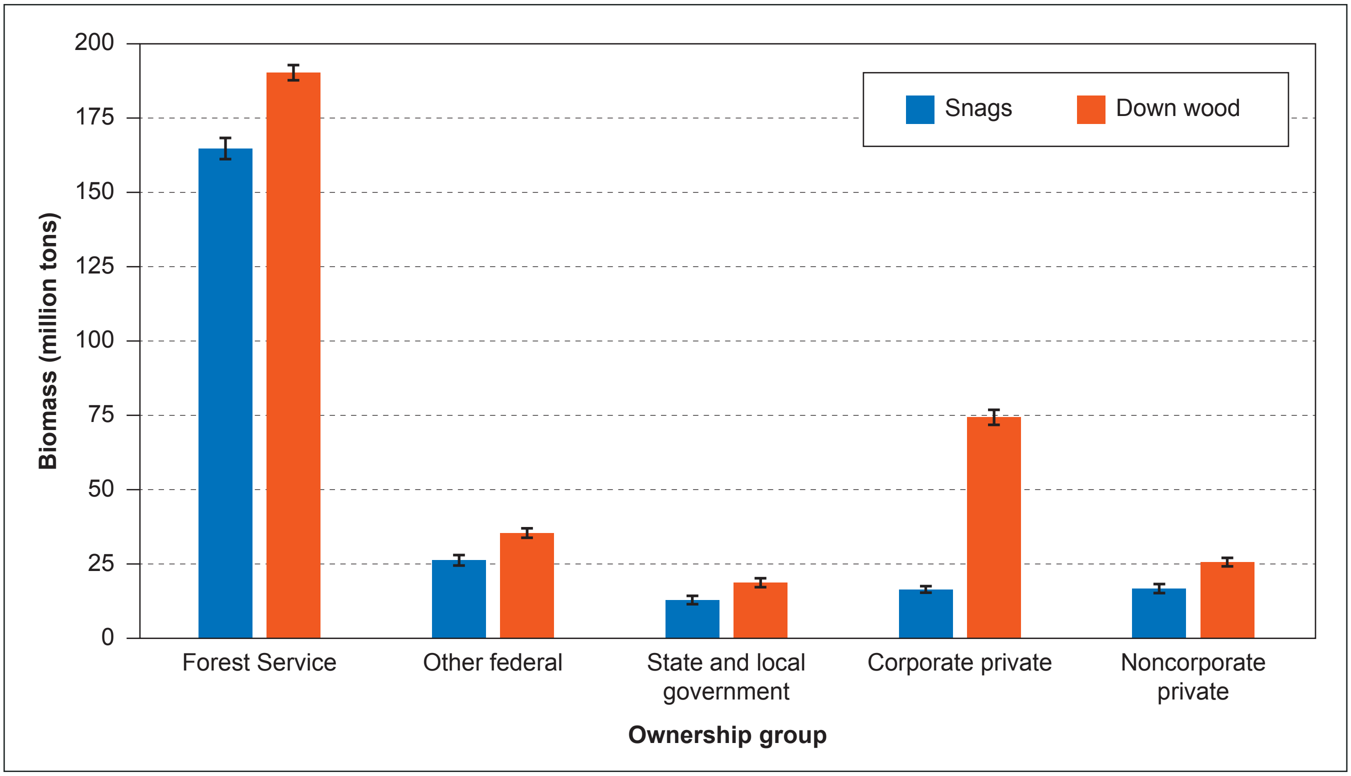


Figure 35—Total biomass (million tons) in standing dead trees (snags) and down wood by ownership group, Oregon, 2006–2015.

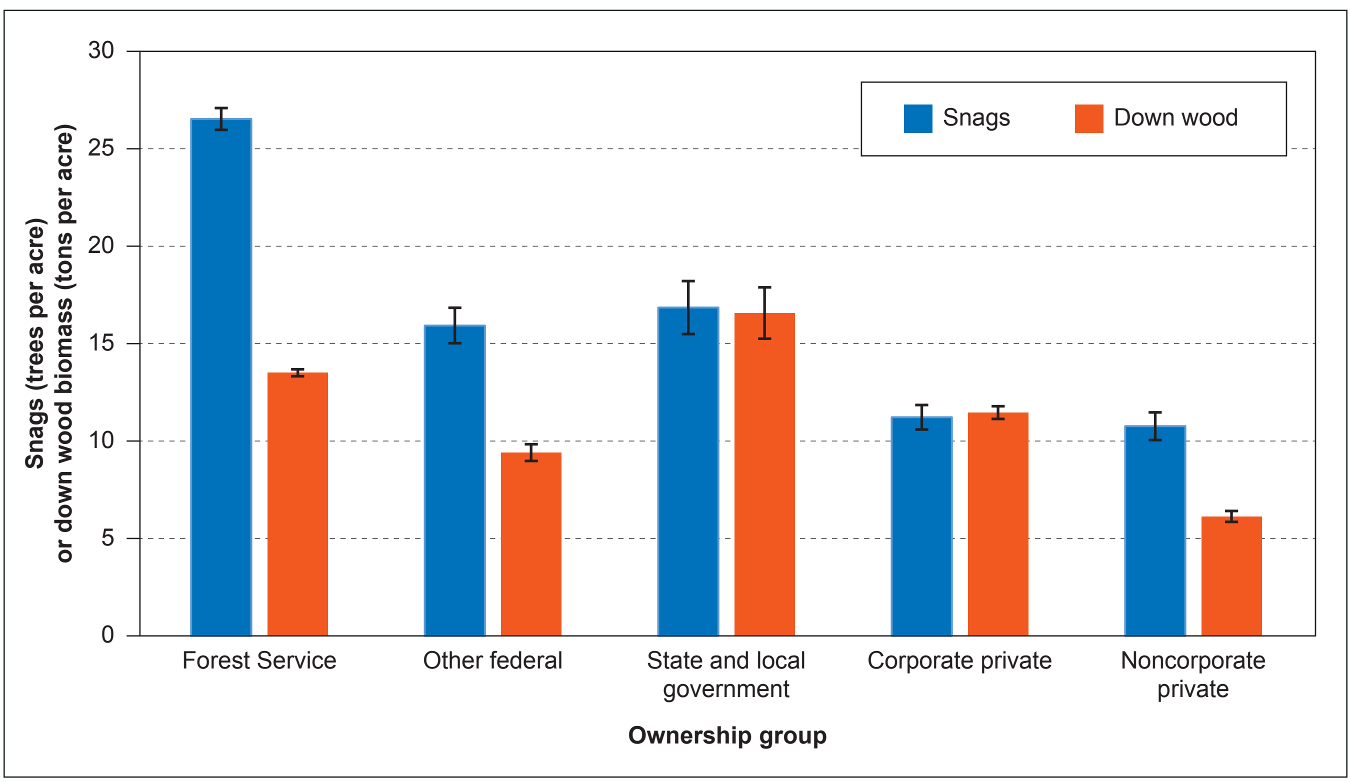
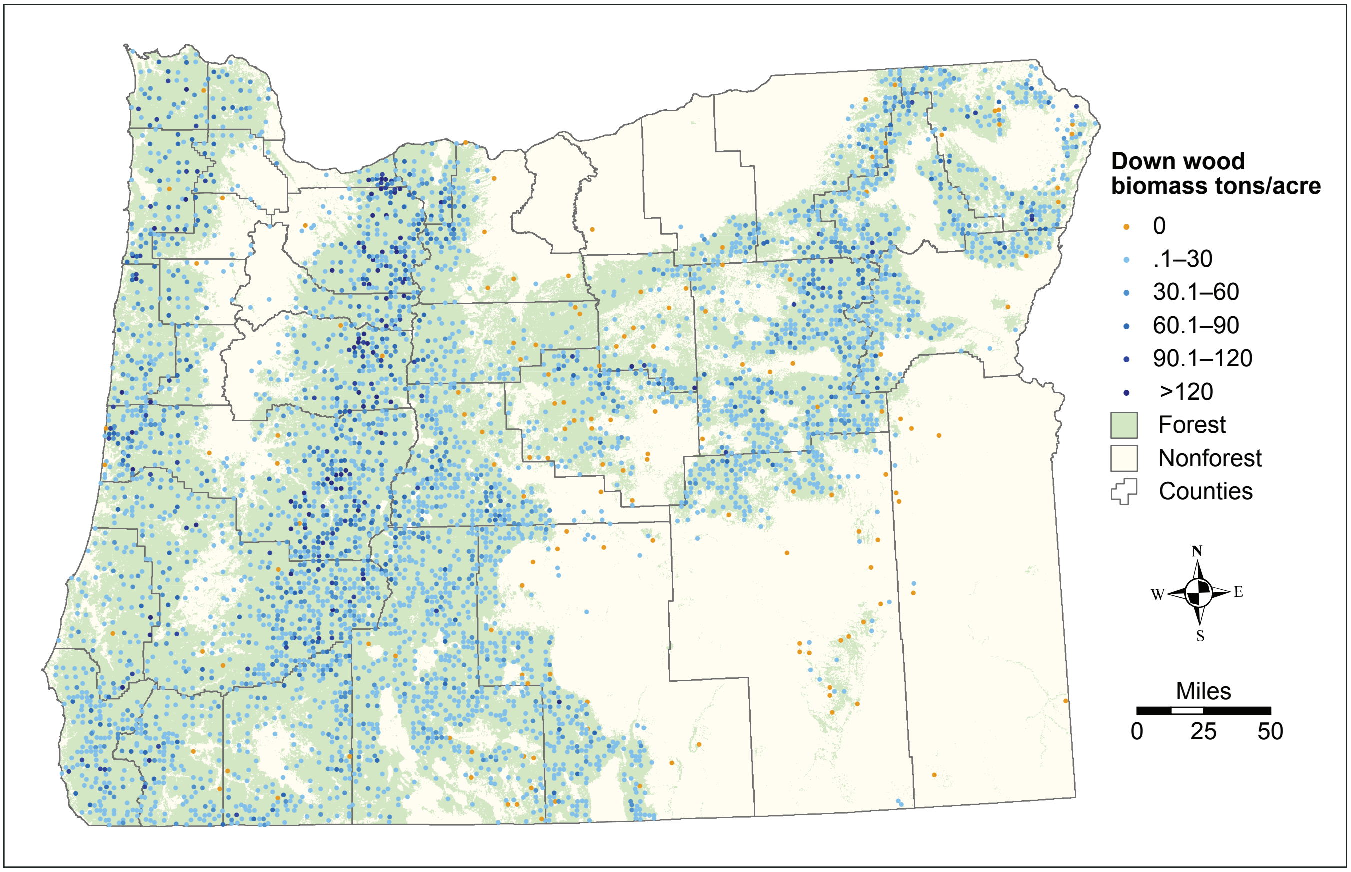


Figure 36—Average number of standing dead trees (snags) per acre and down wood biomass (tons) per acre by ownership group, Oregon, 2006–2015.



J. Chase

Figure 37—Plot distribution of total down wood biomass (tons per acre), Oregon, 2006–2015 (forest/nonforest geographic information system layer: Blackard et al. 2008; Oregon boundary polygons: Oregon Bureau of Land Management). Map: J. Chase.

Research Application: Unpacking Vegetation Mapping Uncertainties[4]

The Forest Inventory and Analysis (FIA) program provides consistent and extensive sampling of forest characteristics and conditions across all U.S. forest lands, but at finer scales higher plot sampling density is desired to improve support for forest planning, monitoring, and decisionmaking. Increased computing power and availability of high-quality satellite imagery offers several opportunities for creating small-area estimates that leverage FIA data for mapping and estimation at finer scales than using FIA data alone. In the Pacific Northwest, gradient nearest neighbor (GNN) imputation has emerged as a powerful tool for informing forest monitoring and planning. Imputation involves the substitution of observations (FIA plot data) for missing data (unmeasured pixels), providing wall-to-wall maps of forest attributes. For entire forested landscapes and regions, the flexible and multivariate GNN approach imputes, or maps, data to a location from the FIA plot that best matches a pixel in terms of satellite imagery,

[4] Author: David M. Bell.

climate, and topography. However, the utility of the resulting maps must be tempered by an understanding of the inherent uncertainties, such as the precision, or variability, of predictions.

In a collaboration between Pacific Northwest Research Station and Oregon State University scientists, we modified existing methods for generating pixel-level measures of imputation-map uncertainties for GNN and examined the geographic patterns of uncertainties in live tree structure, dead tree structure, and species composition across regional environmental gradients in the western Cascade Mountains of Oregon (Bell et al. 2015). We found that live tree structure, which is directly observed by satellite imagery, exhibited the greatest prediction precision, while dead tree structure and composition exhibited less prediction precision. Spatial variation in precision was substantial and regional patterns differed by forest attribute under consideration. These patterns implied that imputation uncertainty may be tied to regional biogeography and disturbance history: mapping certain vegetation types and seral stages involved greater uncertainty than others. For example, quadratic mean diameter, a measure of tree sizes, exhibited substantial uncertainty in postfire environments whereas live aboveground forest biomass exhibited relatively high precision in predictions within the fire, but low precision in neighboring undisturbed old-growth forest (fig. 38). Additionally, this research has identified methods to operationalize pixel-level precision mapping for GNN, allowing for future map distributions to include maps of variable uncertainties along with traditional accuracy assessment reporting.

Literature Cited

Bell, D.M.; Gregory, M.J.; Ohmann, J.L. 2015. Imputed forest structure uncertainty varies across elevational and longitudinal gradients in the western Cascade Mountains, Oregon, USA. Forest Ecology and Management. 358: 154–164.

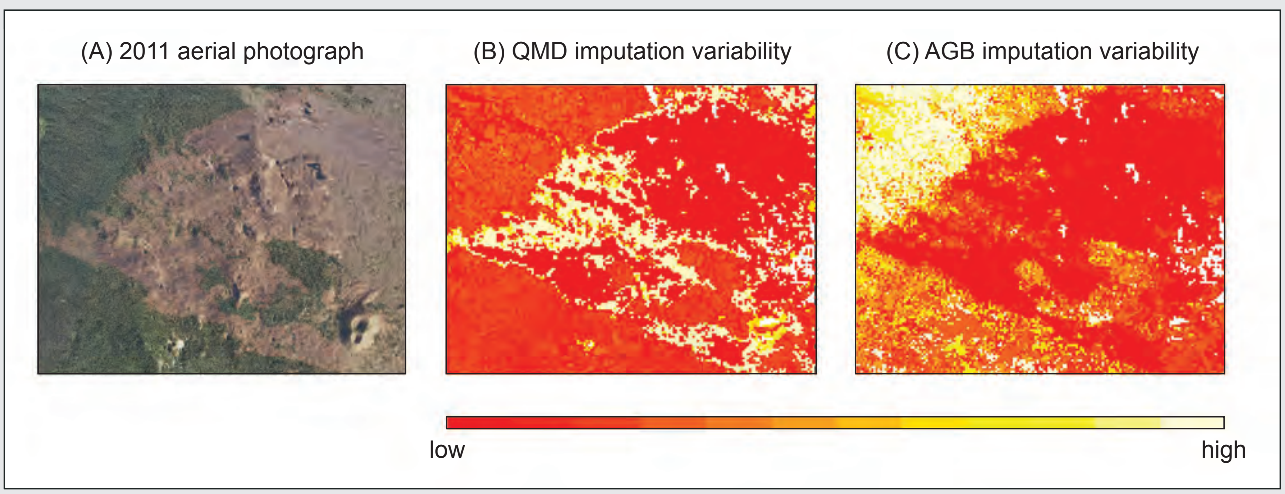


Figure 38—Representation of the impacts of the Scott Mountain Fire west of Sisters, Oregon, on prediction precision. (A) Postfire aerial photograph, (B) quadratic mean diameter (QMD) prediction precision, (C) aboveground live biomass (AGB) prediction precision. Figure reproduced with permission from Bell et al. (2015).

Understory Vegetation and Nontimber Forest Products

Understory vegetation composition in forest communities has long been used as an indicator of forest health, moisture regime, or site productivity, and to classify extant vegetation assemblages. Understory vegetation contributes to the carbon storage of the site, and the composition of understory plants and tree seedlings is important in determining wildlife habitat as well as future forest succession. The Pacific Northwest FIA unit collects information on the predominant understory species in each life form (shrubs, forbs, and graminoids) and structural classifications for each life form on each forested plot.

Average understory vegetation cover across all forested lands in Oregon is about 40 percent but is highly variable depending on each stand's species composition, age, and disturbance history. In general, riparian forest types such as alder/maple tend to have the densest understory cover, while dry site forest types such as lodgepole pine have more sparse understories. Young stands with recent disturbance tend to have the highest cover of forbs and graminoids, while shrub cover tends to be highest in stands 20 to 39 years old (fig. 39).

Nonnative, invasive plants on forest lands can affect forest composition and health, ecosystem processes, and wildlife habitat (Rapp 2005). The nonnative species covering the most forest land area in Oregon include cheatgrass and Himalayan blackberry, each estimated to cover more than 150,000 ac of forest land (fig. 40). Several other annual grasses are common nonnatives on Oregon forest land.

Nontimber forest products (NTFPs) include plants, fungi, and animal products that are used for both commercial and individual use. In the Pacific Northwest, evergreen boughs, floral greens, and edible mushrooms are frequently collected, and these products have tremendous cultural significance in addition to economic value (Alexander et al. 2011). Several forest understory species in Oregon are frequently collected for NTFP uses. The most abundant shrubs, in terms of acres of forest land with cover of each NTFP species, are vine maple, salal, and Cascade barberry (also called dwarf Oregon grape) (fig. 41).

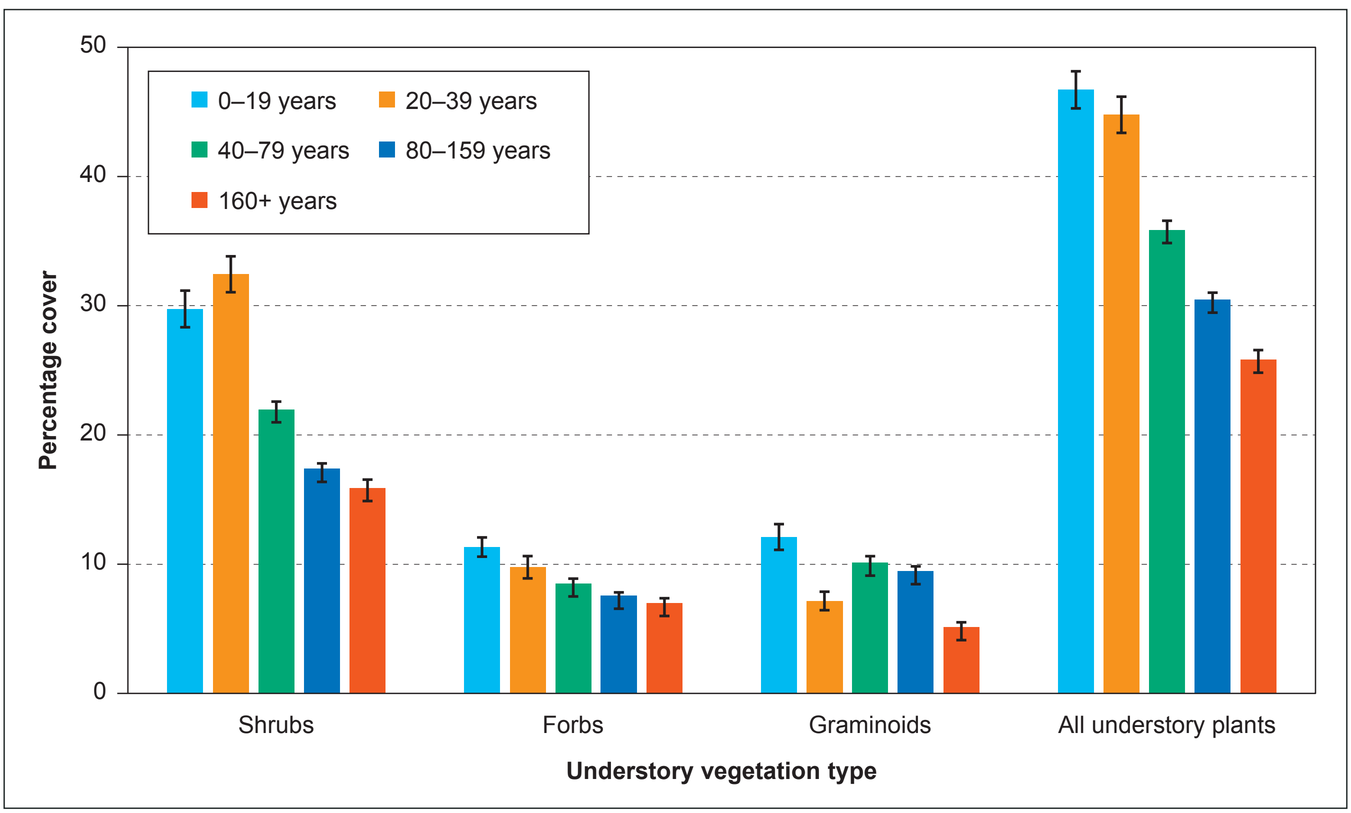


Figure 39—Cover of understory vegetation life forms by forest age class on forest land, Oregon, 2006–2015.

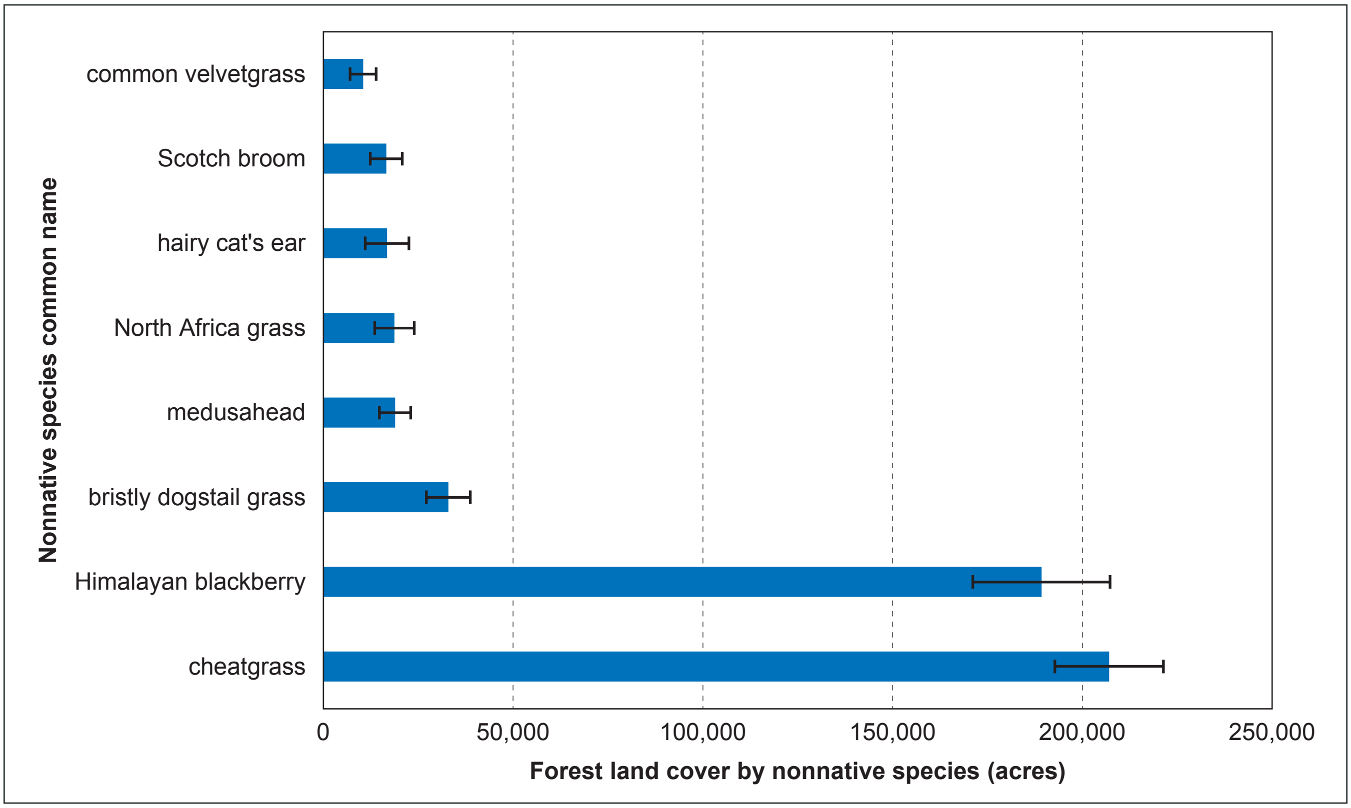


Figure 40—Nonnative invasive species with the highest acreage cover on forest land in Oregon, 2006–2015. Nonnative species estimated to cover at least 10,000 ac are shown.

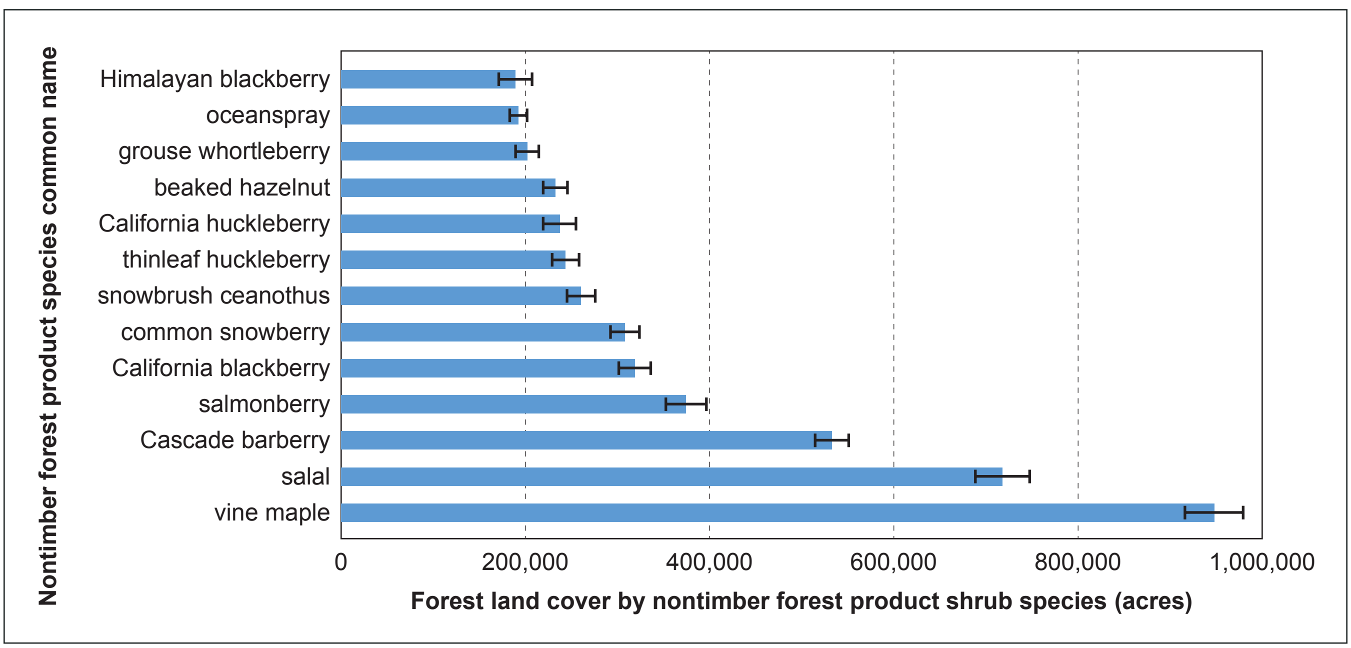


Figure 41—Total shrub cover (acres) on forest land by selected species used in nontimber forest products. Shrub species with at least 150,000 ac cover are shown.

Forest Recreation

Oregon's forest lands provide tremendous recreation value, and user demand at Oregon's recreation sites continues to increase with the state's growing population. Although private landowners recreate on their own lands and some corporate forests are open to the public, most forest recreation activities occur on the 64 percent of Oregon forest lands that are publicly owned. Forest recreation on federal lands takes a multitude of forms, and the values that individuals receive from recreation are difficult to quantify. White et al. (2016) examined the top recreation activities occurring on federal lands, noting that the top activities on NFS lands include viewing scenery/natural features, hiking/walking, relaxing/hanging out, and viewing wildlife. National Forest System visitor recreation fee revenues for the Pacific Northwest Region (covering Oregon and Washington) have steadily increased during the 10-year period of this report, reaching $8,937,597 in 2015 (compiled from Recreation Fee Program Accomplishment Highlights, https://www.fs.usda.gov/detail/r6/passes-permits/recreation/?cid=fsb-dev2_026999USDA FS 2015). A 2012 analysis estimated that recreation visits to federal lands nationwide contributed $51 billion to the U.S. economy and supported 880,000 jobs (English et al. 2014). Rural communities surrounding these recreation destinations benefit from recreation-related spending. Recreation activities expected to increase most in the next 15 years include developed skiing, visiting interpretive sites, day hiking, birding, and equestrian activities (White et al. 2016) (fig. 42). Oregon's 2.8 million ac of reserved forest lands provide many recreation opportunities, and recreation occurs on many of the 19.0 million ac of publicly owned forests.

USDA Forest Service Pacific Northwest Region

Figure 42—Drift Creek Falls Trail, Columbia Gorge National Scenic Area. Day hiking is the most frequent recreation usage type on national forest lands.

Forest Health

Damaging Agents

Although many factors affect the health of each tree, physical signs of stress or damage can often be attributed to a primary agent. Damage can occur from a number of factors including animals, insects and disease, mistletoe, weather, or physical defects. Most of the damages assessed by FIA are natural agents that play a role in forest succession. Detecting trends in tree damages at the stand level can aid in assessments of a forest's future composition and resiliency.

FIA field crews assess each measured live tree for damaging agents. In the Pacific Northwest states, regional damage codes that included location and severity were implemented at the start of the annual inventory. This damage coding system was replaced by a nationally consistent protocol in 2013. Details for both protocols are included in O'Connell et al. 2017, and the two systems are compatible when summarizing to general categories.

A little more than one-quarter of all live trees in Oregon (2.75 billion) are affected by damage or defect. These affected trees represent one-third of Oregon's total live tree volume. The most common damage agent, affecting 15 percent of all live trees and making up 56 percent of all recorded damages, was physical injury and defects (fig. 43). This category includes fire damage; human activities, including damage caused by harvest activity; and deformities such as broken tops, crooks, or open wounds. Trees affected by dwarf mistletoe made up 9 percent of total live tree basal area.

Physical injury and defects affected between 11 and 19 percent of live trees for each of the five most common conifer species in the state (Douglas-fir, lodgepole pine,

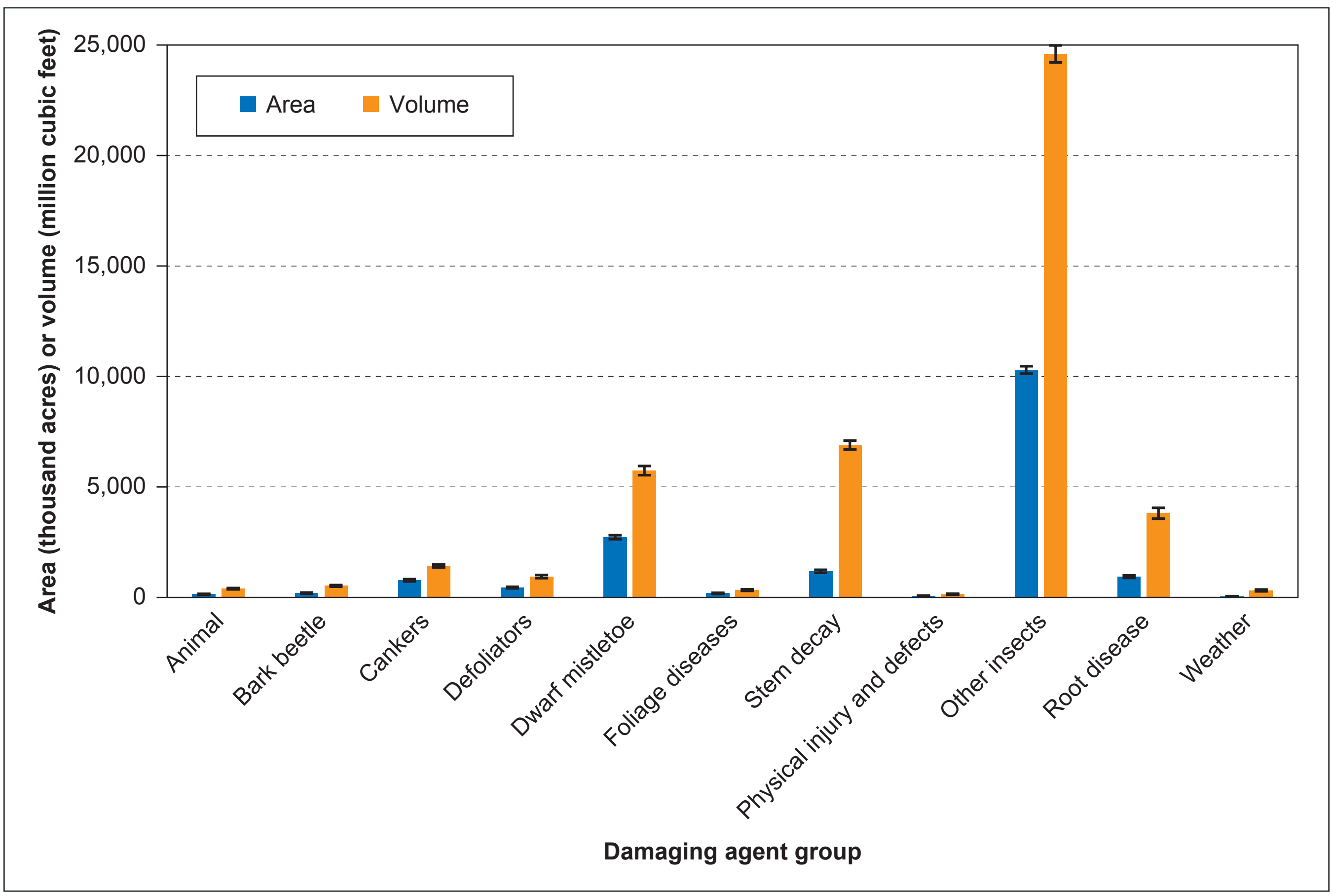


Figure 43—Area and volume of live trees affected by one or more damage agents on forest land, Oregon, 2006–2015; volume is gross volume of live trees >5 inches diameter at breast height; area includes stands with >25 percent of the basal area with damage.

ponderosa pine, western hemlock, and grand fir). Lodgepole pine had the highest damage rate at 46 percent; cankers, dwarf mistletoe, and physical injury and defects each affected more than 15 percent of lodgepole pine. The only other damaging agents that affected more than 3 percent of a top species' trees were dwarf mistletoe (10 percent of ponderosa pines and 9 percent of western hemlocks) and root disease (7 percent of grand firs).

Wildfire

Wildfire plays an important role in both forest and nonforest ecosystems in the Northwest and is a driver of forest succession. Oregon's forest composition today has been shaped by historical fires such as the Tillamook burns in the 1930s and aggressive fire suppression efforts throughout the past century. Wildfire management remains a contentious issue; while some of Oregon's forest ecosystems depend on fire to maintain forest health, uncontrolled wildfires can result in loss of timber value and changes in wildlife habitat, threaten structures and lives, and pose human health risks owing to smoke. The Northwest Interagency Coordination Center tracks wildland fire on an annual basis for Oregon and Washington, compiling statistics for large fires (at least 100 ac on timberlands or 300 ac in grasslands/rangelands). In Oregon, between 2006 and 2015, an average of 492,174 ac burned in large fires annually (NWCC 2017). The Long Draw Fire in sagebrush-dominated southeast Oregon burned 557,628 ac in 2012, the largest recorded fire in the Northwest since 1865. The years 2007, 2014, and 2015 were also active fire years, each with more acres burned than the 10-year average.

FIA collects fire occurrence data on all forested field plots when fire causes mortality or damage to at least 25 percent of all trees in a stand or 50 percent of a single species count, in addition to recording the year each fire occurs. These data can give an indication of the area of forest land burned by all fires regardless of their size. The 10-year average using FIA field plot estimates was 157,821 forested ac burned, with the majority of burned area occurring in eastern Oregon (fig. 44).

The number of burned acres over simplifies fire dynamics in ecosystems because fire severity is not

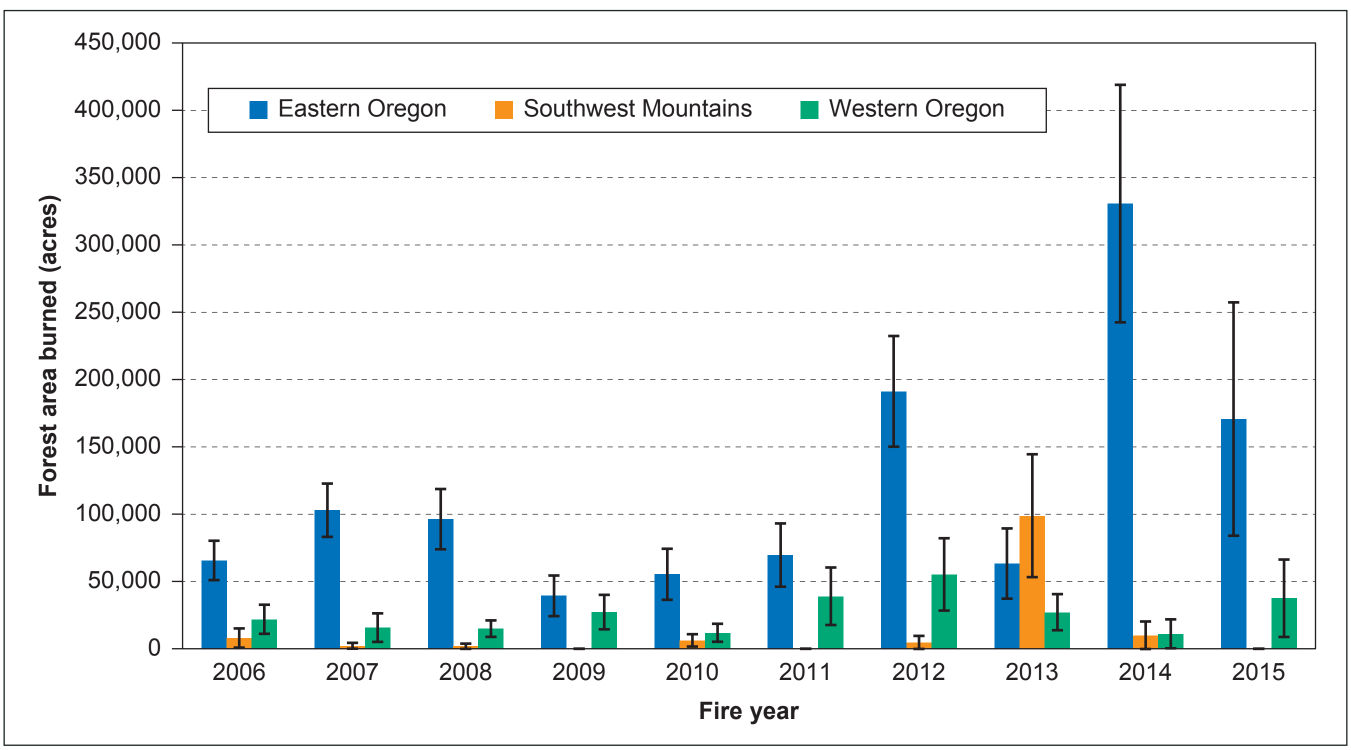


Figure 44—Area of forest land affected by fire, by fire year and region, Oregon, 2006–2015.

uniform even within a single burn; to gauge effects on forest stands, individual tree measurements add valuable information on pre- and postfire carbon dynamics and stand regeneration. A comprehensive analysis of all Oregon and Washington NFS land indicated that less than half the area burned burns at high severity (Whittier and Gray 2016). In addition, the amount of carbon per acre lost from stands within 5 to 10 years of fire is on average comparable to the amount lost from current thinning practices (Gray and Whittier 2014).

The PNW-FIA implemented an additional postfire study starting in 2015 on recently burned plots to capture fire effects and gauge regeneration across the Pacific Northwest. The FIA grid provides prefire and postfire comparisons for a variety of fire intensities. Postfire measurements include individual live tree, dead tree, down wood, and groundcover and fuels variables. A study using these protocols on FIA plots in California determined that the conceptual carbon trajectories frequently used, which assume rapid flux of carbon out of woody pools, may not be appropriate for many postfire stands. Eskelson et al. (2016) found no evidence of net change in total wood carbon (wood in standing trees >5 inches d.b.h. and down wood >3 inches in diameter) over the postfire period regardless of fire severity class. Further analysis of postfire dynamics using this extensive network will provide new insights on the effects of fires on carbon stocks and regeneration.

Research Application: Moss and Urban Pollutants[5]

Since 1998, the Forest Inventory and Analysis (FIA) program has collected 5,500 surveys of epiphytic lichen communities used by scientists and land managers for evaluating air quality on the nation's forests. The program recently piloted another approach to biomonitoring air quality—using chemical analysis of lichens and moss tissue for mapping heavy metals like cadmium, lead, arsenic, cobalt, and chromium. Lichens and moss absorb their nutrients and moisture from the atmosphere along with pollutants present in air and rainwater. Analysis of pollutant concentrations in their tissues provides an estimate of pollutant deposition in the sampled area.

National Forest System air quality managers have used chemical analysis of lichens and moss for over 30 years. The NFS method was adapted and piloted on forested FIA plots in the Midwestern United States. (Will-Wolf et al. 2017) as well as in an urban environment in 2013. For the urban pilot, scientists sampled a common tree-dwelling moss at 346 sites in residential areas across Portland, Oregon, and created fine-scaled maps of heavy metals in moss (Gatziolis et al. 2016). They teamed up with the Oregon Department of Environmental Quality (DEQ), who had measured higher than expected cadmium levels with an air-quality monitoring instrument at Portland's one permanent air quality monitoring site. Using moss as a screening tool, they found elevated cadmium in moss around art glass manufacturers in two neighborhoods, neither of which were known to regulators as major heavy metals sources (Donovan et al. 2016). Moss near the larger facility also had high arsenic levels. The DEQ installed air-monitoring equipment near the larger facility and discovered that cadmium and arsenic levels were 49 and 155 times established Oregon health targets, respectively.

What followed were months of intense media interest, community meetings, protests, and state-sponsored testing for cadmium in the urine and garden soils of residents. Studies evaluating possible public health impacts were initiated. Air quality improved after new pollution controls were installed on the glass furnaces of one of two art glass manufacturers thought to be primary contributors of the pollutants (the other manufacturer relocated to Mexico). Emissions regulations for these kinds of facilities have also been revised. Oregon Governor Kate Brown proposed the "“Cleaner Air Oregon”

[5] Author: Sarah Jovan.

regulatory program (Senate Bill 1541) to overhaul air toxics regulations statewide with a health-based (vs. technology-based) permitting system for industrial sources of air toxics. The bill passed the Oregon State Legislature in March 2018, and the draft rules can be viewed along with related information at the Cleaner Air Oregon website: http://www.oregon.gov/deq/aq/cao/Pages/default.aspx.

The inability to observe air quality at a fine scale has been a long-standing challenge for monitoring the complex air quality of urban areas. Although moss data cannot tell us directly whether human health is at risk, testing moss is inexpensive and allows us to collect a large number of samples. Air monitoring equipment is necessary for understanding potential health concerns but can be too costly to use in more than a few locations at once. Both approaches used together, however, can be a powerful investigative tool that allows effective pollution screening and interpretation (fig. 45).

Literature Cited

Donovan, G.H.; Jovan, S.E.; Gatziolis, D.; Burstyn, I.; Michael, Y.L.; Amacher, M.C.; Monleon, V.J. 2016. Using an epiphytic moss to identify previously unknown sources of atmospheric cadmium pollution. Science of the Total Environment. 559: 84–93.

Gatziolis, D.; Jovan, S.; Donovan, G.; Amacher, M.; Monleon, V. 2016. Elemental atmospheric pollution assessment via moss-based measurements in Portland, Oregon. Gen. Tech. Rep. PNW-GTR-938. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p.

Will-Wolf, S.; Jovan, S.; Amacher, M.C. 2017. Lichen elemental content bioindicators for air quality in upper Midwest, USA: a model for large-scale monitoring. Ecological Indicators. 78: 253–263.

Figure 45—Common tree-dwelling mosses such as (left) *Orthotrichum lyellii* can provide an inexpensive method for sampling air pollutants at finer scales than is possible with (right) costly air monitoring equipment. The combined approach has proved to be a powerful tool for pollution screening.

Online Tables

A suite of 125 summary data tables that accompany this report are available online at https://www.fs.usda.gov/pnw/pubs/pnw_gtr971-supplement.pdf and listed below for reference.

Number of plots:

Table 1—Number of Forest Inventory and Analysis plots measured by sample status, land class, and ownership group, Oregon 2006–2015

Area:

Table 2—Area of sampled land and water by land status and ownership group, Oregon 2006–2015

Table 3—Area of forest land by county and land status, Oregon 2006–2015

Table 4—Area of forest land by county and ownership group, Oregon 2006–2015

Table 5—Area of forest land by ownership and land status, Oregon 2006–2015

Table 6—Area of forest land by forest type group and land status, Oregon 2006–2015

Table 7—Area of forest land by forest type group and site productivity class, Oregon 2006–2015

Table 8—Area of forest land by forest type group, ownership group, and land status, Oregon 2006–2015

Table 9—Area of forest land by forest type group and stand size class, Oregon 2006–2015

Table 10—Area of forest land by forest type group and stand age class, Oregon 2006–2015

Table 11—Area of forest land by ecological section and land status, Oregon 2006–2015

Table 12—Area of forest land by forest type group and stand origin, Oregon 2006–2015

Table 13—Area of timberland by forest type group and stand size class, Oregon 2006–2015

Number of trees:

Table 14—Number of live trees on forest land by county and land status, Oregon 2006–2015

Table 15—Number of dead trees on forest land by county and land status, Oregon 2006–2015

Table 16—Number of live trees on forest land by county and broad species group, Oregon 2006–2015

Table 17—Number of dead trees on forest land by county and broad species group, Oregon 2006–2015

Table 18—Number of live trees on forest land by species group and diameter class, Oregon 2006–2015

Table 19—Number of dead trees on forest land by species group and diameter class, Oregon 2006–2015

Table 20—Number of live trees on forest land by forest type group and ownership group, Oregon 2006–2015

Table 21—Number of dead trees on forest land by forest type group and ownership group, Oregon 2006–2015

Table 22—Average number of live trees per acre on forest land by forest type group and ownership group, Oregon 2006–2015

Table 23—Average number of dead trees per acre on forest land by forest type group and ownership group, Oregon 2006–2015

Table 24—Number of growing stock trees on timberland by species group and diameter class, Oregon 2006–2015

Tree volume:

Table 25—Net volume of live trees on forest land by ownership and land status, Oregon 2006–2015

Biomass:

Carbon:

Table 79—Aboveground carbon mass of live trees on forest land by ownership and land status, Oregon 2006–2015

Table 80—Aboveground carbon mass of dead trees on forest land by ownership and land status, Oregon 2006–2015

Table 81—Aboveground carbon mass of live trees on forest land by forest type group and ownership group, Oregon 2006–2015

Table 82—Aboveground carbon mass of dead trees on forest land by forest type group and ownership group, Oregon 2006–2015

Table 83—Aboveground carbon mass of live trees on forest land by forest type group and stand size class, Oregon 2006–2015

Table 84—Aboveground carbon mass of dead trees on forest land by forest type group and stand size class, Oregon 2006–2015

Table 85—Aboveground carbon mass of live trees on forest land by species group and diameter class, Oregon 2006–2015

Table 86—Aboveground carbon mass of dead trees on forest land by species group and diameter class, Oregon 2006–2015

Table 87—Average aboveground carbon mass per hectare of live trees on forest land by forest type group and ownership group, Oregon 2006–2015

Table 88—Average aboveground carbon mass per hectare of dead trees on forest land by forest type group and ownership group, Oregon 2006–2015

Table 89—Average aboveground carbon mass per hectare of live trees on forest land by forest type group and stand size class, Oregon 2006–2015

Table 90—Average aboveground carbon mass per hectare of dead trees on forest land by forest type group and stand size class, Oregon 2006–2015

Down wood:

Table 91—Biomass of down wood on forest land by forest type group, ownership group, and land status, Oregon 2006–2015

Table 92—Carbon mass of down wood on forest land by forest type group, ownership group, and land status, Oregon 2006–2015

Table 93—Biomass of down wood on forest land by county and land status, Oregon 2006–2015.

Table 94—Carbon mass of down wood on forest land by county and land status, Oregon 2006–2015

Table 95—Average biomass per acre of down wood on forest land by forest type group, ownership group, and land status, Oregon 2006–2015

Table 96—Average biomass per acre of down wood on forest land by ownership and land status, Oregon 2006–2015

Table 97—Average biomass per acre of down wood on forest land by county and land status, Oregon 2006–2015

Combined dead trees and dead wood (standing dead trees and down wood):

Table 98—Average biomass per acre of all dead wood (standing dead trees and down wood) on forest land by county and land status, Oregon 2006–2015

Table 99—Volume of live trees, standing dead trees, and down wood on forest land by stand age class, Oregon 2006–2015

Table 100—Biomass of live trees, standing dead trees, and down wood on forest land by stand age class, Oregon 2006–2015

Table 101—Carbon mass of live trees, standing dead trees and down wood on forest land by stand age class, Oregon 2006–2015

Table 102—Average volume per acre of live trees, standing dead trees, and down wood on forest land by stand age class, Oregon 2006–2015

National Forest System (NFS):

Tree damage:

Understory vegetation:

Timber products output and removals:

Annual growth, removals, and mortality:

Evidence of fire:

Common and Scientific Plant Names

Life form	Common name	Scientific name
Trees:	Alder	*Alnus* spp.
	Ash	*Fraxinus* spp.
	Aspen, quaking aspen	*Populus tremuloides* Michx.
	Birch	*Betula* spp.
	Cottonwood	*Populus* spp.
	Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
	Elm	*Ulmus* spp.
	Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
	Hemlock	*Tsuga* spp.
	Incense cedar	*Calocedrus decurrens* (Torr.) Florin
	Jeffrey pine	*Pinus jeffreyi* Balf.
	Laurel	*Umbellularia californica* (Hook. & Arn.) Nutt.
	Lodgepole pine	*Pinus contorta* Douglas ex Loudon
	Maple	*Acer* spp.
	Mountain hemlock	*Tsuga mertensiana* (Bong.) Carrière
	Oak	*Quercus* spp.
	Ponderosa pine	*Pinus ponderosa* Lawson & C. Lawson
	Red alder	*Alnus rubra* Bong.
	Sitka spruce	*Picea sitchensis* (Bong.) Carrière
	Spruce	*Picea* spp.
	Sugar pine	*Pinus lambertiana* Douglas
	Tanoak	*Lithocarpus densiflorus* (Hook & Arn.) Rehder
	True fir species	*Abies* spp.
	Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
	Western juniper	*Juniperus occidentalis* Hook.
	Western larch	*Larix occidentalis* Nutt.
	Western redcedar	*Thuja plicata* Donn ex D. Don
Shrubs:	Beaked hazelnut	*Corylus cornuta* Marshall
	Cascade barberry, dwarf Oregon grape	*Mahonia nervosa* (Pursh) Nutt.
	California blackberry, trailing blackberry	*Rubus ursinus* Cham. and Schltdl.
	California huckleberry	*Vaccinium ovatum* Pursh
	Common snowberry	*Symphoricarpos albus* (L.) S.F. Blake
	Dwarf mistletoe	*Arceuthobium* spp.
	Grouse whortleberry	*Vaccinium scoparium* Leiberg ex Coville
	Himalayan blackberry	*Rubus discolor* Weihe & Nees
	Oceanspray	*Holodiscus discolor* (Pursh) Maxim.
	Salal	*Gaultheria shallon* Pursh
	Salmonberry	*Rubus spectabilis* Pursh
	Scotch broom	*Cytisus scoparius* (L.) Link

Common and Scientific Plant Names (continued)

Life form	Common name	Scientific name
	Snowbrush ceanothus	*Ceanothus velutinus* Douglas ex Hook.
	Thinleaf huckleberry	*Vaccinium membranaceum* Douglas ex Torr.
	Vine maple	*Acer circinatum* Pursh
Forbs:	Hairy cat's ear	*Hypochaeris radicata* L.
Graminoids:	Bristly dogstail grass	*Cynosurus echinatus* L.
	Cheatgrass	*Bromus tectorum* L.
	Common velvetgrass	*Holcus lanatus* L.
	Medusahead	*Taeniatherum caput-medusae* (L.) Nevski
	North Africa grass	*Ventenata dubia* (Leers) Coss.

Acknowledgments

The tremendous FIA dataset would not be possible without the dozens of field staff who trek near and far each year to collect our field data. Thanks also to our quality assurance staff who work tirelessly to ensure the most accurate datasets possible, and to the information management specialists who compile and store these data and make them available to the public.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	0.3048	Meters
Acres (ac)	0.405	Hectares
Board feet	0.0024	Cubic meters
Cubic feet (ft^3)	0.0283	Cubic meters
Cubic feet per acre (ft^3/ac)	0.0670	Cubic meters per hectare
Tons per acre	2.2417	Megagrams per hectare

U.S. Equivalents

When you know:	Multiply by:	To find:
Kilograms (kg)	2.2046	Pounds
Megagrams (Mg)	1.1023	Tons
Megagrams per hectare	0.4461	Tons per acre

Literature Cited

Alexander, .J.; Oswalt, S.N.; Emery, M.R. 2011. Nontimber forest products in the United States: Montreal Process indicators as measures of current conditions and sustainability. Gen. Tech. Rep. PNW-GTR-851. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 36 p.

Bansal, S.; Brodie, L.; Stanton, S.; Waddell, K.; Palmer, M.; Christenson, G.; Kuegler, O. 2017. Oregon's forest resources, 2001–2010: Ten-year Forest Inventory and Analysis report. Gen. Tech. Rep. PNW-GTR-958. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 130 p.

Bassett, P.M.; Choate, G.A. 1974. Timber resource statistics for Oregon, January 1, 1973. Resour. Bull. PNW-RB-56. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37 p.

Bell, D.M.; Gregory M.J.; Ohmann J.L. 2015. Imputed forest structure uncertainty varies across elevational and longitudinal gradients in the western Cascade Mountains, Oregon, USA. Forest Ecology and Management. 358: 154–164.

Binder, S.; Haight, R.G.; Polasky, S.; Warziniack, T.; Mockrin, M.H.; Deal, R.L.; Arthaud, G. 2017. Assessment and valuation of forest ecosystem services: state of the science review. Gen. Tech. Rep. NRS-170. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 47 p.

Blackard, J.; Finco, M.; Helmer, E.; Holden, G.; Hoppus, M.; Jacobs, D.; Lister, A.; Moisen, G.; Nelson, M.; Riemann, R.; Ruefenacht, B.; Salajanu, D.; Weyermann, D.; Winterberger, K.; Brandeis, T.; Czaplewski, R.; McRoberts, R.; Patterson, P.; Tymcio, R. 2008. Mapping U.S. forest biomass using nationwide forest inventory data and moderate resolution information. Remote Sensing of Environment. 112(4): 1658–1677.

Boyd, J.; Banzhaf, S. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics. 63(2–3): 616–626.

Campbell, S.; Dunham, P.; Azuma, D. 2004. Timber resource statistics for Oregon. Resour. Bull. PNW-RB-242. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 67 p.

Donnegan, J.; Campbell, S.; Azuma, D. 2008. Oregon's forest resources, 2001–2005: five-year forest inventory and analysis report. Gen. Tech. Rep. PNW-GTR-765. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 188 p.

Donovan, G.H.; Jovan, S.E.; Gatziolis, D.; Burstyn, I.; Michael, Y.L.; Amacher, M.C.; Monleon, V.J. 2016. Using an epiphytic moss to identify previously unknown sources of atmospheric cadmium pollution. Science of the Total Environment. 559: 84–93.

English, D.B.K. [et al.]. 2014. Outdoor recreation: jobs and income. Federal Interagency Council on Outdoor Recreation. https://www.fs.fed.us/research/docs/outdoor-recreation/recreation-economy.pdf. (17 October 2017).

Eskelson, B.N.I.; Monleon, V.J.; Fried, J.S. 2016. A 6 year longitudinal study of post-fire woody carbon dynamics in California's forests. Canadian Journal of Forest Research. 46: 610–620.

Farrenkopf, T.O. 1982. Forest statistics for eastern Oregon, 1977. Resour. Bull. PNW-RB-94. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 84 p.

Federal Forest Advisory Committee [FFAC] 2012. National forest health restoration: an economic assessment of forest restoration on Oregon's eastside national forests. Prepared for: Governor John Kitzhaber and Oregon's Legislative Leaders. Portland, OR: Portland State University Northwest Economic Research Center. 94 p.

Fried, J.S.; Potts, L.D.; Loreno, S.M.; Christensen, G.; Barbour, J.R. 2017. Inventory based landscape-scale simulation of management effectiveness and economic feasibility with BioSum. Journal of Forestry. 115: 249–257.

Gatziolis, D.; Jovan, S.; Donovan, G.; Amacher, M.; Monleon, V. 2016. Elemental atmospheric pollution assessment via moss-based measurements in Portland, Oregon. Gen. Tech. Rep. PNW-GTR-938. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p.

Gedney, D.R. 1982. Timber resources of western Oregon—highlights and statistics. Resour. Bull. PNW-RB-97. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 84 p.

Gray, A.N.; Whittier, T.R. 2014. Carbon stocks and changes on Pacific Northwest national forests and the role of disturbance, management, and growth. Forest Ecology and Management. 328: 167–178. http://www.treesearch.fs.fed.us/pubs/46566.

Hanson, E.J.; Azuma, D.L.; Hiserote, B.A. 2003. Site index equations and mean annual increment equations for Pacific Northwest Research Station forest inventory and analysis inventories, 1985–2001. Res. Note PNW-RN-533. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Heath, L.S.; Hansen, M.H.; Smith, J.E.; Miles, P.D. 2009. Investigation into calculating tree biomass and carbon in the FIADB using a biomass expansion factor approach. In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. Forest Inventory and Analysis (FIA) Symposium 2008. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD.

Jain, T.J.; Battaglia, M.A.; Han, H.S.; Graham, R.T.; Keyes, C.R.; Fried, J.S.; Sandquist. J.E. 2012. A comprehensive guide to fuel management practices for dry mixed conifer forests in the northwestern United States. Gen. Tech. Rep. RMRS-GTR-292. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 331 p. https://www.fs.usda.gov/treesearch/pubs/42150.

Keith, H.: Mackey, B.G.; Lindenmayer, D.B. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of the National Academy of Sciences of the United States of America. 106: 11625–11640.

Lettman, G.; Gray, A.; Hubner, D.; McKay, N.; Thompson, J. 2016. Forests, farms, and people: land use change on non-federal land in Oregon 1974–2014. Oregon Department of Forestry. http://hdl.handle.net/1957/58941. (22 November 2017).

Loreno, S.; Fried, J.S.; Yost, A. 2015. Applying management modeling to assess the feasibility of accelerating landscape restoration on federal forests in eastern Oregon. In: Stanton, S.M.; Christensen, G.A., comps. 2015. Pushing boundaries: new directions in inventory techniques and applications: Forest Inventory and Analysis (FIA) symposium 2015: 260–265. https://www.fs.usda.gov/treesearch/pubs/50355.

Metcalf, M.E. 1965. Timber resource statistics for the Pacific Northwest as of January 1, 1963. Resour. Bull. PNW-RB-9. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 38 p.

Moravets, F.L.; Rogers, N.S.; McCullouch, W.F.; Cronemiller, L.F. 1942. Forest resources of Oregon. Salem, OR: Oregon State Board of Forestry. 67 p.

Northwest Interagency Coordination Center [NWCC] 2017. NWCC annual fire report archive, 2006–2015. https://gacc.nifc.gov/nwcc/admin/publications.aspx. (21 November 2017).

O'Connell, B.M.; Conkling, B.L.; Wilson, A.M.; Burrill, E.A.; Turner, J.A.; Pugh, S.A.; Christensen, G.; Ridley, T.; Menlove, J. 2017. The Forest Inventory and Analysis Database: Database description and user guide version 7.0 for Phase 2. U.S. Department of Agriculture, Forest Service. 830 p. http://www.fia.fs.fed.us/library/database-documentation/.

Oregon Department of Forestry [ODF]. 2016. Timber harvest data 1942–2016. https://data.oregon.gov/Natural-Resources/Timber-Harvest-Data-1942-2016/9cuv-nijj. (19 September 2017).

Oregon Forest Resources Institute [OFRI]. 2017. Oregon forest facts 2017–2018 edition. http://oregonforests.org/sites/default/files/2017-05/OFRI_FactsFacts_1718_WEB_1.pdf. (19 September 2017).

Rapp, V. 2005. Invasive plants in 21st century landscapes. Science Update 9. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 12 p.

Rooney, B. 2016. Oregon's wood product manufacturing industry is still important, especially in rural areas. Salem, OR: Oregon Employment Department. https://www.qualityinfo.org/-/oregon-s-wood-product-manufacturing-industry-is-still-important-especially-in-rural-areas. (19 September 2017).

Rose, C.L.; Marcot, B.G.; Mellen T.K.; Ohmann, J.L.; Waddell, K.L.; Lindley, D.L.; Schreiber, B. 2001. Decaying wood in Pacific Northwest forests: concepts and tools for habitat management. In: Johnson, D.H.; O'Neil, T.A., eds. Wildlife-habitat relationships in Oregon and Washington. Corvallis, OR: Oregon State University Press: 580–623. Chapter 24.

Simmons, E.A.; Scudder, M.G.; Morgan, T.A.; Berg, E.C.; Christensen, G.A. 2016. Oregon's forest products industry and timber harvest 2013 with trends through 2014. Gen. Tech. Rep. PNW-GTR-942. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 58 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2013. Accelerated restoration. https://www.fs.usda.gov/detail/r6/landmanagement/resourcemanagement/?cid=stelprdb5423597. (19 December 2017).

U.S. Department of Agriculture, Forest Service[USDA FS] 2015. Recreation fee program accomplishment highlights 2006–2015. https://www.fs.usda.gov/detail/r6/passes-permits/recreation/?cid=fsbdev2_026999**.** (19 October 2017).

White, E.M.; Bowker, J.M.; Askew, A.E.; Langner, L.L.; Arnold, J.R.; English, D.B.K. 2016. Federal outdoor recreation trends: effects on economic opportunities. Gen. Tech. Rep. PNW-GTR-945. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 46 p.

Whittier, T.R.; Gray, A.N. 2016. A tree mortality based fire severity classification for forest inventory surveys: a Pacific Northwest national forests example. Forest Ecology and Management. 359: 199–209. https://www.fs.usda.gov/treesearch/pubs/50918.

Will-Wolf, S.; Jovan, S.; Amacher, M.C. 2017. Lichen elemental content bioindicators for air quality in upper Midwest, USA: a model for large-scale monitoring. Ecological Indicators. 78: 253–263.

Woodall, C.W.; Heath, L.S.; Domke, G.M.; Nichols, M.C. 2011. Methods and equations for estimating aboveground volume, biomass, and carbon for trees in the U.S. forest inventory, 2010. Gen. Tech. Rep. NRS-88. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 30 p.

Pacific Northwest Research Station

Website	http://www.fs.fed.us/pnw/
Telephone	(503) 808–2592
Publication requests	(503) 808–2138
FAX	(503) 808–2130
E-mail	pnw_pnwpubs@fs.fed.us
Mailing address	Publications Distribution Pacific Northwest Research Station P.O. Box 3890 Portland, OR 97208–3890

U.S. Department of Agriculture
Pacific Northwest Research Station
1220 SW 3rd Ave.
P.O. Box 3890
Portland, OR 97208–3890