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NORTHWEST FOREST PLAN
THE FIRST 20 YEARS (1994–2013)

Status and Trends of Late-Successional and Old-Growth Forests

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Cover: left photo by Raymond Davis, right photo by Corey Davis.

Abstract

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This is the third in a series of periodic monitoring reports on LSOG or late-successional and old-growth (older) forest status trends on federally administered lands since implementation of the Northwest Forest Plan (NWFP or the Plan) in 1994. The objective of this monitoring is to determine if the NWFP is providing for conservation and management of older forests as anticipated. This report focused on the amount, distribution, and spatial arrangement of older forests across the NWFP landscape, and how these have changed as a result of disturbance and ingrowth starting with the year of the NWFP analyses in 1993.

We developed maps of older forest using three definitions. The first definition was the same as used to define LSOG for the prior monitoring reports (10- and 15-year reports). The other two definitions were based on 80- and 200-year thresholds using an "old-growth structure index" (OGSI) developed in this report to represent the continuum of forest succession. The 80-year threshold (OGSI-80) represented forests that had achieved structure commonly associated with mature, late-successional, and old-growth forests in this region. The OGSI-200 threshold represented forests that had progressed past maturation and had achieved structure found in the later stages of succession commonly associated with old growth in this region. The OGSI threshold estimates bracketed the LSOG estimates using the previous definition, and changes in forest structure were better interpreted when using them. Thus, we terminated the use of the previous LSOG definition for use of the newer OGSI-based definitions.

We developed older forest maps for the beginning and ending periods of our analyses (1993 and 2012) and called these "bookend" maps. From these bookend maps, we assessed changes in the amount and distribution of older forests over time. We also used an annual time series of forest disturbance maps to characterize the agents of change (harvest, wildfire, and insects/disease) associated with areas mapped as older forest loss. To corroborate the mapped information, we estimated older forest area from Forest Inventory and Analysis plots, and older forest change from two successive forest inventories from which such data were available (Forest Service and Oregon Bureau of Land Management lands).

The maps showed net changes in amount of older forests on federal lands managed under the NWFP have been small (a 2.8 to 2.9 percent net decrease). This occurred despite gross losses from wildfire (4.2 to 5.4 percent), timber harvest (1.2 to 1.3 percent), and from insects or other causes (0.7 to 0.9 percent), suggesting that processes of forest succession have compensated for some of the losses resulting from disturbance. The Plan anticipated a continued decline in older forests for the first few decades until the rate of forest succession exceeds the rate of gross losses. Decadal gross losses of about 5 percent per decade as a result of timber harvesting and wildfire were expected. Observed losses from wildfire were about what was expected, but losses from timber harvesting were about one quarter of what was anticipated. Results were consistent with expectations for older forest abundance, diversity, and connectivity outcomes for this period of time. Nothing in the findings suggests that attainment of desired outcomes over the next few decades is not feasible; however, we noted some portions of the NWFP federal landscape that had been set back from those outcomes, particularly resulting from large wildfires in the fire-prone portions of the NWFP area.

Keywords: Northwest Forest Plan, effectiveness monitoring, late-successional and old-growth forests, Gradient Nearest Neighbor imputation, LandTrendr change detection, Forest Service, Bureau of Land Management, late-successional reserves, physiographic provinces.

Preface

Late-successional and old-growth (LSOG) forest monitoring of the Northwest Forest Plan (NWFP or the Plan) area was approved by an Intergovernmental Advisory Committee and is consistent with the framework for effectiveness monitoring described in "The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan" published in 1999. It follows protocols and guidance in the "Late-Successional and Old-Growth Forest Effectiveness Monitoring Plan for the Northwest Forest Plan" published in 1998. An interagency effectiveness monitoring framework was implemented to meet requirements for tracking the status and trends of LSOG forests, populations and habitats of northern spotted owls (*Strix occidentalis caurina*) and marbled murrelets (*Brachyramphus marmoratus*), watershed conditions, social and economic conditions, and tribal relationships. Monitoring is conducted and reported in 1- to 5-year intervals. Monitoring results for the first 10 and 15 years were documented in a series of general technical reports available online at http://www.fs.fed.us/pnw/publications/gtrs.shtml. This report, and the others in the current series, covers the first 20 years of the Plan.

Contents

Introduction

Slightly more than two decades have passed since the implementation of the Northwest Forest Plan (hereafter referred to as "NWFP" or "the Plan"). The Plan amended 19 existing U.S. Department of Agriculture Forest Service (USFS) and 7 U.S. Department of the Interior Bureau of Land Management (BLM) resource management plans across three states and two Forest Service regions within the range of the northern spotted owl (*Strix occidentalis caurina*). An interagency effectiveness monitoring framework was implemented in the late 1990s to meet the Plan requirements for tracking the status and trends of late-successional and old-growth (LSOG) forests, northern spotted owl populations and habitat, marbled murrelet *(Brachyramphus marmoratus*) populations and habitat, watershed condition, social and economic conditions, and tribal relationships (Mulder et al. 1999). Beginning in 2005, monitoring reports have been published at 5-year intervals and made available at http://www.reo.gov/monitoring/.

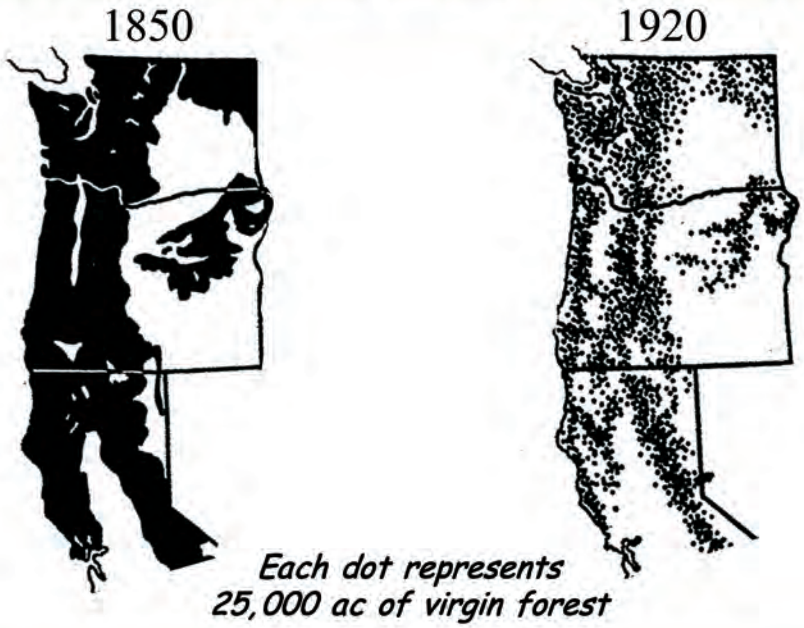
This report is the third in the series of LSOG monitoring reports outlined by the interagency monitoring plan (Hemstrom et al. 1998) and covers the time period from 1993 to 2012. This report summarizes the assessment of LSOG for federally administered lands ("federal lands") affected by the Plan. Information on other ownerships ("nonfederal lands") was provided for context. In previous monitoring reports (Moeur et al. 2005, 2011), the term "older forest" was used interchangeably with the terms "late-successional" and "old-growth" forest. This was done to allow flexibility for assessing and displaying results based on a variety of definitions. We continued the use of this term in the same manner. Because of updates in information sources and improvements in analytical techniques, the results in this report are not directly comparable to those in previous reports.

The goal of this monitoring is to evaluate the success of the Plan in reaching the desired amount and distribution of older forests on federal lands. Three specific monitoring questions were addressed in this report (Hemstrom et al. 1998: 7):

- What was the amount and distribution of older forest at the large-landscape scale (e.g., NWFP area, state, physiographic province)?
- What was the spatial arrangement of older forest stands, interior areas, edges, and interstand distances across the NWFP landscape?
- How did these things change as a result of disturbance and ingrowth starting with the year of the NWFP analyses in 1993?

Our monitoring relied on two types of data to answer these questions—maps and forest inventory plots. The NWFP covers a very large geographic area of over 50 million acres, with about half of it managed by the federal government. Currently, one of the more practical ways to make monitoring maps for such large areas is to integrate forest inventory plot data that is collected periodically with satellite remote

"THE STORY IS TOLD IN THE MAPS…"



A virgin forest in the Pacific Northwest. These coniferous forests now constitute our last great timber resource (Photo from the U.S. Forest Service).

Use of Forest Resources by Industrial Nations

"*The course of these nations in satisfying their requirements for forest-grown materials has usually run through three different stages. At first they have cut freely from their own virgin forests as long as the supply lasted. Then they have cast about for what they might barter from their neighbors. And finally they have settled down to the systematic growing of wood on all the land that could be spared for the purpose…*"

"*The United States is still in the first of these three stages. By far the greater part of wood we use is still obtained from our own virgin forests. But the end of this supply is plainly in sight.*"

W.B. Greeley. 1925. The relation of geography to timber supply. Economic Geography, 1: 1-14.

sensing data that is compiled annually. While maps allow us to monitor amounts and patterns across broad landscapes, the plot data enable us to monitor stand-level changes on the ground that satellites cannot see and also make area-based estimates. Using both, we can compare the results from each to better inform ourselves.

The old saying "a picture is worth a thousand words" might also apply to maps. A map of the forest allows us to see its abundance and distribution at multiple spatial scales. For monitoring purposes, maps from different time periods help us to understand how the forested landscape has changed. As stated by W.B. Greeley, former Chief of the Forest Service in the early 20th century, "The story is told in the maps…" (Greeley 1925).

History of Mapping Old-Growth Forests in the Pacific Northwest

The first mapping of forest resources in the Pacific Northwest was accomplished in 1873 as part of the 9th National Census map atlas (Walker 1874). That map was a hand-drawn representation of the land covered by forest; represented in density classes based on the number of 40-ac blocks per square mile (640 ac) that were wooded (Liknes et al. 2013). It did not focus on any specific timber type or seral stage; those forest attributes became more well-defined in the early 20th century when a statewide map of forest resources in Oregon was produced in 1914 (ODF 1914). Shortly thereafter, the 1928 McSweeney-McNary Act directed the Secretary of Agriculture to "make and keep current an inventory and analysis of the Nation's forest resources." That effort produced maps that included the first comprehensive assessments of older forests across the entire NWFP area (Andrews and Cowlin 1940, Cowlin et al. 1942, Wieslander and Jensen 1946).

The next map of older forests for the NWFP area was not produced until over a half century later (FEMAT 1993) and was used for planning purposes for the NWFP. Since the Plan's implementation, there have been two additional federal efforts to map the older forests within its boundary (Moeur et al. 2005, 2011) and other efforts have mapped older forest within the general area (Strittholt et al. 2006). This report marks the third federal effort.

While not intended for monitoring purposes at the time of their development, the historical maps in conjunction with the newer maps provide us with some idea of how forests have changed over the last century (fig. 1). When monitoring older forest where losses can occur rapidly, but growth and recruitment operate on much longer time scales, it can be easier to see the changes between maps separated by decades or a century than maps separated by years. The longer historical perspective can be important for setting the context for monitoring forest change (e.g., establishing a baseline) and adapting to the information it provides (Liknes et al. 2013).

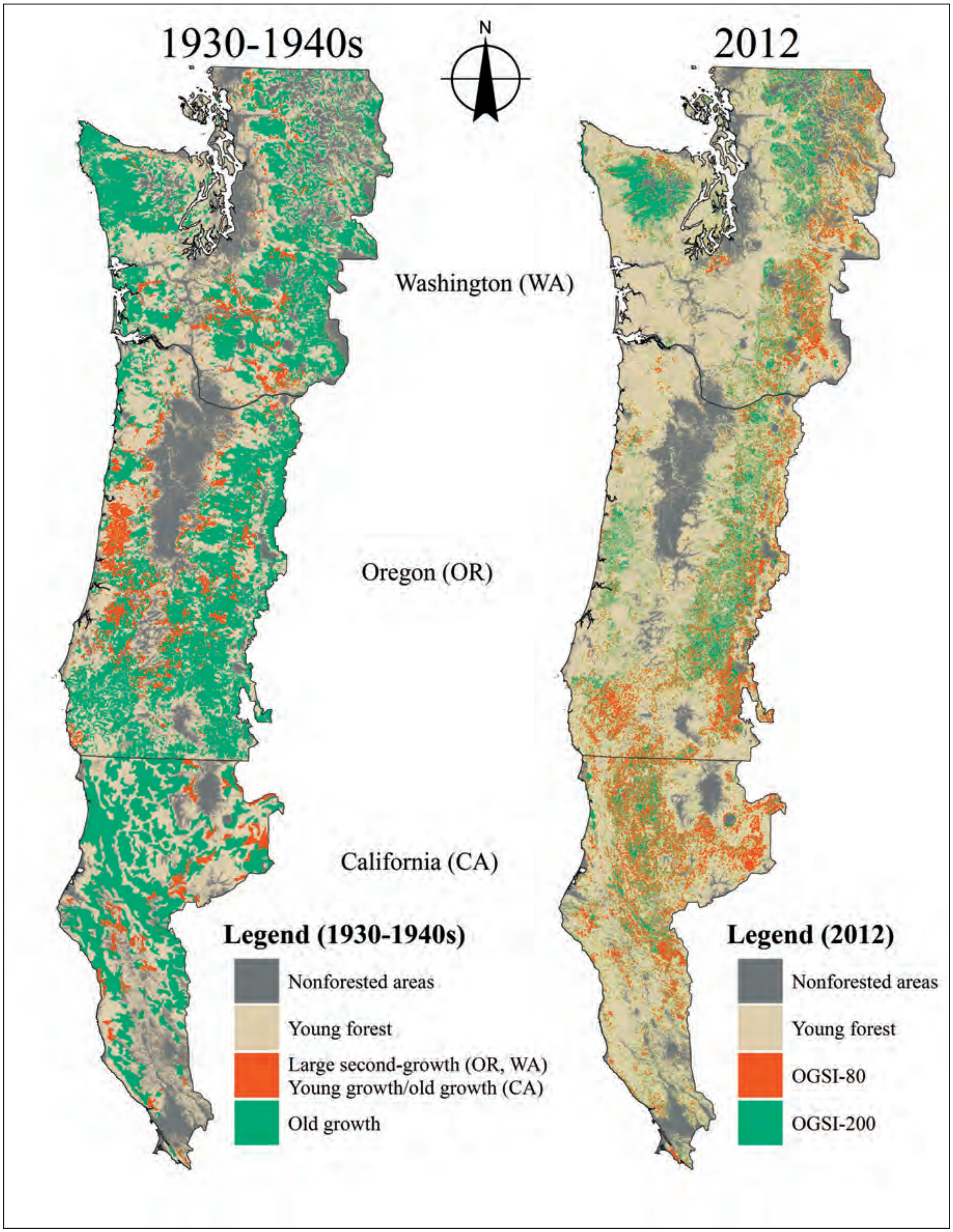


Figure 1—Historical and current maps of older forest within the Northwest Forest Plan area. Map sources for the historical map are Andrews and Cowlin (1940) in Washington and Oregon, and Weislander and Jensen (1946) in California and are extrapolated from stand-level surveys. The current map is from this report and based on remotely sensed data. OGSI refers to the "old-growth structure index" mapped at two different stand-age thresholds: 80 and 200 years.

Defining Late-Successional/Old-Growth Forests

The first step in making a map of old-growth forest requires that old growth be defined in a discrete and mappable way. Yet, old-growth forests are complex and hard to ascribe to terms that separate them distinctly from the intricacy that is forest succession (Franklin and Spies 1991, Frelich and Reich 2003, Marcot et al. 1991, Thomas et al. 1988). Human perceptions of what is an old-growth forest are just as complex, if not more so (Pesklevits et al. 2011, Spies and Duncan 2009). Experience has taught us that defining old-growth forests is problematic; yet, for purposes of monitoring, necessary.

Early attempts at defining old growth in this region date back to the first forest inventory (Andrew and Cowlin 1940, Wieslander and Jensen 1946). Back then, the term "old growth" was a relative one used to differentiate slower-growing older forests from the faster-growing younger forests (Andrews and Cowlin 1940). In addition to a general sense of stand age, it was largely based on the diameter at breast height (dbh) of the largest dominant and co-dominant live trees.

Beginning in the 1980s, ecological definitions that included more elements than just the size of the large live trees began to be formulated (Franklin et al. 1981, Franklin and Spies 1984, SAF 1984). In 1985, an interagency group composed of technical experts from the USFS (management and research station), BLM, and Oregon State University began developing interim definitions of old growth for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests for the Pacific Northwest (Old-Growth Definition Task Group 1986). Thomas et al. (1988) concluded that old growth was best perceived as, "a stage of forest development characterized by more diversity of structure and function than that found in younger successional stages." Furthermore, they recognized that old-growth characteristics differed by forest type, such that a single definition was not feasible. However, they acknowledged that definitions were needed for management purposes (Thomas et al. 1988).

By the end of the decade, the Chief of the Forest Service sent out a memo to regional foresters outlining the Forest Service's position on old growth as well as a generic definition and description of old-growth forests (USDA FS 1989). This definition encompassed the later stages of forest stand development that are usually distinguished by the presence of larger, older trees and structural attributes such as multiple canopy layers, decadence in the form of standing dead trees (snags), and accumulations of fallen trees (logs). It also noted that these characteristics differed by forest types, such that one definition would not fit all. And finally, it made clear that old-growth forest was not necessarily "virgin" or "primeval" forest, but could be developed through thoughtful forest management. This generic definition was to serve as the starting framework for the development or modification of more specific definitions that related to structural components that could be readily identified or measured (USDA FS 1989). Shortly thereafter, interim definitions were established that provided discrete classifications based on minimum amounts of old-growth elements such as snags and logs (USDA FS 1992, 1993).

For monitoring purposes, the definition of "older forest" has been fairly simple in the past, and focused on the average diameter of live overstory trees (Moeur et al. 2005, 2011). However, the effectiveness monitoring plan called for the eventual development of a more refined definition or indices to help assign plots and remotely sensed stands to a position along a continuum of late-successional and old-growth structure and composition development (Hemstrom et al. 1998).

Here, we used an index called the "old-growth structure index" (OGSI) conceptually developed by Spies and Franklin (1988) and further refined as a method to overcome some of the problems with using categorical interim definitions (Franklin and Spies 1991). This index has been found to be useful for monitoring the abundance of old-growth forest across large landscapes (Franklin et al. 2005, Gray at al. 2009, Ohmann et al. 2012). The OGSI consists of measurable forest structure elements, in our case (1) density of large live trees, (2) diversity of live tree size classes, (3) density of large snags, and (4) percentage of cover of down woody material. These are elements commonly considered as key ecological and structural

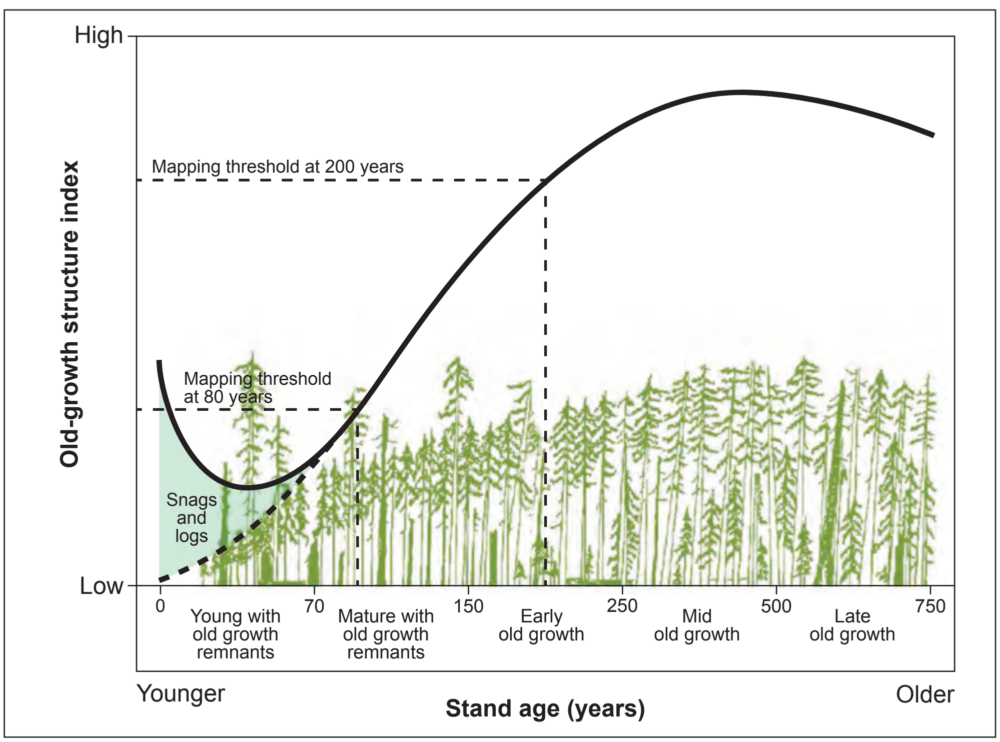


Figure 2—The old-growth structure index from Spies and Franklin (1988) is represented by the solid black line. The dashed line represents the modified index curve used for mapping older forests in this report. It minimized inclusion of young forests with high structural diversity (e.g., post-wildfire snags and logs) and focused on older forests.

attributes of old-growth forests within the NWFP area. Low index values represented younger or less structurally complex forests, and high index values represented older or more structurally complex forests (fig. 2).

The Plan's Expectations

At its implementation in 1994, the NWFP anticipated that the rate of loss of older forests on federally managed lands that had been observed in prior decades would lessen, eventually stabilize, and then begin to increase as younger forests in reserved land use allocations developed into older forests. A continued loss of existing older forests of about 5 percent per decade from timber harvesting and wildfires was expected, but recruitment was expected to eventually exceed these losses. It was estimated that it would take at least 50 to 100 years to restore the amount of older forest on federal lands (fig. 3) to within the typical range that occurred during previous centuries, and closer to what they had been prior to logging and extensive fire suppression (FEMAT 1993, USDA and USD1 1994: chaps. 3 and 4: 36–46).

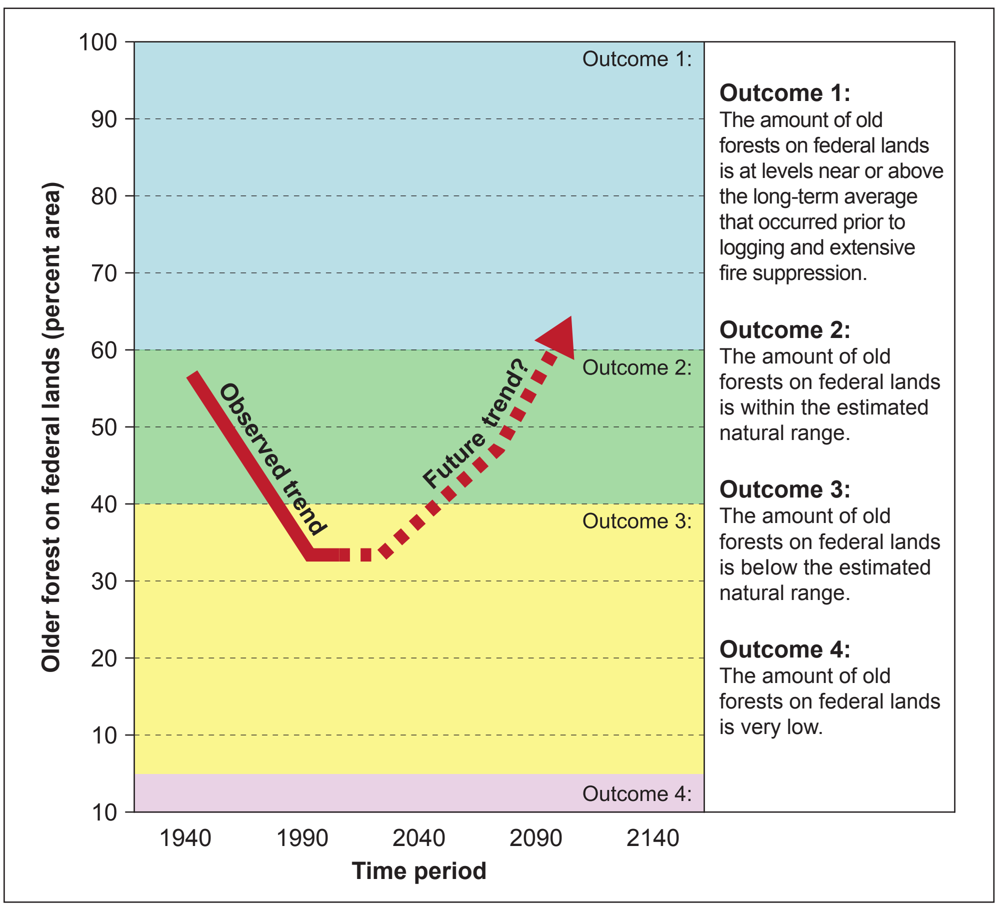


Figure 3—The expectation of the Northwest Forest Plan was that it would take 50 to 100 years to achieve the abundancy, diversity, and connectivity outcomes for older forests on federal lands within the northern spotted owl's range (curve derived from FEMAT (1993) and fig. 5 in Hemstrom et al. (1998: 22).

General outcomes for abundance, diversity, and connectivity of older forest were described in the Forest Ecosystem Management Assessment Team (FEMAT) report (FEMAT 1993), the Plan (USDA and USDI 1994: chaps. 3 and 4: 36–46), and refined into "measureable" outcomes by Hemstrom et al. (1998: 19–21). These measurable outcomes were based on a long-term average, defined as a period of at least 200 to 1,000 years, over which the full potential range of older forest communities could develop following a severe disturbance. The Forest Ecosystem Management Assessment Team (1993) estimated that 60 to 70 percent of the forested area of the region was typically covered by older forests, ranging higher in moister forests and lower in drier forests. The team (FEMAT 1993) also estimated the average centurial low (average of the lows that occur in 100-year periods) at 40 percent, setting the lower limit of the "typical" range for older forest coverage. These averages were to apply to a wide range of stand sizes, from less than 1 ac, to hundreds of thousands of acres. Measurable outcomes were defined in terms of the abundance and diversity (amount and patch size) of older forest (table 1) and connectivity (distance between patches) of older forest (table 2).

Table 1—Thresholds for measuring success in achieving older forest abundance and diversity outcomes[a]

Outcome	Percentage of federal land covered by older forest	Percentage of federal land in older forest stands[b] more than 1,000 acres in patch size	Percentage of provinces that meet both amount and stand patch size criteria
	Percent		
1	60 to 100	80 to 100	80 to 100
2	40 to 60	5 to 80	5 to 80
3	5 to 40	1 to 5	1 to 5
4	Less than 5	Less than 1	Less than 1

[a] Summarized from Hemstrom et al. (1998) (see fig. 3).
[b] Patches of older forest that consist of core plus core-edge pixels (see bottom of fig. 7).

Table 2—Thresholds for measuring success in achieving older forest connectivity outcomes[a]

Outcome	Average distance between old-forest stands of more than 1,000 acres	Percentage of federal land covered by old forest stands[b]	Percentage of adjacent provinces connected with large stands of old forest
	Miles	*Percent*	
1	Less than 6	60 to 100	100
2	6 to 12	50 to 60	100
3	12 to 24	25 to 50	Less than 100
4	More than 24	Less than 25	Less than 100

[a] Summarized from Hemstrom et al. (1998) (see fig. 3).
[b] Consists of patches and fingers of older forest, which include riparian buffers and green tree retention.

Monitoring allows us to evaluate whether or not the Plan is meeting these expected outcomes. The overall expectation (based on expert opinion) was that the Plan had a 77-percent likelihood of achieving outcomes 1 or 2 in moister provinces, and 63-percent likelihood in drier provinces (FEMAT 1993). But, Hemstrom et al. (1998) cautioned that older forest development takes many decades and these outcomes, which were based on the understanding of long-term reference conditions at the time of the Plan's implementation, might need to be adjusted as climate changes and our scientific understanding of forest ecology evolves.

Data Sources and Methods

Many, but not all, of the data sources used in this report were initially developed and used for the 10- and 15-year monitoring reports. During each 5-year monitoring cycle, previously used data sources are updated to incorporate new research findings and other information, or to correct errors. While more detailed descriptions of these data sources can be found in previous monitoring reports (Davis et al. 2011; Lint 2005; Moeur et al. 2005, 2011), we briefly describe them here, and discuss any updates made from previous versions.

Physiographic Provinces

The NWFP boundary was based on the geographic range of the northern spotted owl. Because the range of the owl was so large, it was divided into 12 physiographic provinces for analytical purposes (FEMAT 1993, Thomas et al. 1990, USDA and USDI 1994). Physiographic provinces were delineated in an attempt to reduce the complex and diverse nature of the owl's range into broad areas that represented different forest zones, plant communities, and disturbance regimes that vary geographically with climate, topography, soils, and geology. These physiographic provinces were largely based on subdivisions by Franklin and Dyrness (1973). We use the same physiographic provinces that were used for the 15-year report (Moeur et al. 2011).

Forest Vegetation Zones

The concept of "vegetation zones" (areas dominated by a plant community type) has existed for well over a century (Humboldt 1816) and many efforts to map them have been, and continue to be, made (Franklin and Dyrness 1973, Henderson et al. 2011). Similar to physiographic provinces, potential vegetation zones reflect the physical and climatic conditions of the area and are useful for ascribing ecological processes of forest development and disturbance. Vegetation zones often are drawn at a much finer spatial resolution than provinces. Here, we used vegetation zones to group forest inventory plots from across the NWFP area for analysis and development of unique old-growth structure indices for each zone (fig. 4).

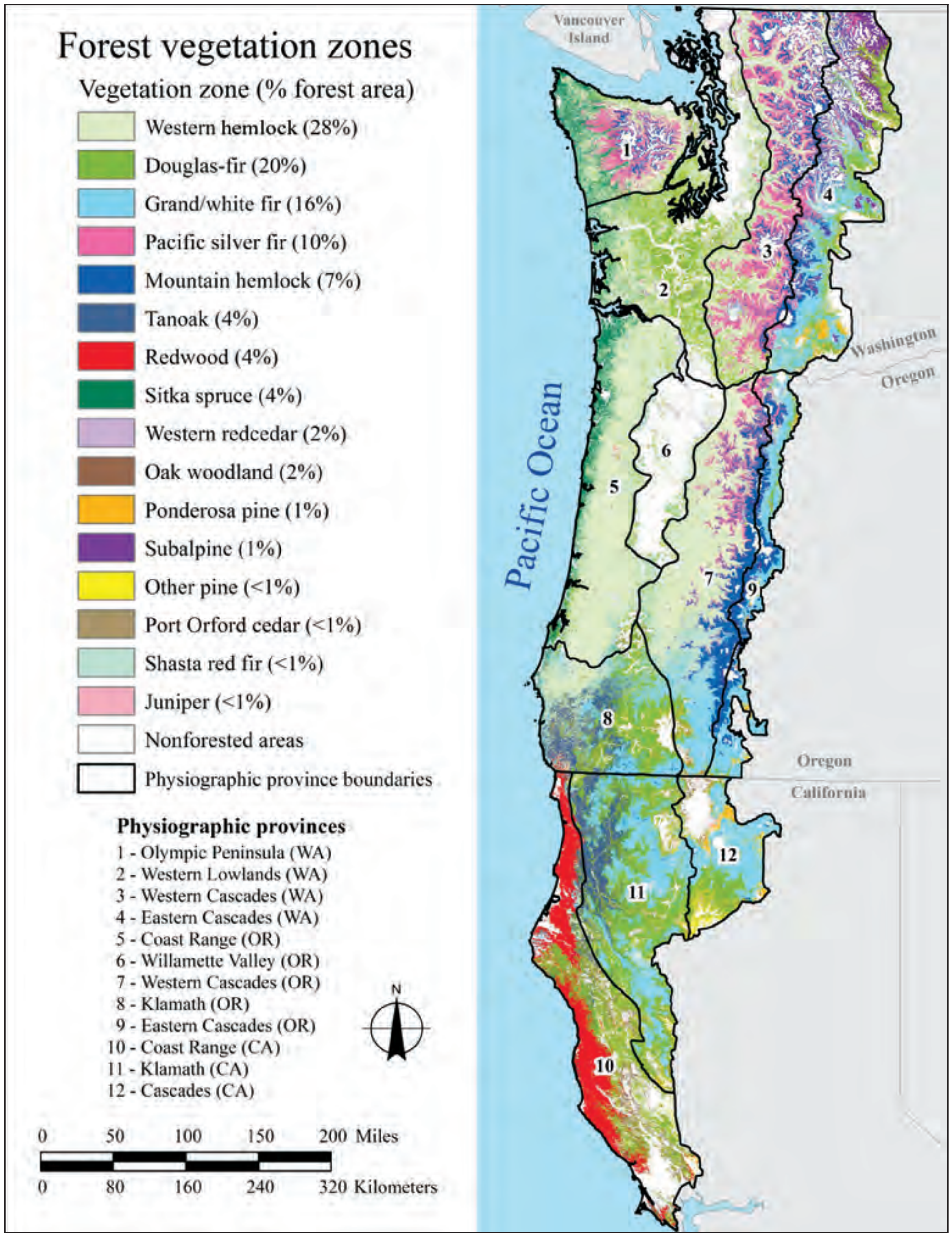


Figure 4—Potential forest vegetation zones used in deriving old-growth structure index equations (Simpson 2013). CA = California, OR = Oregon, WA = Washington.

Our forest vegetation zone map was a 30-m raster map developed by the USFS, Pacific Northwest Region (Region 6), Ecology Program (Simpson 2013). Other maps existed for portions of the region, but this one provided consistent coverage for the entire NWFP area. This layer was derived from understory species composition information in existing Gradient Nearest Neighbor (GNN) maps developed by the Landscape Ecology, Modeling, Mapping, and Analysis group in the Pacific Northwest (http://lemma.forestry.oregonstate.edu/). Understory species serve as indicators for what type of forest will dominate in the absence of disturbance. Multiple map dates (1996, 2000, and 2006) were used to account for species composition changes owing to recent disturbances such as fire or timber harvest. Presence or absence of tree species was used to infer potential forest vegetation zones. Where imputations from different map years disagreed, the more mesic vegetation zone was assigned, with one exception: plots with both mountain hemlock and Pacific silver fir present were assigned to the silver fir zone when mountain hemlock (*Tsuga mertensiana* (Bong.) Carriere) accounted for less than 10 percent of the plot basal area. Independent Ecology Program plots (http://ecoshare.info/category/data-sets/) were used for classification assessment.

The most common forest vegetation zones were low- to moderate-elevation types such as western hemlock, Douglas-fir, and grand fir/white fir, which accounted for about 63 percent of the NWFP forested areas (fig. 4). Higher-elevation types like Pacific silver fir and mountain hemlock covered about 17 percent of the NWFP forests. Coastal areas were dominated by Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in the north and redwoods (*Sequoia sempervirens* (D. Don) Endl.) in the south, which comprised about 7.4 percent of the forested area. The remaining 12.6 percent is composed of various other vegetation zones.

Land Use Allocations

Federal land use allocations (LUAs) have specific management directions under the NWFP. This report groups these allocations into two categories: (1) reserved and (2) nonreserved. Reserved allocations are areas where the maintenance and restoration of older forests over time is expected under the current land use plans. They include the following land use allocations:

Congressionally reserved (CR) areas: Lands reserved by the U.S. Congress such as wilderness areas, wild and scenic rivers, and national parks and monuments.

Late-successional reserves (LSRs): Lands reserved for the protection and restoration of LSOG forest ecosystems and habitat for associated species; including marbled murrelet reserves (LSR3) and northern spotted owl activity core reserves (LSR4).

Managed late-successional areas (MLSAs): Areas for the restoration and maintenance of optimum levels of LSOG stands on a landscape scale, where regular and frequent wildfires occur. Silvicultural and fire hazard reduction treatments are allowed to help prevent older forest losses from large wildfires or disease and insect epidemics.

Administratively withdrawn (AW) areas: Areas identified in local forest and district plans; they include recreation and visual areas, back country, and other areas where management emphasis does not include scheduled timber harvest.

Adaptive management area in reserves (AMR): Identified to develop and test innovative management to integrate and achieve ecological, economic, and other social and community objectives. Emphasis on restoration of late-successional forests and managed as an LSR.

Nonreserved LUAs were designed for multiple land use objectives including sustained-yield management for timber production. They include:

Matrix (other): Federal lands outside of reserved allocations where most timber harvest and silvicultural activities were expected to occur.

Adaptive management area (AMA)–Nonreserved (AMA): Identified to develop and test innovative management to integrate and achieve ecological, economic, and other social and community objectives. Some commercial timber harvest was expected to occur in these areas, but with ecological objectives.

The geographic information system (GIS) layer representing these LUAs was originally delineated during the analysis for the NWFP (USDA and USDI 1994). The LUA GIS layer has been updated three times since it was first developed. Each update was done prior to the monitoring cycle, including this one. Previous updates were described in the 10- and 15-year monitoring reports. The latest update mainly involved addition of congressionally reserved allocations (364,000 ac) as a result of a few new wilderness designations since the 15-year report. Other updates included land exchanges and acquisitions as well as minor editing to correct errors and clean up map features. About 71,000 ac remain without assigned allocations. We attributed these areas as “no data” (ND). Since NWFP implementation, LUA updates document a slight overall increase in federal lands (1.5 percent) with a 0.4 percent increase in reserved land use allocations (fig. 5).

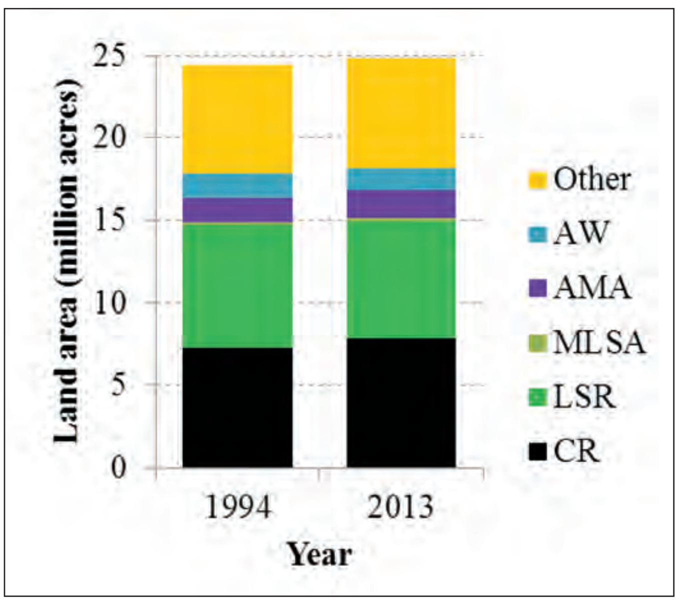


Figure 5—Federal land use allocation by percentage of area at the Northwest Forest Plan’s implementation in 1994 (from USDA and USDI 1994) and two decades later (2013). AW = administratively withdrawn, AMA = adaptive management area, MLSA = managed late-successional areas, LSR = late-successional reserve, CR = congressionally reserved.

As in previous monitoring reports, riparian reserves, another NWFP LUA, were not delineated because of a lack of consistency in defining and delineating the stream network at the Plan, scale and varying site-specific definitions (Moeur et al. 2005). Thus, our estimates for "reserved" federal lands were biased low, and "nonreserved" estimates were biased slightly higher than they would be if riparian reserves had been accounted for, owing to unmapped riparian reserves on "nonreserved" LUAs.

Forest Inventory Plots

The forest attributes used in this report were derived from field measurements of forest conditions on forest inventory plots distributed across the region. We used these plot data as imputed by GNN map production to estimate vegetation conditions for specific years of interest (Ohmann and Gregory 2002). We also used the plot data directly for the range of years they were measured for comparison to our map-based estimates.

Plot data from several inventory efforts were used in this assessment (table 3). On BLM and Pacific Northwest Region (USFS R6) USFS lands, Current Vegetation Survey (CVS) (Max et al. 1996, USDA FS 2001, USDI BLM 2001) plots were established on a systematic grid in the mid-1990s and remeasured in the late 1990s and early 2000s (table 3). Outside of wilderness on Region 6 lands, the CVS grid was established on a 1.7-mi spacing (one plot per 1,850 ac) on BLM lands and Region 6 Wilderness, the CVS grid was on a 3.4-mi spacing (one plot per 7,400 ac). On Pacific Southwest Region (R5-FIA) USFS lands, plots were randomly installed within predefined strata in the mid-1990s (USDA FS 2000). Beginning in 2001, the Forest Inventory and Analysis (FIA) program of the Forest Service Pacific Northwest Research Station installed plots across all ownerships with a spacing of one plot per 6,000 ac on a 10-year remeasurement cycle (FIA annual; Betchtold and Patterson 2005). There were 11,511 forested plots in the NWFP area used to assess recent condition.

Every inventory plot sampled lands within a 2.47-ac area, with four subsample points for the FIA annual sample and five subsample points for the CVS and R5-FIA. We only used plots that contained areas classified as forested (currently or previously ≥10-percent stocked with tree species not primarily managed for a nonforest land use, ≥1 ac, and ≥120 ft wide).

The FIA annual plot data (2002–2011) were used to compare against map estimates for all landowners in the NWFP area. To do this, we averaged the map-based estimates across time periods (1993 and 2012), which spanned the FIA plot sampling period. We also compared mapped change estimates with plot-based change estimates using CVS plots, which were remeasured twice with the same plot design, and between R5-FIA and FIA annual plots, where the plot design differed between measurements. However, as found in the 15-year report (Moeur et al. 2011), substantial unexplained differences were found between R5-FIA, FIA annual, and

Table 3—Distribution and sampled area of plots on U.S. Forest Service (USFS) and western Oregon Bureau of Land Management (BLM) lands in the Northwest Forest Plan area by measurement year

	CVS occasion 1		CVS occasion 2		R5-FIA		FIA annual	
Year	Number of plots	Area sampled	Number of plots	Area sampled	Number of plots	Area sampled	Number of plots	Area sampled
	Thousand acres							
1993	384	984			19	13		
1994	927	2,862			2	8		
1995	1,792	4,940			22	49		
1996	2,114	4,861			309	1,924		
1997	552	520	542	1,123	352	1,342		
1998			595	1,207	505	1,934		
1999			594	1,326	22	85		
2000			283	548	3	8		
2001			449	914				
2002			759	2,466			79	488
2003			639	1,403			81	527
2004			579	2,246			90	563
2005			491	1,127			76	464
2006			406	927			102	626
2007			432	880			89	533
2008							73	484
2009							103	647
2010							92	588
2011							87	544
Totals	5,769	14,167	5,769	14,167	1,234	5,363	872	5,464

Current Vegetation Survey (CVS) = USFS Pacific Northwest Region (Region 6) and BLM; Pacific Southwest Region (Region 5) Forest Inventory and Analysis (FIA) and FIA annual = USFS R5.

GNN map estimates that make them incomparable on account of the differences in the plot sampling designs, so the R5-FIA results were not shown here.

For a general sense of how our map-based estimates of older forest compared to plot-based estimates at the large-landscape scale, we estimated older forest area for federal, nonfederal, and all ownerships combined using FIA annual inventory plots measured between the years 2002 to 2011 and standard FIA inventory procedures (e.g., Campbell et al. 2010). These plot measurements occurred between the time periods of our maps (time 1 = 1993 and time 2 = 2012) with the midpoint being around 2006, so for map-to-plot comparisons, we used the averaged mapped areal estimate for time 1 and time 2.

For a comparison of map- and plot-based estimates of older forest change, we used CVS data from remeasured plots from USFS and BLM lands. Plots were first measured from 1993 to 1997, and then remeasured from 1997 to 2007 (table 4). On average, the time between the measurements was 7.1 years. The USFS CVS data were initially compiled by Waddell and Hiserote (2005), with additional compilation, land classification, and disturbance attribution done by Gray and Whittier (2014). Standard stratification layers were built in GIS using National Land Cover Database (NLCD) classified satellite data, vegetation zone GIS layers, and USFS parcel ownership layers for inventory plot compilation. Standard errors were calculated for all plot-based estimates using post-stratification and double-sampling statistics to calculate sample error (Bechtold and Patterson 2005).

Table 4—Distribution and sample area of forest inventory plots by sample occasions used for the plot-based assessment of older forest change

	First sample occasion (1993–1997)		Second sample occasion (1997–2007)	
State and physiographic province	**Number of plots**	**Area sampled**[a]	**Number of plots**	**Area sampled**
		Thousand acres		*Thousand acres*
Washington:				
Olympic Peninsula	291	631.2	291	631.2
Western Lowlands	0	0.0	0	0.0
Western Cascades	1,153	2,948.4	1,153	2,948.4
Eastern Cascades	1,004	3,413.7	1,004	3,413.7
Total	2,448	6,993.3	2,448	6,993.3
Oregon:				
Coast Range	430	1,426.6	430	1,426.6
Willamette Valley	3	25.9	3	25.9
Western Cascades	1,795	4,355.3	1,795	4,355.3
Klamath	675	2,105.8	679	2,133.0
Eastern Cascades	641	1,560.8	641	1,560.8
Total	3,544	9,474.4	3,548	9,501.5
California:				
Coast Range	17	91.4	12	70.6
Klamath	973	4,357.8	742	4,348.6
Cascades	315	1,038.1	193	1,103.0
Total	1,305	5,487.4	947	5,522.3
Northwest Forest Plan total	7,297	21,955.1	6,943	22,017.1

[a] Area sampled based on plot expansion factors and not the actual area of the plots.

Old-Growth Structure Index

The concept of the old-growth structure index was a departure from the normal approach to defining old growth. It was designed to reflect the continuous nature of ecological succession as opposed to identifying one point along the continuum to separate old growth from younger forests (Spies and Franklin 1988). It is a composite index that simply sums the values of old-growth characteristics so that the highest index values occur in the later stages of forest succession. The first step in developing an OGSI is to determine the proper old-growth characteristics (elements) to sum.

As stated previously, our OGSI was calculated using one to four measurable old-growth structure elements including (1) density of large live trees, (2) diversity of live-tree size classes, (3) density of large snags, and (4) percentage cover of down woody material. These elements vary in size (e.g., what diameter constitutes a "large" tree) and importance by forest vegetation zone. To account for these differences, we used forest inventory plots and the Random Forest algorithm (Breiman 2001) as the first step to determining the appropriate elements to use for each forest vegetation zone. Random Forests is a common method used for variable selection (Genuer 2010). We used it to rank potential structure elements based on their relationship (explained variance) to stand age. For example, in the ponderosa pine vegetation zone, the density of large conifer explained most of the variance in the plot data for older forests, whereas dead wood elements explained little. In drier forests, such as ponderosa pine, the natural disturbance regime and relatively high decomposition rates result in very low levels of snags and down wood. Thus, in that forest zone, the OGSI was simply based on the density of large live trees.

Once structure elements were selected, we used forest inventory plot data to examine the age class distributions (e.g., <25, 25 to 50, 50 to 75, 75 to 100, 100 to 150, 150 to 200, ≥200 years) for different diameter classifications (e.g., ≥9.8, 19.7, 29.5, and 39.4 in dbh) of the large live tree, snag, and down wood elements within each mapped forest vegetation zone (fig. 4). Based on the distributions of the means (taking into consideration the standard deviations), we used expert opinion and guidance from interim definitions (USDA FS 1992, 1993) to select minimum diameters for each structure element within each forest vegetation zone (table 5). The diameter size classes were chosen such that the structure element consistently increased with age and distinguished well between the older age classes (e.g., >150 year) and the younger ones (app. A).

Next, an OGSI was calculated for every forest inventory plot using methods described in Pabst (2005). Each element was scored on a continuous scale from 0 to 100 determined from regression equations for single or segmented lines linked to statistical distributions from the plot data (app. B). For the live tree element, we used the minimum, 25th, 75th, and 99th percentiles) as our regression inflexion

Table 5—Minimum old-growth structure index (OGSI) element thresholds and minimum stand ages for selection of plots used to calculate OGSI by forest vegetation zone[a]

Forest vegetation zone	Percentage of NWFP forest area	Large live tree element min dbh	Snag element min dbh	Down wood element min dia.	Plot minimum stand age threshold	Mean plot age ± 1 SD	General interim definition ages[b]
	Percent	---------------- *Inches* ----------------			---------------- *Years* ----------------		
Western hemlock	28.0	39.4	29.5	9.8	200	273 ± 62	200
Douglas-fir	19.5	29.5	19.7	9.8	150	200 ± 55	180-295
White fir/grand fir	15.8	29.5	19.7	9.8	200	249 ± 47	150-300
Pacific silver fir	9.8	29.5	19.7	9.8	200	293 ± 74	180-360
Mountain hemlock	7.2	29.5	19.7	9.8	200	272 ± 62	150-200
Tanoak	3.9	39.4	19.7	9.8	200	242 ± 38	240
Redwood	3.7	39.4	29.5	9.8	150	245 ± 127	None
Sitka spruce	3.7	39.4	29.5	9.8	200	305 ± 116	None
Western redcedar	2.2	39.4	29.5	9.8	200	250 ± 38	200
Oak woodland	1.9	19.7	n/a	n/a	100	118 ± 18	None
Ponderosa pine	1.5	29.5	n/a	n/a	150	201 ± 71	150-200
Subalpine	1.2	19.7	19.7	9.8	150	200 ± 50	150-200
Other pine	<1	19.7	n/a	n/a	100	124 ± 22	120-200
Port Orford cedar	<1	29.5	19.7	9.8	200	247 ± 42	240
Shasta red fir	<1	29.5	19.7	9.8	200	231 ± 23	150-200
Juniper	<1	19.7	n/a	n/a	100	132 ± 22	None

NWFP = Northwest Forest Plan[a]. dbh = diameter at breast height. SD = standard deviation.
[b] The last two columns compare mean and standard deviation (±1 SD) of plot stand ages used in the calculations of OGSI to existing interim definition guidance.
Source: USDA FS 1992,1993.

points. For dead wood elements, we used the minimum, median, 75th , and 99th percentiles. To develop these regressions, we only used forest inventory plots for stands that were older than 100 to 200 years, depending on the forest zone in which they occurred (table 5). For the stand structure element, we used a diameter diversity index (a measure of the structural diversity of a forest stand, based on tree densities in different dbh classes) as implemented in Pabst (2005). Each element was given equal weighting and our OGSI was the sum of the element scores divided by the total number of elements in the equation.

The OGSI reflected the continuous nature of forest succession, but for monitoring purposes, we are required to identify thresholds along that continuum to produce binary maps and plot estimates of older forests (0 = not old forest, 1 = old forest) for analysis of abundance and distribution. To select mapping and plot analysis thresholds, we used forest inventory plot data to fit a nonparametric curve to the relationship between OGSI and stand age using locally weighted polynomial regression in R version 3.0.2. (R Core Team 2013) (app. C). The first threshold we chose was based on stand age of 80 years for all forest vegetation zones except ponderosa pine, which was 120 years. We called this threshold the "OGSI-80" (even though ponderosa pine was 120) and used it to describe the general point on the forest succession time scale (fig. 2) at which young forests in this region generally begin to "mature" and start exhibiting stand structure associated with older forests (FEMAT 1993, Franklin and Johnson 2013, USDA and USDI 1994). The second analytical threshold used in this report was called the "OGSI-200" and was based on a 200-year stand age (160 years for oak woodlands), which generally corresponds to the range of stand ages used to define the "old-growth" condition in this region (table 5). We also provided thresholds at 120 and 160 years in appendix C, table C-1.

We intentionally excluded stand age from the equations used to calculate OGSI as in Pabst (2005) because, as can be seen in the scatter graphs in appendix C, forests develop old-forest structure at different rates depending on site conditions and many other factors (Zenner 2004). For example, Franklin and Spies (1991) illustrated that a young stand with high amounts of dead wood (snags and down wood) inherited from the previous old stand could achieve an index value in the mid range of the scale. Our analysis of the plot and map data verified this, as we noted mid-range index values in several unsalvaged postfire areas with high levels of snags and down wood. As our focus was to estimate amounts of older forest, not structurally complex early-seral forest, we modified the binary older forest thresholds to only include stands with ≥10-percent tree canopy cover and either the presence of at least one large live-tree exceeding the diameter threshold or an average stand diameter greater than half the size of the live tree diameter threshold for that vegetation zone.

Thus, our classified maps of "older forest" based on these thresholds are not maps of age per se. Rather, they are maps of old-growth structure that represent two different points in a continuum of forest succession and stand development: one at which forests begin to have elements of mature forest structure, and one occuring later when the characteristics of old growth are well established (Franklin et al. 2002, Spies 2004).

Forest-Capable Area

This data source is a 30-m resolution raster coverage used for map analyses that represents areas within the NWFP boundary that are capable of developing into forests. This map was developed for the 15-year monitoring reports (Davis et al. 2011, Raphael et al. 2011) and was not updated for this report. It is largely based on the U.S. Geological Survey (USGS) Gap Analysis Program (GAP) and the "impervious layer" from NLCD (Herold et al. 2003, Vogelmann et al. 2001). It excludes urbanized areas, major roads, agricultural areas, water, lands above tree line, snow, rock, and other nonforested features. We used this map to "mask out" nonforested areas for each time period map. Map areal estimates and other analyses in this report only apply to forest-capable areas.

LandTrendr Maps

LandTrendr maps identified where, when, how much, and how long disturbance had occurred between 1993 and 2012. They also showed us areas where the forest vegetation had been stable or was recovering (fig. 6). These annual time-series maps of forest vegetation disturbance and recovery were similar to what was used in the 15-year monitoring reports. They were developed following methods in Kennedy et al. (2010,

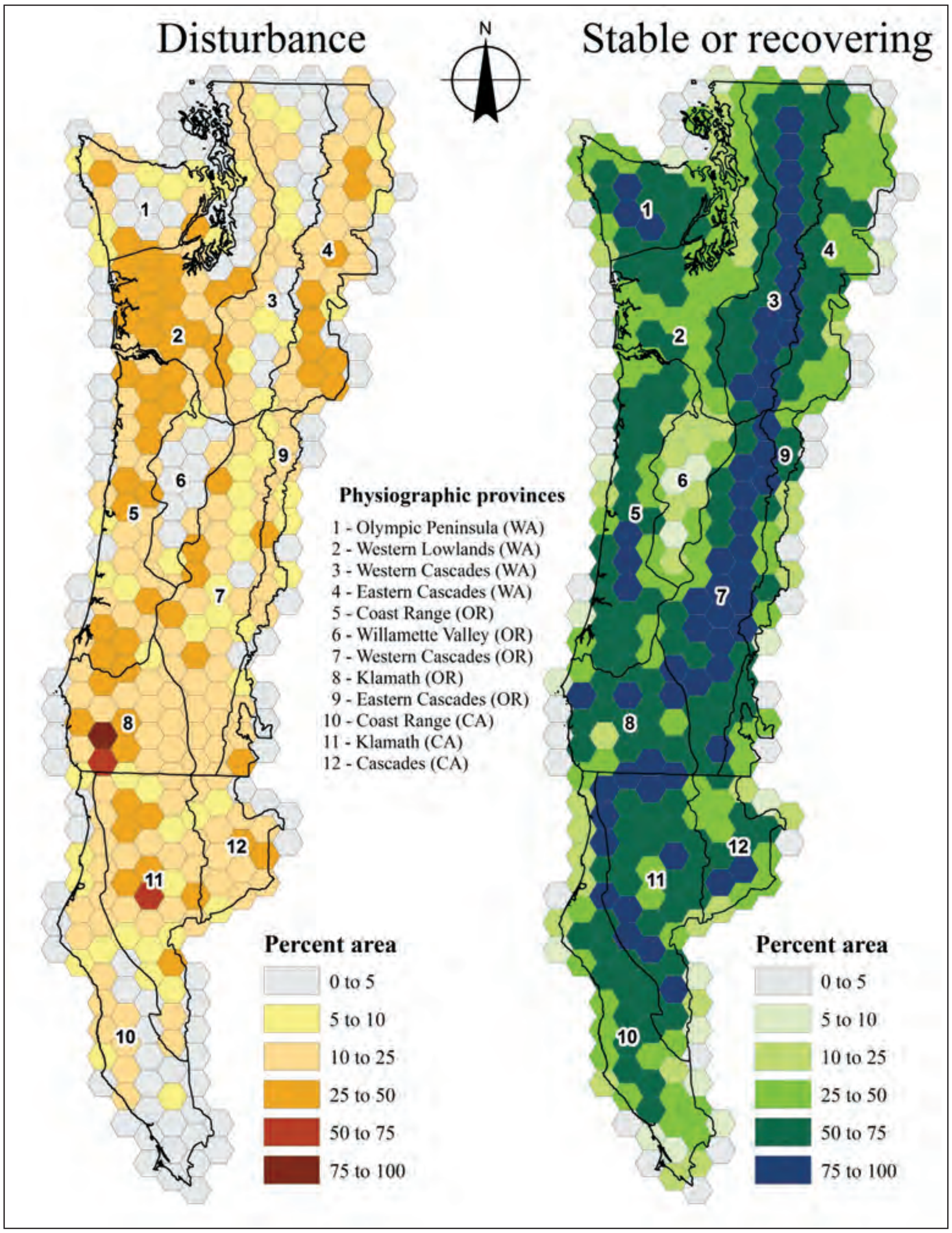


Figure 6—LandTrendr data (1993–2012) provide us with a picture of both forest disturbance (left) and stable/recovering areas (right). CA = California, OR = Oregon, WA = Washington.

2012) and verified for accuracy using the TimeSync method (Cohen et al. 2010). The LandTrendr maps represented three aspects of vegetation change: (1) year of disturbance, (2) magnitude of disturbance, and (3) duration of disturbance. We classified these maps to produce a map of where timber harvesting, wildfire, insect and disease, and other natural disturbances (e.g., blowdown, floods, landslides) have occurred between 1993 and 2012 (app. D). Where this map overlapped losses of older forest, it helped to explain the causes for older forest loss since the Plan's implementation.

Landsat imagery that covered the NWFP area was acquired from the USGS Glovis website (glovis.usgs.gov) for the summer period (usually July and August) from 1984 to 2012. Images were atmospherically corrected using Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) methodology (Masek et al. 2008). This was different from the multivariate alteration detection and calibration (MADCAL) radiometric normalization methods (Canty et al. 2004) used in the 15-year report (Moeur et al. 2011). To minimize cloud coverage, multiple image dates within a given season were used to produce a clear-pixel composite image for that year.

The composite imagery was then processed using the LandTrendr segmentation algorithm (Kennedy et al. 2010), which computes the normalized burn ratio (NBR) (Key and Benson 2006, van Wagtendonk et al. 2004) spectral index for each pixel in the time series. The algorithm performed a temporal segmentation for each pixel to find year-dates (vertices) where changes in NBR had occurred (normally associated with changes in vegetation). Between sets of any two vertices, temporal segments were established and each segment was labeled as disturbance, recovery, or stable based on spectral direction. For disturbance segments, the year of disturbance declared was always one year after the first (or start) vertex of the segment. The "year of detection" did not always represent the "year of disturbance." Sometimes the disturbance occurred after the Landsat image was acquired for that year. The disturbance was then detected in the imagery from the following year (or years) depending on image quality and other factors. Usually, the disturbance was detected within 1 to 2 years of the event. Because many disturbances can last more than one year, the number of years of the disturbance segment was used as the duration of the segment. Both duration and magnitude were also provided for recovery segments. Where there was no change in NBR over a segment, the segment was declared as stable, with duration equal to the number of years of the segment and magnitude equal to zero. Each segment was subsequently fitted with a linear regression to smooth the NBR response over the segment length, thereby removing unwanted spectral noise. This is referred to as temporal normalization. For each temporally normalized segment, we estimated the percentage of vegetation cover for the beginning and ending vertices using a statistical model that relates NBR to vegetation cover (Cohen et al. 2010). The difference between vertex predictions represented the magnitude of the disturbance or recovery segment in terms of percentage vegetation cover. We scaled the absolute magnitude to the starting value to compensate for varying predisturbance forest cover values, such that all reported magnitudes were expressed as a proportion of the starting condition. The final step was to spatially filter the pixels to a minimum mapping unit of 11 pixels, or about 2.47 ac.

Occasionally, there were temporally overlapping disturbances detected during our monitoring period. However, Kennedy et al. (2012) found that overlapping secondary disturbances within the NWFP area covered less than 5 percent of the area of primary disturbances. For simplicity, our LandTrendr products and analyses were based on the highest magnitude disturbance that occurred throughout the entire Landsat time series. We used duration and magnitude to reclassify the three LandTrendr disturbance map products (year, duration, and magnitude) into one map that represented the cause of most significant disturbance between 1993 and 2012. An analysis of wildfire and timber harvest unit polygons showed an average disturbance duration signal of about 1.5 ± 1.0 years (mean ± 1 SD) for regeneration harvests, 1.7 ± 1.7 years for wildfires, and 2.2 ± 2.2 years for thinning harvests. Based on this information, we classified the duration map into a binary map of fast (1 to 4 years) and slow (>4 years) disturbance. Fast disturbance represented abrupt events such as a wildfire, timber harvest, or debris flow. Slow disturbances represented insects or disease, or postfire mortality. To attribute the cause of disturbance, we used a map of wildfire perimeters (see Davis et al. 2011: chap. 4) that was updated to include mapped wildfires that occurred between 1993 and 2012 to classify disturbances caused by wildfire. We used aerial insect damage detection GIS data (USDA FS 2008) to help classify disturbance that was likely associated with spruce budworm (*Choristoneura occidentalis*) and bark beetles (*Dendroctonus* spp.). Finally, we used LUAs for congressionally reserved or administratively withdrawn lands to help classify areas where timber harvesting was not likely to be the cause of the disturbance. See appendix D, table D-1 for the complete classification rule set used to produce our map of cause of disturbance and classification accuracy assessment. Our maps of wildfire disturbance are fairly inclusive of all major wildfires exceeding a few acres, but there are many wildfires each year that are smaller than this, which were not mapped. We used agency "forest activity" harvest GIS layers, where available, but did not have similar GIS layers for harvesting on nonfederal lands.

Given the disturbance detection time lag previously discussed, our disturbance maps did not capture all disturbances that occurred during the final year of our analysis (2012), particularly for those disturbances that occurred later in that year after the satellite image acquisition date, or were obscured by smoke from wildfires. Those changes will be captured in subsequent monitoring efforts, and, in general, our classified disturbance map provided us a general sense of the amount of and change agents behind older forest losses between 1993 and 2012.

Gradient Nearest Neighbor Maps

We used GNN maps of forest composition and structure (Ohmann and Gregory 2002) on forest-capable lands from two different dates, 1993 and 2012. We developed GNN maps specifically for landscape- and regional-scale analysis and monitoring (Moeur et al. 2005, 2011; Ohmann and Gregory 2002; Spies et al. 2007). They have also been used for other broad-scale vegetation analyses across a wide range of forest ecosystems for multiple objectives (Ohmann et al. 2007, 2011, 2012; Pierce et al. 2009; USDI FWS 2011). Along with each map, a large suite of diagnostics detailing model reliability and map accuracy were provided and are summarized in appendix E.

Our mapping method for this report was the single neighbor (k = 1) GNN imputation as described by Ohmann and Gregory (2002) and Ohmann et al. (2014), and similar to the method used for the 15-year monitoring (Moeur et al. 2011, Ohmann et al. 2012). The process uses the nearest-neighbor plot identified for each map pixel based on the weighted Euclidean distance within a multivariate gradient space as determined from canonical correspondence analysis (CCA) (ter Braak 1986), a method of constrained ordination (direct gradient analysis). All of the forest attributes from that plot are then assigned (or imputed) to each map pixel. The k = 1 approach produces realistic representations of the range of variation of forest conditions over broad regions, including the “extreme tails” of the distributions (Ohmann et al. 2014), which can represent rare conditions (e.g., very large conifer forest). It also maintains the covariance structure of plot attributes within each map pixel such that there will be no illogical combinations of species or structures not found in the plot data.

We only used plots that were at least 50 percent forest. For each plot, tree-level data from all forest subplots were combined and converted to per-hectare (per-acre) values that described the forest portion of the plot, which was treated as homogeneous. We did not average conditions across forest and nonforest land classes within a plot because our modeling and mapping approach applied only to the forested component of the landscape. Imputation was applied to pixels of all land classes, but nonforest areas were masked in the final vegetation map using the previously described forest-capable layer.

To determine values for spatial predictors associated with each plot observation, we used a 3- by 3-pixel “plot footprint” that encompassed the outer extent of the forested area sampled by the field plot. We intersected the 3- by 3-pixel block with the LandTrendr data described in the previous section for the same year as plot measurement, and the means of the tasseled cap indices (composite images representing brightness, greenness, and wetness based on weighted combinations of Landsat TM image bands) and fitted NBR for this footprint were associated with the plot observation. Values for the abiotic explanatory variables (e.g., climate) were similarly extracted for the plot footprints, but assumed constant over the range of plot measurement dates.

For both the 15- and 20-year reports, the GNN maps were developed using Landsat time-series data that were temporally normalized using the LandTrendr algorithm as described in the previous section. The LandTrendr data allowed us to develop GNN maps for multiple years with improved consistency across years. For the 20-year report maps, we made several incremental improvements to our data and methods as summarized below, some of which are also documented in Ohmann et al. (2014):

New plots added: The 15-year maps were based on plots measured through 2007. For the 20-year maps, we added four more years of field plots, measured through 2011.

Screening for plot outliers: This process benefited immensely from having yearly LandTrendr time-series mosaics from 1984 to 2012, as well as LandTrendr disturbance maps, to aid in determination of timing of disturbances relative to plot measurement. In screening, potential outlier plots were flagged using various algorithms that compared observed plot attributes to predicted map attributes to identify mismatches. These plots were viewed in the LandTrendr imagery and digital aerial photography to identify and exclude plots that straddled contrasting forest conditions (e.g., older forest and clearcut), or that had been disturbed between plot measurement and imagery dates (uncommon with the yearly plot-imagery matching).

New spatial predictor: Spatial predictor variables normally used in the GNN process include maps of abiotic variables such as climate, topography, latitude, and longitude, as well as Landsat imagery of tasseled cap brightness, greenness, and wetness. For the 20-year report, we added the NBR from the LandTrendr data. The LandTrendr segmentation algorithms for creating disturbance maps were based on NBR, and we hoped to gain more consistency between the older forest and disturbance maps by adding this variable.

Matching of plots to imagery: For the 15-year report, we had only two LandTrendr imagery dates to work with, and plots were matched either to imagery time 1 or time 2. This resulted in as much as a 6-year difference between plot measurement date and imagery date. Many plots were excluded from modeling because of disturbance between plot and imagery dates. For this 20-year report, we implemented yearly matching of field plots to LandTrendr data, with plots matched to the same year as plot measurement. This was made possible by having yearly LandTrendr mosaics available from 1984 to 2012. This resulted in many fewer plots excluded because of disturbance and effectively eliminated differences between plot and imagery dates associated with growth.

From these GNN maps, we derived maps of "older forest" for time 1 (1993) and time 2 (2012) using the established "LSOG" definition based on quadratic mean diameter (QMD ≥ 20 in and conifer cover ≥ 10 percent) from previous monitoring reports (Moeur et al. 2005, 2011) and two additional definitions based on the previously described age thresholds (80 years and 200 years) applied to the OGSI maps. We termed these classified maps of older forest at time 1 and 2 as "bookend" maps. They portrayed older forest conditions at the beginning and ending of the Plan monitoring period covered by this report (1993 to 2012).

While GNN was designed for regional-scale analyses, the maps portray forest structure and composition at finer spatial scales. In a recent assessment of the OGSI, GNN performed well at the scale of a 30-km (18.6-mi) hexagon (distance from the center of one hexagon to the next), which covered slightly more than 190,000 ac (Ohmann et al. 2014). In addition to conducting our analyses at regional, state, and physiographic scales, we used 30-km (18.6-mi) hexagons to summarize our maps for interpretation and visual displays of older forest abundance, diversity, and connectivity at times 1 and 2, as well as changes between these time periods.

Bookend Analysis

We first analyzed the change in areal frequency distribution of OGSI as a continuous index divided into 10 equal-interval bins (e.g., 0 to 10, 10 to 20, 20 to 30, 90 to 100) for both time periods (1993 and 2012). This allowed us to look at changes along the entire spectrum of older forest development, instead of some threshold set to portray just the older forest portion.

We then analyzed abundance and distribution of older forests using GNN data to produce binary bookend maps of older forest for the two time periods, and for three different definitions (LSOG, OGSI-80, and OGSI-200). We analyzed the spatial patterns of each binary map using software GUIDOS v1.4, which was developed for analysis of forest spatial patterns extracted from satellite images (Soille and Vogt 2009). GUIDOS assigned each older forest pixel an attribute that described its landscape membership by segmenting binary map patterns into seven mutually exclusive classes: core, perforation, edge, bridge, branch, loop, and islet. We then combined these morphological classes into five general landscape categories (fig. 7):

Core—The interior portion of a group of older forest pixels that is large enough to contain at least one pixel 98 ft from the edge.

Core-edge—Pixels along the edge of group of older forest pixels large enough to contain at least one core pixel. Given the resolution of the binary maps, edges are 98 ft wide.

Patch—Consists of core plus core-edge pixels. Represents stands of older forest that contain some interior area and are at least 2.47 ac (the approximate size of a forest inventory plot).

Finger—Stringers of older forest pixels that bridge, branch, or loop out from a patch, but are not wide enough to contain any core pixels (1 to 2 pixels wide but can be several pixels in length).

Scatter—Isolated pixels or groups of older forest (islet) pixels that are too small (<2.47 ac) to contain core pixels and do not connect to any patches of older forest.

From each bookend, we produced areal estimates of older forest amounts and patterns for both time periods (1993 and 2012). We then differenced the bookend maps to quantify net changes in both amount and distribution between the two time periods. Areal map estimates were prepared for each OGSI threshold (80 and 200 year) by physiographic province, state, and NWFP area.

Finally, geographic representations of the conditions in 1993 and 1992, as well as the net changes between these two time periods, were provided using 30-km (18.6-mi) hexagons. For these geographical representations, areal amounts were summarized as the percentage area of each hexagon (192,000 ac) regardless of the area within the hexagon that was forest capable. This produced maps where the percentage value of each hexagon was comparable to the next.

Outcome Analysis

To determine the Plan's effectiveness in achieving outcomes 1 or 2 for abundance, distribution, and connectivity of older forest, we summarized four things: (1) area covered by old forest, (2) area covered by patches and fingers only (>2.47 ac), (3) area covered by large patches only (>1,000 ac), and (4) average distance between large patches. We used 30-km (18.6-mi) hexagons (center to center) to represent "relatively large areas" as described in FEMAT (1993: IV–50). Each hexagon covered about 192,000 ac. Using zonal statistics in ArcGIS, each hexagon was attributed with the percentage of federal forest lands, older forest amounts (total, patches and fingers only, and large patches only), and mean distance to large patches of older forest as calculated in ArcGIS using the Euclidean Distance tool in Spatial Analyst.

These statistics were based on the entire area of the hexagon, and not just the forest-capable portions within them. Thus, they were comparable between all hexagons across the Plan area. Only hexagons that contained at least 10 percent federally managed forest lands (or about 19,200 ac, which is roughly equivalent to one sixth-field watershed) were attributed with outcomes outlined in tables 1

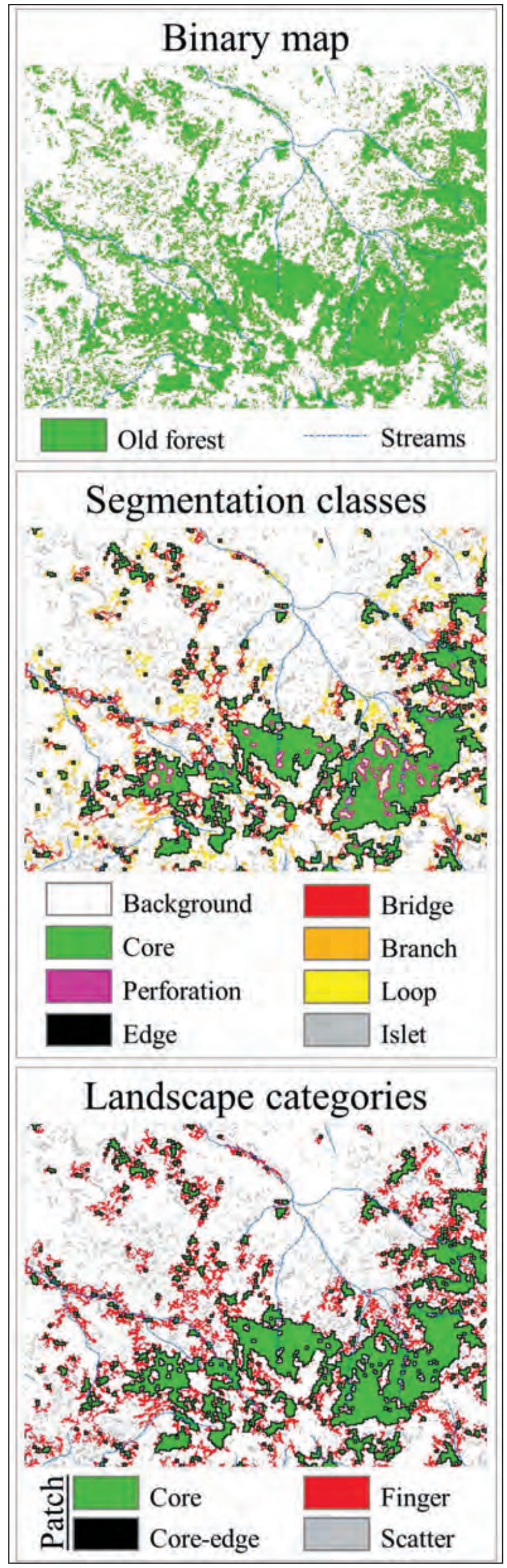


Figure 7—Morphologic spatial patterns and landscape categories used to assess old-forest patterns and connectivity.

and 2 for each time period. We then differenced the time periods to determine if the trend was toward improving or degrading the outcome. Finally, we determined which hexagons met the threshold criteria for outcomes 1 or 2 for abundance and diversity (table 1) as well as connectivity (table 2) for each time period.

Results

Bookend Map Analysis

Observed frequency distributions of OGSI for all lands across the NWFP area varied between different land manager groupings (fig. 8). The national parks showed a larger proportion of their forests with higher OGSI scores; whereas nonfederal forest lands had the largest proportion of lower OGSI scores. Forests managed by the BLM and USFS were intermediate, with the USFS having slightly larger proportions of higher OGSI scores than BLM. These OGSI distributions did not change much between 1993 and 2012, with the exception of increases in the first bin (0 to 10) that likely resulted from losses from disturbances in all other bins.

Overall, the amount of older forest on all lands within the NWFP boundary has decreased by 5.9 to 6.2 percent between 1993 and 2012, depending on which older forest definition was used (fig. 9a). The amount of decrease was less on federal lands (2.0 to 2.9 percent) than on nonfederal lands (11.6 to 18.1 percent) (figs. 9b and 9c, respectively). When subdivided into smaller landscape areas, we noted net gains in certain portions of the NWFP area (app. F). Most of the areas with net gains coincided

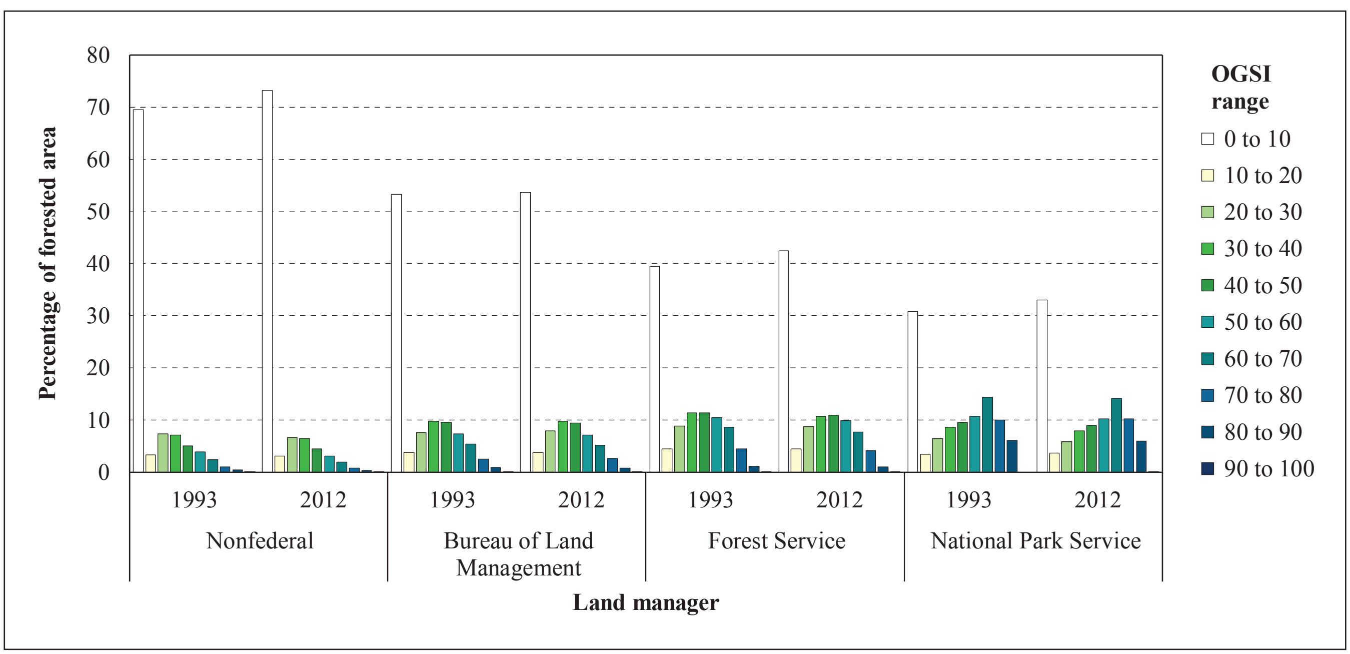


Figure 8—Frequency distributions of the old-growth structure index (OGSI) based on 10 equal-interval bins for the major federal land managers between bookend time periods (1993 and 2012).

with locations of historical large wildfires that burned in mid-19th or early-20th centuries (e.g., Yaquina Fire, Nestucca Fire, Yacolt Fire). Landscapes that exhibited net losses were mainly coincident with recent large wildfires (e.g., Biscuit Fire, Megram Fire, B&B Fire) or nonfederal timber lands. The physiographic provinces that incurred the largest losses of older forest (OGSI-80 and OGSI-200) on federal lands (based on area) were the Oregon Western Cascades, Oregon Klamath, and California Klamath.

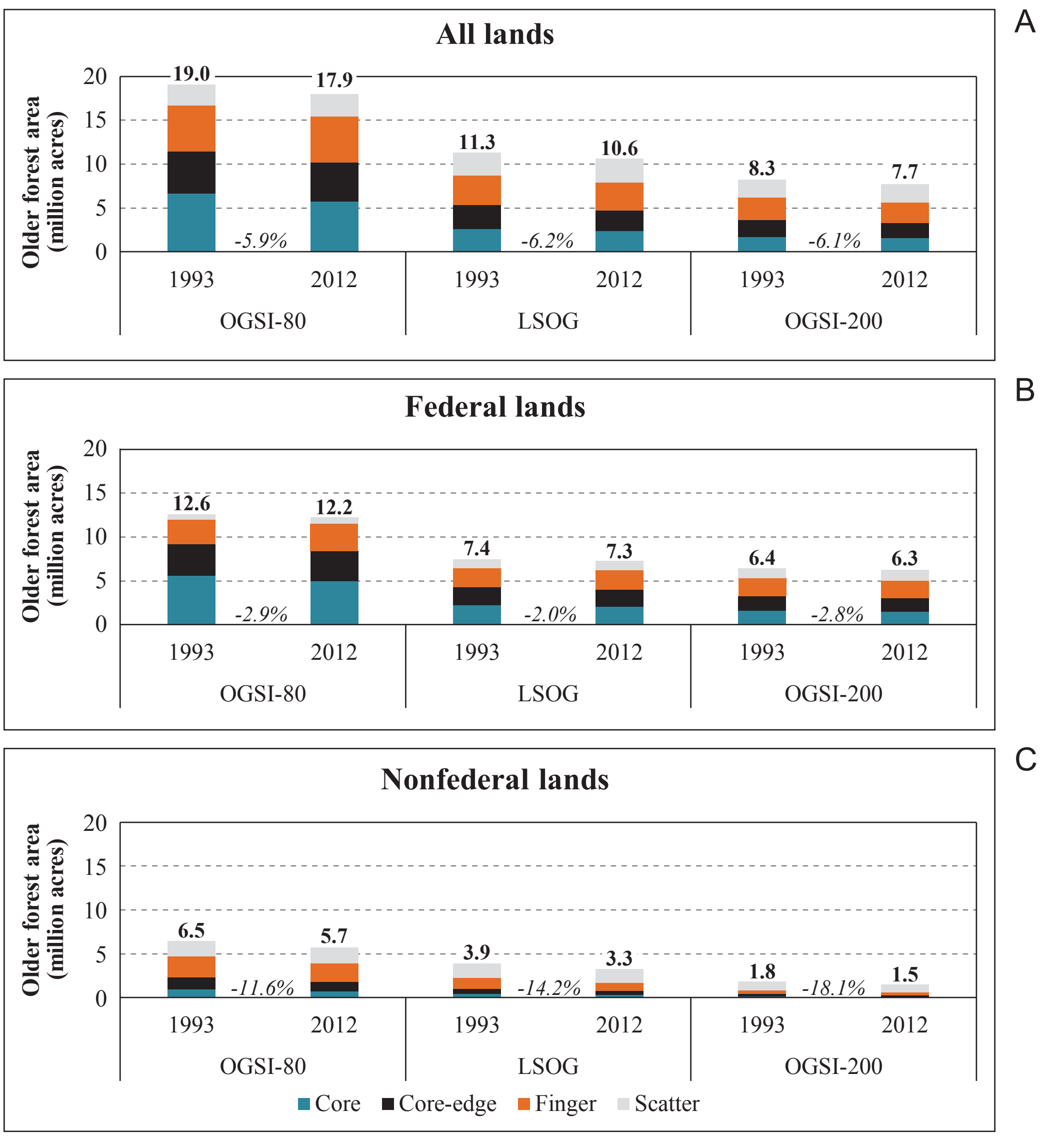
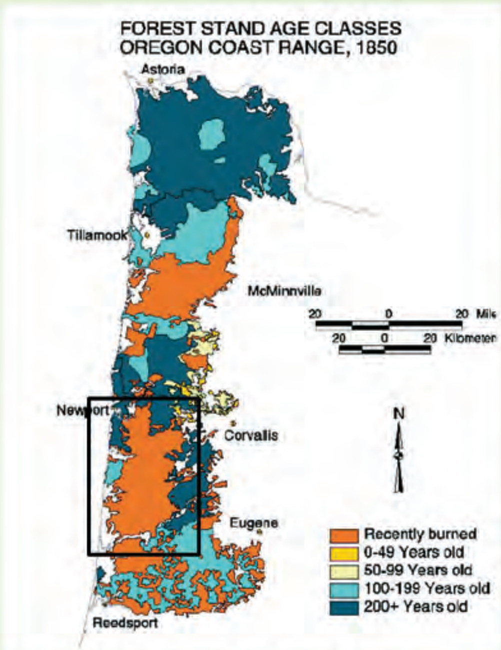


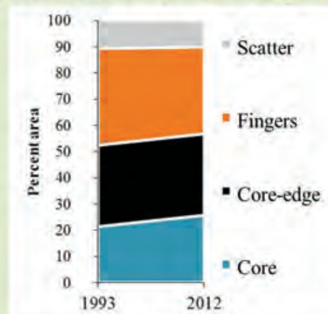
Figure 9—Change in area of older forests by ownership class from the map-based bookend analysis of binary maps of old forest using three definitions; old-growth structure index at the 80-year threshold (OGSI-80) (left), late-seral old growth (LSOG) (b), and OGSI at the 200-year threshold (OGSI-200) right. Percentage net changes in old-forest area between bookends (1993 and 2012) are shown in italics.

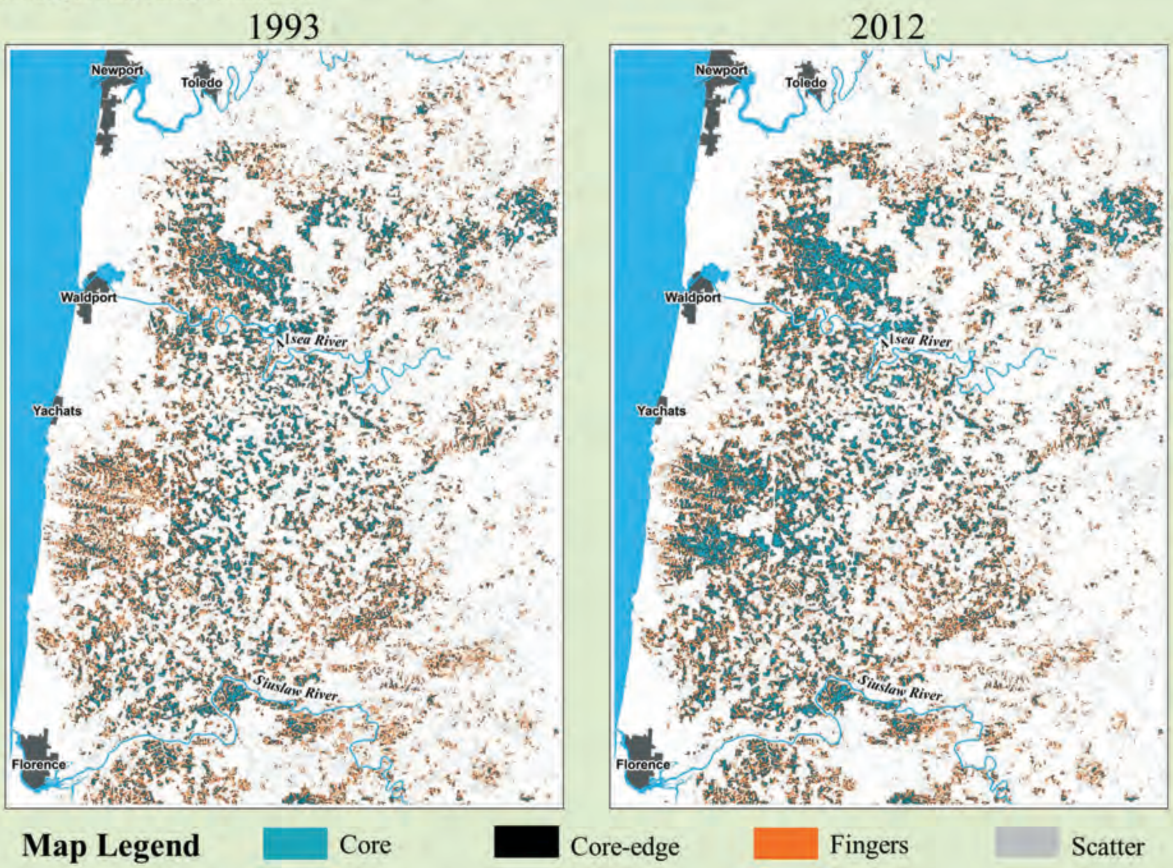


Teensma, P.D.A.; Rienstra, J.T.; Yeiter, M.A. 1991. Preliminary reconstruction and analysis of change in forest stand age classes of the Oregon Coast Range from 1850 to 1940. USDI Bureau of Land Management Technical Note T/N OR-9. Oregon State Office, Portland, OR.

Decades to Centuries

Old-growth forests take several decades to centuries to develop in the Pacific Northwest Region. Our monitoring focuses on forest changes since the implementation of the Northwest Forest Plan, which is now two decades old. We are just starting to detect portions of the Plan's area that are beginning to redevelop into old growth following disturbances that occurred decades to over a century ago. For example, we have detected net gains in OGSI 200 on portions of the Siuslaw National Forest (outlined in black in the figure on the left and shown below). The Oregon Coast Range experienced large stand-replacing wildfires in the mid-1800s (left). This area is now exhibiting gains in the amount (+15 percent) and connectivity of older forests as seen by increases in core and core-edge pixels (right).





The spatial arrangement of older forest is distinctly different on federal versus nonfederal lands. Core and core-edge account for a smaller proportion on nonfederal forests (fig. 9c), but account for half or more of the total amount of older forest on federal lands (fig. 9b). Combined, these two components (core and core-edge) form relatively contiguous patches of older forest ranging from 2.47 to >10,000 ac. The remaining older forest consists of fragmented fingers and small pieces or remnants scattered throughout a matrix of younger forests. Over the last 20 years, older forests have become slightly more fragmented from disturbances on federal lands at the scale of the Plan, but again, in some smaller landscapes such as the Siuslaw National Forest, the older forests have not only increased in abundance, but have also become somewhat less fragmented.

In the above analysis, we compared amounts and spatial patterns of older forest using three different definitions: (1) the OGSI threshold at 80 years, (2) the LSOG definition used in previous monitoring reports (QMD ≥ 20 in and conifer cover ≥10 percent), and (3) the OGSI threshold at 200 years. As noted by Moeur et al. (2011) and Ohmann et al. (2012), the LSOG definition's reliance on QMD rendered it susceptible to blinking on or off as the result of loss or gain of just a few trees on a plot (e.g., an underburn or thinning from below can create instant older forest). The OGSI definitions avoided this problem by not using QMD, but small changes in the live-tree tally may still affect the diameter diversity index component of the index. Based on these definitions, the amount of LSOG fell in between the amounts for OGSI at the 80- and 200-year thresholds. Because LSOG was bracketed by the OGSI thresholds (fig. 9), we discontinued its use to simplify our analyses and also for the reasons stated above. For the remainder of this report, we framed the analyses using only the OGSI at the 80- and 200-year thresholds shown in appendix C. Time period areal map estimates and estimates of net change for both map thresholds are shown by physiographic province, state, and NWFP area and displayed in tables 6 through 9.

Geographical representations of federal land management agencies, federal forest, and reserved federal forest were visually catagorized using 30-km (18.6-mi) hexagons (fig. 10). Estimates of losses by disturbance category for both map thresholds are shown by physiographic province, state, and NWFP area and displayed in tables 6 through 9. Geographical representation of the information in these tables is shown in figures 11, 12, and 13. Over all federal lands, the leading disturbance agent for loss of older forest on federal lands was wildfire, which accounted for 71 to 73 percent of the loss in OGSI-80 and OGSI-200, respectively (fig. 14). Federal timber harvesting accounted for 16 to 19 percent (OGSI-200 and OGSI-80, respectively). Other natural disturbances and insects and disease accounted for about 10 to 11 percent (OGSI-80 and OGSI-200, respectively). At the Plan scale, the rate of loss of older forests on federal lands from timber harvesting was 1.2 to 1.3 percent (tables 6

Table 6—Bookend map areal estimates of older forests (OGSI-80) on federal lands (left), net area and percentage changes from 1993 to 2012, and assigned losses from LandTrendr disturbance maps (right)

State and physiographic province	Older forest area estimates from bookend maps: 1993	2012	Net area change	Net percent change	LandTrendr disturbance assignment for losses: Harvest	Wildfire	Insects	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	909.2	910.8	1.6	0.2	2.5	1.2	1.2	2.6	7.4	-0.8
Western Lowlands	38.0	40.3	2.3	6.1	0.0	0.0	0.1	1.5	1.5	-4.0
Western Cascades	1,685.8	1,704.9	19.1	1.1	8.4	2.5	1.3	5.3	17.5	-1.0
Eastern Cascades	1,427.8	1,395.9	-31.9	-2.2	25.3	78.3	36.2	5.2	145.1	-10.2
Total	4,060.7	4,060.7	-8.8	-0.2	36.2	82.0	38.8	14.6	171.5	-4.2
Oregon:										
Coast Range	633.5	639.7	6.3	1.0	12.2	0.1	0.5	0.1	12.9	-2.0
Willamette Valley	5.7	5.7	0.0	-0.4	0.3	0.0	0.0	0.0	0.3	-5.0
Western Cascades	2,640.9	2,512.4	-128.5	-4.9	35.5	72.3	4.1	1.6	113.5	-4.3
Klamath	1,132.8	1,020.5	-112.3	-9.9	17.8	138.5	1.3	0.4	158.0	-13.9
Eastern Cascades	789.5	767.1	-22.4	-2.8	17.8	35.1	9.6	1.0	63.5	-8.0
Total	5,202.4	4,945.3	-257.0	-4.9	83.5	246.0	15.6	3.0	348.2	-6.7
California:										
Coast Range	157.9	163.2	5.3	3.4	0.4	3.9	0.1	0.6	5.1	-3.2
Klamath	2,683.3	2,573.0	-110.3	-4.1	13.8	186.7	3.1	3.3	206.9	-7.7
Cascades	478.8	487.7	8.9	1.9	14.2	7.9	3.3	0.8	26.3	-5.5
Total	3,320.0	3,224.0	-96.0	-2.9	28.4	198.6	6.5	4.8	238.2	-7.2
Northwest Forest Plan total	12,583.0	12,221.2	-361.8	-2.9	148.1	526.6	60.9	22.4	757.9	-6.0

Table 7—Bookend map areal estimates of older forests (OGSI-80) on nonfederal lands (left), net area and percentage changes from 1993 to 2012, and assigned losses from LandTrendr disturbance maps (right)

	Older forest area estimates from bookend maps				LandTrendr disturbance assignment for losses					
State and physiographic province	1993	2012	Net area change	Net percentage change	Harvest	Wildfire	Insects	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	294.0	233.5	-60.5	-20.6	80.7	0.0	2.5	0.0	83.2	-28.3
Western Lowlands	866.4	666.2	-200.2	-23.1	289.4	0.0	5.9	0.0	295.3	-34.1
Western Cascades	527.6	462.2	-65.4	-12.4	131.6	0.3	2.2	0.0	134.0	-25.4
Eastern Cascades	584.9	514.9	-70.0	-12.0	106.0	10.6	9.1	0.0	125.7	-21.5
Total	2,272.9	1,876.9	-396.0	-17.4	607.7	10.9	19.6	0.0	638.2	-28.1
Oregon:										
Coast Range	815.3	596.6	-218.7	-26.8	285.1	0.4	4.8	0.0	290.3	-35.6
Willamette Valley	127.6	107.8	-19.8	-15.5	27.1	0.0	0.5	0.0	27.5	-21.6
Western Cascades	476.7	370.5	-106.2	-22.3	158.7	3.3	2.8	0.0	164.9	-34.6
Klamath	390.5	351.0	-39.5	-10.1	90.5	3.4	2.1	0.0	95.9	-24.6
Eastern Cascades	236.5	203.2	-33.3	-14.1	48.8	7.3	3.1	0.0	59.2	-25.0
Total	2,046.6	1,629.1	-417.5	-20.4	610.2	14.4	13.2	0.0	637.8	-31.2
California:										
Coast Range	1,267.0	1,358.6	91.6	7.2	90.8	6.6	3.8	0.0	101.2	-8.0
Klamath	503.2	494.2	-9.0	-1.8	50.6	10.1	3.8	0.0	64.5	-12.8
Cascades	372.3	350.3	-22.0	-5.9	49.1	5.4	4.4	0.0	58.9	-15.8
Total	2,142.6	2,203.2	60.6	2.8	190.5	22.0	12.0	0.0	224.5	-10.5
Northwest Forest Plan total	6,462.0	5,709.2	-752.8	-11.7	1,408.3	47.3	44.9	0.0	1,500.5	-23.2

OGSI-80 = old-growth structure index at the 80-year threshold.

Table 8—Bookend map areal estimates of older forests (OGSI-200) on federal lands (left), net area and percentage changes from 1993 to 2012, and assigned losses from LandTrendr disturbance maps (right)

	Older forest area estimates from bookend maps				LandTrendr disturbance assignment for losses					
State and physiographic province	1993	2012	Net area change	Net percentage change	Harvest	Wildfire	Insects	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	720.0	727.4	7.4	1.0	1.8	1.0	1.3	2.5	6.6	-0.9
Western Lowlands	9.5	8.9	-0.7	-7.0	0.0	0.0	0.0	0.6	0.6	-6.7
Western Cascades	1,104.8	1,110.8	6.0	0.5	5.6	1.8	0.9	3.6	11.9	-1.1
Eastern Cascades	534.2	536.3	2.0	0.4	14.6	38.0	29.2	4.2	86.1	-16.1
Total	2,368.5	2,383.3	14.8	0.6	22.0	40.9	31.5	10.8	105.2	-4.4
Oregon:										
Coast Range	373.6	415.6	42.0	11.2	6.2	0.1	0.3	0.0	6.6	-1.8
Willamette Valley	1.7	1.8	0.1	6.8	0.1	0.0	0.0	0.0	0.1	-6.2
Western Cascades	1,556.3	1,463.3	-92.9	-6.0	26.0	58.5	2.8	1.3	88.6	-5.7
Klamath	447.3	402.1	-45.3	-10.1	9.5	64.1	0.8	0.1	74.5	-16.6
Eastern Cascades	298.1	295.7	-2.4	-0.8	7.0	17.9	3.8	0.7	29.4	-9.9
Total	2,676.9	2,578.4	-98.5	-3.7	48.8	140.6	7.6	2.2	199.2	-7.4
California:										
Coast Range	49.7	48.3	-1.5	-3.0	0.2	2.3	0.0	0.2	2.8	-5.6
Klamath	1,239.8	1,141.8	-98.0	-7.9	9.0	161.9	3.4	2.7	177.0	-14.3
Cascades	103.7	108.4	4.6	4.5	2.7	3.2	0.8	0.3	7.0	-6.8
Total	1,393.3	1,298.5	-94.8	-6.8	11.9	167.4	4.3	3.2	186.9	-13.4
Northwest Forest Plan total	6,438.7	6,260.2	-178.5	-2.8	82.7	348.9	43.4	16.2	491.2	-7.6

OGSI-200 = old-growth structure index at the 200-year threshold. NWFP = Northwest Forest Plan.

Table 9—Bookend map areal estimates of older forests (OGSI-200) on nonfederal lands (left), net area and percent changes from 1993 to 2012, and assigned losses from LandTrendr disturbance maps (right)

State and physiographic province	Older forest area estimates from bookend maps				LandTrendr disturbance assignment for losses					
	1993	2012	Net area change	Net percentage change	Harvest	Wildfire	Insects	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	137.8	102.7	-35.1	-25.5	31.8	0.0	1.3	0.0	33.1	-24.0
Western Lowlands	240.6	160.9	-79.6	-33.1	109.9	0.0	1.9	0.0	111.8	-46.5
Western Cascades	248.2	210.4	-37.8	-15.2	58.9	0.2	1.1	0.0	60.1	-24.2
Eastern Cascades	138.3	106.6	-31.7	-22.9	31.3	4.7	3.4	0.0	39.5	-28.6
Total	764.9	580.7	-184.2	-24.1	231.9	4.9	7.8	0.0	244.6	-32.0
Oregon:										
Coast Range	254.3	190.5	-63.8	-25.1	105.3	0.3	1.6	0.0	107.2	-42.1
Willamette Valley	15.9	13.8	-2.1	-12.9	5.1	0.0	0.1	0.0	5.2	-32.8
Western Cascades	178.4	122.0	-56.4	-31.6	72.8	1.4	1.0	0.0	75.2	-42.1
Klamath	100.4	86.1	-14.3	-14.2	34.7	1.1	0.8	0.0	36.6	-36.5
Eastern Cascades	55.8	44.8	-10.9	-19.6	13.1	4.1	1.0	0.0	18.2	-32.5
Total	604.8	457.3	-147.5	-24.4	231.0	6.9	4.5	0.0	242.3	-40.1
California:										
Coast Range	235.8	247.3	11.5	4.9	29.9	1.9	1.2	0.0	33.0	-14.0
Klamath	153.7	147.5	-6.2	-4.0	26.1	4.5	1.9	0.0	32.4	-21.1
Cascades	59.0	56.4	-2.6	-4.5	10.2	1.6	1.1	0.0	13.0	-22.0
Total	448.5	451.2	2.7	0.6	66.3	8.0	4.1	0.0	78.4	-17.5
Northwest Forest Plan total	1,818.2	1,489.2	-329.0	-18.1	529.2	19.8	16.4	0.0	565.3	-31.1

OGSI-200 = old-growth structural index at the 200-year threshold.

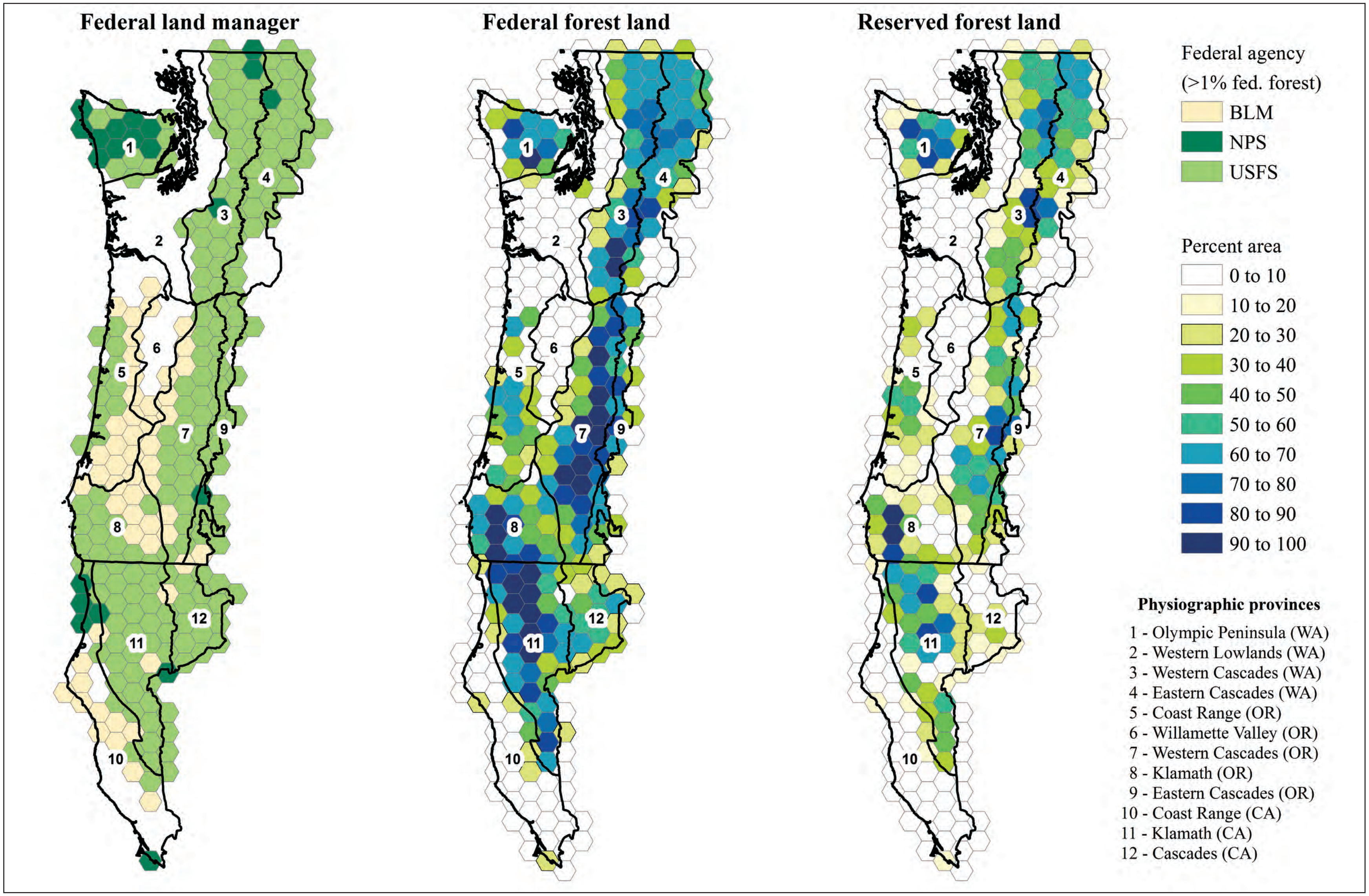


Figure 10—Geographical patterns of federally managed lands and forest using 30-km (18.6-mi) hexagons. To illustrate the spatial distribution of federal land managers, hexagons containing at least 1 percent federal land ownerships were displayed and based on the majority of ownership. BLM = Bureau of Land Management, NPS = National Park Service, USFS = U.S. Forest Service, CA = California, WA = Washington, OR = Oregon.

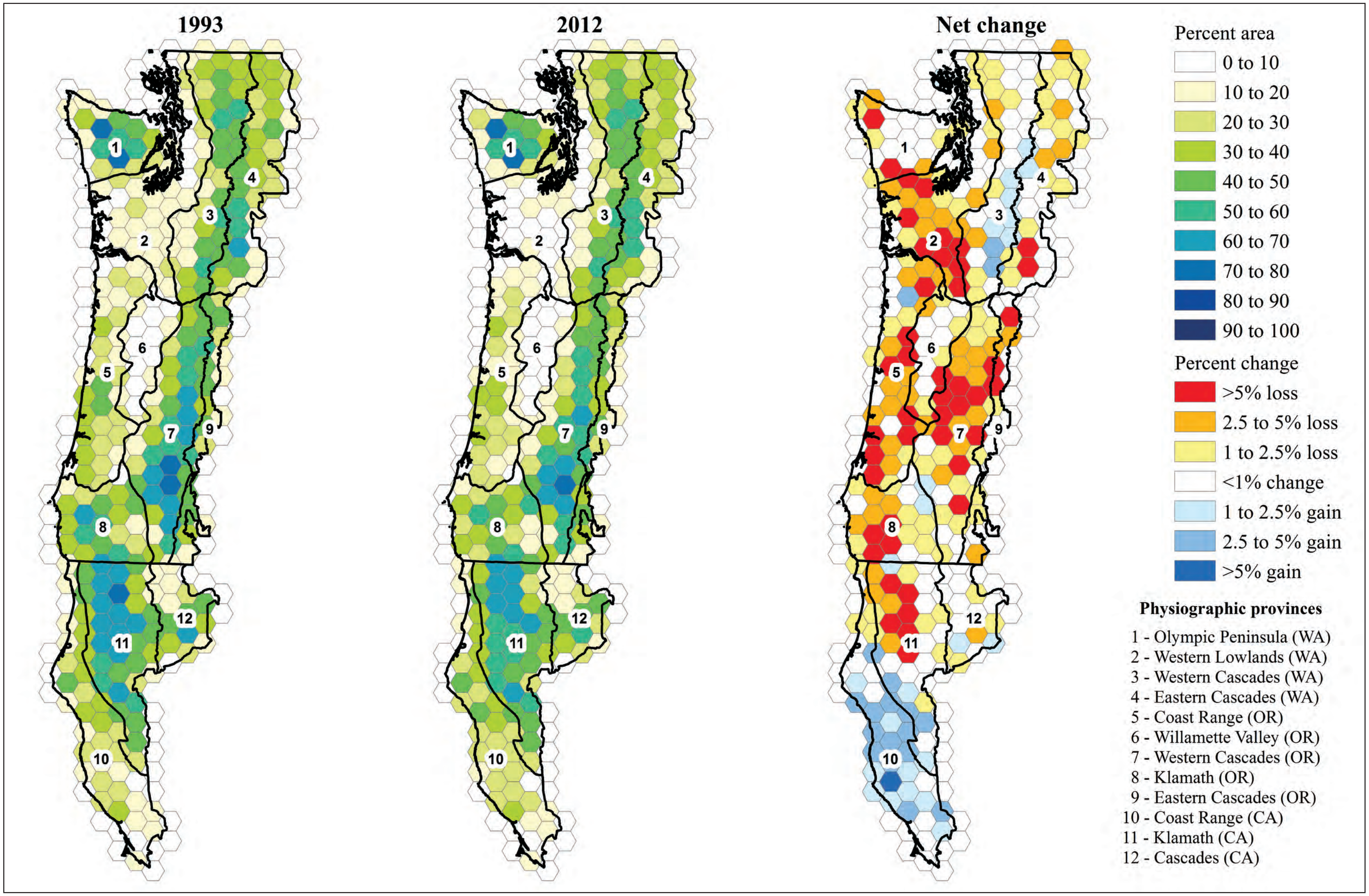


Figure 11—Geographical patterns for all lands showing old-growth structure index at the 80-year threshold for bookend time periods of 1993 and 2012, as well as patterns of net change between the bookends. CA = California, OR = Oregon, WA = Washington.

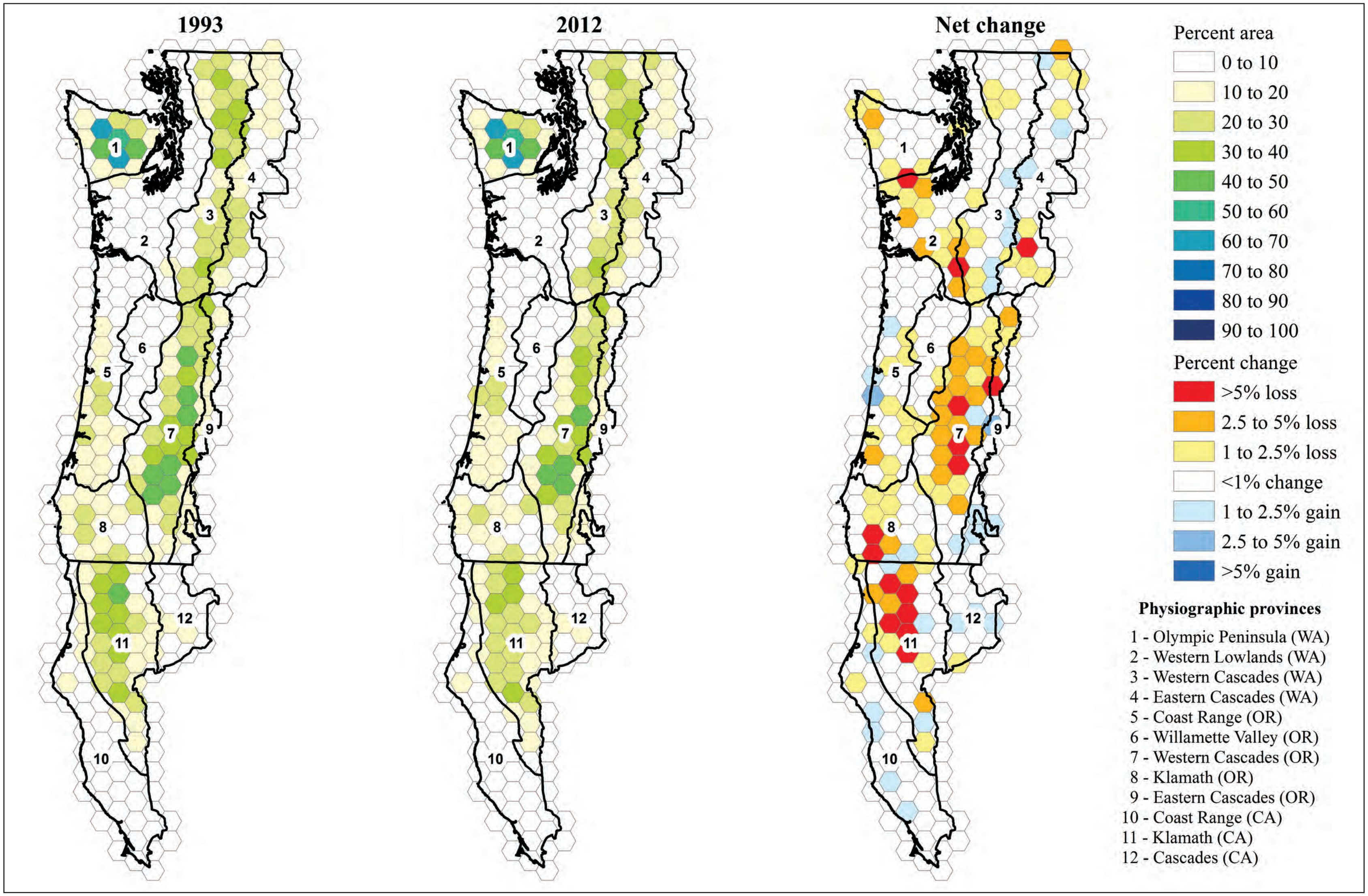


Figure 12—Geographical patterns for all lands showing old-growth structure index at the 200-year threshold for bookend time periods of 1993 and 2012, as well as patterns of net change between the bookends. CA = California, OR = Oregon, WA = Washington.

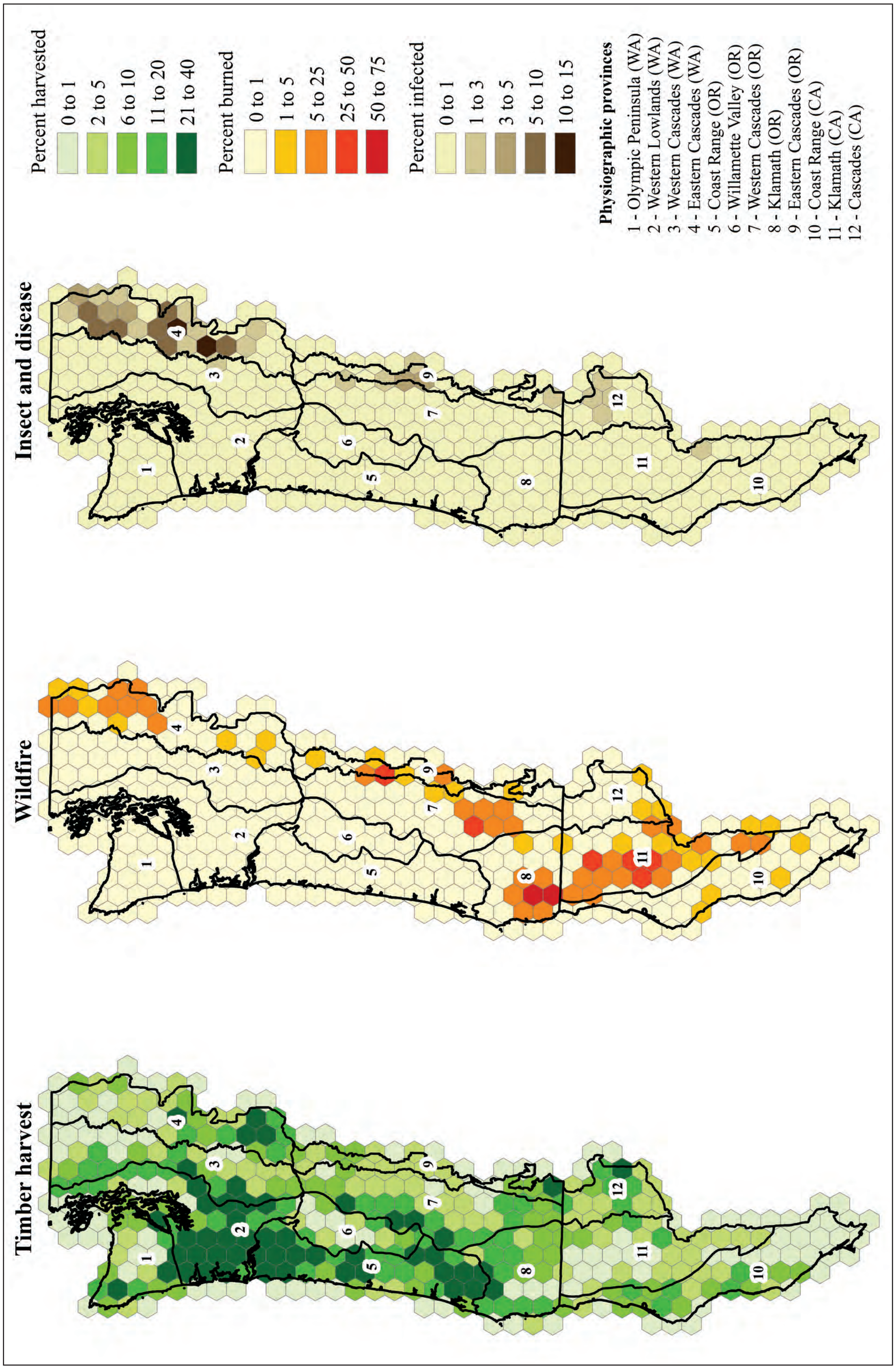


Figure 13—Geographical patterns for all lands showing forest disturbance between 1993 and 2012 as detected by LandTrendr. CA = California, OR = Washington, WA = Washington.

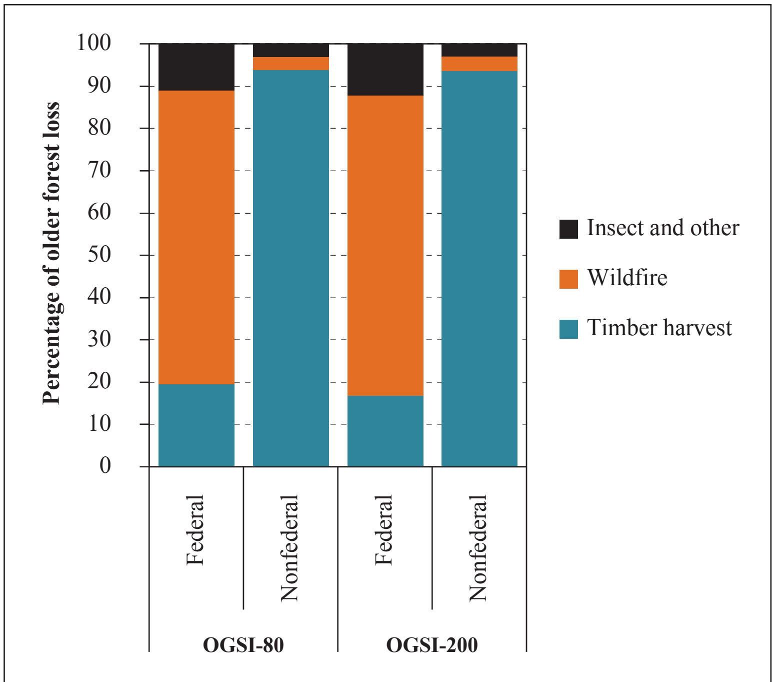


Figure 14—LandTrendr explained causes for losses of older forests between 1993 and 2012. Old-growth structure index at the 80-year (OGSI-80) and 200-year threshold (OGSI-200).

and 8). This was less than the anticipated loss of 5 percent loss over two decades (FEMAT 1993). Losses from wildfire were also anticipated to be about 5 percent over two decades (FEMAT 1993) and were close to that expectation, at 4.2 to 5.4 percent (tables 6 and 8). Losses from wildfire were highest in fire-prone physiographic provinces, specifically the Washington Eastern Cascades (5.5 to 7.1 percent) and the Klamath Provinces of Oregon and California (12.2 to 14.3 percent and 7.0 to 13.1 percent, respectively). Most of the losses from wildfire occurred in reserved land use allocations. Losses from insects were notable in the Washington Eastern Cascades at 2.5 to 5.5 percent and Oregon Eastern Cascades at 1.2 to 1.3 percent (tables 6 and 8).

Outcome Analysis

At the implementation of the Plan, about 80.9 percent of hexagons that contained 10 percent or more federal lands met the older forest abundance and diversity outcomes 1 or 2 as represented by OGSI-80 (fig. 15). Using the same threshold and for the same time, about 56.8 percent met older forest connectivity outcome 1 or 2 (fig. 16). Twenty years later, slightly less (78.6 percent and 54.5 percent, respectively) met these outcomes. Overall, we estimated a 2.3 percent decrease in both the abundance/diversity outcome and connectivity outcome for OGSI-80 on the federal landscape.

For older forests represented by OGSI-200, about 16.8 percent of the federal landscape met outcomes 1 or 2 for abundance and diversity in 1993, which decreased to 12.7 percent (a 4.1 percent decrease) by 2012 (fig. 17). Very little (3.2 percent) of the federal landscape met connectivity outcomes 1 or 2 for OGSI-200. There was some loss balanced by gains to keep this percentage stable across the monitoring period (fig. 18).

Small portions of the federal landscape (hexagons with at least 10 percent federal forest lands by area) improved (e.g., moved into or closer to outcomes 1 or 2) in these terms, over the last 20 years, but not to the extent that they contributed to the overall measures for abundant and well-distributed older forests at this time. Most of these improved areas were for OGSI-200 and occurred within historical old wildfire perimeters, but also in some high elevations (figs. 15 to 18).

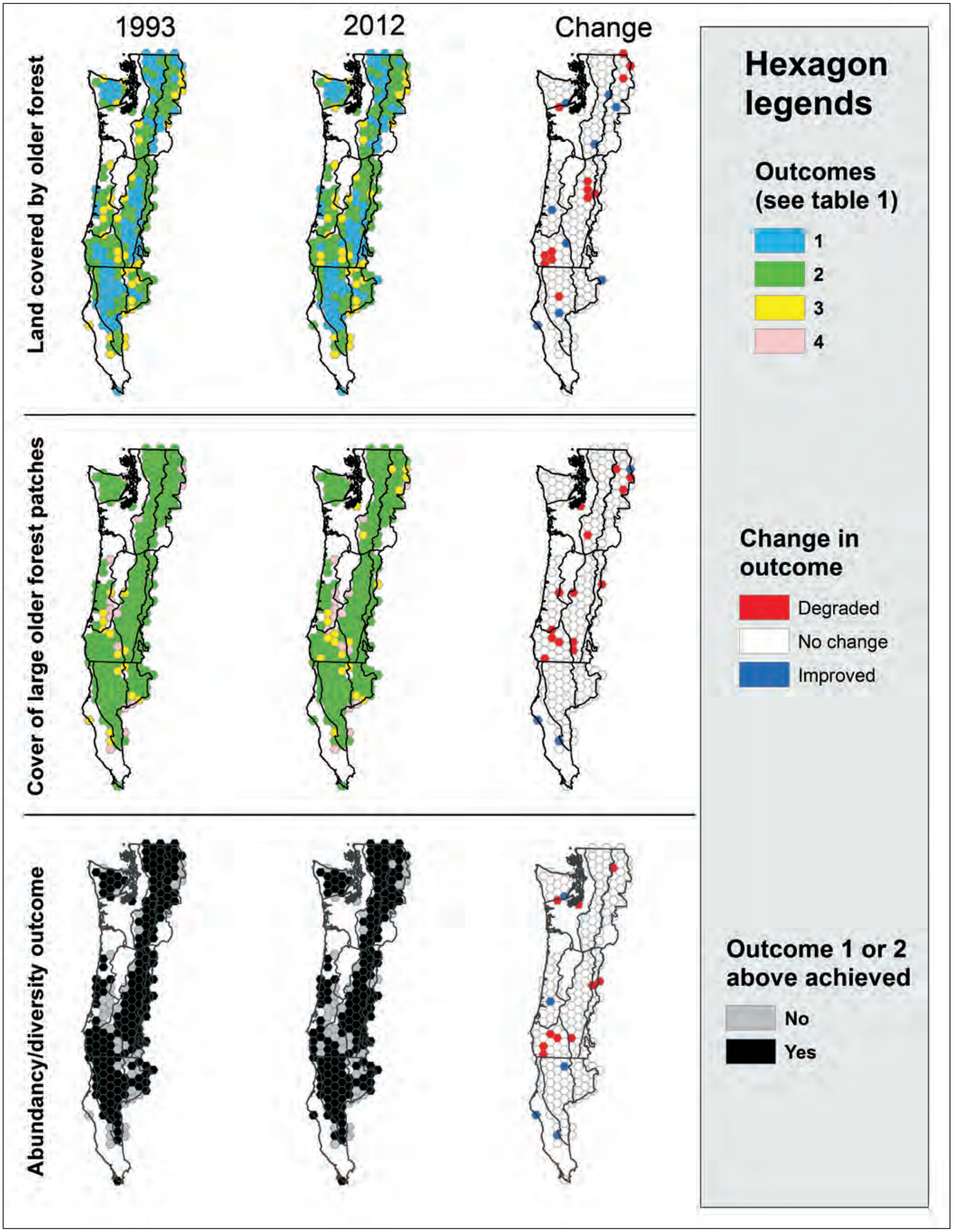


Figure 15—Geographical patterns for the abundance and diversity outcomes for old-growth structure index at the 80-year threshold.

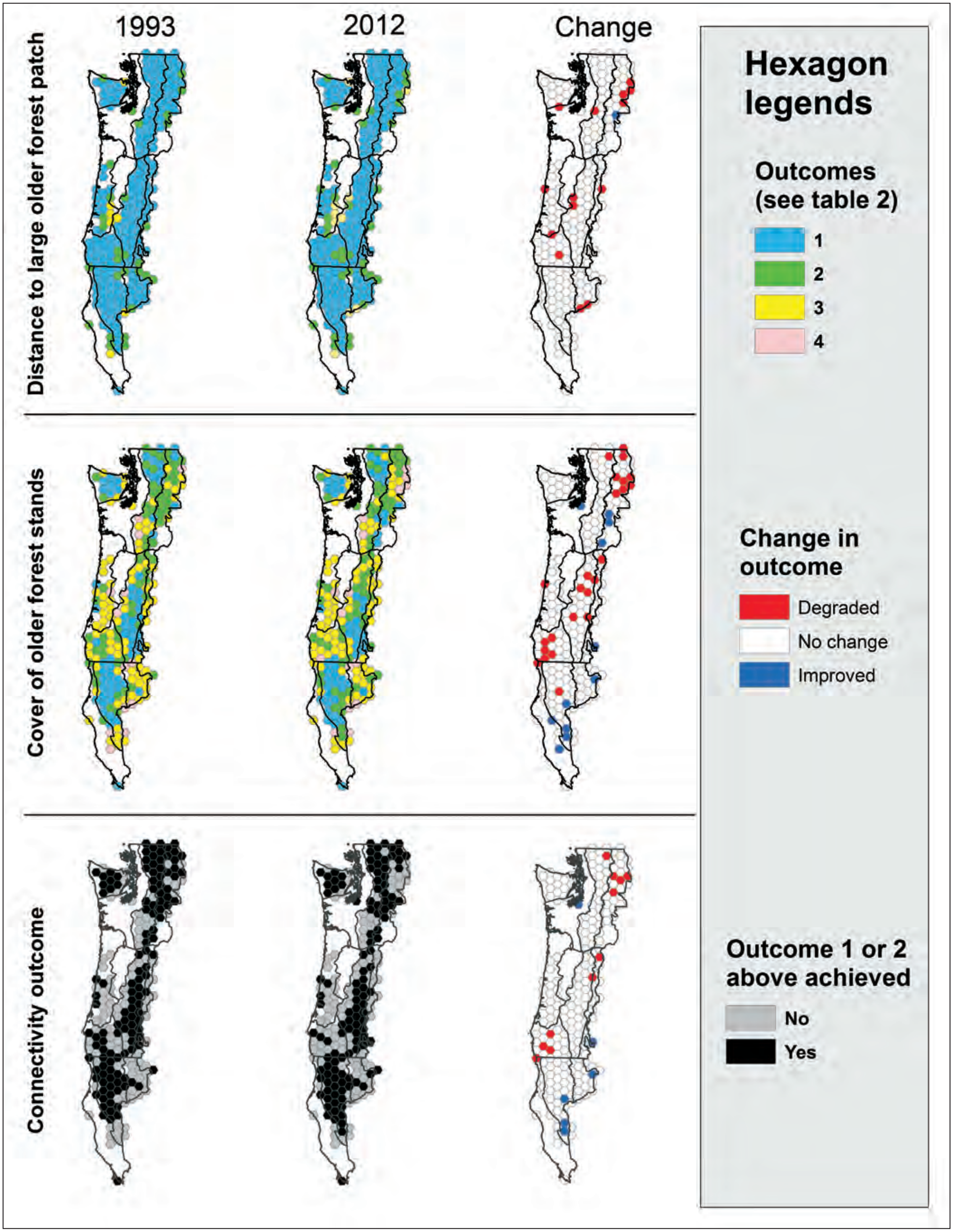


Figure 16—Geographical patterns for the connectivity outcomes for old-growth structure index at the 80-year threshold.

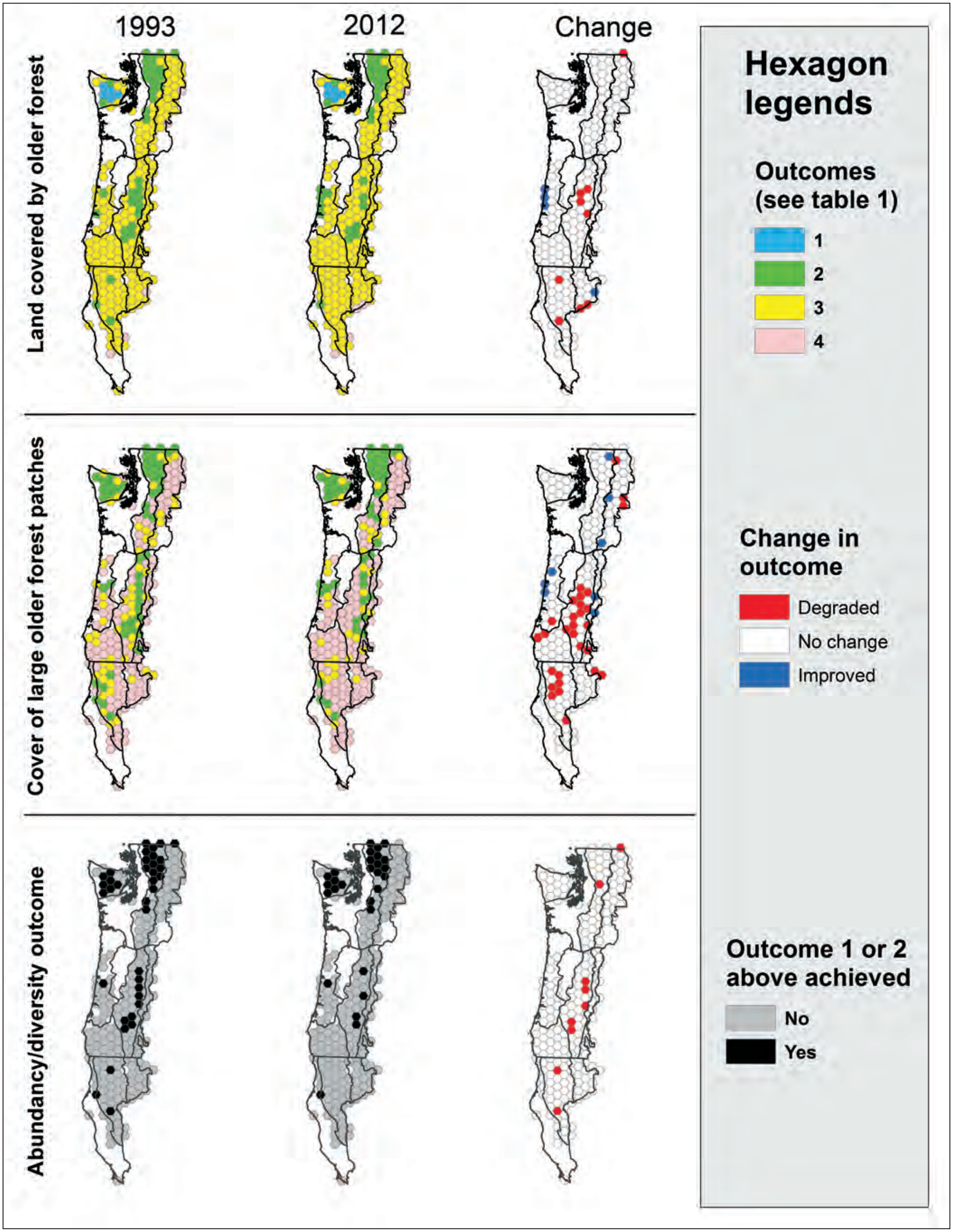


Figure 17—Geographical patterns for the abundance and diversity outcomes for old-growth structure index at the 200-year threshold.

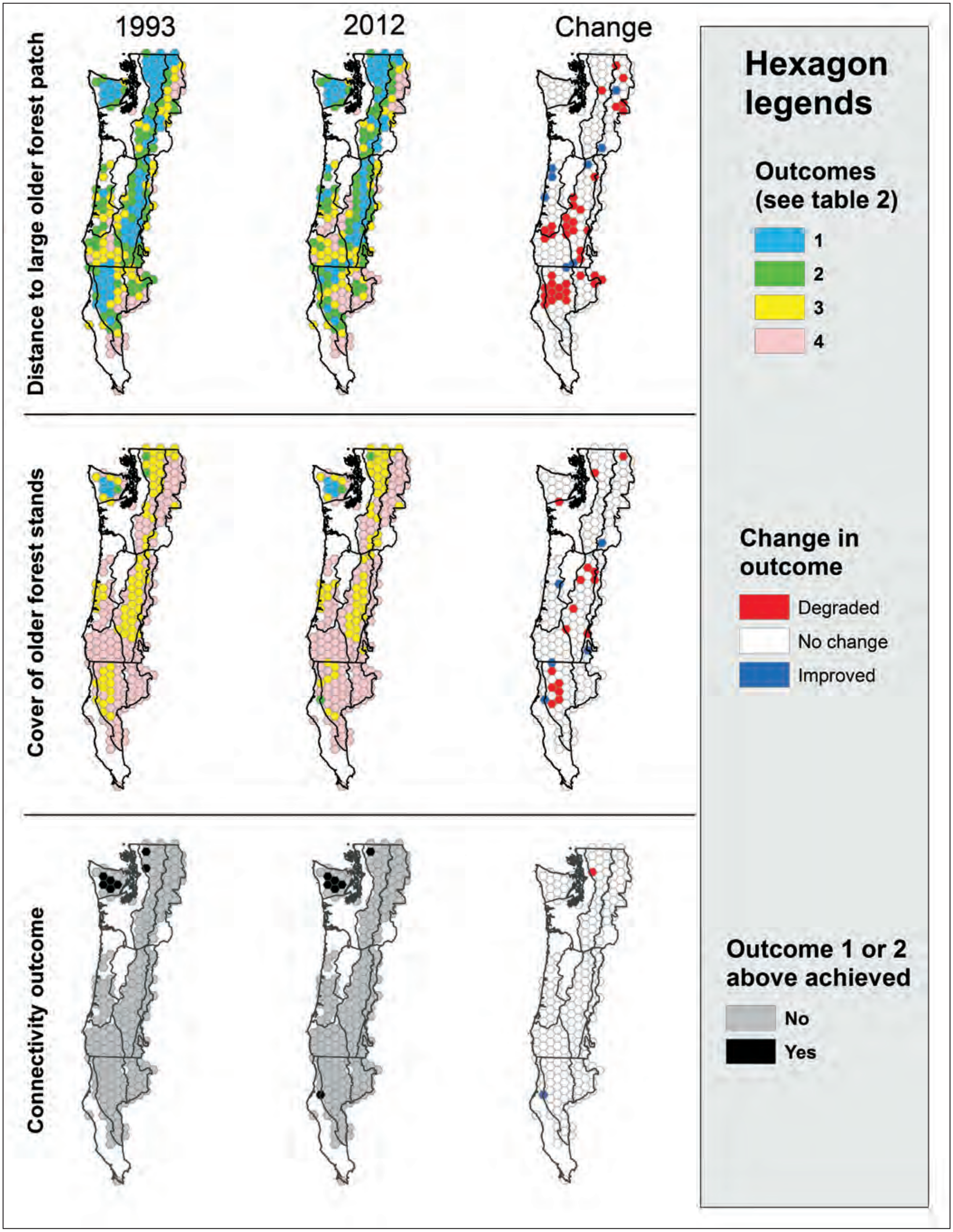


Figure 18—Geographical patterns for the connectivity outcomes for old-growth structure index at the 200-year threshold.

Maps Versus FIA Annual Plots

At the large-landscape scale, averaged (average for time 1 and time 2) map estimates for OGSI-80 on federal lands were within the bounds of error estimation of the FIA annual plot-based estimates in 4 of the 10 physiographic provinces that contain significant amounts of federally managed lands (excluding the Washington Lowlands and the Oregon Willamette Valley provinces). The averaged map estimates were also within the plot error bounds for California (fig. 19a). Averaged map-based estimates by physiographic province were 6 to 12 percent lower than

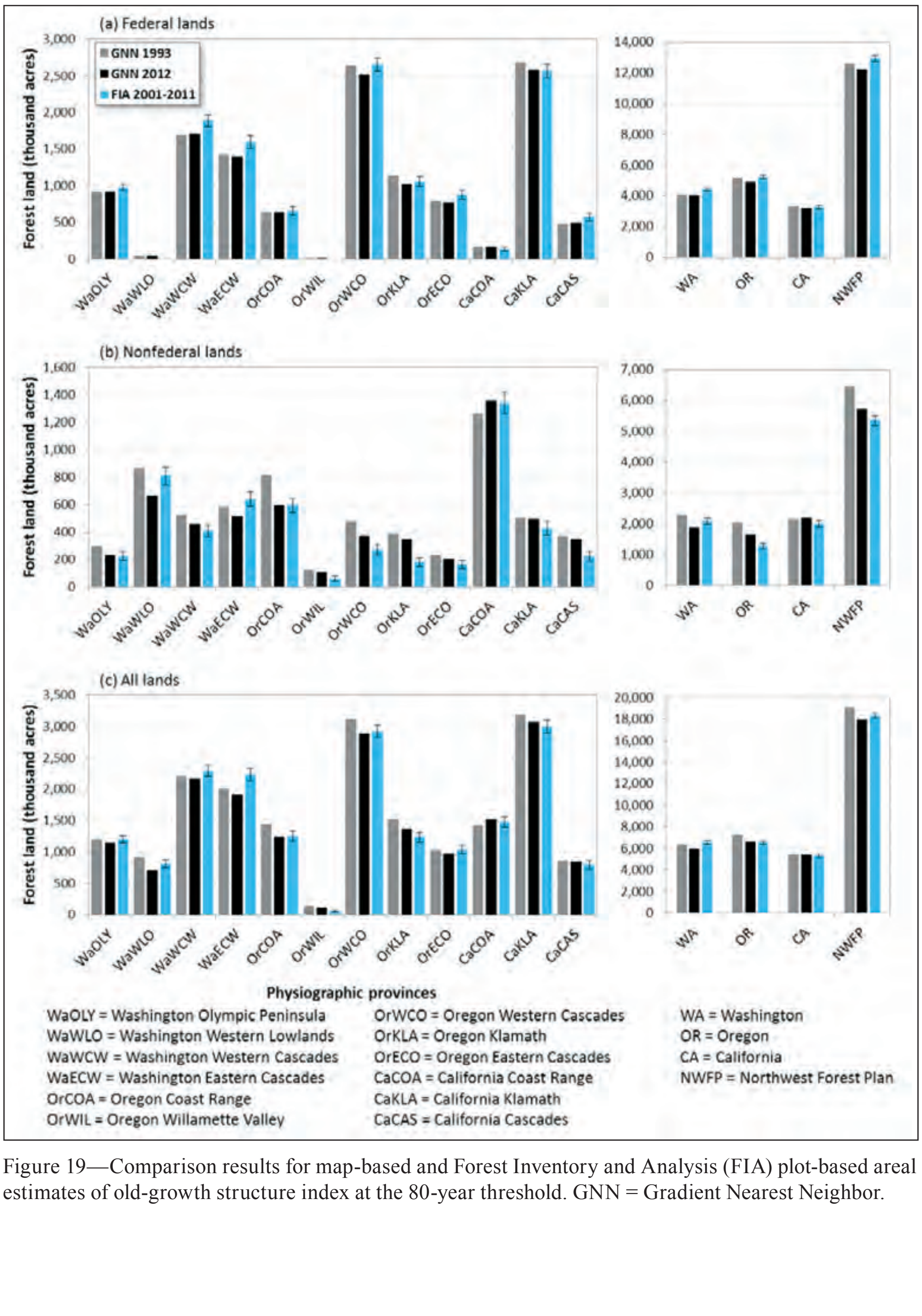


Figure 19—Comparison results for map-based and Forest Inventory and Analysis (FIA) plot-based areal estimates of old-growth structure index at the 80-year threshold. GNN = Gradient Nearest Neighbor.

plot-based estimates for Washington (62,000 to 193,000 ac, respectively). Some of this difference was due to the use of the forest-capable mask in the mapping, which excluded some forested lands at or near the high-elevation timber lines, particularly in the Eastern Cascades of Oregon and Washington. Averaged map-based estimates were 12 to 17 percent lower than plot-based estimates for the Oregon Eastern Cascades and California Cascades provinces (about 100,000 ac less for each). For the California Coast, our averaged map estimates were slightly higher (29,000 ac) than plot estimates. The Plan area estimate from averaged maps was about 4 percent, or 584,000 ac, less than the plot-based estimate.

Averaged map estimates for OGSI-200 on federal lands were within the error bounds of FIA annual plot-based estimates in 5 of 10 physiographic provinces containing significant amounts of federally managed lands. They were also within the bounds for both Washington and California (fig. 20a). Map-based estimates were again lower than plot-based estimates for the Washington Western Cascades (8 percent or 90,000 ac) and also for the Oregon Klamath and Eastern Cascades (12 to 18 percent or 59,000 to 65,000 ac, respectively) as well as the California Cascades (29 percent or 44,000 ac). For the California Klamath, our averaged map estimate was slightly higher (8 percent or 83,000 ac) than the plot estimate.

The differences between map-based and plot-based areal estimates were smaller on federal lands than for nonfederal lands (figs. 19b, 20b). Our maps tended to estimate more acres of older forest (both OGSI-80 and -200) on nonfederal lands than the FIA plots did. At the broadest spatial extent (all forested lands within the NWFP area), the similarity between map-based and plot-based areal estimates was the greatest. At this scale, the maps were within plot error bounds for half of all physiographic provinces and the NWFP area scale, and for the OGSI-200 definition, within the error bounds for all three states (figs. 19c and 20c).

Maps Versus Remeasured CVS Plots

A comparison of map- versus plot-based forest change estimates on USFS and BLM lands was done for Oregon and Washington, where we had remeasured CVS plot data. Similar to map-based versus FIA plot-based areal estimates, our OGSI-80 map estimates were mostly lower than CVS plot estimates for both time periods (fig. 21a); the exceptions being the Washington Olympic Peninsula (WaOLY) physiographic province, where map estimates were within plot error bars for both time periods, and time 1 map estimates for Oregon Western Cascades (OrWCO) and Klamath (OrKLA) provinces were also within the plot error bars (fig. 21a). The combined map-based OGSI-80 estimates showed a net loss for Washington and Oregon of 2.5 percent, ranging from 0.1 percent in Washington to 5.0 percent in Oregon. For the same combined area, plots showed a net increase of 0.3 percent, ranging from a 1.2 percent increase in Washington to a 0.3 percent decrease in Oregon (fig. 21a).

For OGSI-200, map-based estimates were more similar to plot-based estimates than for OGSI-80 (fig. 21b); the exception being the Oregon Eastern Cascades (OrECO) province where map estimates showed a marked increase in OGSI-200 compared to plot estimates. For the combined area of Washington and Oregon, the maps estimated a net decrease of 1.9 percent; whereas, the plots showed a net gain of 3.2 percent. Most of the mapped decrease occurred in Oregon (-3.8 percent) while maps

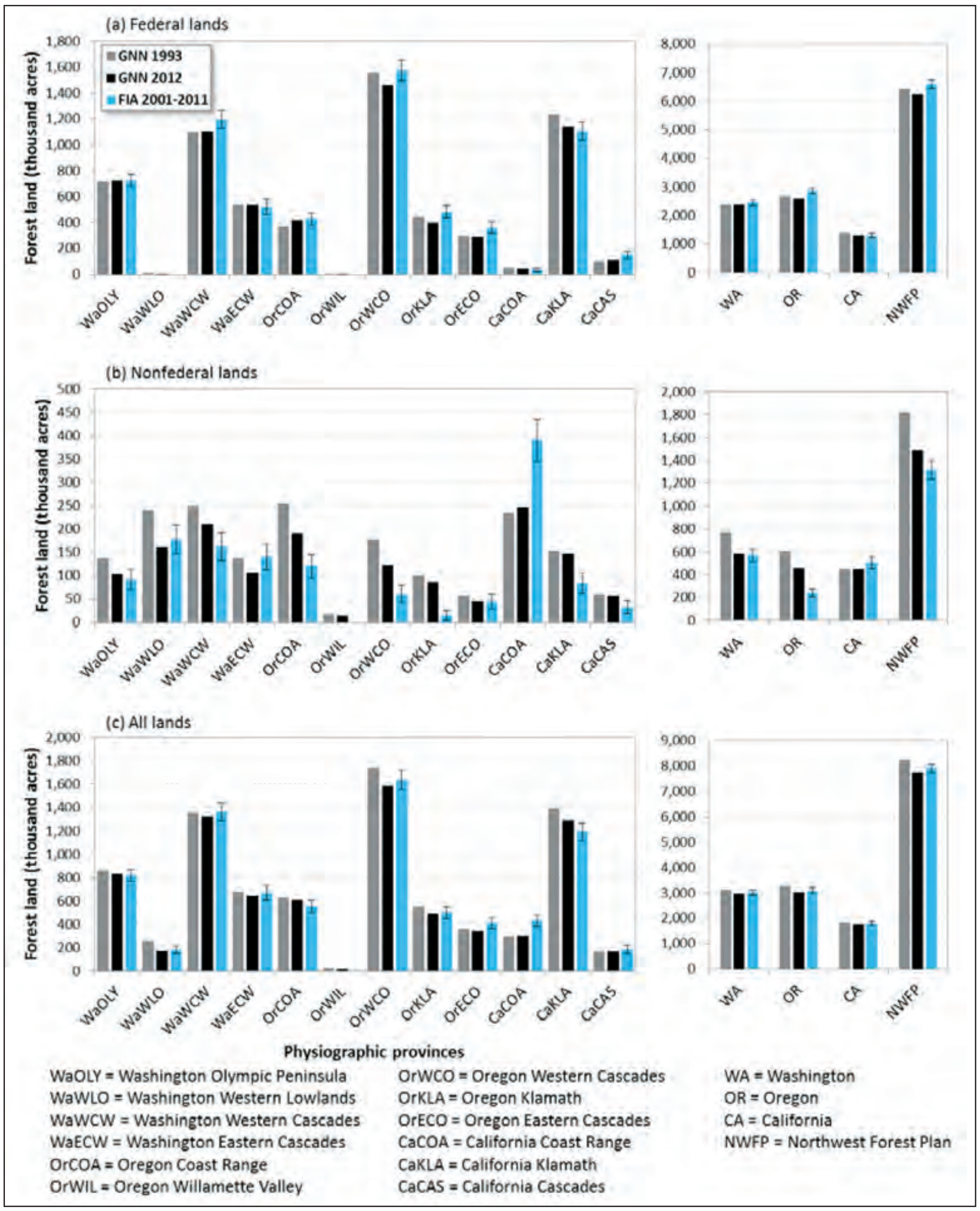


Figure 20—Comparison results for map-based and Forest Inventory and Analysis (FIA) plot-based areal estimates of OGSI-200. GNN = Gradient Nearest Neighbor.

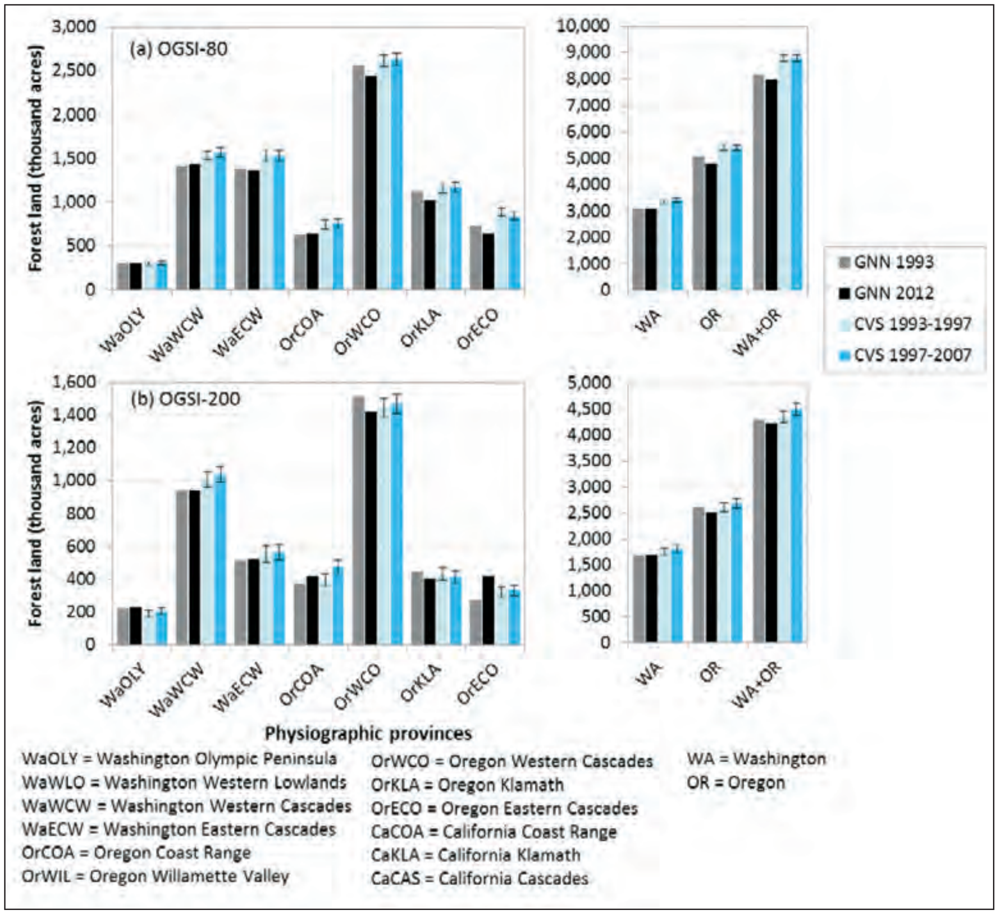


Figure 21—Comparison results for map-based and current vegetation survey (CVS) plot-based areal estimates for both bookend time periods. OGSI-80 and -200 = old-growth structure index at the 80- and 200-year threshold, respectively. GNN = Gradient Nearest Neighbor.

estimated a 1.0 percent increase in Washington. The plot-based net changes showed a 3.3 and 3.2 percent increase in Washington and Oregon, respectively (fig. 21b).

Most of the remeasured plot-based increases in older forest using either OGSI threshold occurred in Oregon on BLM CVS plots, with a 1.8 percent and 4.8 percent increase of BLM forested lands qualifying as OGSI-80 and OGSI-200, respectively. For USFS forested lands, the net changes based on plot data were small, with an estimated 0.3 percent loss of OGSI-80 and a 0.1 percent gain of OGSI-200. For the BLM and USFS plots that crossed the OGSI-80 or OGSI-200 thresholds, the largest changes were increases in the down wood element scores, with slight increases in the live tree element scores for both large tree density and diameter diversity. Thirty-six percent of the USFS plots that qualified as OGSI-200 at time 1, but not at time 2, had experienced burning or cutting between measurements. For the remainder, the biggest changes in OGSI scores were due to lower snag and down wood element scores at time 2.

Discussion

The main focus of our monitoring was on status and trends of older forest on federal lands managed under the NWFP. How older forests were defined was important. We compared definitions from previous monitoring reports (Moeur et al. 2005, 2011) with a new definition based on OGSI that better represented the continuous nature of forest succession and development. Our baseline (1993) map estimate of older forest using the old definition (LSOG) was 7.4 million acres; slightly higher than the 7.3-million-ac baseline (1994/1996) estimate in Moeur et al. (2011). Because our baseline time period preceded the baseline time period in Moeur et al. (2011) by 1 to 3 years, this is not surprising. Our map-based estimate of LSOG acres was bracketed by mapped acres from our new definitions, OGSI-80 (12.6 million ac) and OGSI-200 (6.3 million ac), which represented forests at the time they begin to exhibit older-forest attributes (OGSI-80) and well into the older-forest development stage (OGSI-200). Given the simplistic nature of the LSOG definition, and the difficulty in interpreting changes based on it, we discontinued its use for older-forest monitoring.

Based on the new definitions, the map-based analysis results in this report suggest that at the scale of the Plan, area of older forests have decreased over the last two decades on federal lands by 2.8 to 2.9 percent. The amount and rate of mapped change varied by federal ownership and geographic scale (app. F). On federal land, wildfire was the leading cause for older-forest losses, while on nonfederal lands, timber harvesting, was the main cause for loss (fig. 14). Losses of older forest area were highest on lands managed by the USFS, especially in reserved LUAs (table 10). The highest percentage loss (-8.6 percent) was on reserved allocations on USFS lands in northwest California (table 10).

Table 10—Summary of net percentage changes from 1993 to 2012 for federal lands managed by the Forest Service, Bureau of Land Management, and National Park Service

	Nonreserved		Reserved	
Federal land management agency	**OGSI-80**	**OGSI-200**	**OGSI-80**	**OGSI-200**
	Net percent change			
Forest Service–Region 6	-2.1	-3.5	-4.0	-1.8
Forest Service–Region 5	-0.81	-3.9	-5.3	-8.6
Bureau of Land Management–Oregon	+0.7	+0.9	-1.3	+1.1
Bureau of Land Management–Northern California	+9.3	-1.8	+2.6	-5.8
National Park Service	NA	NA	-1.1	-0.3

NA = not applicable. OGSI-80 and -200 = old-growth structural index at the 80- and 200-year threshold, respectively.

Comparisons between map-based estimates and plot-based estimates showed that map estimates of older forests were usually slightly lower than plot estimates on federal lands. Reasons for this include differences in how maps versus plots account for forest-capable area along the tree line of the high elevations and other large nonforested areas (e.g., agricultural, urban). Another potential cause for differences might be due to changes in the dead wood elements (e.g., snags and down wood) that are not easily detectable with Landsat technology. We did not have a plot-based estimate of old-forest change for the entire Plan area, but for federal lands (USFS and BLM) in Washington and Oregon we were able to estimate changes at the physiographic province and state scales using CVS plots that were measured at two different time periods. For that analysis, again our map-based net changes differed from plot-based net changes, sometimes in the opposite direction (loss vs. gain), with maps showing more net losses and plots showing more net gains. We suspect that net change differences were due in part to the reasons above, but perhaps more so to the difference in the bookend time periods between the maps (1993–2012) and plots (based on mid-points of measurement occasions: 1995–2002). The 2012 satellite image used for our time 2 map showed millions of acres of forest that had burned or was harvested since 2007, the last measurement year for CVS plots.

While overall changes in older forest have mostly been negative, we observed portions (e.g., individual forests, 30-km [18.6-mi] hexagons) of the federal landscape where recruitment of older forests was beginning to occur. Areas where we observed net gains in older forest sometimes overlaid extremely large wildfires that burned over a century ago, such as the Yaquina Fire (1843) and the Nestucca Fire (1846) in the Siuslaw National Forest. For the most part, areas showing net gains of older forest are occurring outside of the areas prone to more frequent large wildfires. As witnessed by the historical record (including the above fires), those areas appear to experience extremely large wildfires that happen relatively infrequently compared to the rest of the NWFP area.

Expected outcomes for abundance, diversity, and connectivity of older forests on federal lands have not yet been achieved. In addition to reducing the abundance of older forests, large wildfires also contributed to declines in its connectivity. The vast majority of these large wildfires have occurred in the more fire-prone portions of the NWFP area as mapped in the 15-year reporting period (see Davis et al. 2011: chap. 4). However, not all wildfire removes older forests. In fact, low- to moderate-severity wildfires can positively influence the development of old-growth stand structure and often add structural elements (e.g., snags and down wood) important for its development (Donato et al. 2009, Spies and Franklin 1991, Taylor and Skinner 1998, Tepley et al. 2013) and function (Clark et al. 2011, Franklin et al. 2000). High-severity wildfire currently is causing most of the loss of older forests on federal lands.

Following methods in Kennedy et al. (2012), we used LandTrendr disturbance magnitude data from inside the perimeters of wildfires that burned since the Plan's implementation to analyze patterns of fire severity. We classified LandTrendr into three equal intervals of disturbance magnitude (low = 0 to 33 percent, moderate = 33 to 66 percent, and high = 66 to 100 percent). We compared this to Monitoring Trends in Burn Severity (MTBS) classified data (http://www.mtbs.gov/methods.html). Comparing our three disturbance magnitude classes to the four MTBS burn-severity classes (unburned to low, low, moderate, and high severity), we found that our "high magnitude" class comprised mostly MTBS "moderate" and "high" burn-severity classes (fig. 22). Between 1994 and 2011, on average, forests burned mostly at lower magnitudes (57 ± 14 percent; mean ± 1 SD). Moderate-burn magnitudes accounted for 21 ± 7 percent, while high-burn magnitudes occurred on 23 ± 11 percent of the burned area (see wildfire inset).

Although wildfires accounted for the majority of older forest loss on federal lands, timber harvesting accounted for about 17 to 20 percent. Using LandTrendr data, we analyzed the pattern of timber harvest disturbance magnitude between 1993 and 2012. We used the same disturbance magnitude classes as for the wildfire analysis above (low, moderate, and high), where a low magnitude was associated with thinning and a high magnitude with regeneration harvest. In addition to proportion of magnitude, we also looked at amount of timber harvest by magnitude. Since 1993, the amount of timber harvesting on federal lands increased (fig. 23c) concurrent with an

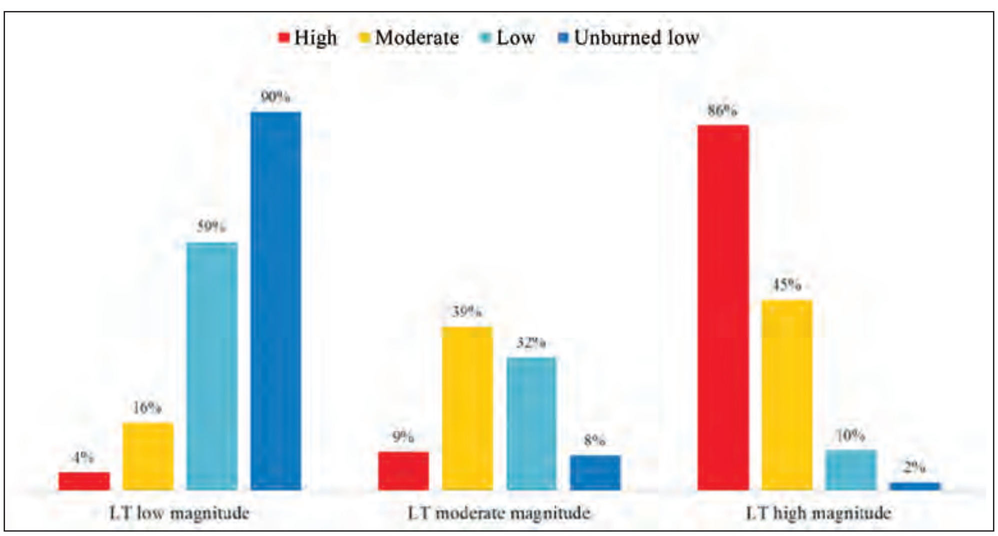
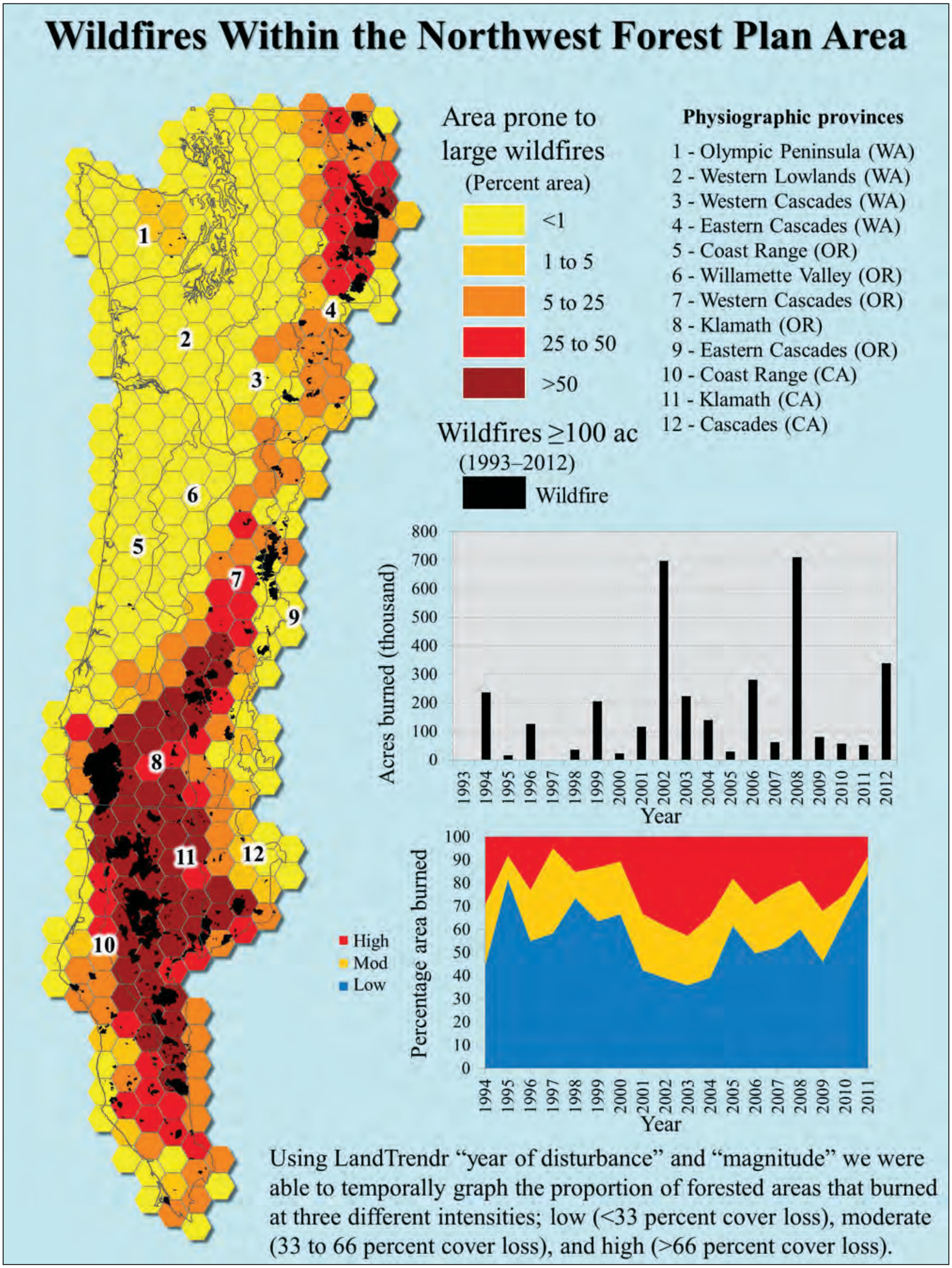


Figure 22—Frequency histogram comparing Monitoring Trends in Burn Severity (MTBS) and LandTrendr (LT) disturbance magnitude within large wildfire perimeters in the Northwest Forest Plan area. Percentages above bars show what percentage of the LT class consisted of each MTBS class.


Wildfires Within the Northwest Forest Plan Area
Area prone to large wildfires
(Percent area)
<1
1 to 5
5 to 25
25 to 50
>50
Wildfires ≥100 ac
(1993–2012)
Wildfire
Physiographic provinces
1 - Olympic Peninsula (WA)
2 - Western Lowlands (WA)
3 - Western Cascades (WA)
4 - Eastern Cascades (WA)
5 - Coast Range (OR)
6 - Willamette Valley (OR)
7 - Western Cascades (OR)
8 - Klamath (OR)
9 - Eastern Cascades (OR)
10 - Coast Range (CA)
11 - Klamath (CA)
12 - Cascades (CA)
1
2
3
4
5
6
7
8
9
10
11
12
Acres burned (thousand)
0
100
200
300
400
500
600
700
800
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Percentage area burned
0
10
20
30
40
50
60
70
80
90
100
High
Mod
Low
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Year
Using LandTrendr "year of disturbance" and "magnitude" we were able to temporally graph the proportion of forested areas that burned at three different intensities; low (<33 percent cover loss), moderate (33 to 66 percent cover loss), and high (>66 percent cover loss).

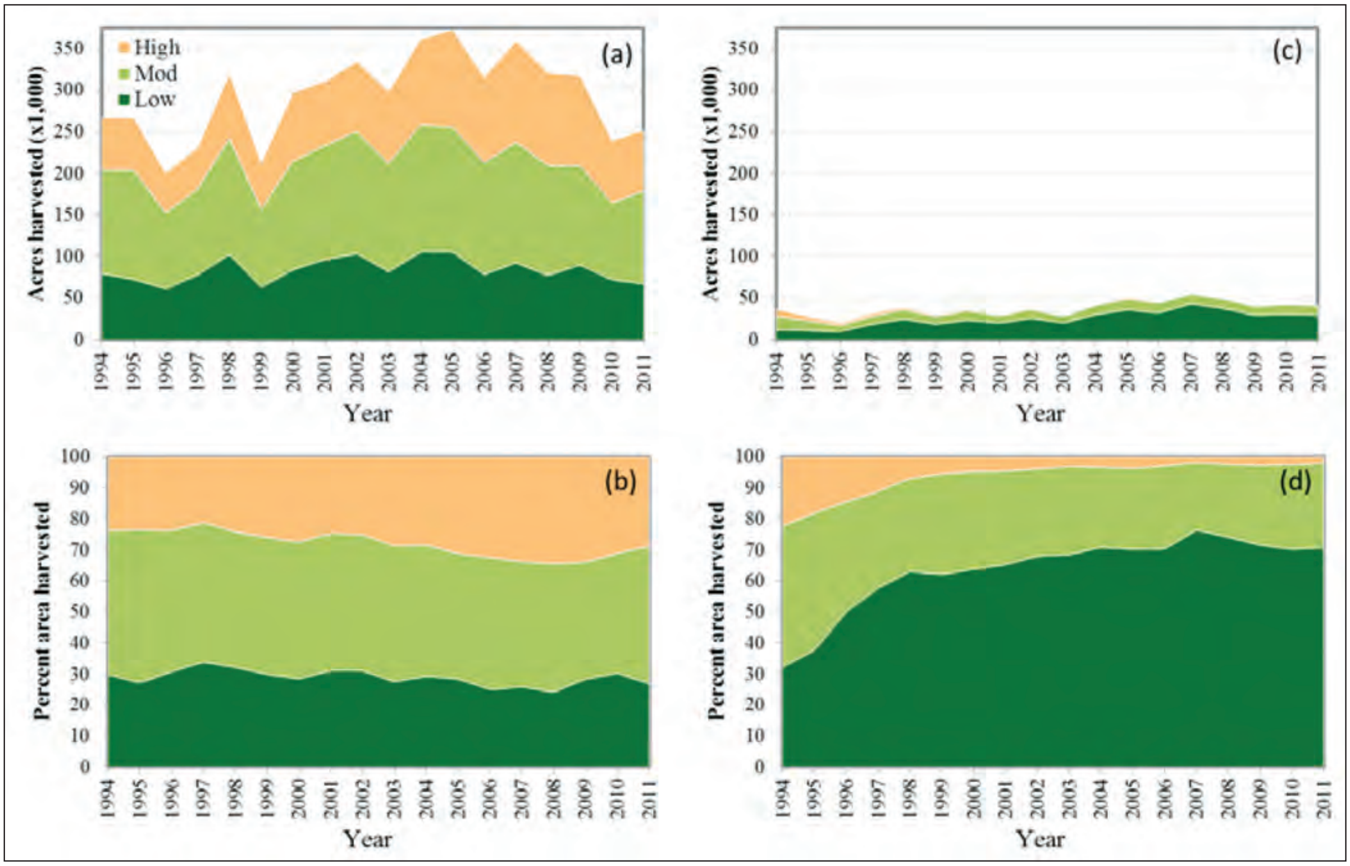


Figure 23—Timber harvesting patterns of harvesting on nonfederal land (a and b), and federal land (c and d) during the monitoring period as detected by LandTrendr. Low magnitude = 0 to 33 percent vegetation cover loss, moderate = 33 to 66 percent cover loss, and high = 66 to 100 percent cover loss. Note: Y-axis scale for graph (c) is not the same as for graph (a).

increase in the amount of low-magnitude harvest (e.g., thinning) (fig. 23d). The amount of harvest on nonfederal lands increased shortly after the implementation of the Plan, then decreased around 2008 (fig. 23a). The proportions of nonfederal harvest by magnitude did not change significantly over this time period (fig. 23b). Similar patterns of timber harvesting trends were also noted by Kennedy et al. (2013).

Uncertainty in Mapping and Estimating Losses, Gains, and Net Change

There are many sources of potential error when making map-based or plot-based areal estimates for large geographic areas that cover thousands or millions of acres. This is confounded when making estimates for two different time periods and analyzing the differences between them. Remote sensing techniques used in this report are relatively new and constantly being improved upon as research progresses. Still, they are subject to errors. The following issues noted during our analyses are briefly discussed here to give the reader a general sense of the uncertainties involved in large-scale forest monitoring.

When using time-series maps for monitoring purposes, a challenge is to make each annual map as consistent with all other annual maps as possible. This reduces "artificial" changes caused only by mapping errors, such as spatial misregistration where pixels and edges of mapped stands do not exactly line up from year to year. The LandTrendr disturbance map production process that precedes the GNN map production attempted to geometrically rectify and radiometrically normalize (through time) the Landsat imagery used in the GNN mapping process. While this reduced artificial differences between annual imagery dates, it did not totally remove them.

In portions of our maps at the pixel scale, we observed some erroneous mapped losses of older forest, particularly along eastern and northeastern edges of clearcuts and in other areas with distinct stand boundaries. This appeared to be caused by the combined effects of shadows cast by adjacent older forest into the clearcut and a slight geographic misregistration of one to two pixels in the LandTrendr imagery between 1993 and 2012 (shifting from southwest to northeast). Shadow differences between annual maps are often due to satellite images for the same area being taken at different times of the day or month in each year. Shadows in some recent clearcuts were (erroneously) mapped as older forest in 1993, then as those plantations developed into dense, closed-canopy young forests, shadows diminished by 2012 resulting in false losses of older forest in the bookend analysis. These problems likely resulted in a bias toward loss of older forest in our analyses. However, these errors can be diluted by summarizing the map information to broader spatial extents than the modeled 30-m (98-ft) pixels (Ohmann et al. 2014).

Uncertainty in plot-based estimates can arise from general sampling errors and is sensitive to differences in plot design, size, or transect length (Gray 2003). Additionally, field-based decisions on which trees belong to the dominant or codominant class, which was a key attribute in the calculation of the LSOG attribute used in previous reports, can have significant impacts on many stand attributes.

Because the OGSI variables consider snags and down dead wood, older forest may blink on and off as a result of changes in the dead wood population (e.g., as a result of pulses of mortality and subsequent decay or consumption by fire). This problem is exacerbated by the large sampling errors associated with dead wood on the plots. However, application of the index at the regional scale rather than at the plot level should reflect overall changes in the abundance of older-forests attributes in the NWFP area.

Because of the uncertainties involved with large-scale monitoring, we included both map- and plot-based estimations in this report. In general, the summarization of older forest change in this report may be more readily interpreted by the differences in the maps because each bookend map is based on one specific Landsat image year, whereas the plot estimates were based on plot measurements that spanned multiple years.

Conclusions

Twenty years after implementation of the NWFP in 1994, net changes in amount of older forests on federal lands managed under the Plan's guidance have been small (a 2.8 to 2.9 percent decrease). This occurred despite losses from wildfire (4.2 to 5.4 percent), timber harvest (1.2 to 1.3 percent), and insects or other causes (0.7 to 0.9 percent), suggesting that processes of forest succession have compensated for some of these losses. Losses from wildfire were about what was expected when the Plan was designed, but losses from timber harvesting were about one quarter of what was anticipated.

Overall, these results are consistent with the Plan's expectations for older forest outcomes for this period of time. Nothing in these findings suggested that overall achievement of abundance, diversity, and connectivity outcomes over the next few decades is not feasible; however, we noted that some areas, represented by 30-km (18.6-mi) hexagons, have moved further away from those outcomes at this spatial resolution and at this time (figs. 15 through 18). At the implementation of the Plan, the connectivity of older forests, especially those represented by OGSI-200, was and is now further below the outcomes set forth in the Plan, and recent large wildfires are largely to blame for localized degradation of this condition. Nonetheless, we found that some areas, most notably in the central Coast Range of Oregon because of its fire history, are now showing redevelopment of connected older forest conditions.

Losses of older forest to large wildfires were anticipated as part of the disturbance regimes of the NWFP landscape, and these losses were considered in the Plan's reserved network design. However, recent findings by Westerling et al. (2006) and Miller et al. (2012) reported an increased frequency of large wildfire occurrence and area burned annually, compared to the recent decades preceding the development of the Plan. Consistent with this, monitoring has shown an increased occurrence of large wildfire within the NWFP area (Davis et al. 2011). Most of these large wildfires have occurred primarily in the warmer and drier, fire-prone landscapes (see Wildfire Inset). So, while wildfire-related loss of older forest within the reserve network was anticipated, and monitoring results show some reserved areas have been set back by decades to centuries with respect to achieving Plan outcomes, the increased frequency of these large wildfires is concerning.

Whereas the amount of annual area burned has increased, it is unclear how much if any has burned at uncharacteristically high severity that might be due to fire exclusion during the 20th century or climate change. It is also unclear if the observed trend in large wildfire occurrence will continue or change as a result of climate change or changes in forest management and fire suppression policies on federal lands. The effect large wildfires are having on the current reserve network warrants further monitoring.

It will take continued monitoring to answer these questions and track the abundance and patterns of older forests and the processes (disturbance, growth, and mortality) that shape them throughout the next decades. While net changes have so far been small, it is possible that more rapid changes could be coming as large areas of forest develop into structural conditions that are near the threshold of our older forest definitions, or if rates of wildfire increase.

Monitoring older forests is a long-term commitment to remeasurement of permanent field plots; management of field, remotely sensed, and GIS data layers; and modeling and inventory analyses of change over time. The federal agencies have maintained that commitment for 20 years. In that time, recent technologies and methodologies have made some significant advancements, allowing us to accomplish our monitoring tasks with increased accuracy and efficiency. In contrast, reductions in field effort have resulted in fewer measurements of large trees (on the hectare (acre) plot on USFS lands) and down wood (shorter transects on all lands). There is still some uncertainty in our estimates that we will continue to address in future monitoring cycles. One focus for future monitoring might be the inclusion of finer resolution remote sensed imagery, along with regional forest inventory plots in our mapping framework. Some exploration of this has already been accomplished, with the inclusion of light detection and ranging (lidar) data in the GNN process (Zald et al. 2014). Every year that passes brings new data to help address this issue, such as additional inventory plots and more remeasured plots that will allow us to track trends in species-specific tree mortality and ingrowth patterns. This finer ecological resolution will help us to understand the changes we see in remote sensing. When combined with new remote sensing technologies, our ability to anticipate and understand forest change is likely to increase in the future.

We have made progress transitioning from discrete definitions of older forest to an index that represents the continuum of forest development. However, this is just the first step in that direction. Continuing research to improve upon the concept of the OGSI and its use to project expected trends of forest succession into the future is important. In doing so, we would allow ourselves a consistent method for not only mapping and monitoring older forests, but also the entire forest mosaic including recently disturbed forests and younger regenerating and rapidly growing forests, especially those with complex structure, that are as ecologically important as older forests. The loss of older forests to wildfire is also a gain in early seral habitat—the question is, what mix and pattern of these forests do we want on our landscapes?

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Acres (ac)	0.405	Hectares (ha)
Basal area (ft^2/ac)	0.2296	Basal area (m^2/ha)
Square miles (mi^2)	2.59	Square kilometers (km^2)
Trees per acre (trees/ac)	2.47	Trees per hectare (trees/ha)
Tons (ton)	907.0	Kilograms (kg)
Tons per acre (ton/ac)	2.24	Megagrams per hectare (Mg/ha)
Cubic feet per acre (ft^3/ac)	0.07	Cubic meters per hectare (m^3/ha)

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Appendix A: Forest Inventory Plot Summaries of Old-Growth Structure Elements

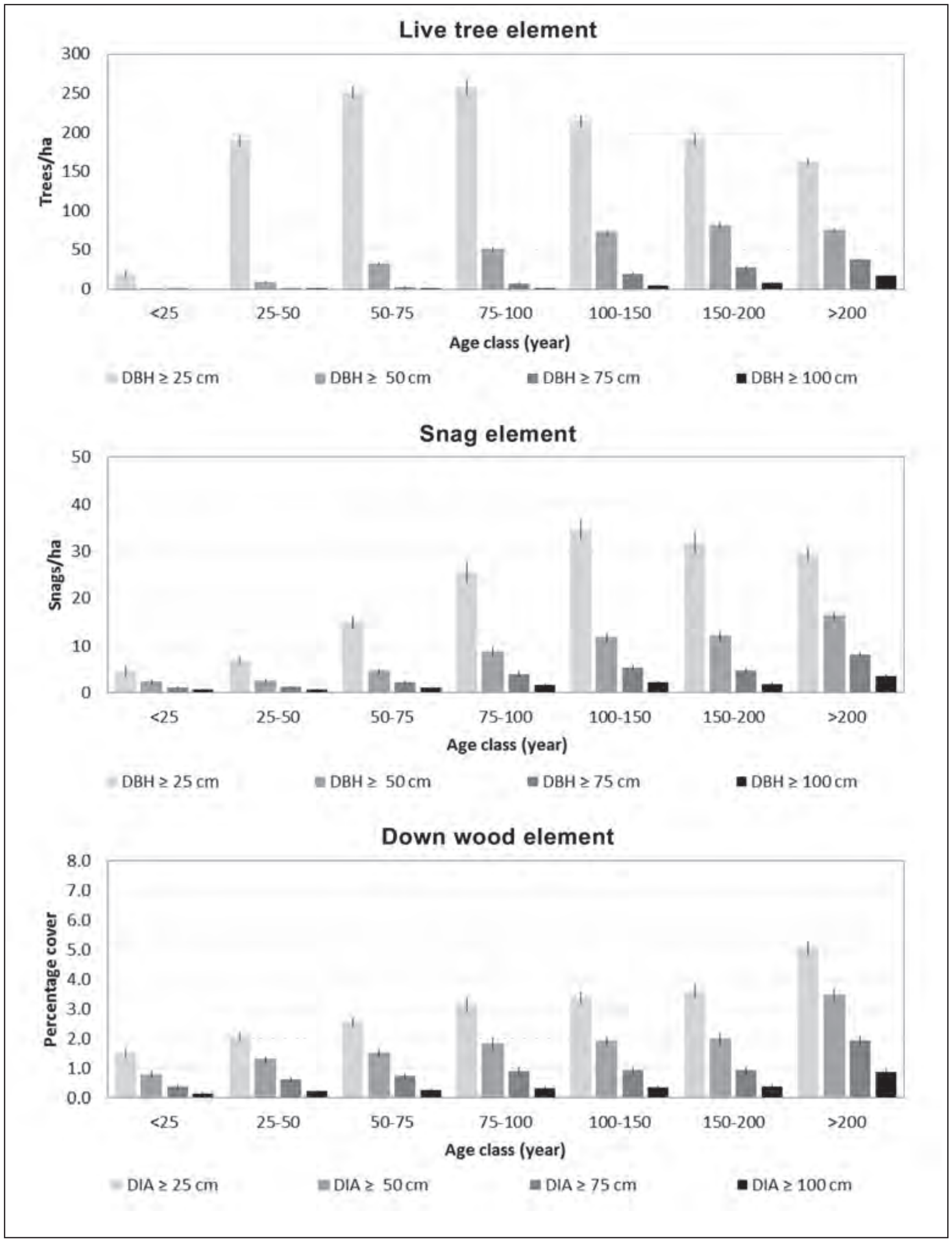


Figure A-1—Western hemlock forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

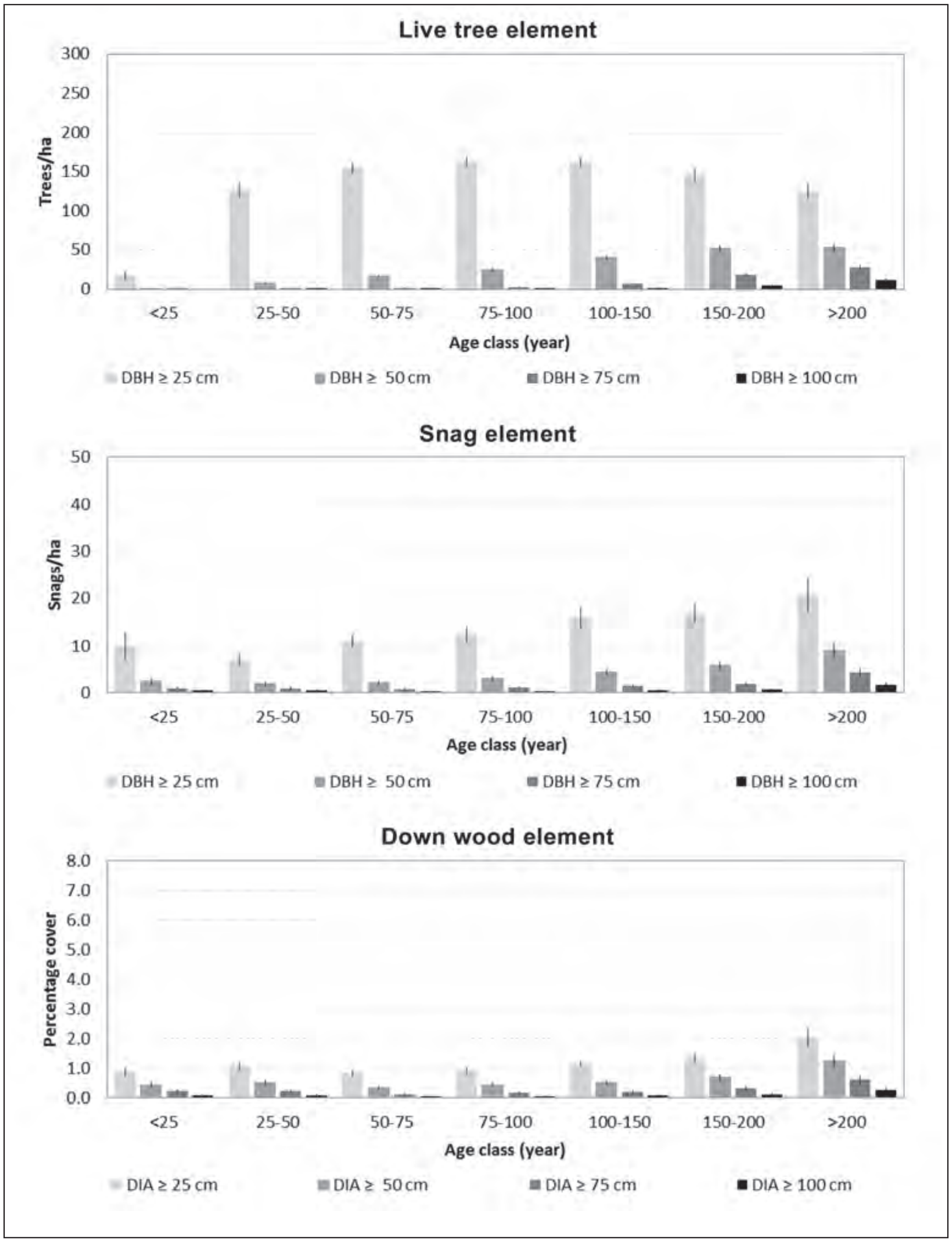


Figure A-2—Douglas-fir forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

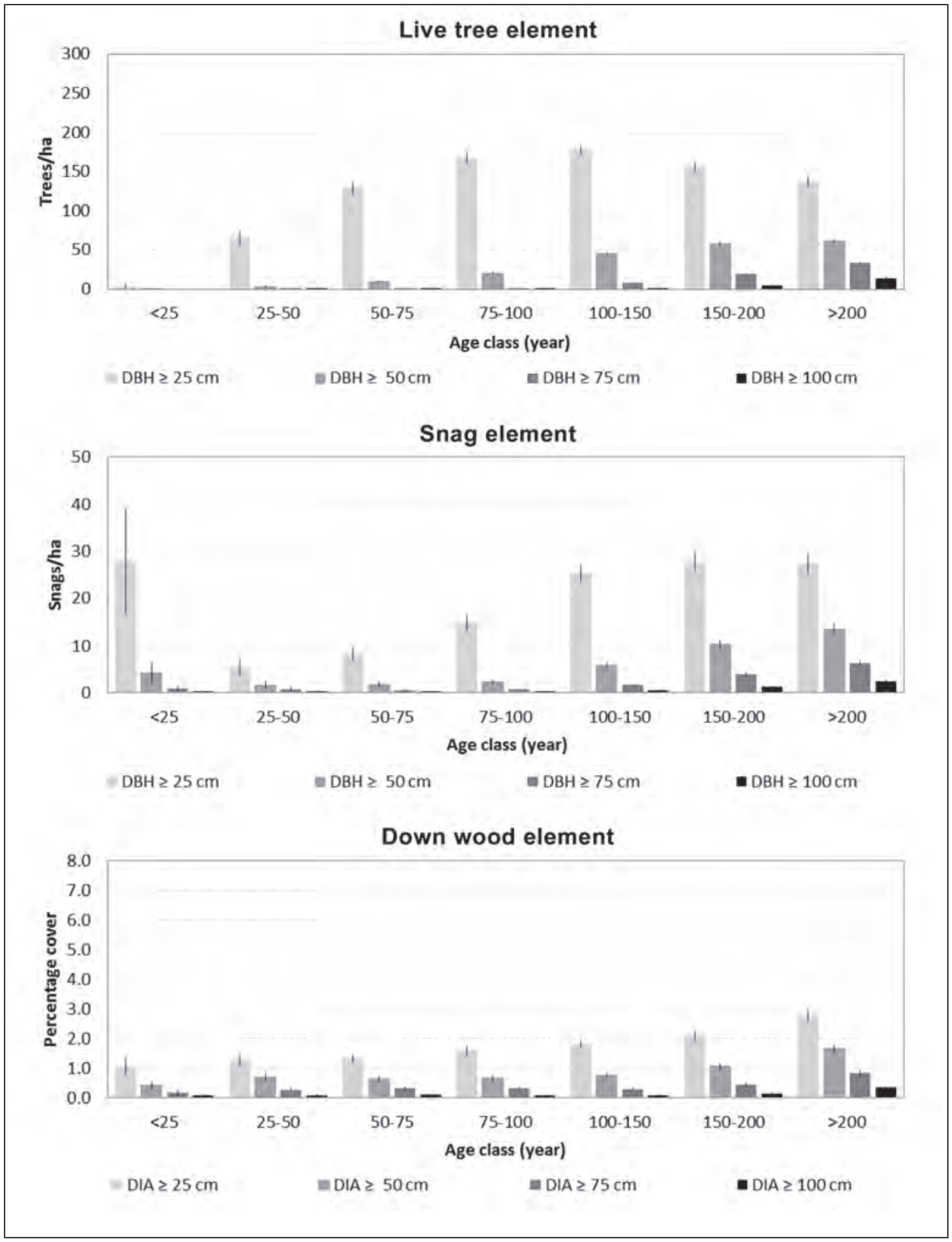


Figure A-3—Grand fir/white fir forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

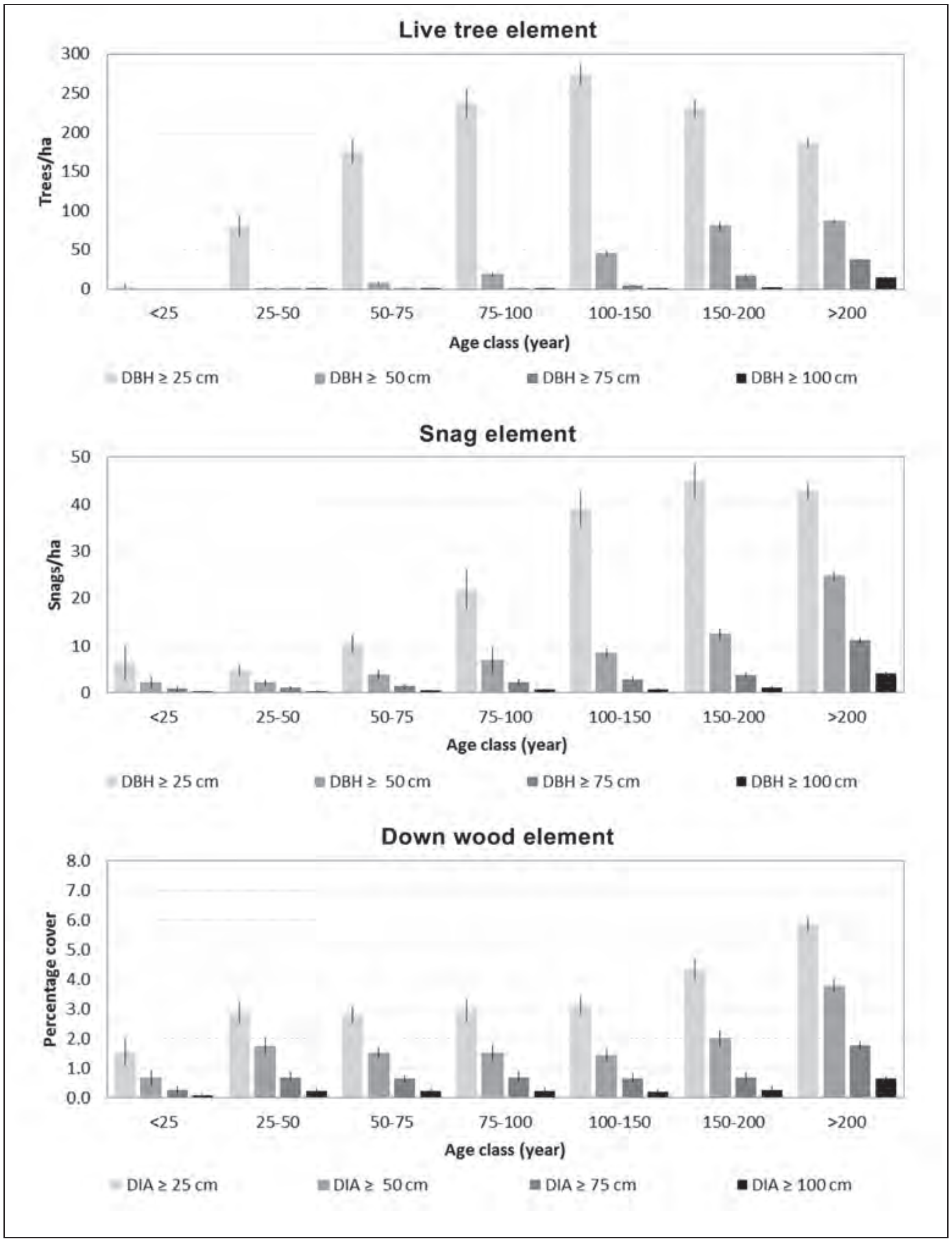


Figure A-4—Pacific silver fir forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

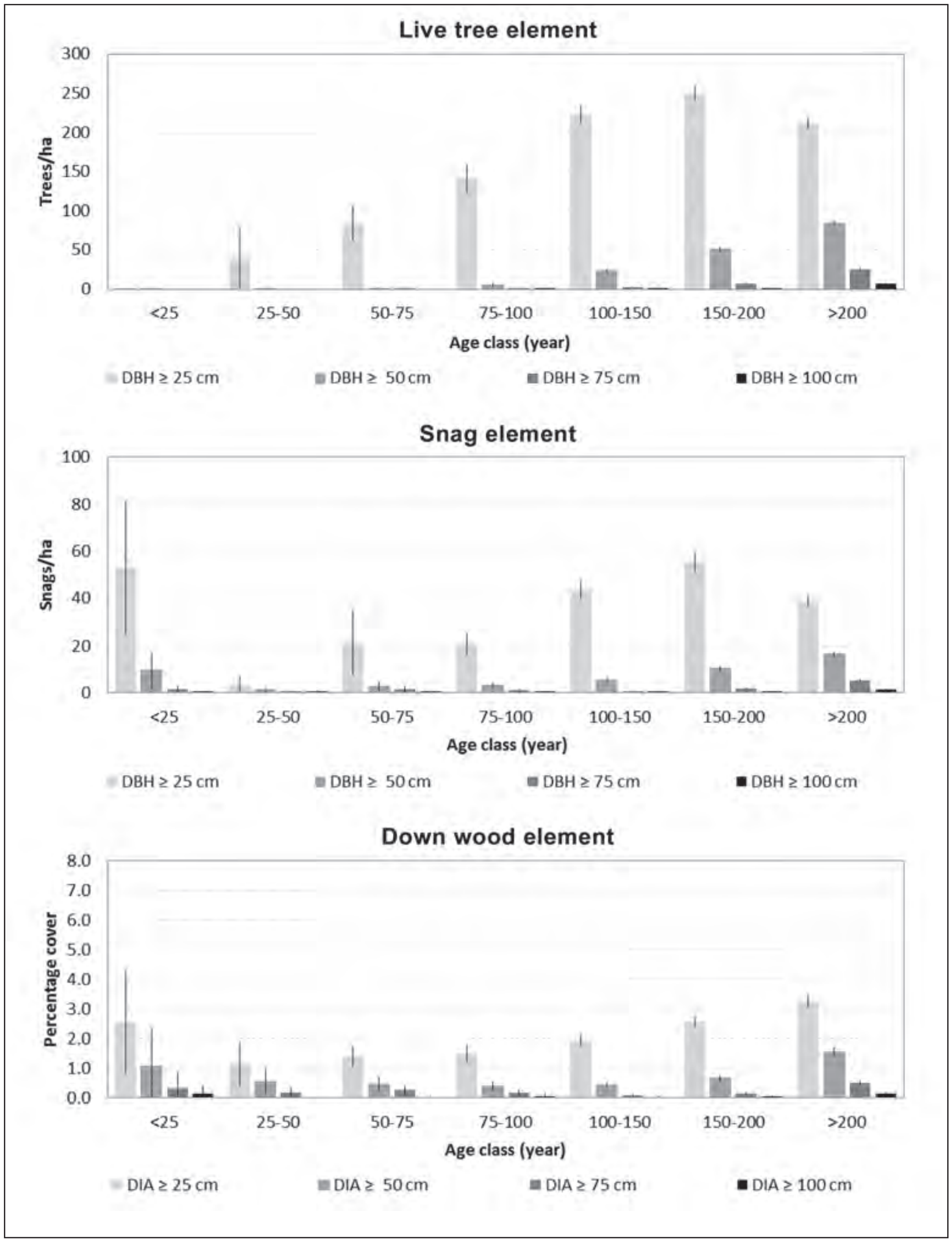


Figure A-5—Mountain hemlock forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

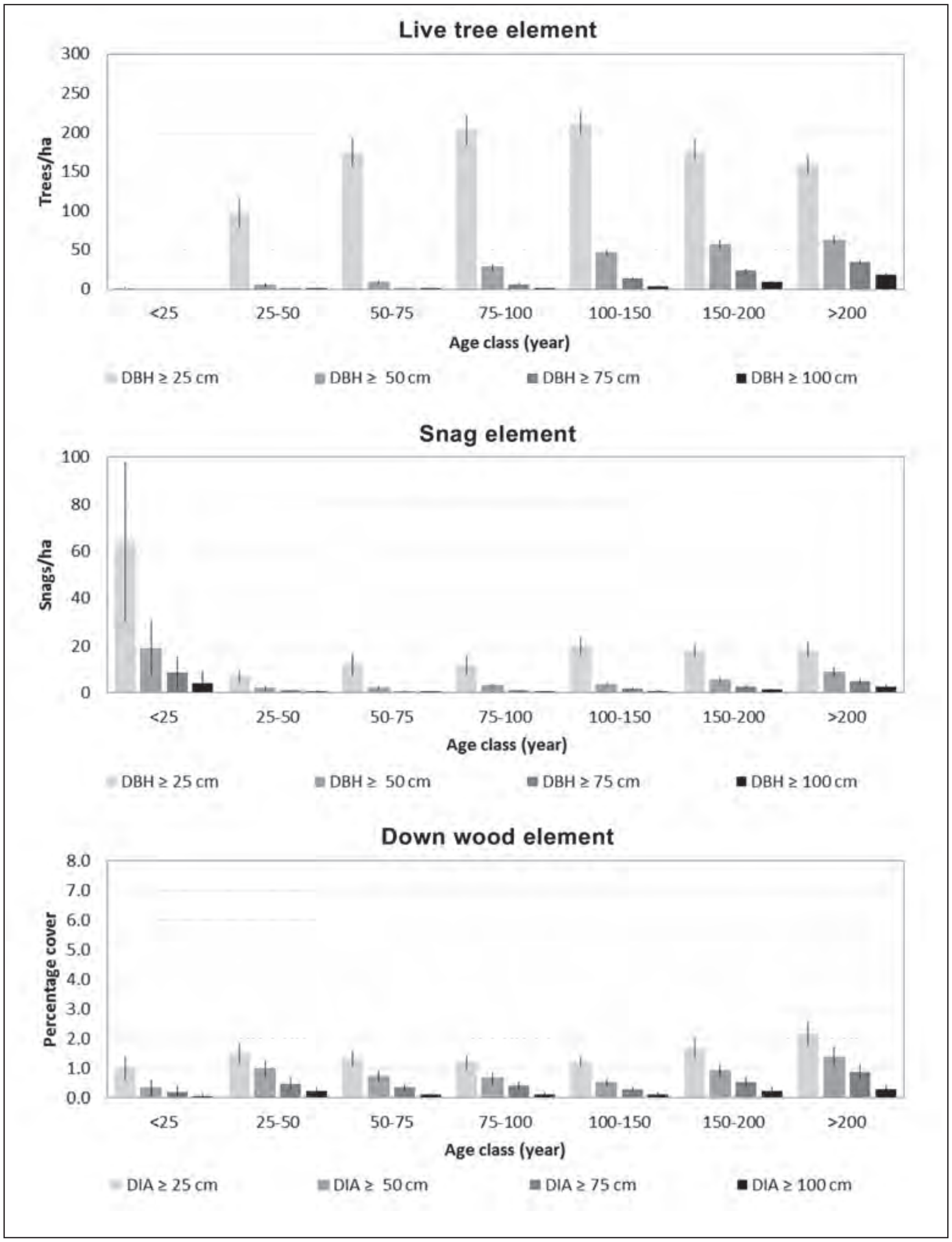


Figure A-6—Tanoak forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

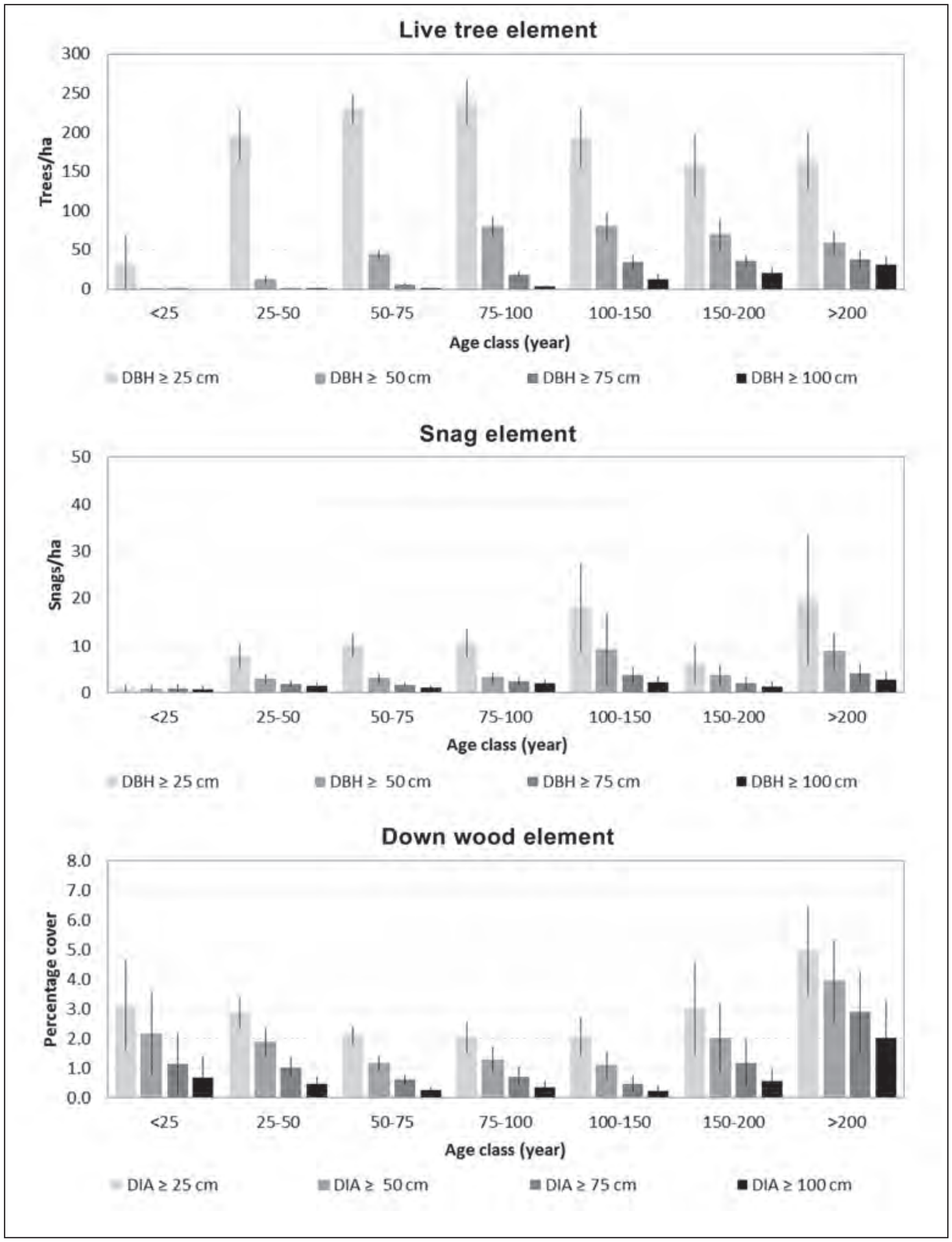


Figure A-7—Redwood forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

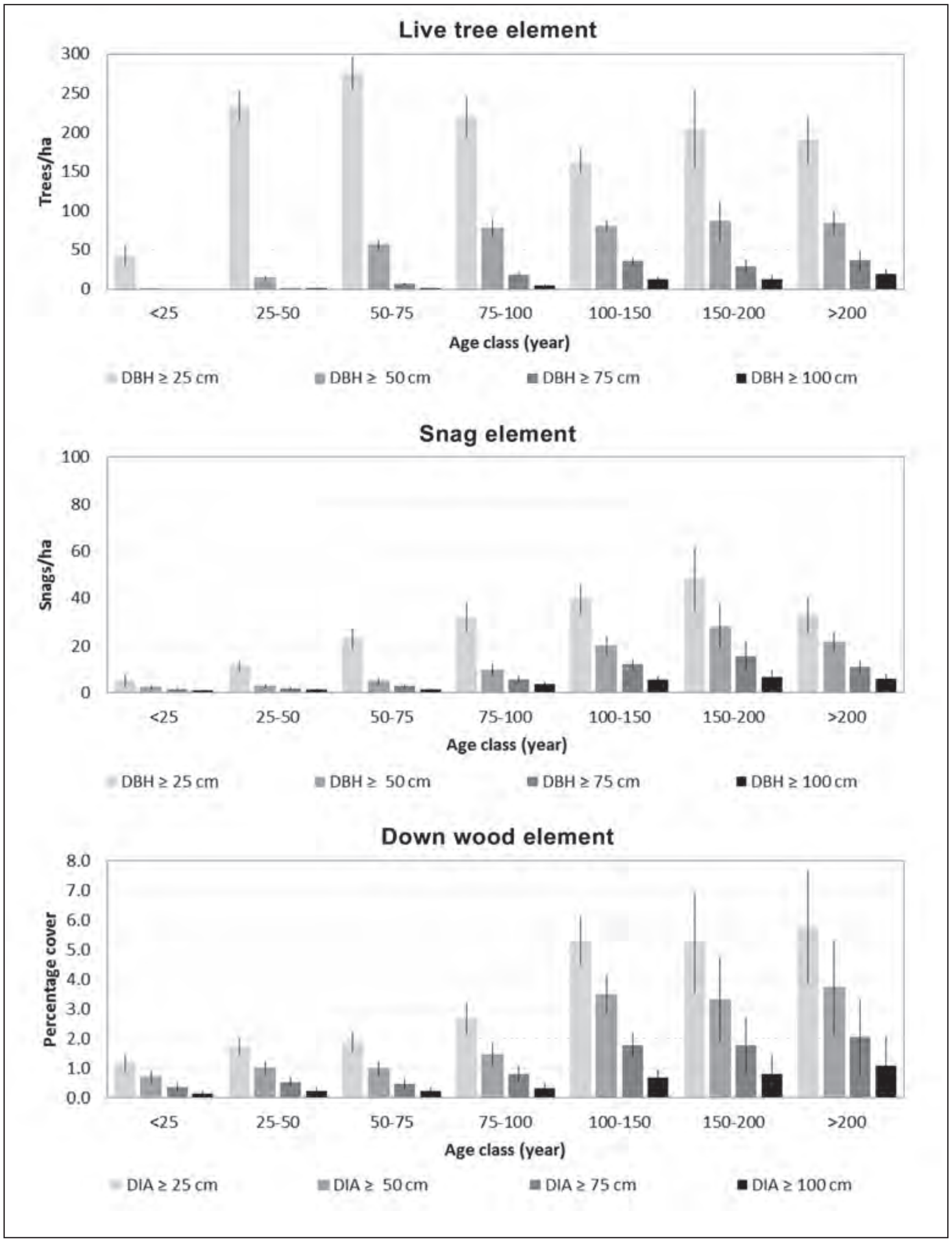


Figure A-8—Sitka spruce forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

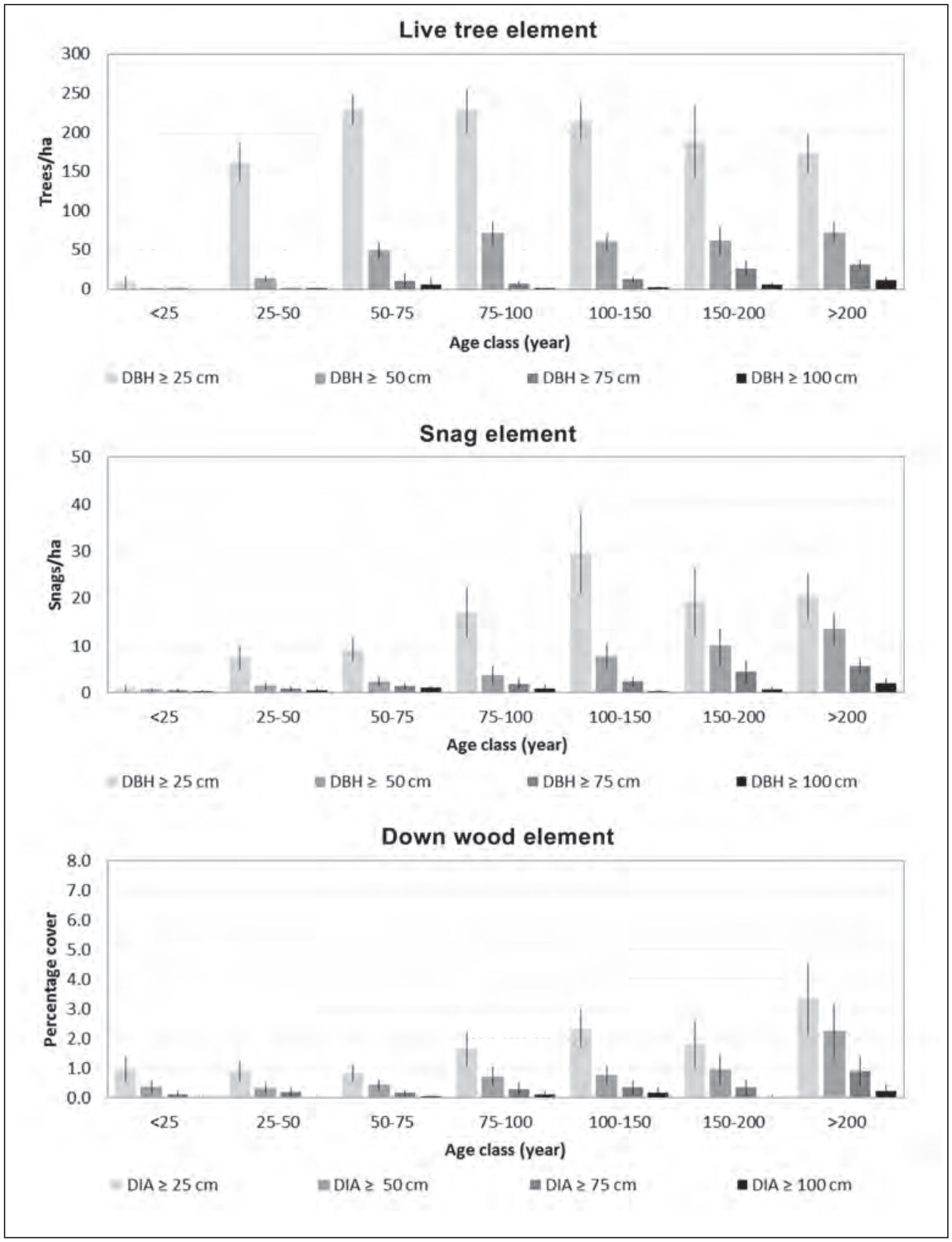


Figure A-9—Western redcedar forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

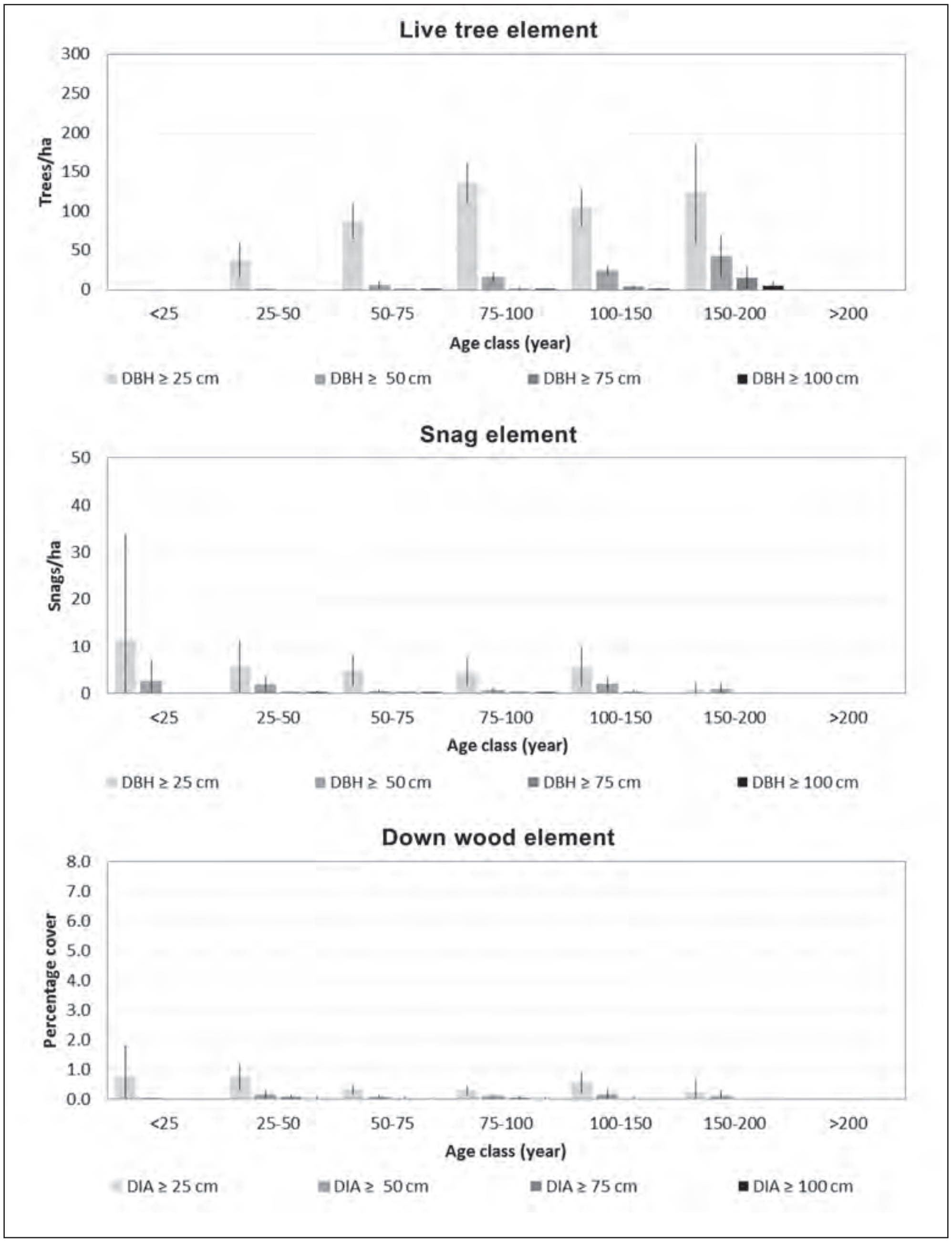


Figure A-10—Oak woodland forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

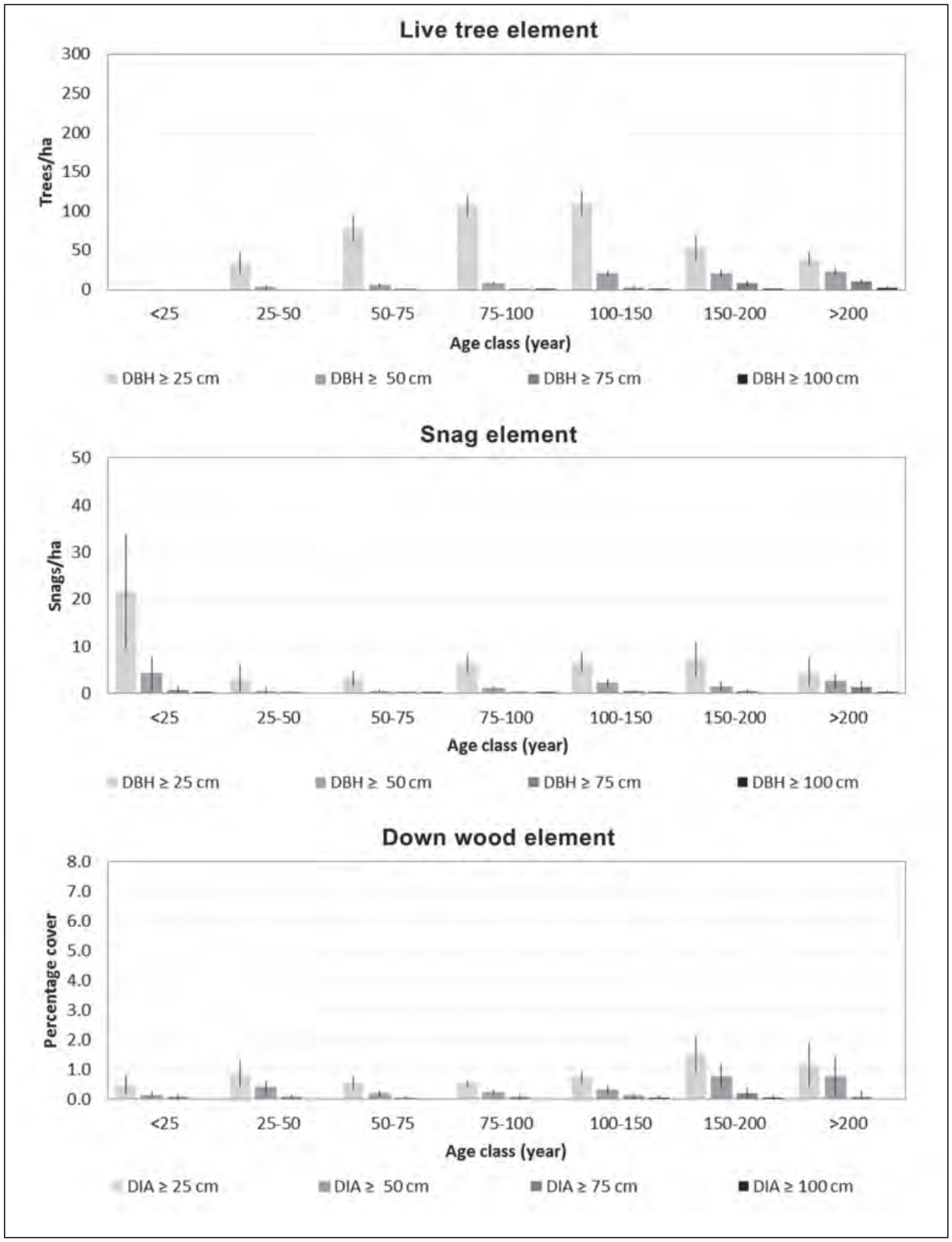


Figure A-11—Ponderosa pine forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

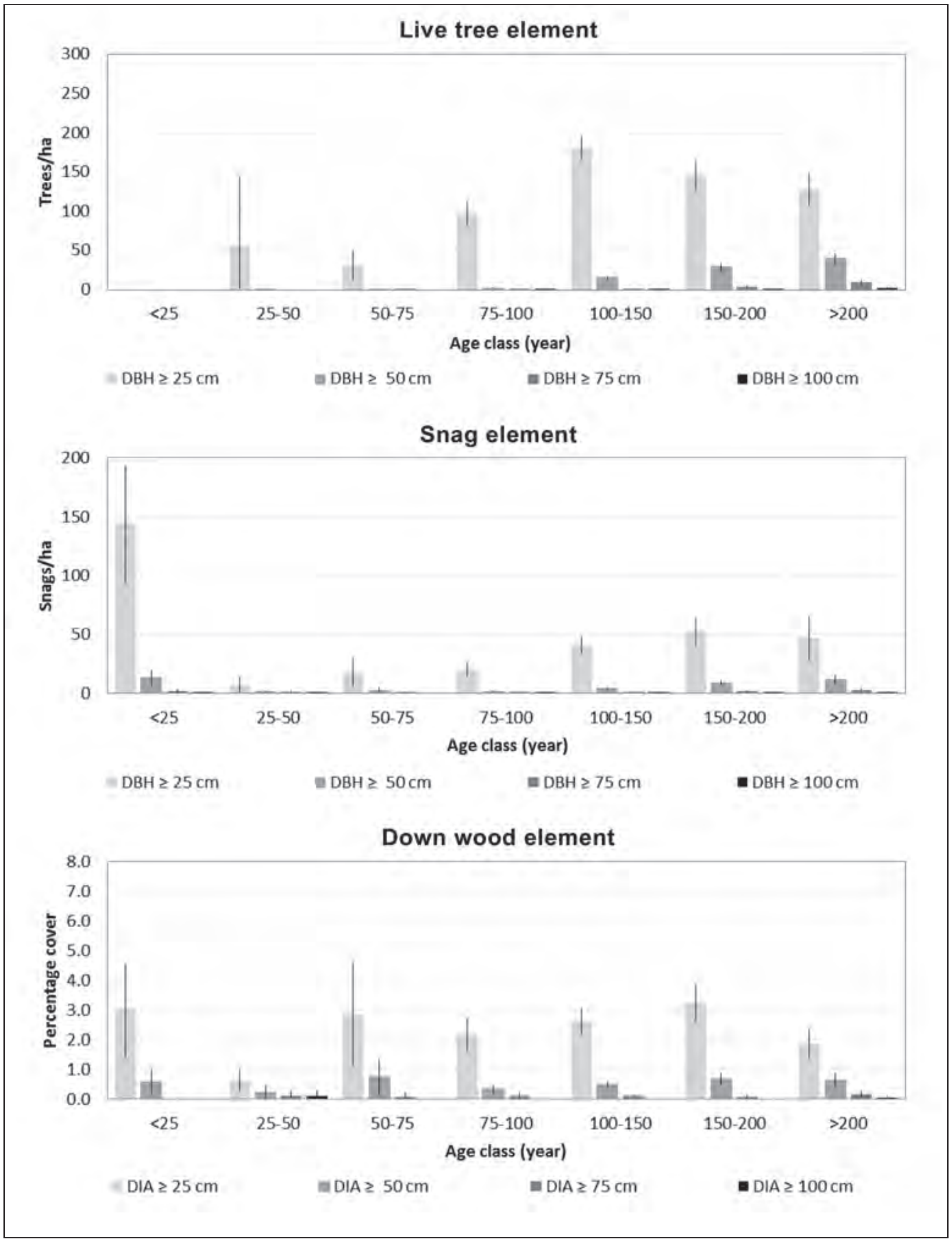


Figure A-12—Subalpine forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

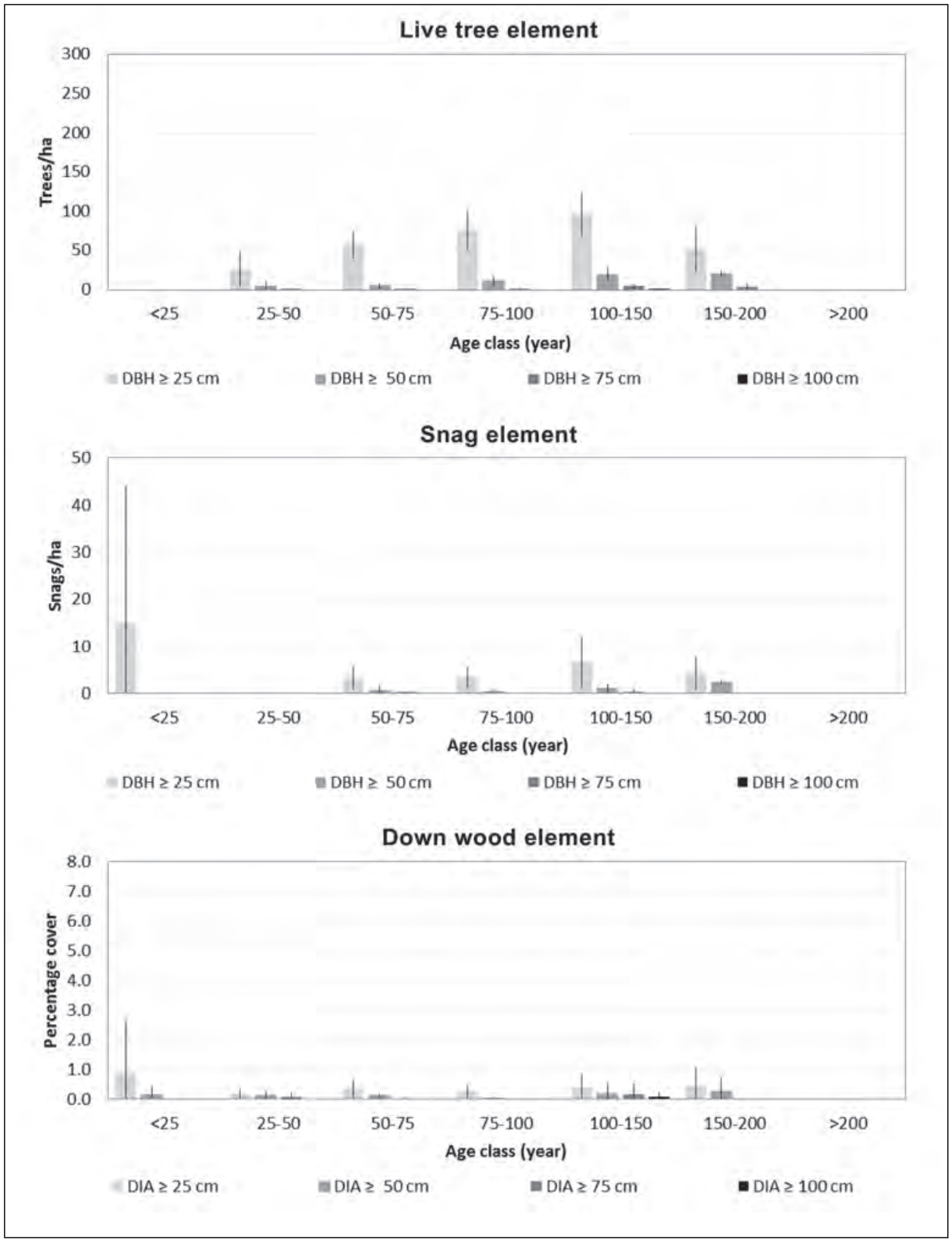


Figure A-13—Other pine forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

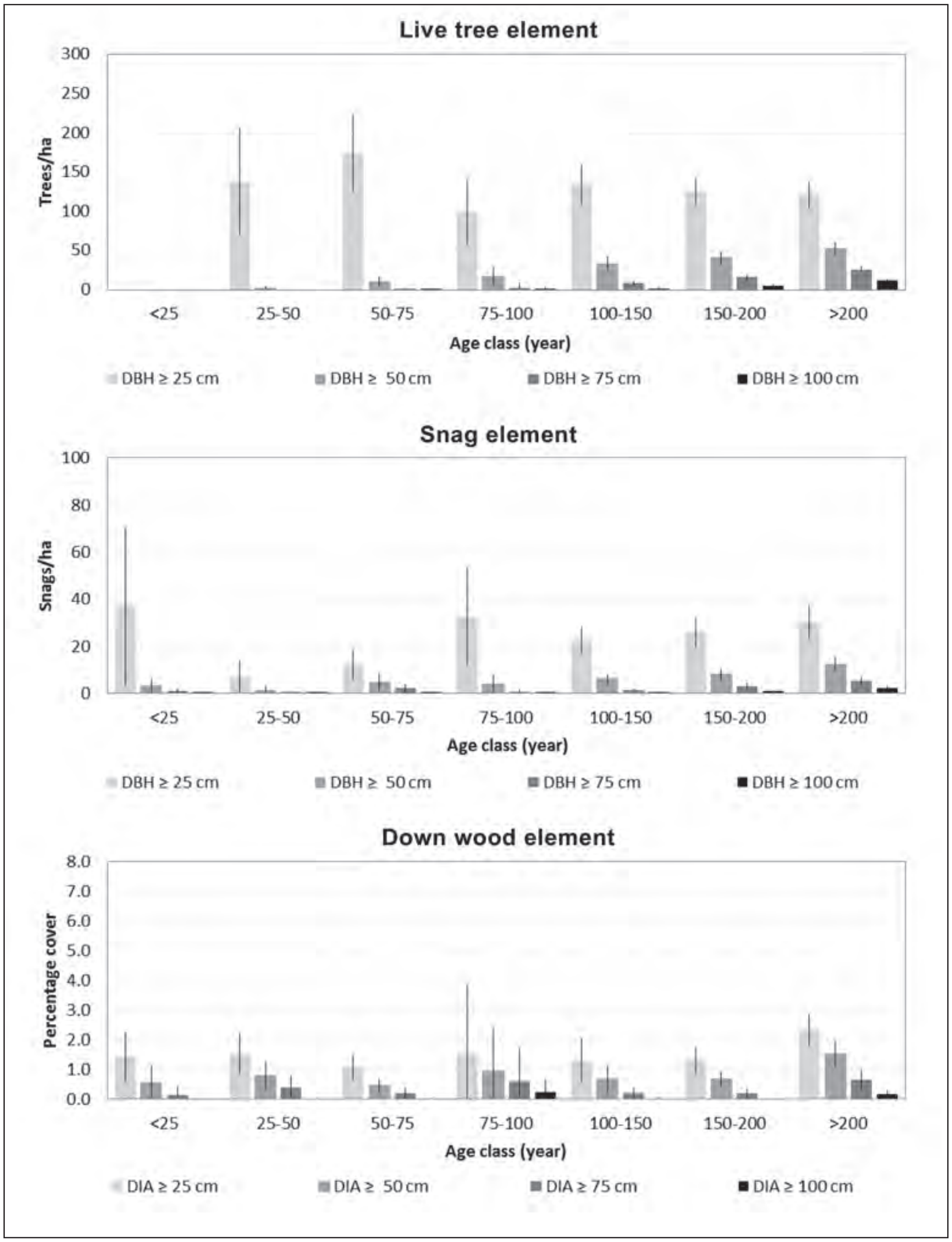


Figure A-14—Port Orford cedar forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

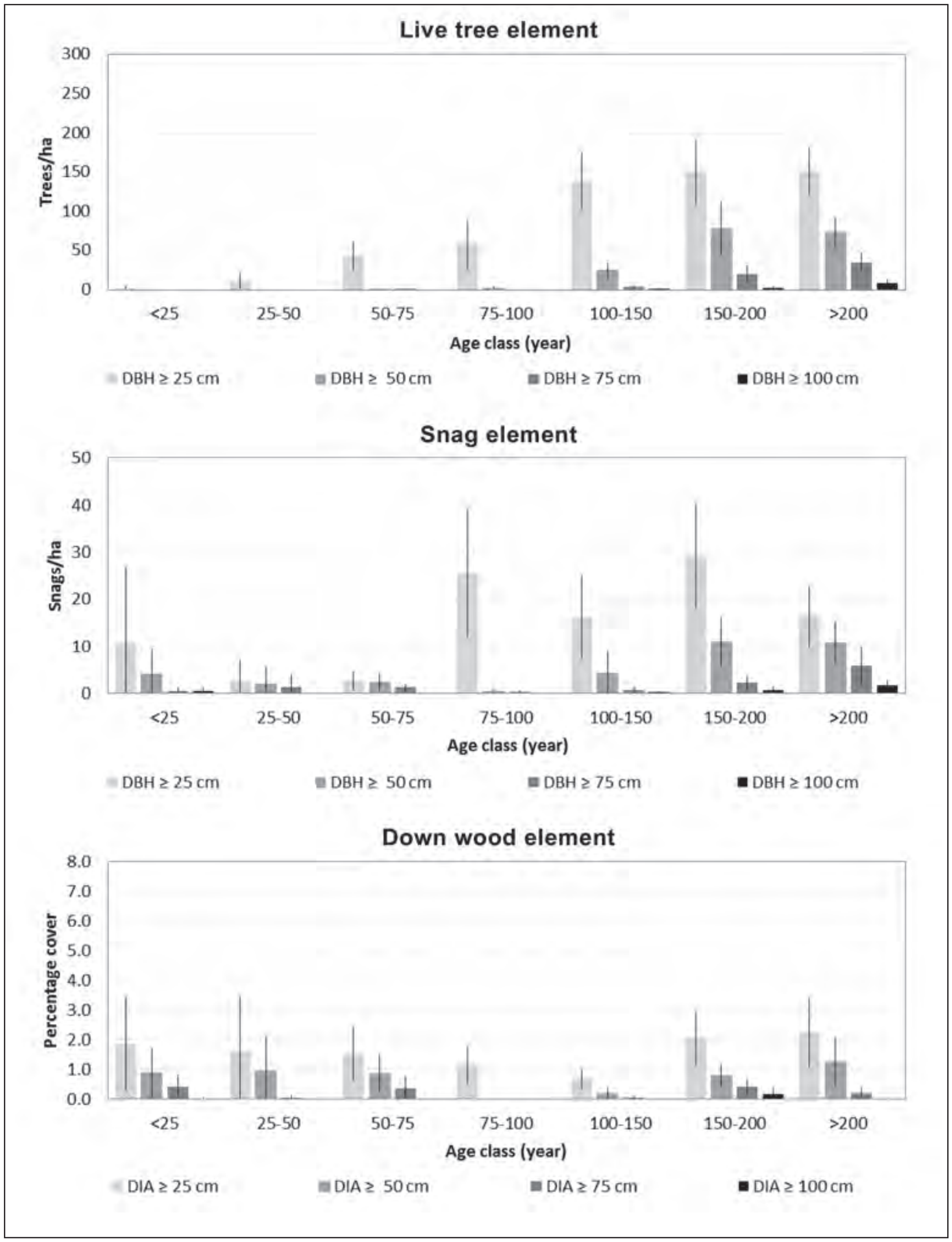


Figure A-15—Shasta red fir forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

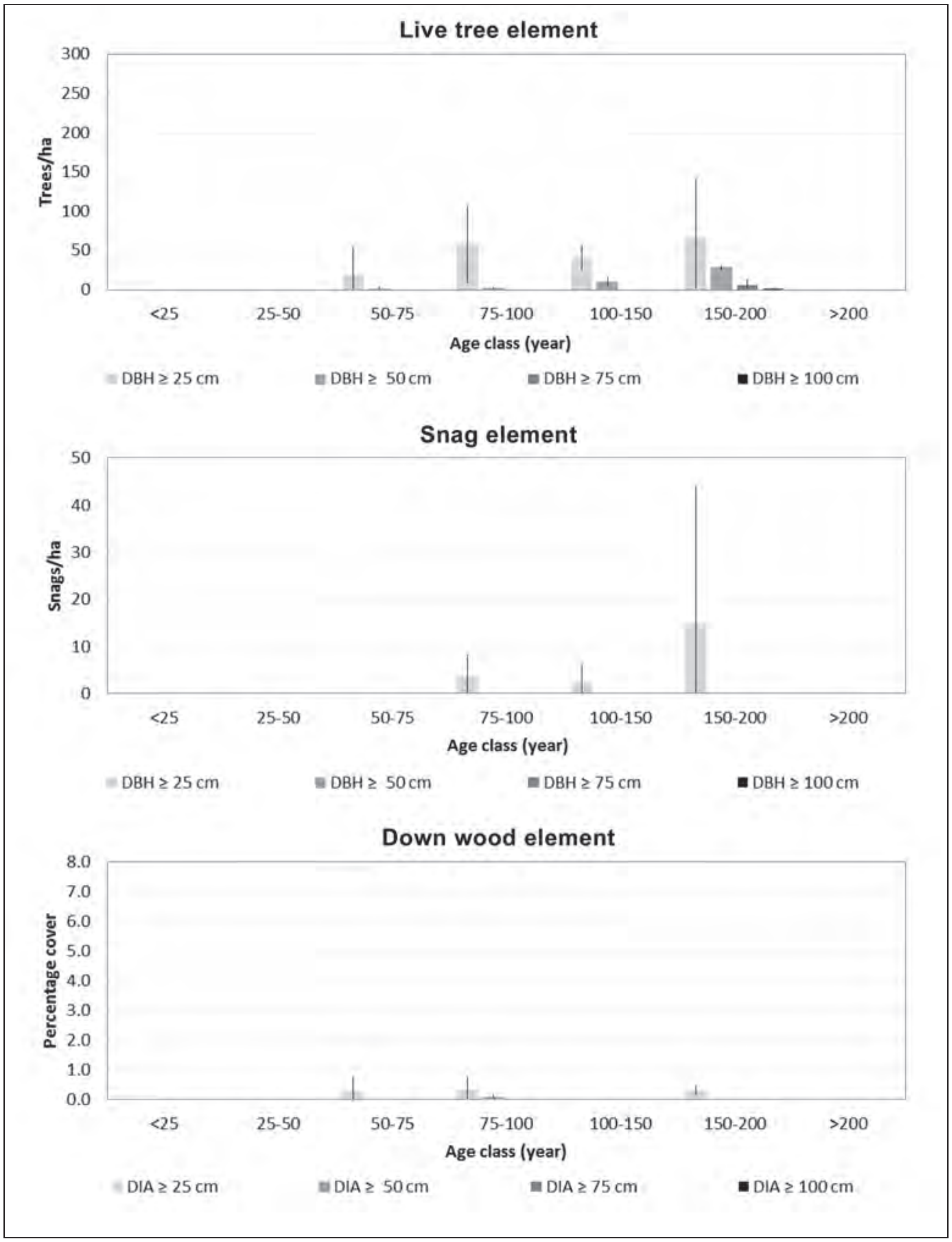
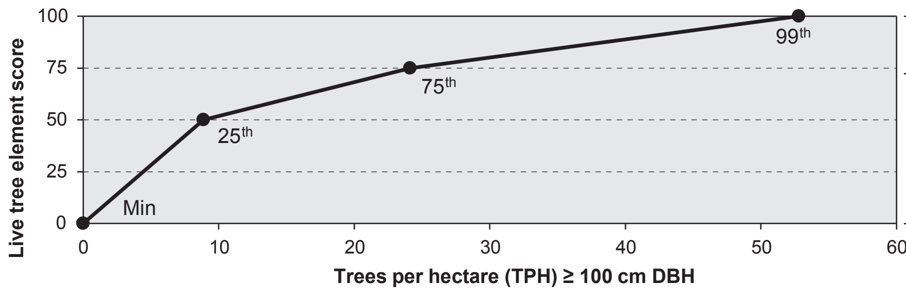
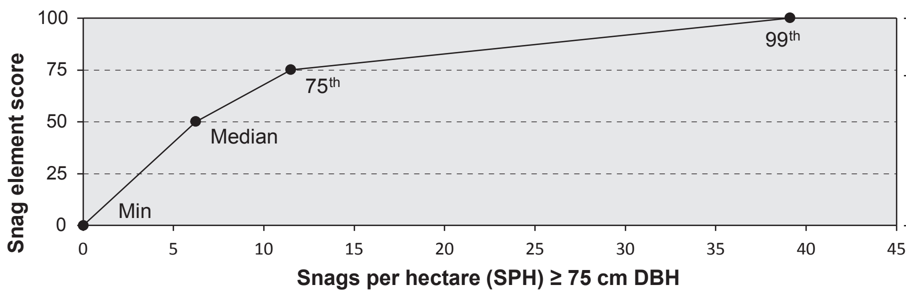


Figure A-16—Juniper woodlands forest vegetation zone. DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long.

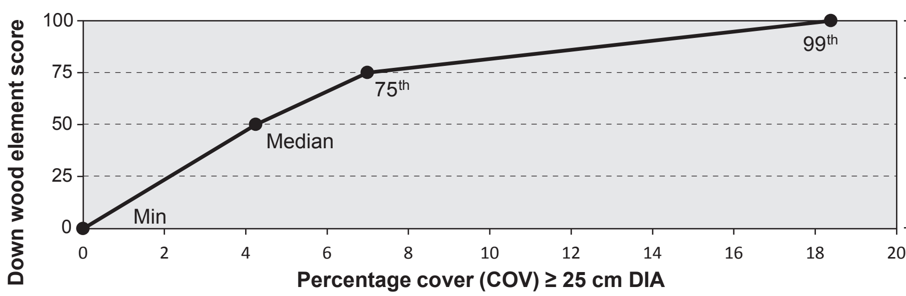
Appendix B: Old-Growth Structure Index Element Curves



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	8.9	50	5.64	0.00
75th	24.1	75	1.64	35.45
99th	52.8	100	0.87	53.98

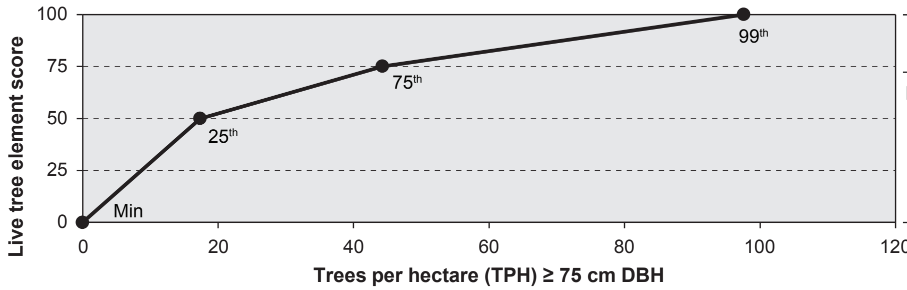


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	6.2	50	8.00	0.00
75th	11.5	75	4.76	20.24
99th	39.1	100	0.91	64.59

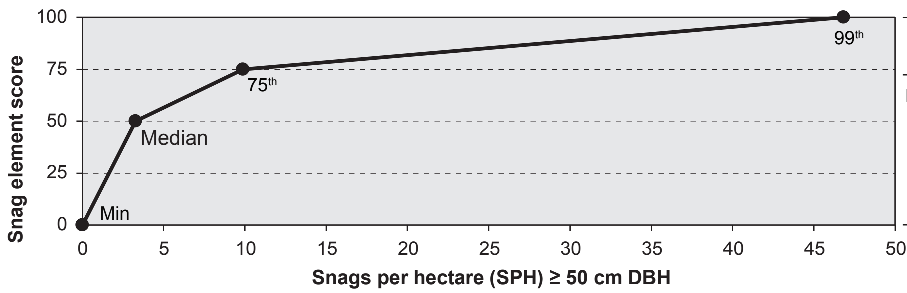


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	4.3	50	11.76	0.00
75th	7.0	75	9.12	11.20
99th	18.4	100	2.19	59.67

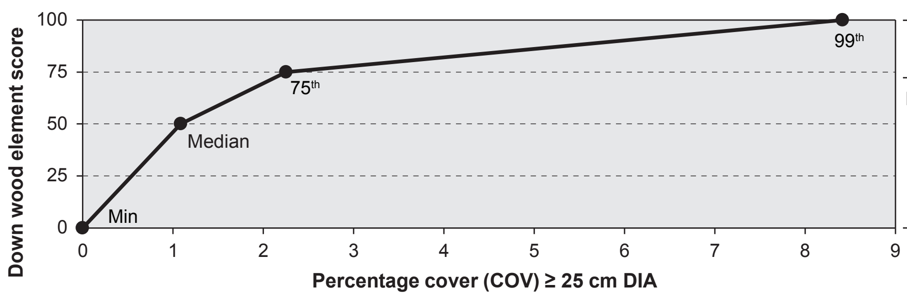
Figure B-1—Western hemlock curves for stands ≥200 years of age (n = 1,151). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	17.4	50	2.87	0.00
75th	44.3	75	0.93	33.83
99th	97.6	100	0.47	54.22

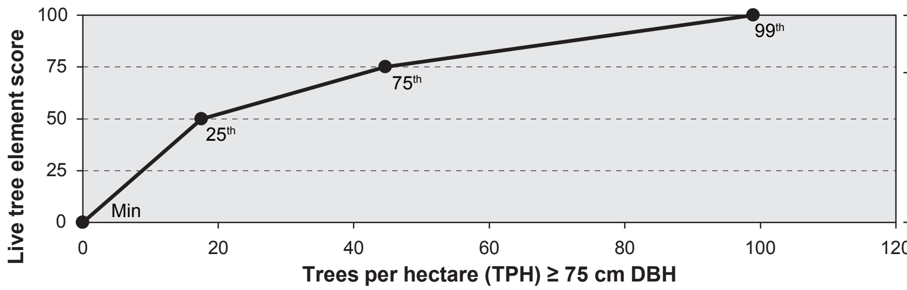


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	3.3	50	15.24	0.00
75th	9.9	75	3.79	37.57
99th	46.8	100	0.68	68.32

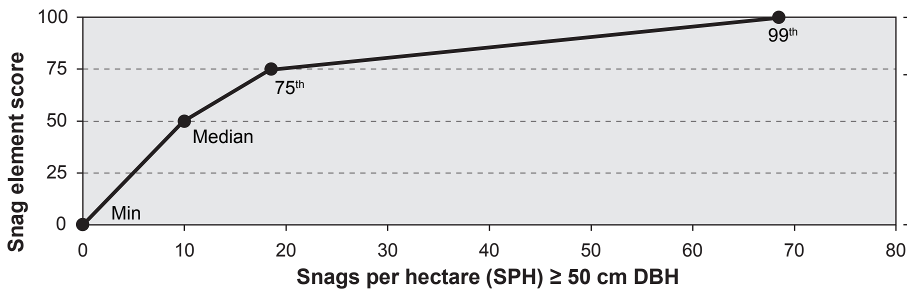


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	1.1	50	45.96	0.00
75th	2.3	75	21.43	6.68
99th	8.4	100	4.06	65.85

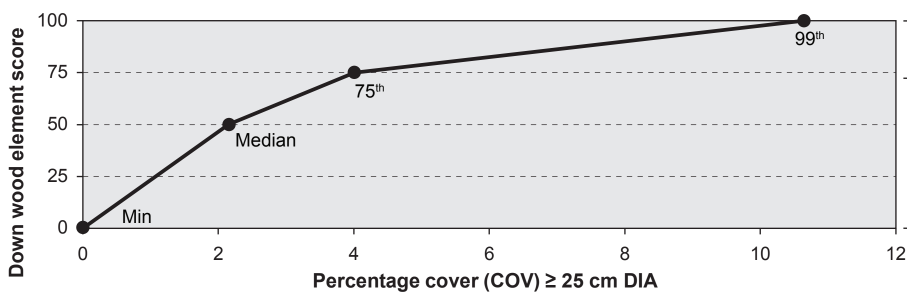
Figure B-2—Douglas-fir curves for stands ≥150 years of age (n = 635). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	17.5	50	2.85	0.00
75th	44.7	75	0.92	33.86
99th	99.0	100	0.46	54.41

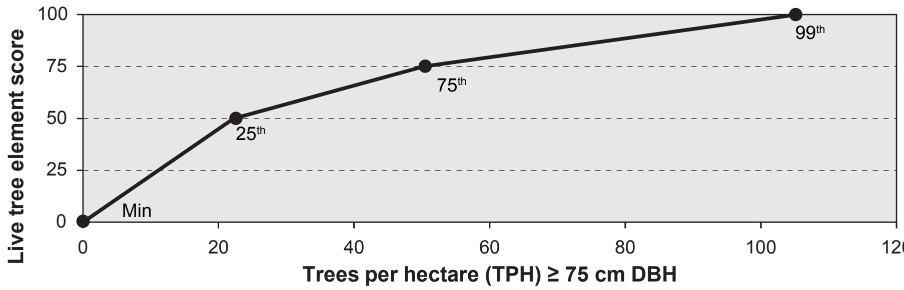


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	9.9	50	5.06	0.00
75th	18.4	75	2.94	20.93
99th	68.3	100	0.50	65.80

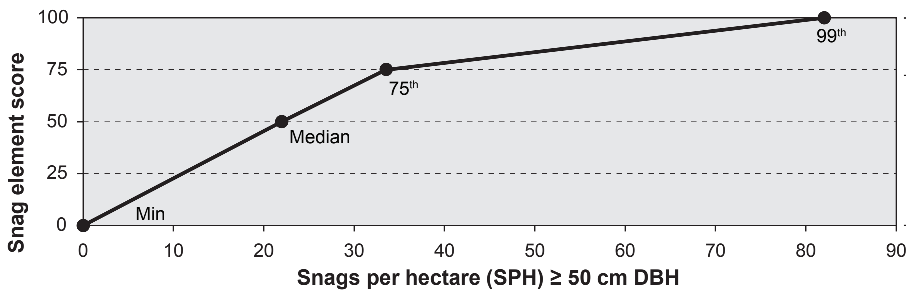


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	2.2	50	23.22	0.00
75th	4.0	75	13.46	1.01
99th	10.6	100	3.77	59.89

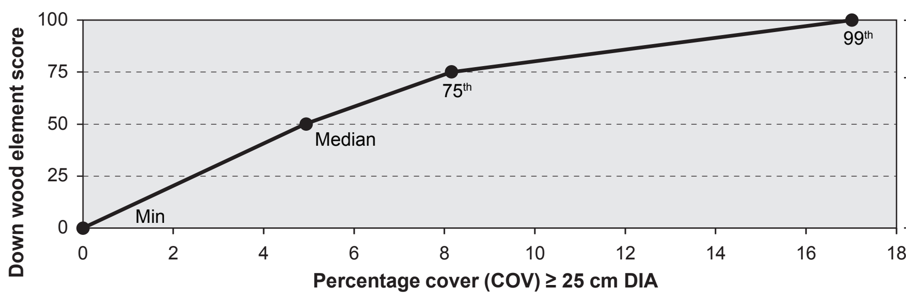
Figure B-3—Grand fir/white fir curves for stands ≥200 years of age (n = 714). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	22.2	50	2.25	0.00
75th	50.3	75	0.89	30.22
99th	105.3	100	0.45	52.13

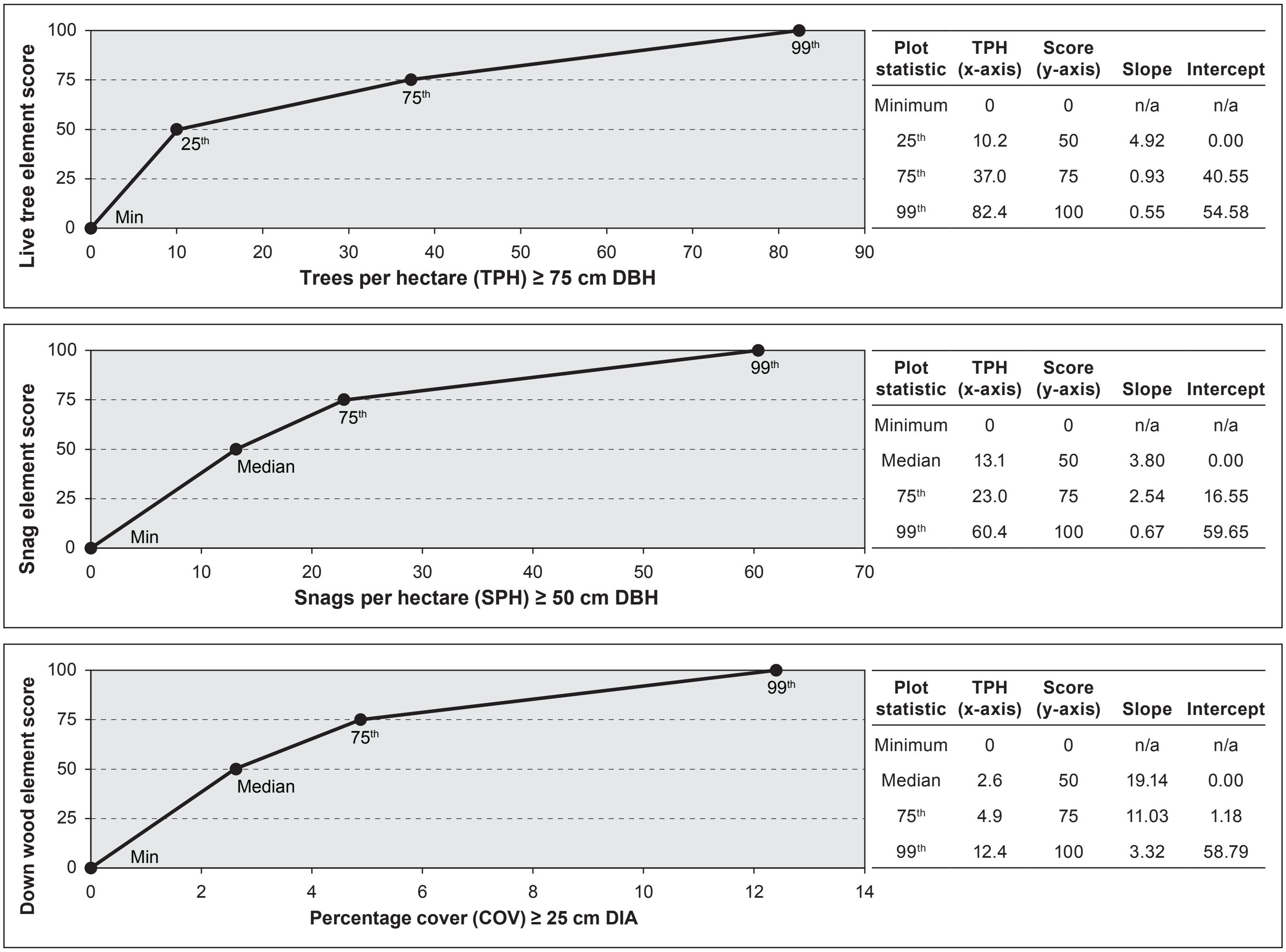


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	22.0	50	2.27	0.00
75th	33.5	75	2.17	2.17
99th	82.0	100	0.51	57.76



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	4.9	50	10.15	0.00
75th	8.1	75	7.76	11.78
99th	17.0	100	2.82	52.06

Figure B-4—Pacific silver fir curves for stands ≥200 years of age (n = 1,270). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.

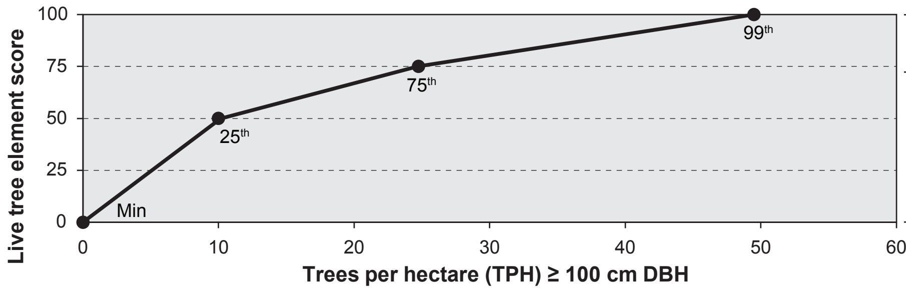


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	10.2	50	4.92	0.00
75th	37.0	75	0.93	40.55
99th	82.4	100	0.55	54.58

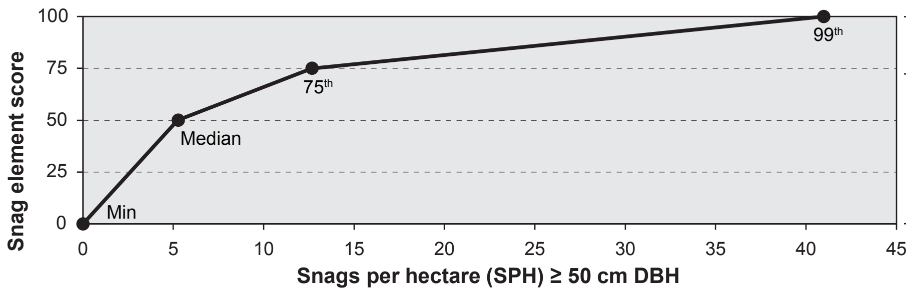
Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	13.1	50	3.80	0.00
75th	23.0	75	2.54	16.55
99th	60.4	100	0.67	59.65

Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	2.6	50	19.14	0.00
75th	4.9	75	11.03	1.18
99th	12.4	100	3.32	58.79

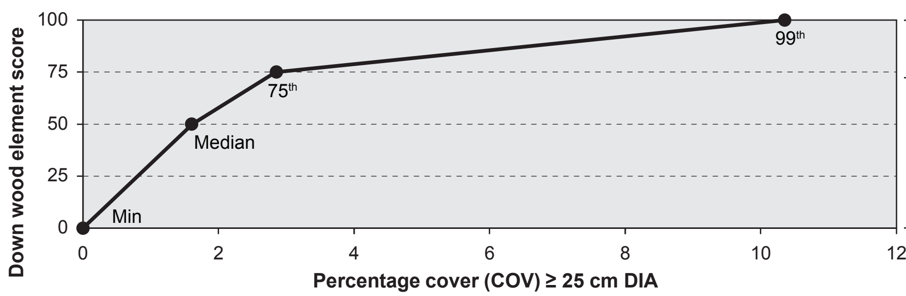
Figure B-5—Mountain hemlock curves for stands ≥200 years of age (n = 900). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	10.2	50	4.92	0.00
75th	24.7	75	1.72	32.55
99th	49.5	100	1.01	50.09

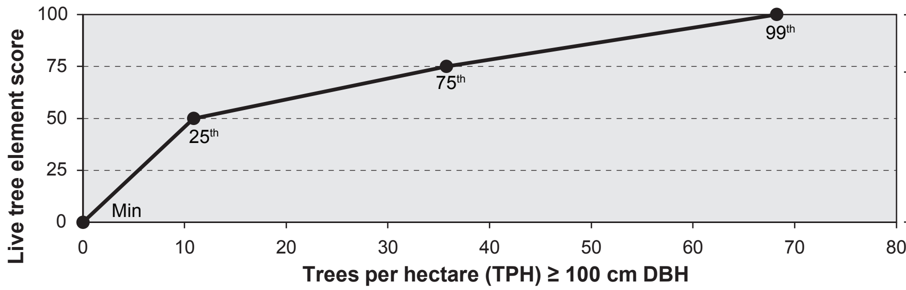


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	5.2	50	9.53	0.00
75th	12.7	75	3.38	32.28
99th	41.0	100	0.88	63.84

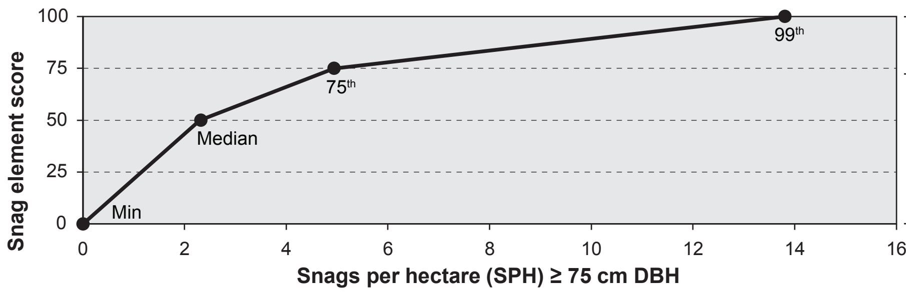


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	1.6	50	30.84	0.00
75th	2.8	75	20.46	6.84
99th	10.4	100	3.33	65.54

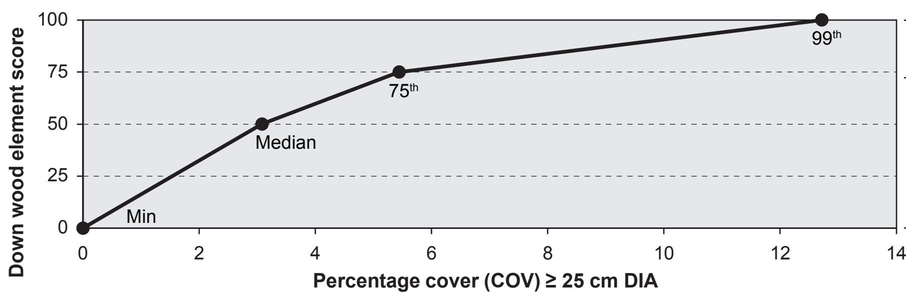
Figure B-6—Tanoak curves for stands ≥200 years of age (n = 140). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	10.9	50	4.59	0.00
75th	35.8	75	1.00	39.07
99th	68.2	100	0.77	47.41

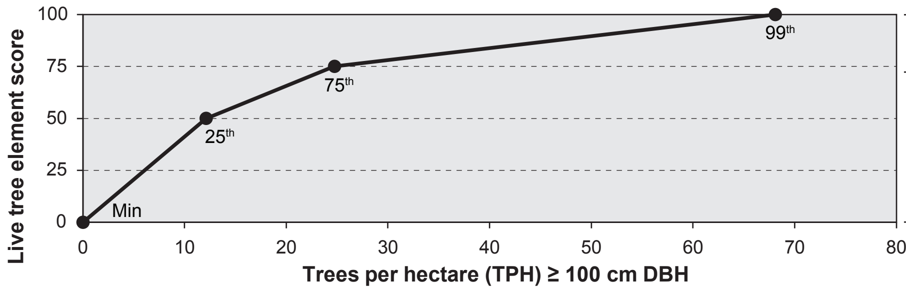


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	2.3	50	21.70	0.00
75th	4.9	75	9.49	28.13
99th	13.8	100	2.82	61.08

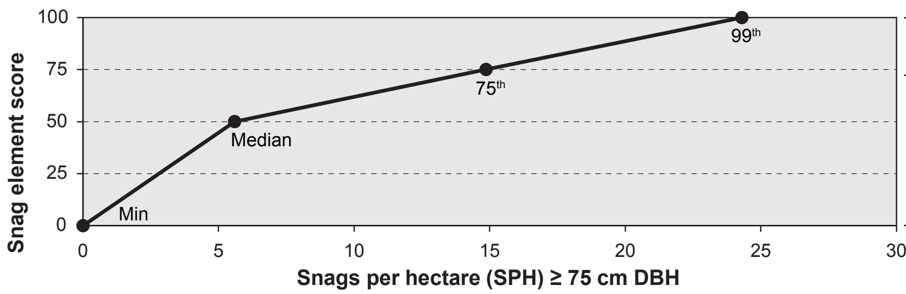


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	3.1	50	16.21	0.00
75th	5.4	75	10.62	7.26
99th	12.7	100	3.44	56.31

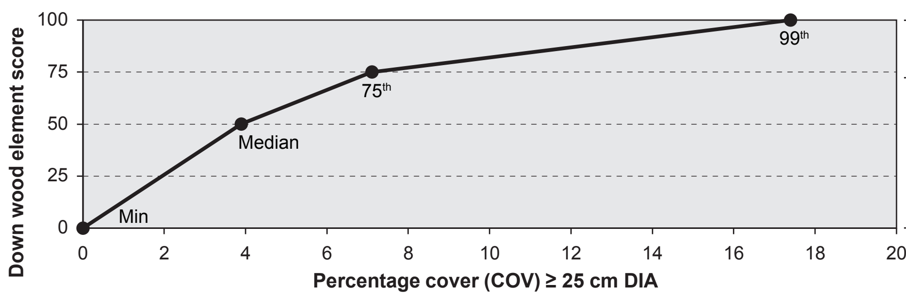
Figure B-7—Redwood curves for stands ≥150 years of age (n = 35). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	12.1	50	4.13	0.00
75th	24.7	75	1.98	25.99
99th	68.1	100	0.58	60.77

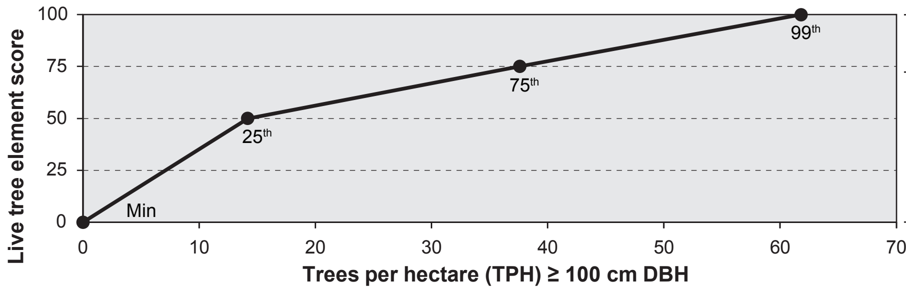


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	5.6	50	8.93	0.00
75th	14.8	75	2.72	34.78
99th	24.3	100	2.63	36.05

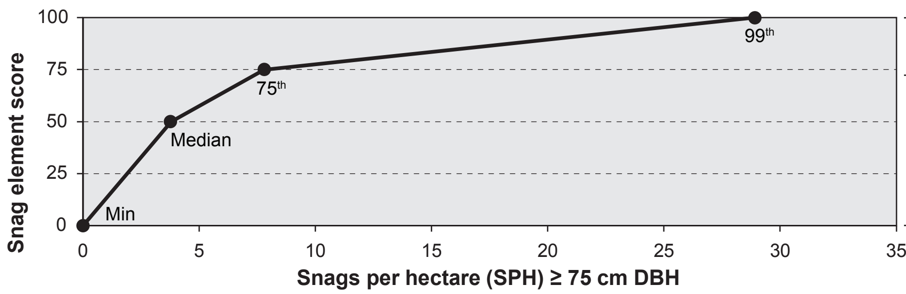


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	3.9	50	12.82	0.00
75th	7.1	75	7.81	19.53
99th	17.4	100	2.43	57.77

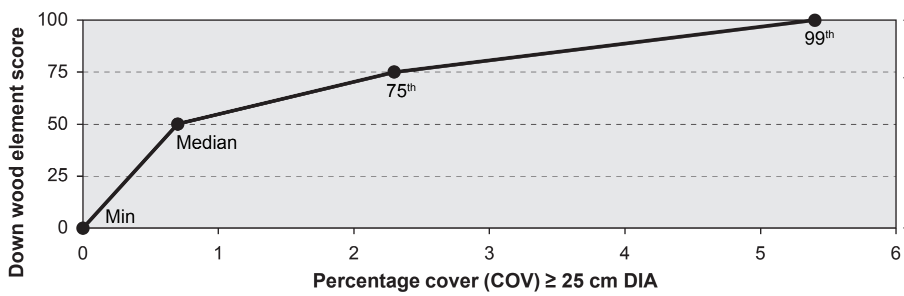
Figure B-8—Sitka spruce curves for stands ≥200 years of age (n = 21). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	14.2	50	3.52	0.00
75th	37.6	75	1.07	34.83
99th	61.8	100	1.03	36.16

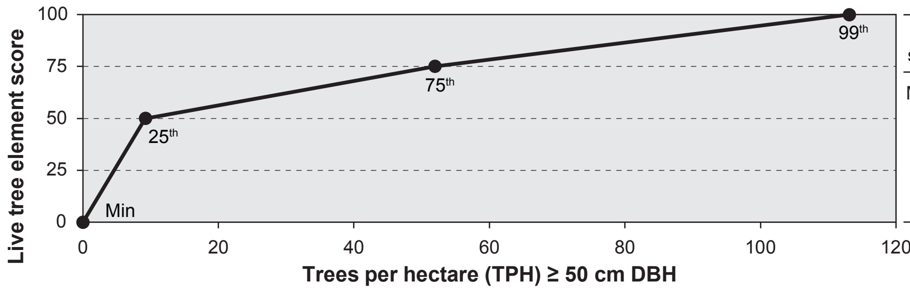


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	3.8	50	13.16	0.00
75th	7.8	75	6.25	26.25
99th	28.9	100	1.18	65.76

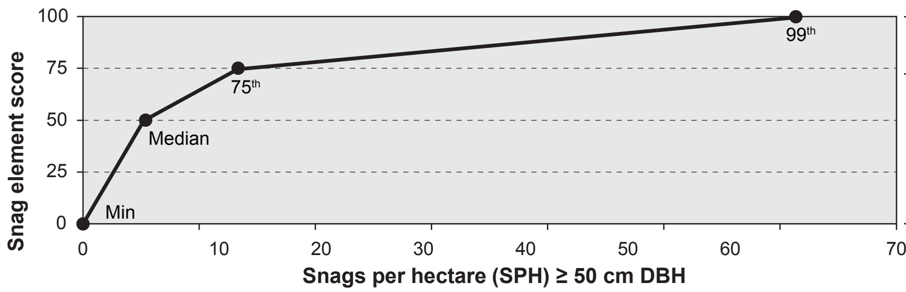


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	0.7	50	71.43	0.00
75th	2.3	75	15.63	9.06
99th	5.4	100	8.06	56.45

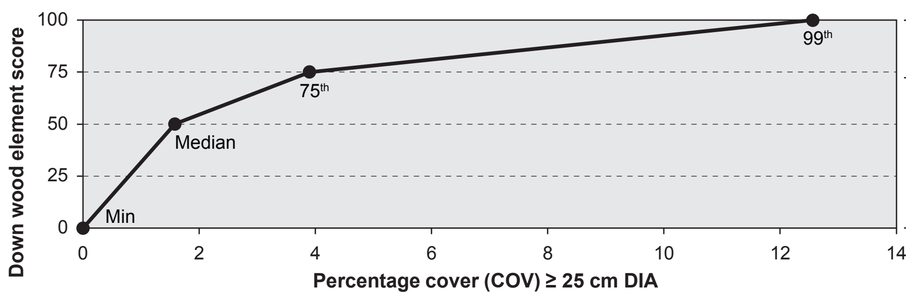
Figure B-9—Western redcedar curves for stands ≥200 years of age (n = 26). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	9.2	50	5.43	0.00
75th	52.0	75	0.58	44.63
99th	113.1	100	0.41	53.72

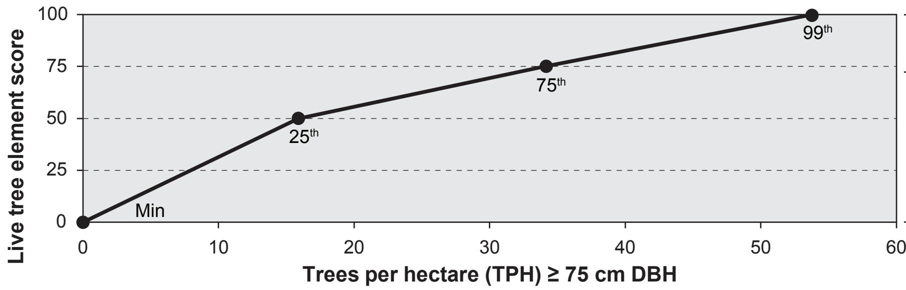


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	5.2	50	9.53	0.00
75th	13.3	75	3.10	33.72
99th	61.4	100	0.52	68.07

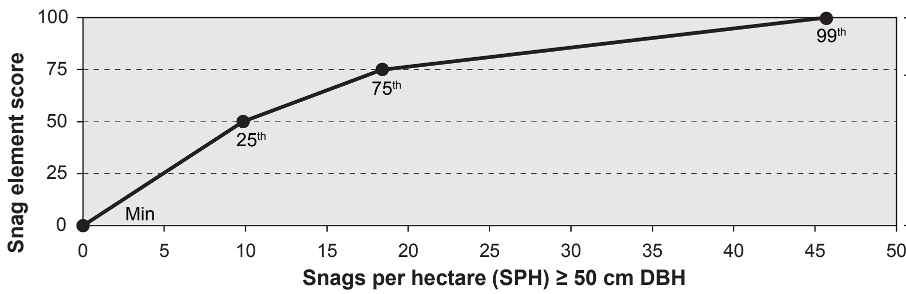


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	1.6	50	31.48	0.00
75th	3.9	75	10.78	32.87
99th	12.6	100	2.89	63.71

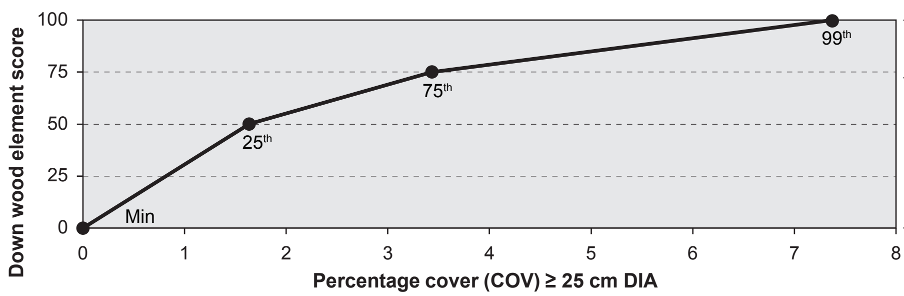
Figure B-10—Subalpine curves for stands ≥150 years of age (n = 191). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	15.9	50	3.14	0.00
75th	34.1	75	1.37	28.16
99th	53.8	100	1.27	31.76

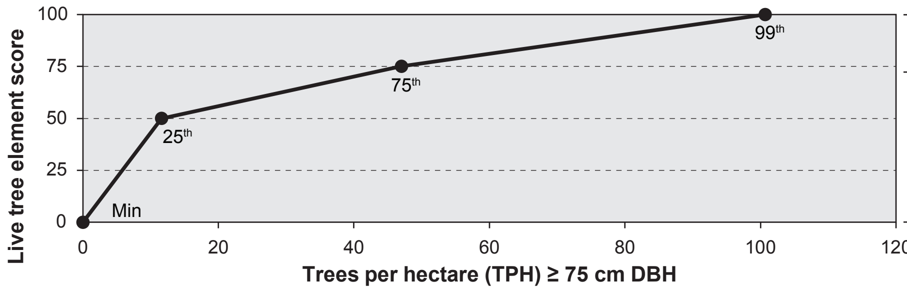


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	9.8	50	5.08	0.00
75th	18.4	75	2.93	21.15
99th	45.7	100	0.91	58.20

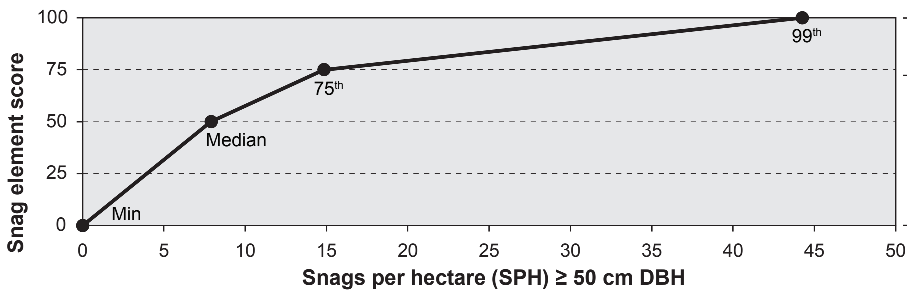


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	1.6	50	30.50	0.00
75th	3.4	75	13.96	27.11
99th	7.4	100	6.34	53.25

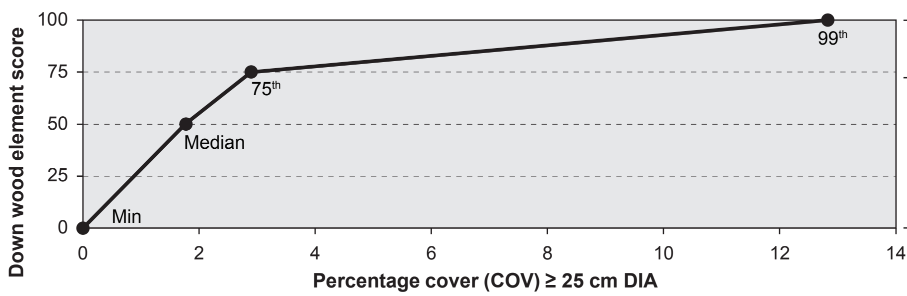
Figure B-11—Port Orford cedar curves for stands ≥200 years of age (n = 59). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	11.6	50	4.30	0.00
75th	46.9	75	0.71	41.75
99th	100.7	100	0.46	53.19

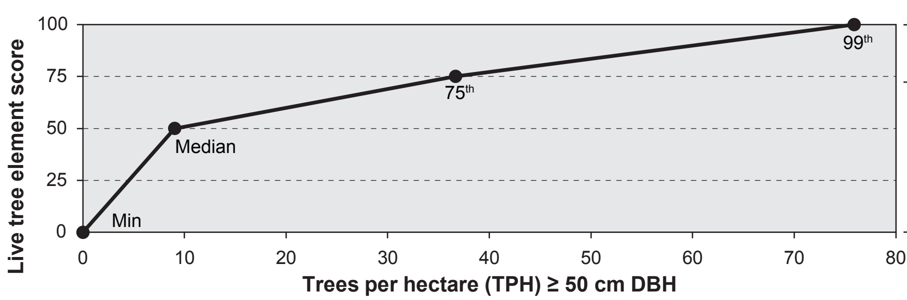


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	7.9	50	6.33	0.00
75th	14.8	75	3.62	21.43
99th	44.3	100	0.83	62.42



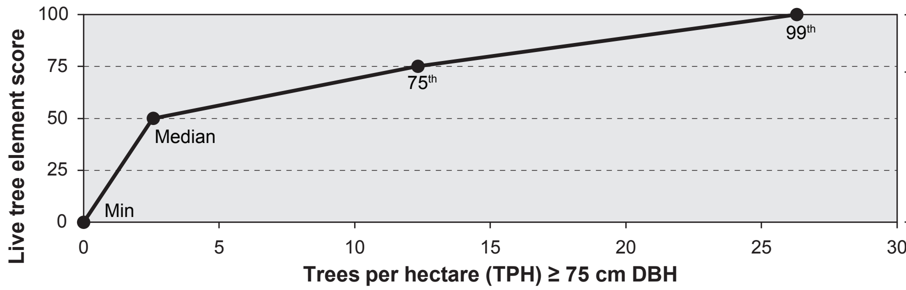
Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
Median	1.8	50	28.30	0.00
75th	2.9	75	22.07	11.02
99th	12.8	100	2.52	67.70

Figure B-12—Shasta red fir curves for stands ≥200 years of age (n = 25). DBH = diameter at breast height. DIA = diameter at large end and ≥3 m long. NA = not applicable.



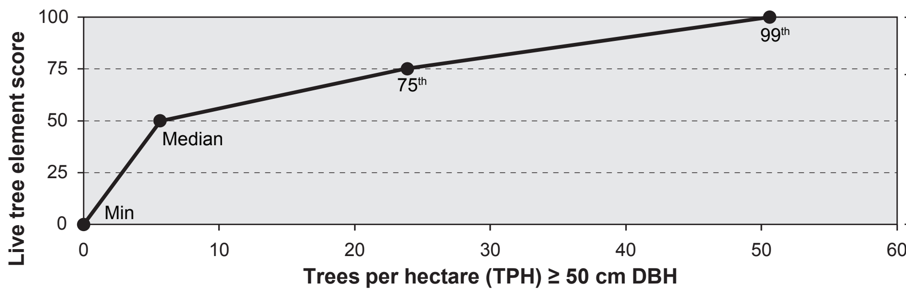
Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	9.0	50	5.53	0.00
75th	36.7	75	0.91	41.81
99th	75.9	100	0.64	51.65

Figure B-13—Oak woodland curves for stands ≥100 years of age (n = 40). DBH = diameter at breast height. NA = not applicable.



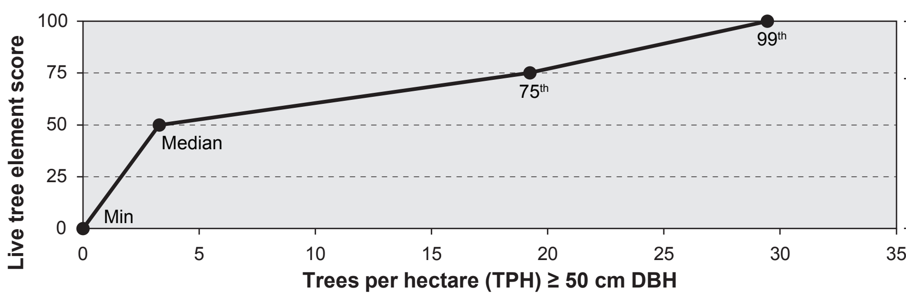
Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	2.5	50	19.63	0.00
75th	12.3	75	2.56	43.47
99th	26.3	100	1.79	53.04

Figure B-14—Ponderosa pine curves for stands ≥150 years of age (n = 39). DBH = diameter at breast height. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	5.7	50	8.77	0.00
75th	23.7	75	1.39	42.08
99th	50.6	100	0.93	52.97

Figure B-15—Other pine species curves for stands ≥100 years of age (n =1 6). DBH = diameter at breast height. NA = not applicable.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	n/a	n/a
25th	3.3	50	15.24	0.00
75th	19.2	75	1.57	44.84
99th	29.5	100	2.43	28.34

Figure B-16—Juniper woodland curves for stands ≥100 years of age (n = 10). DBH = diameter at breast height. NA = not applicable.

Appendix C: Old-Growth Structure Index Mapping and Analysis Thresholds

Table C-1—Old-growth structure index (OGSI) mapping thresholds (80, 120, 160, and 200 years) by forest vegetation zone

Scatter plot	Pseudo[a] R^2	Forest vegetation zone	OGSI-80	OGSI-120	OGSI-160	OGSI-200
A	0.57	Western hemlock	23.9	30.9	37.7	44.9
B	0.33	Douglas-fir	21.6	30.9	40.8	49.3
C	0.51	Grand fir/white fir	19.8	29.9	40.6	49.2
D	0.67	Pacific silver fir	18.0	25.2	34.1	43.3
E	0.52	Mountain hemlock	14.3	22.9	32.8	43.5
F	0.53	Tanoak	22.8	31.2	40.4	49.1
G	0.28	Redwood	30.0	40.7	47.9	53.4
H	0.55	Sitka spruce	30.8	47.7	56.2	59.8
I	0.45	Western redcedar	25.7	36.6	42.6	47.6
J	0.27	Oak woodlands	26.2	57.3	74.0	n/a
K	0.28	Ponderosa pine	NA	19.1	45.5	67.7
L	0.26	Subalpine	19.1	32.4	42.0	43.5
M	0.10	Other pine	29.8	35.0	40.5	49.9
N	0.46	Port Orford cedar	20.7	28.5	39.7	47.9
O	0.39	Shasta red fir	17.2	24.8	34.5	41.3
P	0.53	Juniper	10.8	49.4	88.2	71.9

NA = not applicable.

[a] See Schabenberger and Pierce (2002: 213).

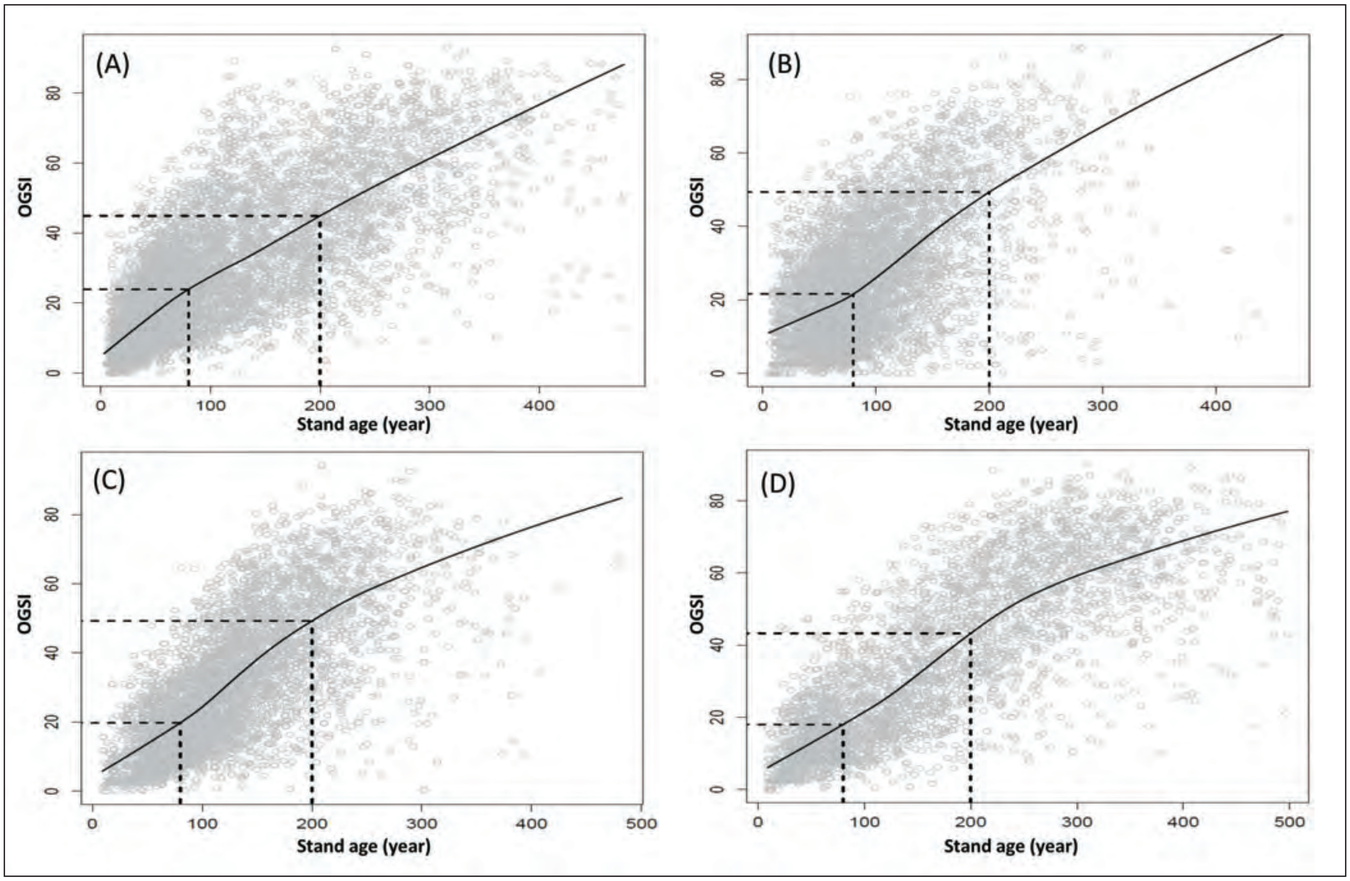


Figure C-1—Scatter plot of OGSI and stand age for forest inventory plots showing a locally weighted polynomial regression line used to develop mapping thresholds at 80 and 200 years (dashed lines).

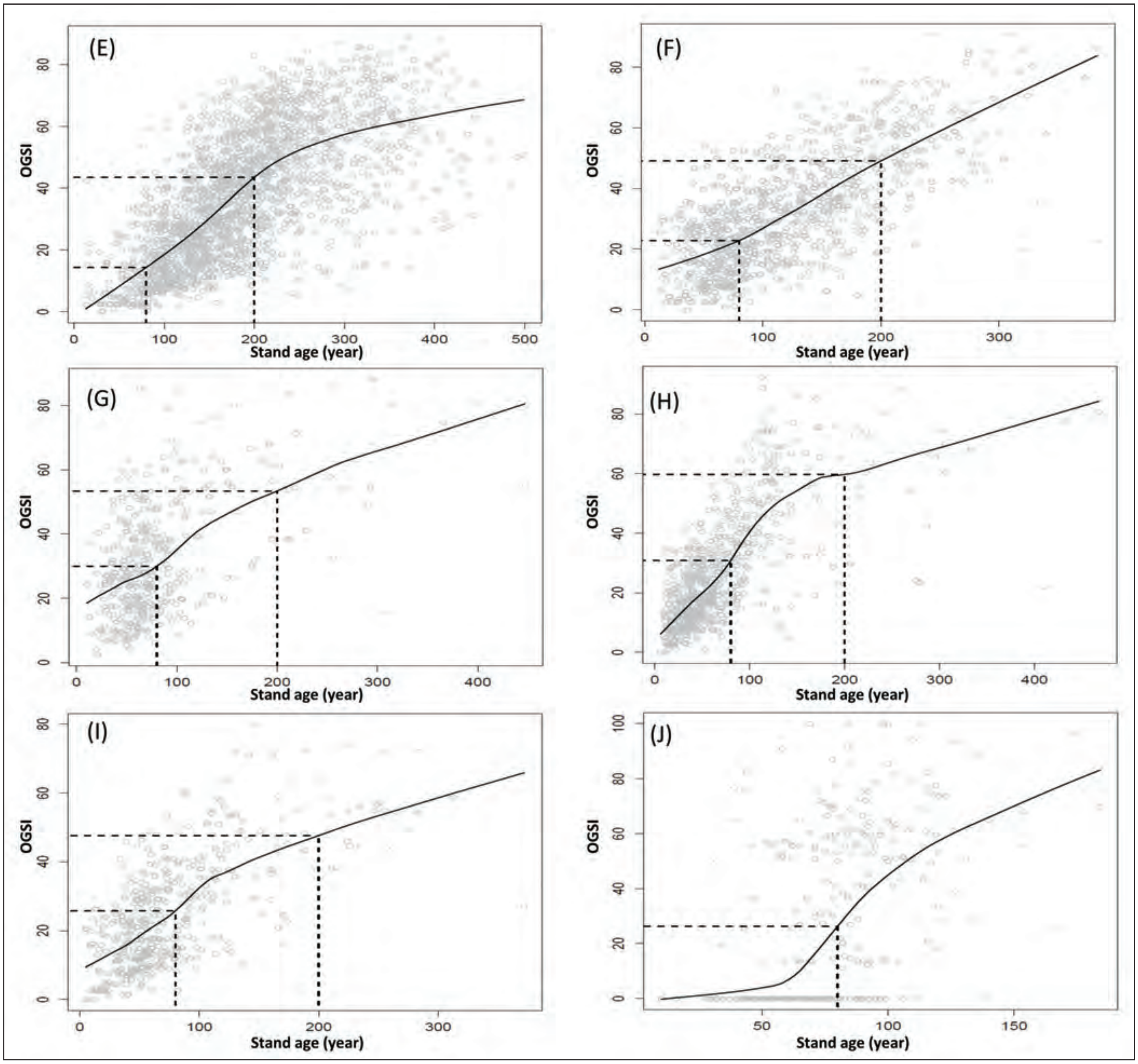


Figure C-1 (continued)—Scatter plot of OGSI and stand age for forest inventory plots showing a locally weighted polynomial regression line used to develop mapping thresholds at 80 and 200 years (dashed lines).

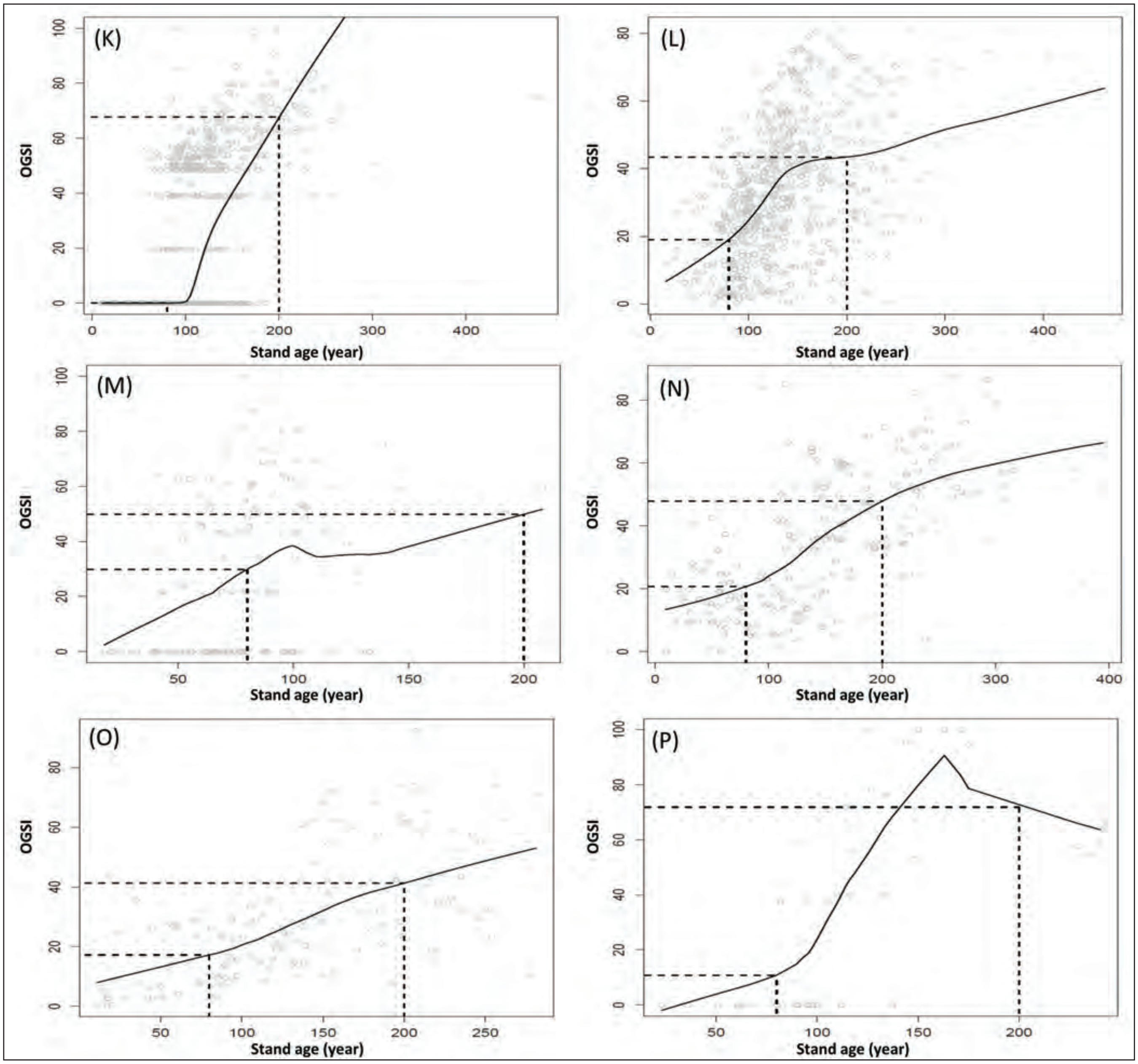


Figure C-1 (continued)—Scatter plot of OGSI and stand age for forest inventory plots showing a locally weighted polynomial regression line used to develop mapping thresholds at 80 and 200 years (dashed lines).

References:

Cleveland, W.S. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association. 74: 829-836.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/. (12 November 2014).

Schabenberger, O.; Pierce, F.J. 2002. Contemporary statistical models for the plant and soil sciences. Boca Raton, FL: CRC Press. 738 p.

Appendix D: Attributing and Accuracy of LandTrendr Disturbance Maps

LandTrendr disturbance maps were attributed with a "cause agent" through the interpretation of the duration of the disturbance, the location of the disturbance in relationship to federal land use allocations, relationship to aerial detection survey (ADS) maps for insects (USDA FS 2011), spatial relationship to mapped wildfire perimeters, and inside wildfire perimeters, year of disturbance in relationship to the wildfire year. If a disturbance inside a wildfire perimeter predated the wildfire year by more than 2 years, it was attributed to some other cause, not wildfire (e.g., insects or timber harvest). We classified disturbance into four general classes as follows:

Timber harvest—Represents timber harvesting including thinning and regeneration harvests. Classified as fast (duration ≤4 years) disturbances outside of congressionally reserved or administratively withdrawn (CRAW) lands and also outside of wildfire perimeters; or if within a wildfire perimeter, then predating the fire year by more than 2 years. Some fast disturbances meeting these criteria occurred within ADS mapped areas for insects. Visual inspection with high-resolution aerial imagery showed that most of these disturbances were from timber harvesting, likely related to insect damage salvage.

Wildfire—Fast or slow (duration >4 years) disturbances inside a mapped wildfire perimeter, but only when no other disturbance preceded the fire year. Slow disturbances inside wildfire perimeters likely represent postfire mortality.

Insect and disease—Slow-duration disturbances that occurred outside of wildfire perimeters, or if inside a wildfire perimeter, preceded the fire year. Also includes fast disturbances that occurred in ADS maps of insects, where mapped for 2 or more consecutive years.

Other disturbance —Fast disturbances that occurred on CRAW lands and outside of wildfire perimeters, or if inside fire perimeters, then preceded fire year.

All disturbance maps were produced at a minimum mapping unit of 11 map pixels (30-m resolution). This equates to about 2.5 ac as the minimum patch size for a disturbance. This removes some "noise" from the satellite imagery, but there is still some amount of uncertainty with our classification. Our highest confidence is for the wildfire classification, which is largely corroborated with mapped fire perimeters acquired from various sources (e.g., GEOMAC 2012, MTBS 2012). We also have harvest unit maps for much of the federal (but not all) landscape, but lack these data for nonfederal lands. We suspect that some of the "harvest" class includes fast disturbances related to nontimber harvesting causes (e.g., urbanization, landslides, blowdown, floods, etc.). This is likely more the case on nonfederal lands. To get a general sense for the accuracy of our harvest classification, we compared the amount of harvest to timber harvest records from the Forest Service and Bureau of Land Management (fig. D-1). Overall, LandTrendr estimated 8,955 MBF (thousand board feet), compared to agency records of 8,064 MBF for the 17-year period 1995–2011.

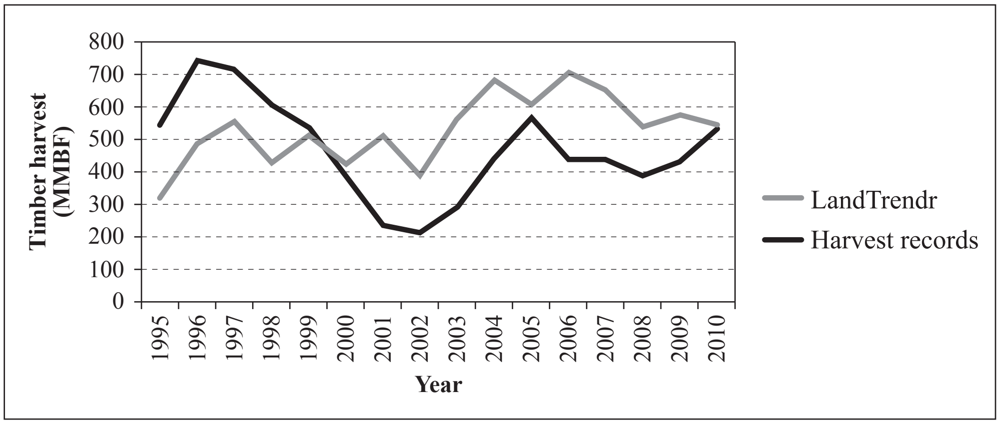


Figure D-1—Comparison between LandTrendr timber harvest estimate and agency records from the Forest Service and Bureau of Land Management within the Northwest Forest Plan area. LandTrendr magnitude was converted into MMBF using the following assumption: low (0 to 33 percent) = 10 MBF/ac, mod (33 to 66 percent) = 20 MBF/ac, high (66 to 100 percent) = 30 MBF/ac.

Table D-1—Classification table for LandTrendr cause agents

All possible map overlay combinations	First classification	Final classification[a]
slow - outside of CRAW - outside of fire	Insect and disease	Insect and disease
slow - inside of CRAW - outside of fire	Insect and disease	Insect and disease
slow - outside of CRAW - outside of fire - in ADS	Insect and disease	Insect and disease
fast - inside of CRAW - outside of fire - in ADS	Insect and disease	Insect and disease
slow - inside of CRAW - outside of fire - in ADS	Insect and disease	Insect and disease
slow - outside of CRAW - inside of fire - prefire	Insect and disease then wildfire	Insect and disease
slow - inside of CRAW - inside of fire - prefire	Insect and disease then wildfire	Insect and disease
slow - outside of CRAW - inside of fire - in ADS - prefire	Insect and disease then wildfire	Insect and disease
fast - inside of CRAW - inside of fire - in ADS - prefire	Insect and disease then wildfire	Insect and disease
slow - inside of CRAW - inside of fire - in ADS - prefire	Insect and disease then wildfire	Insect and disease
fast - inside of CRAW - outside of fire	Other disturbance	Other disturbance
fast - inside of CRAW - inside of fire - prefire	Other disturbance then wildfire	Other disturbance
fast - outside of CRAW - outside of fire	Timber harvest	Timber harvest
fast - outside of CRAW - outside of fire - in ADS	Insect–possible harvest	Timber harvest
fast - outside of CRAW - inside of fire - prefire	Timber harvest then wildfire	Timber harvest
fast - outside of CRAW - inside of fire - in ADS - prefire	Insect or harvest then wildfire	Timber harvest
fast - outside of CRAW - inside of fire	Wildfire	Wildfire
slow - outside of CRAW - inside of fire	Wildfire	Wildfire
fast - inside of CRAW - inside of fire	Wildfire	Wildfire
slow - inside of CRAW - inside of fire	Wildfire	Wildfire
fast - outside of CRAW - inside of fire - in ADS	Wildfire	Wildfire
slow - outside of CRAW - inside of fire - in ADS	Wildfire	Wildfire
fast - inside of CRAW - inside of fire - in ADS	Wildfire	Wildfire
slow - inside of CRAW - inside of fire - in ADS	Wildfire	Wildfire

[a] General classes used for monitoring reporting. Final classifications reviewed visually with high-resolution color aerial imagery.

Accuracy Assessment:

The following accuracy matrices are based on TimeSync (TS) analyses of the LandTrendr (LT) disturbance map.

	TS DISTURB	TS NOT DISTURB	
LT DISTURB	556	817	1,373
LT NOT DISTURB	174	32,019	32,193
	730	32,836	33,566

Overall accuracy was 97 percent, Kappa = 0.52

	LT INSECT/ DISEASE	LT FIRE	LT HARVEST	LT OTHER	
TS INSECT/DISEASE	2	0	1	0	3
TS FIRE	0	38	1	0	39
TS HARVEST	1	1	124	1	127
TS OTHER	2	0	5	0	7
	5	39	131	1	186

Overall accuracy was 93 percent, Kappa = 0.84

References:

Monitoring Trends in Burn Severity [MTBS]. 2012. Data accessible through the Forest Service's Remote Sensing Applications Center (RSAC). http://www.mtbs.gov/compositfire/mosaic/bin-release/burnedarea.html. (2 February 2014).

Geospatial Multi-Agency Coordination Group [GeoMAC]. 2012. An internet-based mapping application originally designed for fire managers to access online maps of current fire locations and perimeters in the conterminous 48 states. http://rmgsc.cr.usgs.gov/outgoing/GeoMAC/. (2 February 2014).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2011. Forest health protection aerial survey data. http://www.fs.fed.us/r6/nr/fid/as/index.shtml. (4 January 2011).

Appendix E: Gradient Nearest Neighbor (GNN) Older Forest Map Accuracy Report

A large suite of diagnostics detailing GNN model reliability and map accuracy is produced as a standard part of GNN modeling, and a report is provided with all data downloads. For local- (plot-) scale accuracy assessment, we used a modified leave-one-out cross-validation for all plots used in the model (Ohmann and Gregory 2002). Predicted map values for vegetation attributes at plot locations were compared to the field-measured values. For evaluation of the bookend models, the predicted value was from the bookend model date closest to the year of plot measurement. Because none of the plot inventories provide a valid, representative sample of forest conditions across all ownerships at either of the bookend dates, it was not possible to assess the accuracy of each bookend model independently. Rather, the cross-validation provides a general indication of the reliability of both bookend models.

To quantify old-forest map accuracy for this report, we summarized the cross-validation data (predicted-observed pairs) by GNN model region (fig. E-1). For each bookend map, we compared plot-observed old-forest classification to independent GNN prediction at the plot's location and constructed a binary error matrix of observed (plot) and predicted (mapped) late-successional and old-growth (LSOG) designations to derive several map diagnostics (tables E-1 and E-2).

Map accuracy as a percentage correct is the percentage of plots where the observed and predicted agree (either LSOG present or LSOG absent). Sensitivity is based on the percentage of field plots where the map correctly predicted LSOG presence, and specificity is the percentage of plots where the map correctly predicted LSOG absence. The kappa statistic takes into account the agreement occurring by chance (Cohen 1960) but still is not independent of prevalence (Kappas tend to be lower where LSOG comprises a smaller percentage of the forest landscape). The assessment of "overall map agreement" in tables E-1 and E-2 is a subjective classification of Kappa by Landis and Koch (1977).

Overall, the bookend maps had fair to moderate agreement with the plot data. The bookend 2 (2012) map was slightly more accurate than bookend 1 (1993). Drier model regions (MR 222 and MR 226) had lower map accuracies than moister model regions.

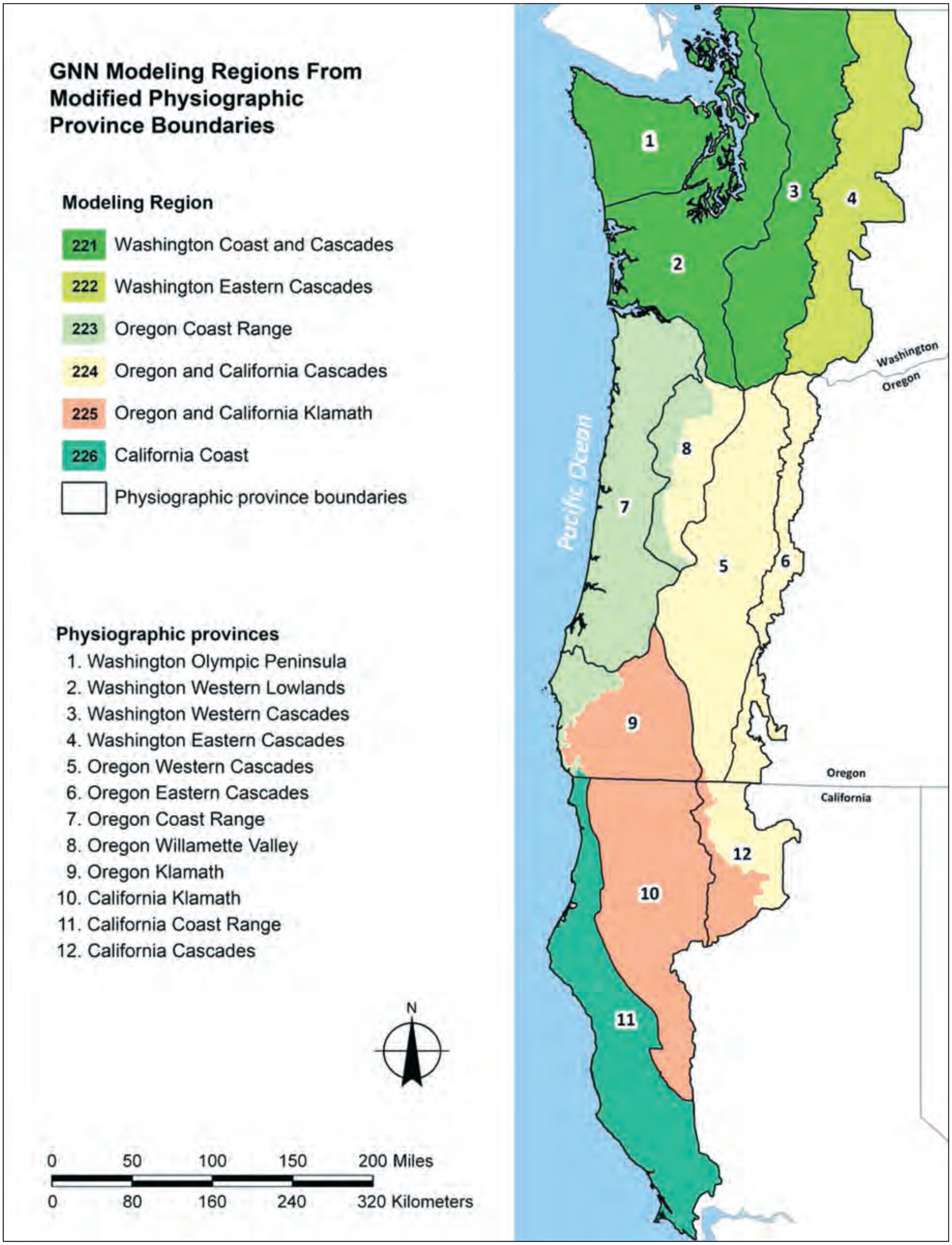


Figure E-1—Gradient Nearest Neighbor (GNN) modeling regions shown in color (from Moeur et al. 2011).

Table E-1—Map versus plot accuracy statistics for bookend map 1 (1993)

Model region	Old-forest definition	Number of plots	Prevalence	Percent correct	Sensitivity	Specificity	Kappa	Overall map agreement
221	OGSI 80	2937	0.41	78.6	0.73	0.83	0.56	Moderate
221	OGSI 200	2937	0.24	82.4	0.61	0.89	0.51	Moderate
222	OGSI 80	2650	0.47	63.7	0.62	0.65	0.27	Fair
222	OGSI 200	2650	0.16	80.8	0.36	0.89	0.26	Fair
223	OGSI 80	2024	0.34	80.4	0.67	0.87	0.55	Moderate
223	OGSI 200	2024	0.16	88.9	0.61	0.94	0.57	Moderate
224	OGSI 80	5124	0.49	71.7	0.71	0.72	0.43	Moderate
224	OGSI 200	5124	0.22	79.5	0.50	0.88	0.39	Fair
225	OGSI 80	3703	0.52	72.0	0.74	0.70	0.44	Moderate
225	OGSI 200	3703	0.20	80.0	0.40	0.90	0.32	Fair
226	OGSI 80	975	0.40	63.8	0.53	0.71	0.24	Fair
226	OGSI 200	975	0.11	88.8	0.36	0.95	0.34	Fair

OGSI = old-growth structure index.

Table E-2—Map versus plot accuracy statistics for bookend map 2 (2012)

Model region	Old-forest definition	Number of plots	Prevalence	Percentage correct	Sensitivity	Specificity	Kappa	Overall map agreement
221	OGSI 80	2937	0.42	78.2	0.73	0.82	0.55	Moderate
221	OGSI 200	2937	0.25	82.6	0.63	0.89	0.53	Moderate
222	OGSI 80	2650	0.46	64.3	0.62	0.66	0.28	Fair
222	OGSI 200	2650	0.16	80.5	0.37	0.89	0.27	Fair
223	OGSI 80	2024	0.34	80.2	0.67	0.87	0.55	Moderate
223	OGSI 200	2024	0.17	88.6	0.61	0.94	0.58	Moderate
224	OGSI 80	5124	0.49	71.7	0.71	0.72	0.43	Moderate
224	OGSI 200	5124	0.22	79.9	0.51	0.88	0.40	Moderate
225	OGSI 80	3703	0.51	72.3	0.74	0.71	0.45	Moderate
225	OGSI 200	3703	0.20	79.3	0.40	0.89	0.31	Fair
226	OGSI 80	975	0.40	64.9	0.54	0.72	0.27	Fair
226	OGSI 200	975	0.10	88.9	0.33	0.95	0.34	Fair

References:

Cohen, J. 1960. A coefficient of agreement for nominal scales. Educational and Psychological Measurement. 20: 37–46.

Landis, J.R.; Koch, G.G. 1977. The measurement of observer agreement for categorical data. Biometrics. 33: 159–174.

Moeur, M.; Ohmann, J.L.; Kennedy, R.E.; Cohen, W.B.; Gregory, M.J.; Yang, Z.; Roberts, H.M.; Spies, T.A.; Fiorella, M. 2011. Northwest Forest Plan–status and trends of late-successional and old-growth forests from 1994 to 2007. Gen. Tech. Rep. PNW-GTR-853. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

Appendix F: Older Forest Summaries by Federal Land Ownerships

The following summaries cover the Northwest Forest Plan (NWFP or the Plan) area by major land management agency (region and state) for the time period between 1993 and 2012. These trend lines are based on annual time series maps produced for NWFP monitoring. Individual federal unit (e.g., forest or Bureau of Land Management [BLM] district) summary sheets can be downloaded from the NWFP Interagency Monitoring website at: http://www.reo.gov/monitoring/.

Trend lines for two different older forest definitions are provided:

- OGSI-80–old-growth structure index threshold of ≥80 years average stand age.
- OGSI-200–old-growth structure index threshold of ≥200 years average stand age.

Summary sheets are interpreted as follows:

- Top graph (a) shows older forest trends on all federal lands, showing beginning and end period areal estimates and net percentage change in parenthesis.
- The two middle graphs show older forest trends for the same area, but partitioned into nonreserved (b) and reserved (c) land use allocations.
- The bottom graphs (d) and (e) describe landscape pattern changes in old forest over the last 20 years since the Plan's implementation. OGSI-80 graphs for nonreserved and reserved land use allocations (LUAs) on the left (d), and OGSI-200 graphs on the right (e). Core and core edge represent intact stands of old forest; whereas, fingers and scatter represent fragmented old forest. A decrease in core and core edge and increase in fingers and scatter represents an increase in landscape fragmentation.

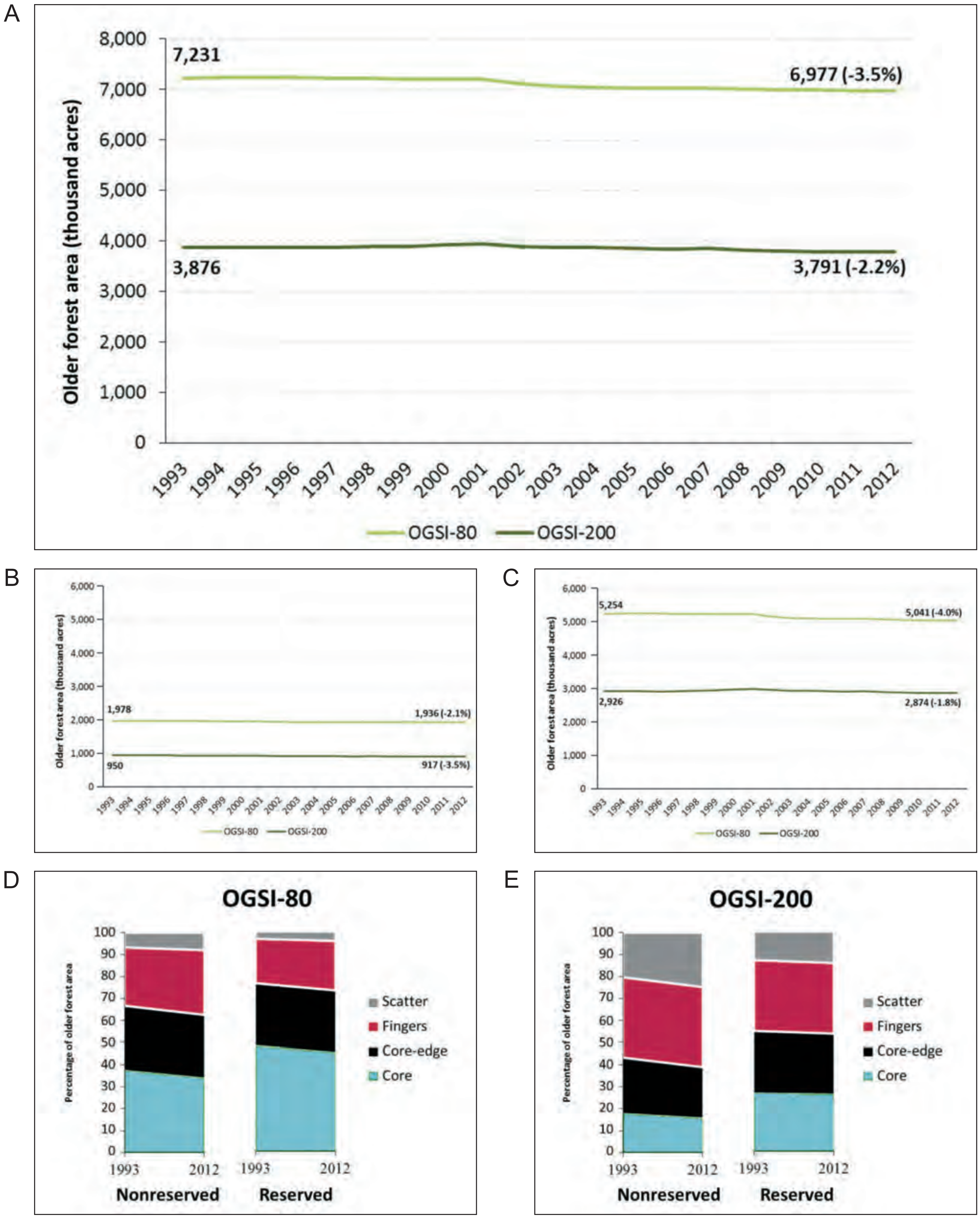


Figure F-1—Older forest trends summary for U.S. Department of Agriculture Forest Service, Pacific Northwest Region. OGSI = old-growth structure index at the 80- and 200-year threshold. NWFP = Northwest Forest Plan Area.

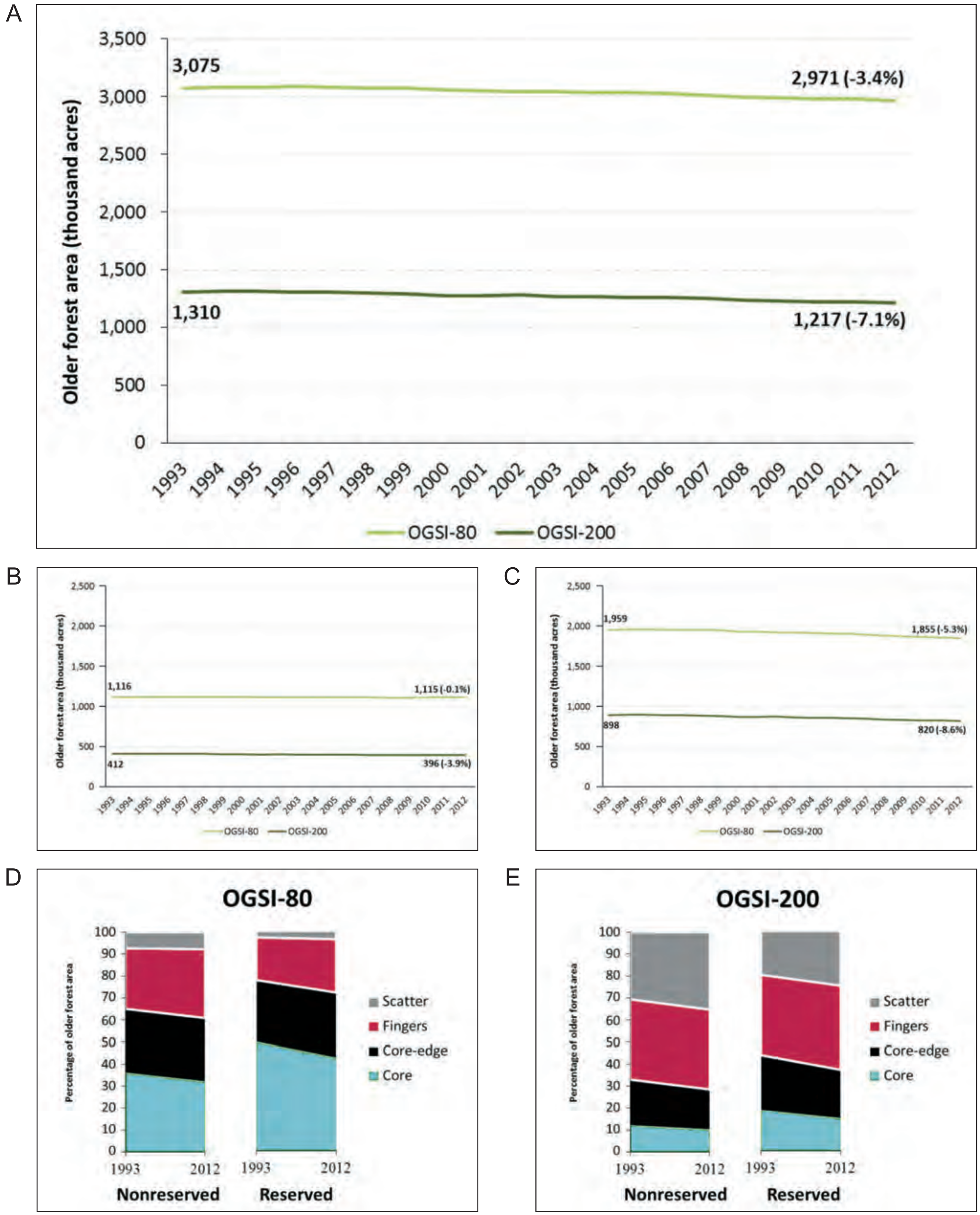


Figure F-2—Older forest trends summary for U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. OGSI = old-growth structure index at the 80- and 200-year threshold.

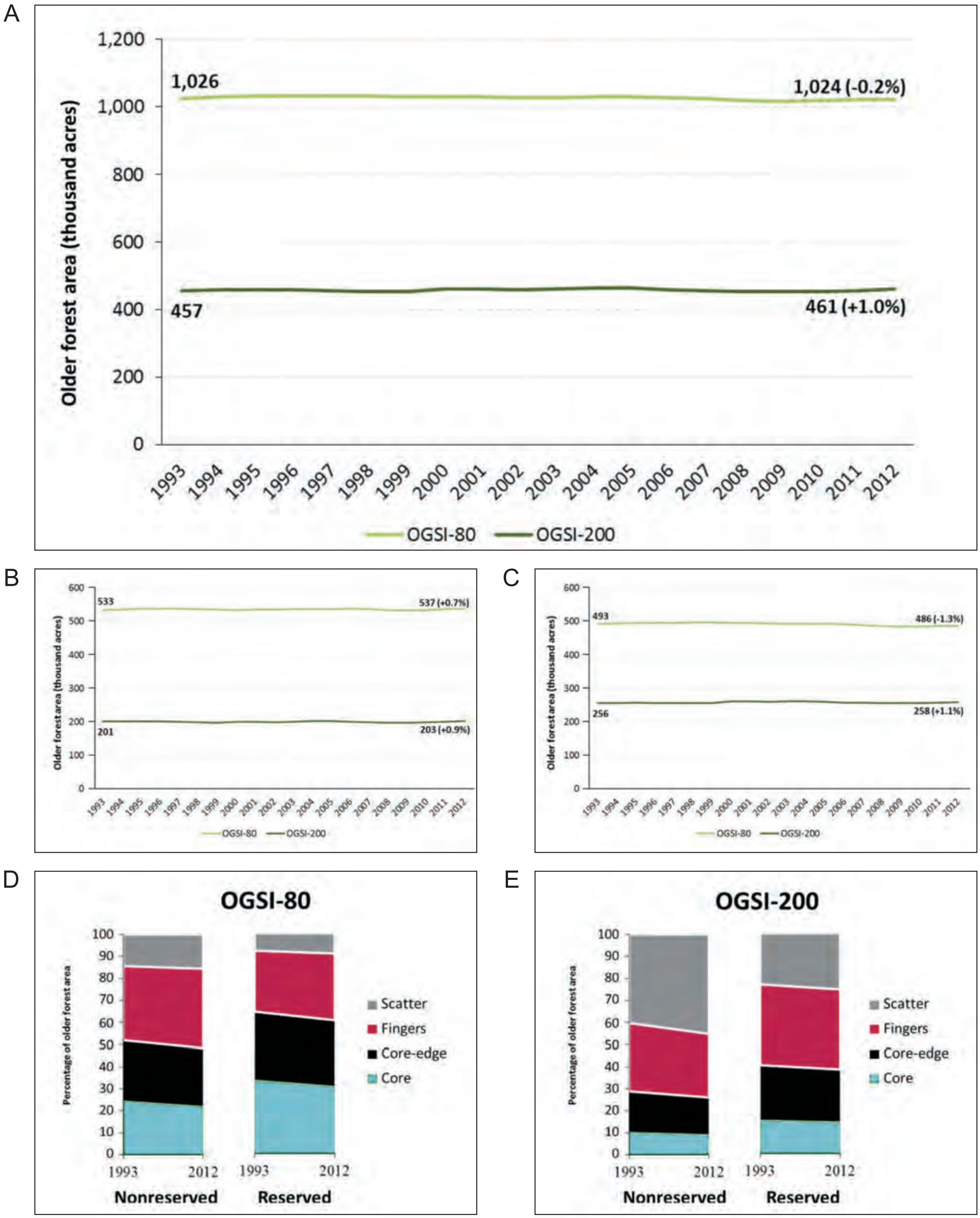


Figure F-3—Older forest trends summary for U.S. Department of the Interior, Bureau of Land Management, Oregon. OGSI = old-growth structure index at the 80- and 200-year threshold. NWFP = Northwest Forest Plan Area.

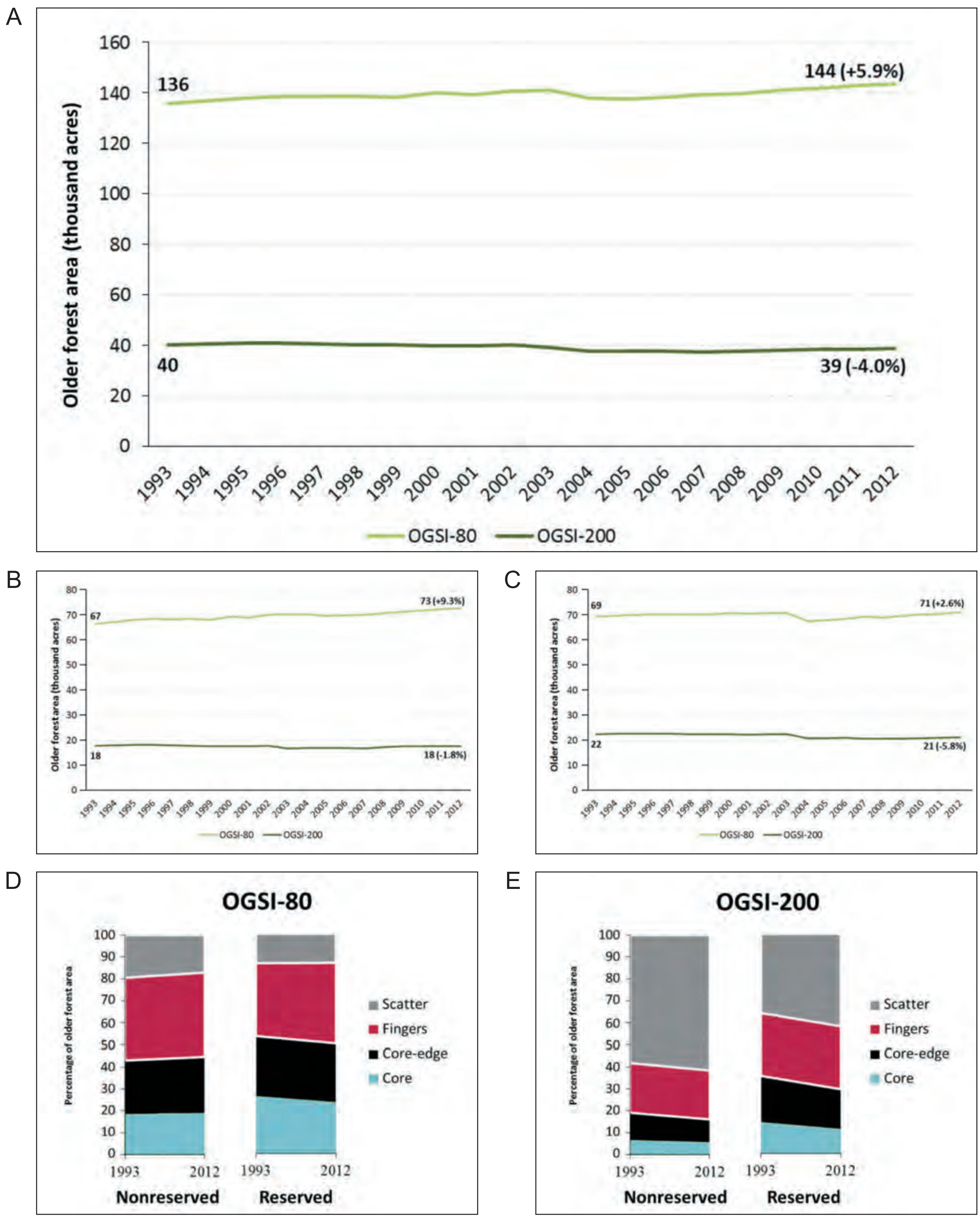


Figure F-4—Older forest trends summary for U.S. Department of the Interior, Bureau of Land Management, Northern California. OGSI = old-growth structure index at the 80- and 200-year threshold. NWFP = Northwest Forest Plan Area.

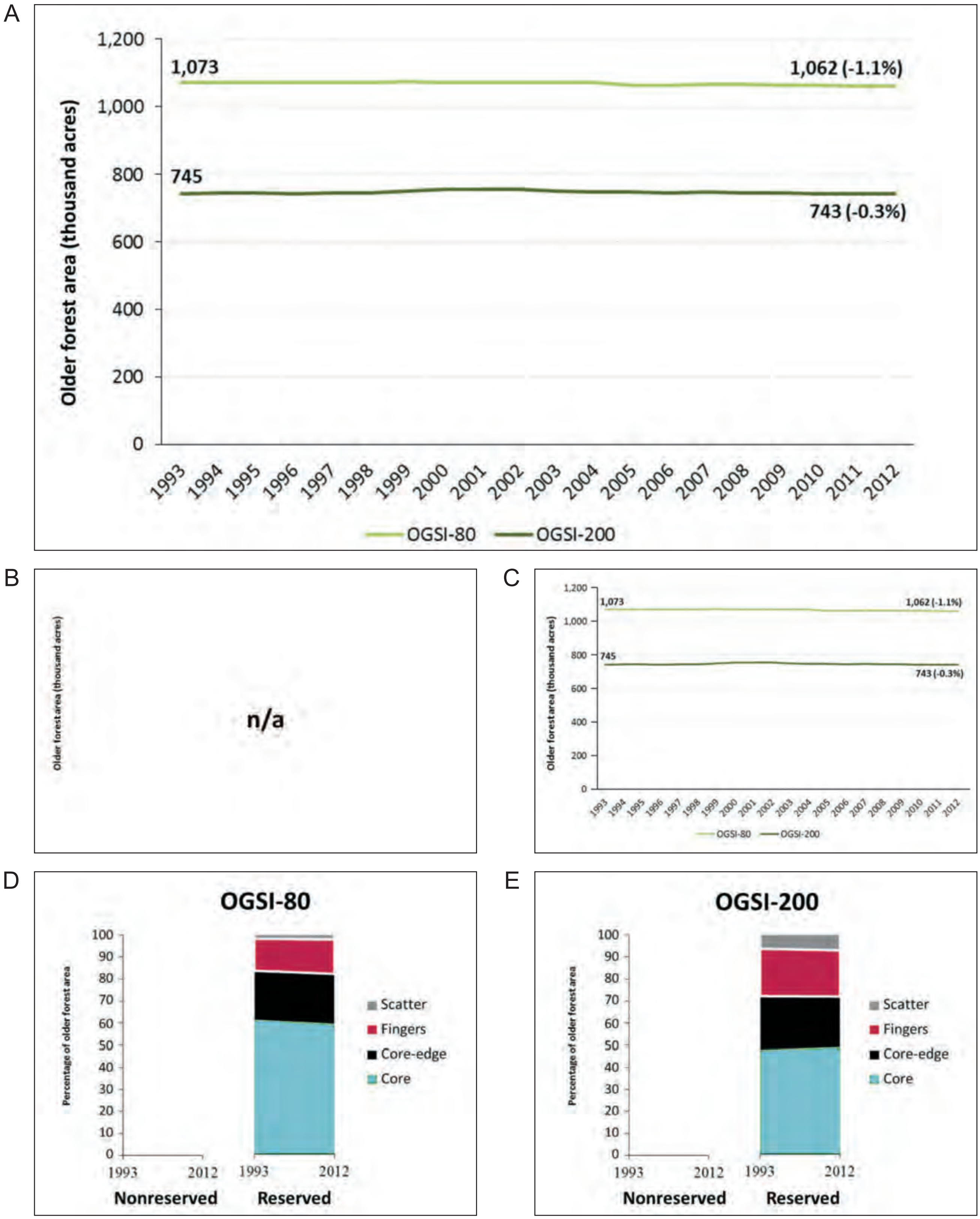


Figure F-5—Older forest trends summary for U.S. Department of the Interior, National Park Service. OGSI = old-growth structure index at the 80- and 200-year threshold. NWFP = Northwest Forest Plan Area. n/a = not applicable.

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