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Northwest Forest Plan—The First 25 Years (1994–2018): Status and Trends of Late-Successional and Old-Growth Forests

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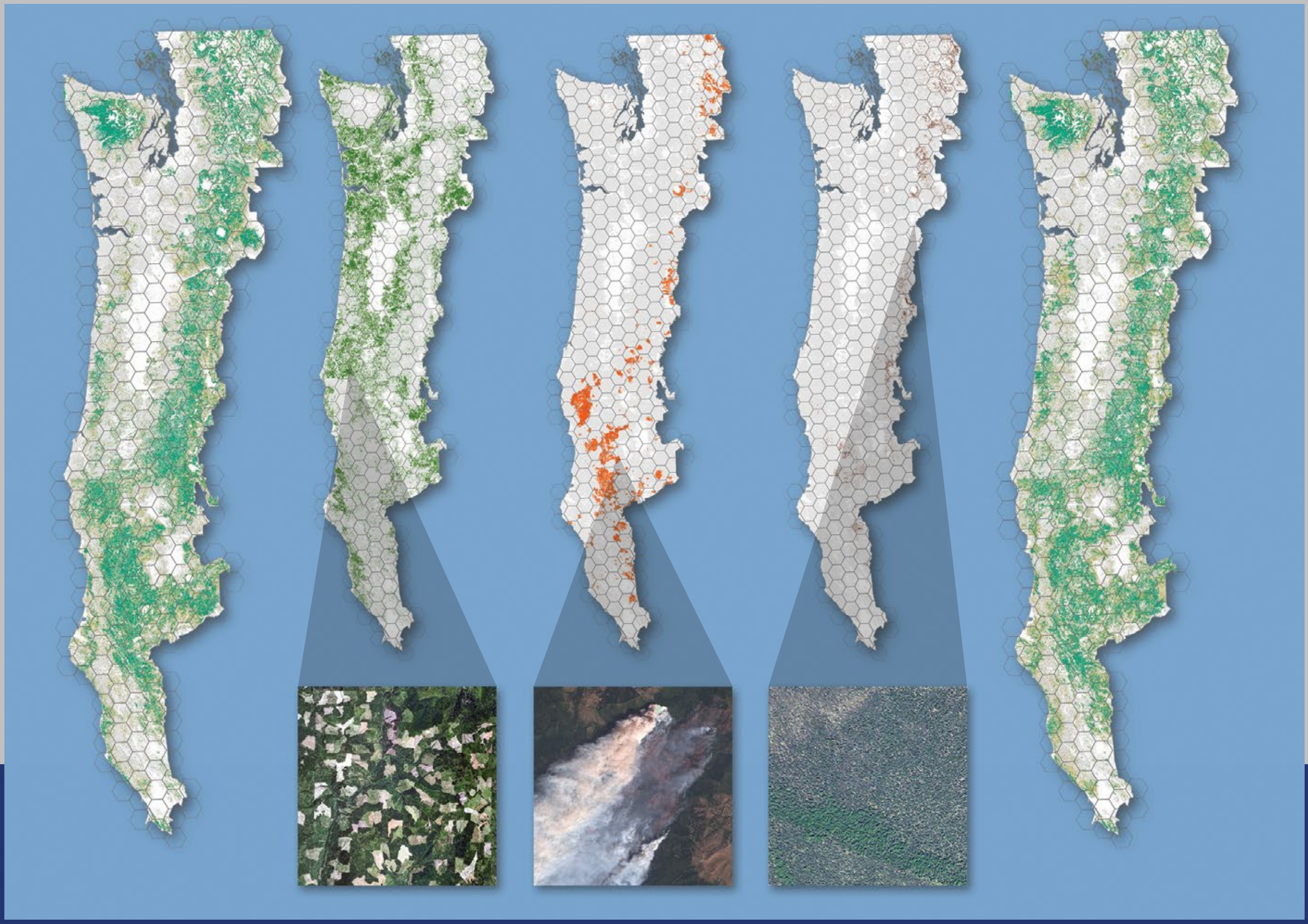

NORTHWEST FOREST PLAN
THE FIRST 25 YEARS (1994–2018)

Authors

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Cover: Older forest patterns as they looked in 1993 (left) and 2017 (right) after 25 years of forest growth and disturbance from timber harvest (middle left), wildfires (center), and insects and disease (middle right). By Raymond J. Davis.

Abstract

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This is the fourth in a series of periodic monitoring reports on the status and trends of late-successional and old-growth (LSOG) forests since the implementation of the Northwest Forest Plan (NWFP) in 1994. The objective of this monitoring is to evaluate the success of the plan in reaching its desired amount and distribution of LSOG forest on federal lands within the range of the northern spotted owl (*Strix occidentalis caurina*) in the United States. We began our assessment in the years shortly preceding the NWFP, but primarily focused on how LSOG forests have changed as a result of disturbance and forest succession since 1993, the year of the assessment that led to the implementation of the NWFP. We developed an annual time series (1986–2017) of LSOG maps based on an "old-growth structure index" (OGSI) using two age thresholds: ≥80 and ≥200 years. These ages represent when forests commonly attain stand structure associated with late-successional forests (OGSI 80) and old-growth forests (OGSI 200) in this region.

Maps showed a slightly increasing trend in LSOG forests (OGSI 80) on federal lands with a 0.3-percent net gain between 1993 and 2017. Forest Inventory and Analysis plot data from two measurement/remeasurement periods (2000s and 2010s) were used to corroborate mapped estimates. For OGSI 80 and OGSI 200 forests, we estimated gross losses from wildfire at 6.2 and 6.9 percent, respectively; timber harvest losses at 1.9 and 2 percent, respectively; and loss from insects or other causes at 0.7 and 0.9 percent, respectively. This indicates that, at the NWFP scale, processes of forest succession compensated for losses. The NWFP anticipated a continued decline in LSOG forests for the first few decades until the rate of forest succession exceeds the rate of losses. Decadal gross losses of about 5 percent per decade from timber harvesting and wildfire (combined) were expected. Over the extent of the NWFP, observed losses from wildfire generally met expectations, but losses from timber harvesting were about one-third of what was anticipated. Results were consistent with expectations for OGSI 80 abundance, diversity, and connectivity outcomes for this period of time. For OGSI 200, these outcomes were slightly degraded. Given that we are only one quarter into a 100-year plan, nothing in these findings suggests that desired outcomes are unattainable over the next 75 years. However, observed increases in frequency and extent of large wildfires, and expected additional increases owing to climate change, provide reasons for concern.

Keywords: Northwest Forest Plan, effectiveness monitoring, late-successional and old-growth forests, old-growth structure index, Gradient Nearest Neighbor imputation, GNN, Landscape Change and Monitoring System, LCMS, Forest Service, Bureau of Land Management, late-successional reserves, physiographic provinces.

Preface

Monitoring late-successional and old-growth forests within the Northwest Forest Plan (NWFP) area was approved by an Intergovernmental Advisory Committee. The monitoring program 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 and follows protocols and guidance in the "Late-Successional and Old-Growth Forest Effectiveness Monitoring Plan for the Northwest Forest Plan," published in 1998. The interagency effectiveness monitoring framework was implemented to meet requirements for tracking the status and trends of older 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 in 1- to 5-year intervals, and results are documented in a series of technical reports. This report, and the others in the current series, covers the first 25 years of the NWFP.

Contents

Introduction

The Northwest Forest Plan (NWFP) amended 19 U.S. Department of Agriculture, Forest Service forest management plans and 7 U.S. Department of the Interior, Bureau of Land Management (BLM) resource management plans in western Washington and Oregon, northwestern California, and the Forest Service's Pacific Northwest and Pacific Southwest 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 NWFP 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). This report is the fourth in the series of LSOG monitoring reports outlined by the interagency monitoring plan (Hemstrom et al. 1998); it covers the time period from 1986 to 2017, but primarily focuses on the time since the NWFP was designed in 1993. As was done in previous monitoring reports (Davis et al. 2015; Moeur et al. 2005, 2011), the term "older forest" is used here 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. The following summarizes the assessment of older forests for federally administered forest lands ("federal lands") affected by the NWFP. Information on other ownerships ("nonfederal lands") was provided for context. Because of updates in information sources and improvements in analytical techniques, the results in this report supersede and are not directly comparable to those in previous reports.

The goal of LSOG monitoring is to evaluate the success of the NWFP in achieving the desired amount and spatial 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 inter-stand distances across the NWFP landscape?
- How did these things change as a result of disturbance and forest succession starting with the year of the NWFP analyses in 1993?

This 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 more than 50 million ac, with about half managed by the federal government. A cost-effective way to map forest conditions across such large areas is to integrate periodically collected forest inventory plot data with satellite remote sensing data that is compiled annually. The plot data provide area estimates and enable monitoring of stand-level changes that satellites cannot see. The remotely sensed maps allow us to monitor amounts and spatial patterns across broad landscapes on an annual basis. Together, remotely sensed maps corroborated with plot-based estimates increase our confidence in observed trends and patterns in older forests over time.

NWFP Expectations

At its implementation, the NWFP anticipated that the rate of loss of older forests on federally managed lands that had been observed in prior decades would diminish, stabilize, and eventually 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 5 to 10 decades to restore the amount of older forest on federal lands 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 FS and USDI BLM 1994: chapters 3 and 4: 36–46).

General goals for abundance, diversity, and connectivity of older forest were described by the Forest Ecosystem Management Assessment Team (FEMAT 1993), the NWFP (USDA FS and USDI BLM 1994: chapters 3 and 4: 36–46), and refined into "measurable outcomes" by Hemstrom et al. (1998: 19–21). Measurable outcomes were based on long-term averages, defined as a period of at least 200 to 1,000 years, over which the full potential range of older forest communities could develop after a severe disturbance. It was estimated that 60 to 70 percent of the forested area under the NWFP was typically covered by older forests (higher proportions in moister forests and lower in drier forests). It was also estimated that the average centurial low (average of the lows that occur in 100-year periods) was 40 percent, setting the lower limit of the "typical" range for older forest coverage (FEMAT 1993). These outcome thresholds were based on the understanding of long-term reference conditions when the NWFP was designed (1993); we acknowledge that they might need to be adjusted as the climate changes and our scientific understanding of forest ecology in this region evolves.

At the start of the NWFP, much of the federal forest landscape did not meet these conditions for old-growth forests. The monitoring conducted here allowed us to evaluate whether the NWFP has yet met these expected outcomes. The overall expectation in 1993 (based on expert opinions) was that the NWFP had a 77-percent likelihood of achieving desired outcomes in moister forest provinces, and a 63-percent likelihood in drier provinces (FEMAT 1993). Hemstrom et al. (1998) cautioned that it would take many decades of older forest development to achieve these outcomes.

Data Sources and Methods

Many, but not all, of the data sources used in this report were initially developed and used in previous monitoring reports. During each 5-year monitoring cycle, data sources are updated to incorporate new research findings and other information, or to correct errors. Although more detailed descriptions of these data sources can be found in previous monitoring reports (Davis et al. 2011, 2015; 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 is based on the geographic range of the northern spotted owl in the United States. It was divided into 12 physiographic provinces for analytical purposes (FEMAT 1993, Thomas et al. 1990, USDA FS and USDI BLM 1994). Physiographic provinces were delineated 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 used the same physiographic provinces that have been used since the 15-year report (Moeur et al. 2011).

Forest Vegetation Zones

Similar to physiographic provinces, potential forest vegetation zones reflect the physical and climatic conditions of the area and are useful for ascribing ecological processes of forest development and disturbance, but at a finer spatial resolution. The potential vegetation zone map is a 30-m raster map developed by the Forest Service Pacific Northwest Region Ecology Program (Simpson 2019), which provided consistent coverage for all forest lands in Washington, Oregon, and California. The layer is similar to the layer used in the 20-year monitoring effort but was geographically expanded beyond the NWFP footprint for use in other broad-scale assessments. It was similarly derived from overstory and understory tree species composition and abundance (percentage of cover) information in existing Gradient Nearest Neighbor (GNN) vegetation maps developed by the Landscape Ecology, Modeling, Mapping, and Analysis group (LEMMA 2020). Although presence and percentage cover of tree species were used to infer potential forest vegetation zones, other indicator species (trees not used in vegetation zone delineation and understory species) were grouped by moisture and temperature regimes. The abundance and number of species in a group served as indicators for subzones within a vegetation zone. This delineation often indicated different disturbance regimes, rates of development after disturbance, and ultimately what type of forest would dominate in the absence of disturbance.

GNN annual time series maps from LandTrendr-normalized products (Davis et al. 2015, Kennedy et al. 2018) were used to account for species composition changes owing to recent disturbances such as fire or timber harvest. Where mapped vegetation was highly variable (indicating one or more disturbances), the higher ranked (generally more mesic) vegetation zone was assigned. Independent Ecology Program plots (ECOSHARE 2020) were used for classification assessment.

The most common forest vegetation zones within the NWFP area were low- to moderate-elevation types, such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and grand fir/white fir (*Abies grandis* (Douglas ex D. Don) Lindl. var. *grandis/A. concolor* (Gord. & Glend.) Lindl. ex Hildebr.), which accounted for about 65 percent of the forested areas (fig. 1). Higher elevation types such as Pacific silver fir (*A. amabilis* (Douglas ex Loudon) Douglas ex Forbes), mountain hemlock (*T. mertensiana* (Bong.) Carri*ère*), and subalpine accounted for about 18 percent of NWFP forests. Coastal areas are dominated by Sitka spruce (*Picea sitchensis* [Bong.]. Carrière) to the north and redwoods (*Sequoia sempervirens* (Lamb. ex D. Don) Endl.) to the south and comprised about 7 percent of the forested area. The remaining 10 percent is composed of various other vegetation zones. Broadly, the term "moist forest" used in this report refers to the western hemlock, Sitka spruce, and coastal redwood zones (fig. 1). The term "dry forest" refers to Douglas-fir, grand fir, and the pine zones (e.g., ponderosa pine [*Pinus ponderosa* Lawson & C. Lawson].).

Land Use Allocations

Land use allocations (LUAs) describe overarching forest management direction. The geographic information system (GIS) layer representing LUAs was originally delineated during the analysis for the NWFP (USDA FS and USDI BLM 1994). It has been updated prior to each monitoring cycle to account for LUA changes that occurred in the previous 5 years as well as minor editing to correct mapping errors. Updates include federal surface ownership boundary adjustments, changes in federal land ownership (e.g., land exchanges, land acquisitions and disposals), and changes due to forest resource management plan amendments or revisions. Since the previous monitoring report, BLM revised its LUAs in western Oregon (USDI Bureau of Land Management 2016a, 2016b). However, new LUAs have adopted management direction that is similar to management direction under the NWFP (fig. 2). One noteworthy change in the BLM revision is the division of its forests into areas characterized as moist (northwestern and coastal Oregon) and dry (southwestern Oregon) to recognize ecological differences between the historical fire regimes of western Oregon.

Similar to the standards and guidelines in the NWFP, BLM management direction allows for timber harvesting within late-successional reserves (LSRs) that is designed to benefit the development of late-successional conditions suited to these two different historical fire regimes. On BLM moist forests, stands (generally <80 years old) not currently providing nesting/roosting function for northern spotted owls can be treated using a variety of methods to speed the development of, or improve, northern spotted owl habitat quality in the long term. Silvicultural treatments are limited to those that do not preclude or delay by 20 years or more the development of northern spotted owl nesting-roosting habitat in the stand and in adjacent stands, as compared to development without treatment (USDI BLM 2016a: 64–67).

Management direction for dry forests includes the same management direction as for moist forests except that management direction is reflective of the more frequent, fire-driven stand and landscape dynamics. Focus is therefore on restoring resistance and resilience against fire, insects, and drought through vegetation treatments. To ensure sufficient areas were treated to meet objectives, management direction for dry forests includes a target treatment of 21,500 ac/decade (USDI BLM 2016b: 74–75).

Management under the NWFP split the forested area into two parts when it came to management direction in LSRs. West of the Cascade crest, timber harvesting is allowed in stands up to 80 years old (110 years in the Northern Coast Range Adaptive Management Area) regardless of stand origin (e.g., plantations or naturally regenerated) if it benefits the creation of, hastens the transition to, or maintains late-successional forest conditions. East of the crest and in the Oregon and California Klamath Physiographic Provinces, it allows for silvicultural activities aimed at reducing the risk of large high-severity wildfires. The focus of these treatments is to make the reserved forests in fire-prone environments less susceptible to losses from large-scale high-severity fire. Such management activities are encouraged in LSRs even if a portion of the activities must take place in late-successional forests. Such activities in older stands may also be undertaken in LSRs in other provinces if levels of fire risk are shown to be particularly high (USDA FS and USDI BLM 1994: C-12).

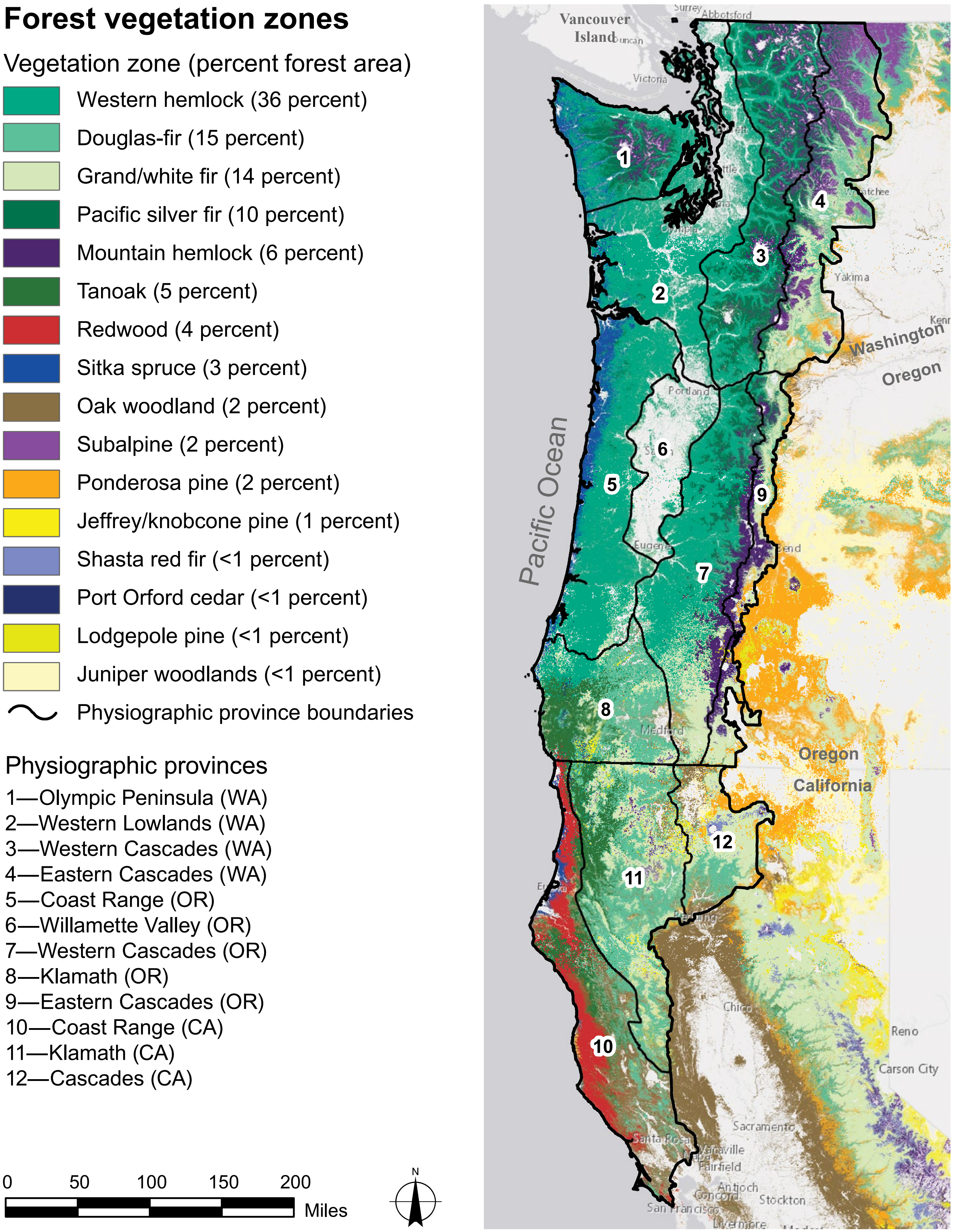

Figure 1—Potential forest vegetation zones used in deriving old-growth structure index equations. CA = California, OR = Oregon, WA = Washington.

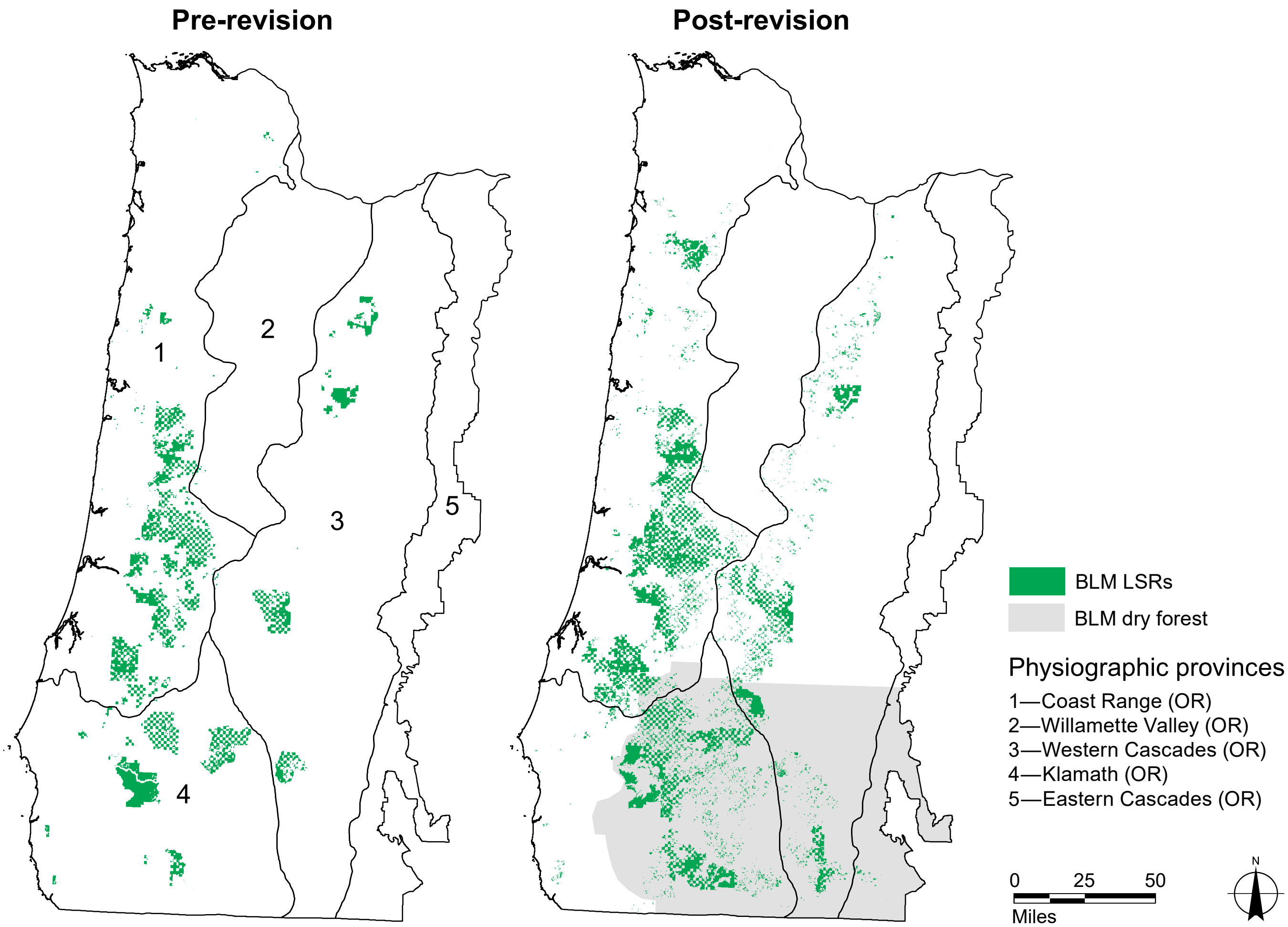

Figure 2—Revised Bureau of Land Management (BLM) late-successional reserves (LSRs) in western Oregon.

Federal 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, including:

- Congressionally reserved areas (CR)—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; this includes 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 forest on a landscape scale, where regular and frequent wildfires historically occurred. Silvicultural and fire hazard reduction treatments are allowed to help prevent older forest losses from large wildfires or disease and insect epidemics.
- Administratively withdrawn areas (AW)—areas identified in local forest and district plans, including recreation and visual retention areas, backcountry, and other areas where management emphasis does not include scheduled timber harvest.
- Adaptive management area in reserves (AMR)—areas identified to develop and test innovative management to integrate and achieve ecological, economic, and other social and community objectives. Emphasis is on restoration of late-successional forests, and they are managed as LSRs.

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

- Matrix (other)—federal lands outside of reserved allocations where most timber harvest and silvicultural activities were expected to occur.
- Adaptive management area nonreserved (AMA)—identified to develop and test innovative management to integrate and achieve ecological, economic, and other social and community objectives. Commercial timber harvest was expected to occur in these areas, testing alternative approaches to meet NWFP objectives.

This report updates the LUA layer through the end of 2017. Since NWFP implementation, there has been a slight overall increase in federal lands (1.8 percent) with an 8-percent increase in reserved LUAs (fig. 3), largely owing to new LSR designations by the BLM in western Oregon (fig. 2). We used the latest updated LUA layer to frame the status and trend analyses in this report. As in previous monitoring reports, riparian reserves, another NWFP LUA, were not delineated because they were supposed to be delineated based on site-specific analysis.

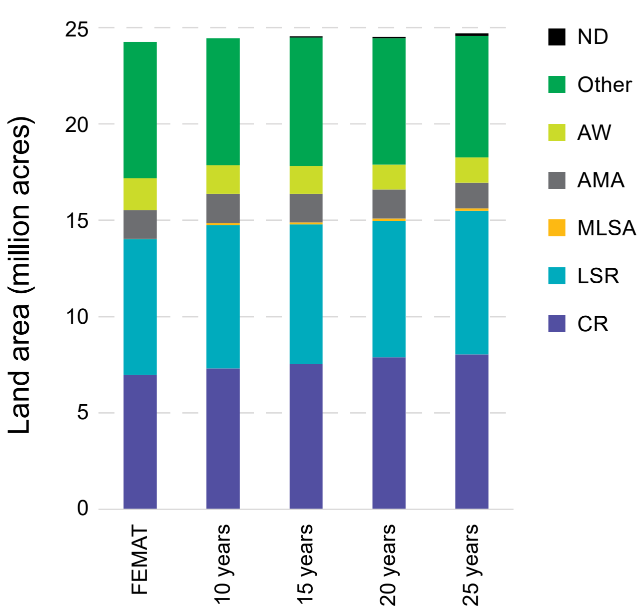

Figure 3—Land use allocation updates and change in land area through time. ND = no data, AW = administratively withdrawn, AMA = adaptive management area, MLSA = managed late-successional area, LSR = late-successional reserve, CR = Congressionally reserved, FEMAT = Forest Ecosystem Management Assessment Team (FEMAT 1993).

Old-Growth Structure Index

The old-growth structure index (OGSI) 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). The 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 (app. 5). These are elements commonly considered as key ecological and structural attributes of old-growth forests within the NWFP area and vary by vegetation zone. The index ranges from 0 to 100, where higher values indicate increasing old-growth structural characteristics. See the previous LSOG report (Davis et al. 2015: 16–18, table 5) for more details.

For NWFP monitoring purposes, we are required to identify thresholds along the OGSI gradient (fig. 4) to produce plot estimates and binary maps of older forests for analysis of abundance and distribution (0 = not older forest, 1 = older forest). We used Forest Inventory and Analysis (FIA) plot data (Burrill et al. 2018), grouped by vegetation zone from the expanded three-state mapping area, to fit nonparametric curves to the relationship between OGSI and the average age of the dominant overstory trees in a stand using locally weighted polynomial regression in R version 3.0.2. (R Core Team 2013) (app. 6). The R^2 for polynomial regressions ranged from 0.22 to 0.67 (mean = 0.41), reflecting a large degree of variation in forest structure at a given stand age. However, the consistent positive relationship between stand age and OGSI supports its use for assessing LSOG forest conditions. The first threshold we chose was based on a stand age of ≥80 years for all forest vegetation zones with the exception of the ponderosa pine zone, which was ≥120 years owing to the shape of the OGSI curve being flat until the stand age was >80 years. We called this threshold "OGSI 80" and used it to describe the point on the forest succession time scale at which young forests in the NWFP area generally begin to "mature" and start exhibiting stand structure associated with older forests (FEMAT 1993, Franklin and Johnson 2013, USDA FS and USDI BLM 1994). The second analytical threshold used in this report was called

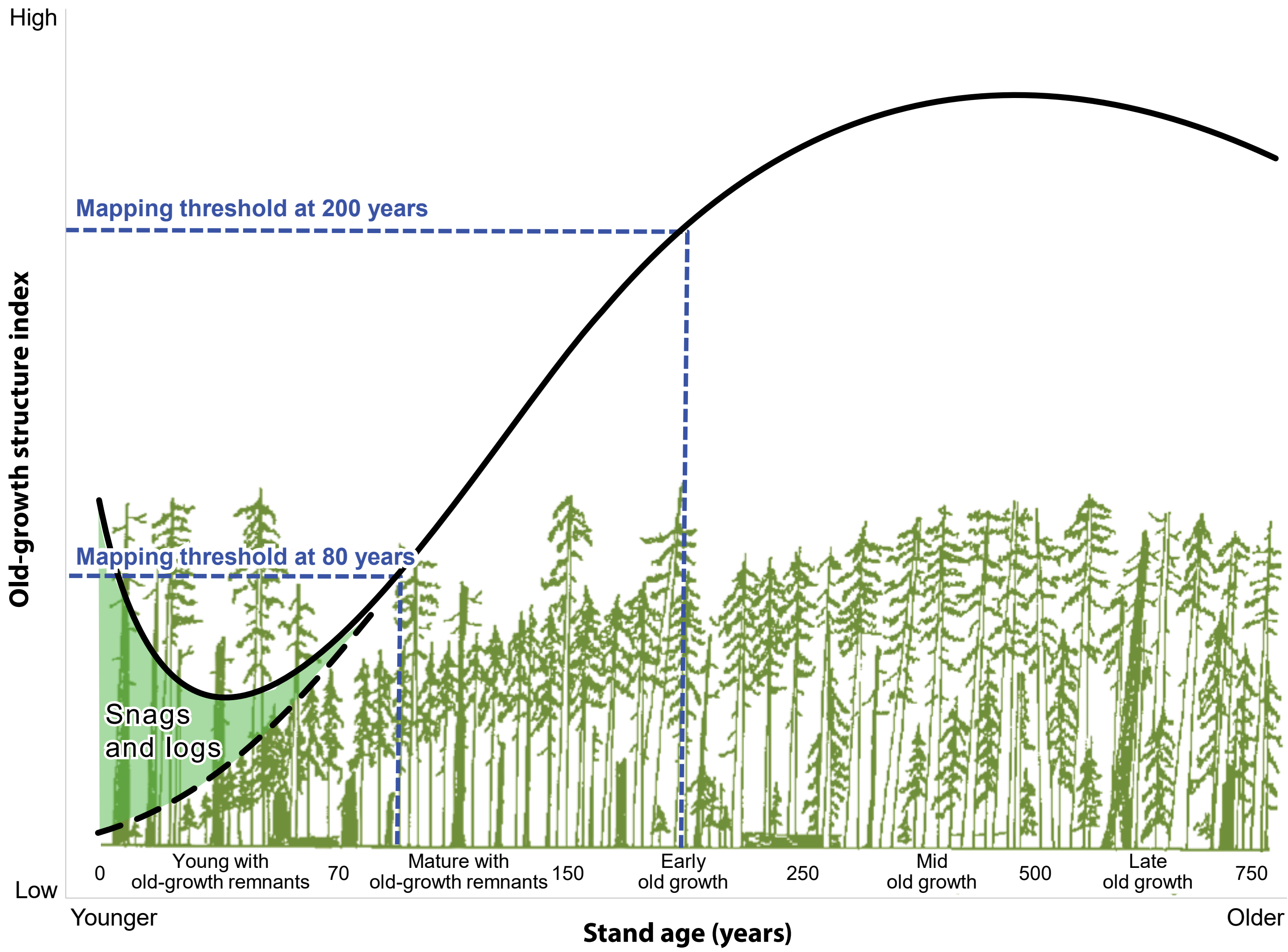

Figure 4—The old-growth structure index from Spies and Franklin (1988) is represented by the solid curved line. The dashed curve line represents the modified index curve used for mapping older forests in this report. It minimized inclusion of young forests with high structural diversity (e.g., post-wildfire snags and logs) and is focused on older forests.

"OGSI 200" and was based on a ≥200-year stand age (≥160 years for oak woodlands and lodgepole pine (*Pinus contorta* Douglas ex Loudon) due to the curves remaining flat or declining after that age threshold), which generally corresponds to the range of stand ages used to define the "old-growth" condition in this region (see Davis et al. 2015: table 5). We also produced thresholds for ≥120 and ≥160 years in table 6-1.

As discussed in the previous report (Davis et al. 2015), young forest stands with high amounts of dead wood (snags and down wood) inherited from the previous old stand can achieve an index value in the midrange of the scale (see shaded area in fig. 4). As the focus of this monitoring was to estimate amounts of older forest, not structurally complex early-seral forest, we modified the binary older forest thresholds using a live-tree qualifier to only include stands with ≥10 percent of live-tree canopy cover (the same threshold used by the FIA program to qualify a plot as "forested") 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.

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

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 (Bechtold and Patterson 2005). We used these plot data for GNN map production to estimate vegetation conditions for specific years of interest (Ohmann and Gregory 2002). We also used the plot data with standard FIA estimators for comparison against our map-based estimates.

Plot data from regionally standardized forest inventories with a single sampling design were used exclusively in this assessment. Specifically, we used plots from the FIA program as well as a regional inventory plot intensification on nonwilderness Forest Service lands, all of which employ the standard FIA plot design. This design utilizes a cluster of four circular subplots on which a variety of forest attributes are measured (Bechtold and Patterson 2005). Prior monitoring reports included data from older inventories, but differences in plot design and field protocols among inventories can affect OGSI calculations, particularly estimates of change. The FIA sample since 2001 provides a set of plots remeasured with a consistent design, making the comparison of OGSI and changes in OGSI across all land ownerships more robust (Gray et al. 2009). FIA regularly reports on the conditions of forestland in states in the NWFP area (Christensen et al. 2016; Palmer et al. 2018, 2019).

Beginning in 2001 in California and Oregon, and 2002 in Washington, the 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 (Bechtold and Patterson 2005). Except for wilderness on National Forest System (NFS) lands in the Forest Service's Pacific Northwest Region, the same FIA procedures were used on the old current vegetation survey (or "CVS") inventory grid locations on a 1.7-mile spacing (one plot per 1,850 ac). A full set of FIA plots ("cycle") is measured over a 10-year period in the West, with each year's measurements distributed uniformly across each state. Plot remeasurements began in 2011 (2012 in Washington).

For the direct plot analysis, we analyzed the subset of plots that had been installed and remeasured to get the most accurate estimate of change. For California and Oregon, this consisted of plots that were installed in 2001–2006 and remeasured in 2011–2016; for Washington, it consisted of plots that were installed in 2002–2006 and remeasured in 2012–2016. In the results, the first measurement is called "2000s" and the second measurement is called "2010s." The plot analysis therefore presents the average change over a 10-year period for plots measured in 2001–2016. During both time periods, some plot measurements predated forest disturbances, such as large wildfires, that occurred during the averaged time period. A total of 5,920 FIA plots sampled 44.8 million ac of forestland and were installed and remeasured within the NWFP area between 2001 and 2016 (table 1). Forestland is defined by FIA as areas with the potential to support ≥10-percent cover of tree species, ≥1 ac in size, ≥120 ft wide, and exclusive of areas primarily managed for a nonforest land use. The FIA inventory post-stratifies plot measurements using satellite imagery, land ownership, and other ancillary layers to improve inventory precision, using statistics for known strata weights to calculate sample error (Bechtold and Patterson 2005, MacLean 1972). To better match estimates for the NWFP boundary, we adjusted the plot expansion factors to match the total acres in each federal ownership, as delineated in the LUA layer.

The FIA dataset compiled for this report differs somewhat from that used in the previous report. The previous report only used the base FIA grid without the NFS Pacific Northwest Region spatial intensification plots, and only the initial installation data (2001–2011) were available. The previous report included very large trees measured on a hectare surrounding the FIA plot on NFS and BLM lands; because those trees were not included in the remeasurement protocols, they were excluded from the current analysis. The previous report used down wood measured on longer transects (for a total of 472 ft/plot); because transects were shortened to reduce expense during remeasurement (for a total of 192 ft/plot), data from the earlier measurements were subset to ensure equal transect length samples between measurement periods.

Forest Mask

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 (a.k.a. forest capable). It was developed for the 15-year monitoring

Table 1—Distribution and forested area sampled by forest inventory plots used for the plot-based assessment of older forest change

State and physiographic province	Number of plots	Forested area	SE
		Thousand acres	
Washington:			
Olympic Peninsula	313	2,785	141
Western Lowlands	332	3,844	171
Western Cascades	749	5,163	166
Eastern Cascades	686	4,700	167
Total	2,080	16,492	214
Oregon:			
Coast Range	602	5,068	165
Willamette Valley	58	505	66
Western Cascades	1,208	6,151	161
Klamath	516	3,374	141
Eastern Cascades	451	2,227	107
Total	2,835	17,324	183
California:			
Coast Range	303	3,348	164
Klamath	525	5,608	211
Cascades	177	1,982	141
Total	1,005	10,938	270
Northwest Forest Plan total	5,920	44,754	390

SE = standard error.

report (Davis et al. 2011) and is largely based on the U.S. Geological Survey Gap Analysis Program and the “impervious layer” from the National Land Cover Database (Herold et al. 2003, Vogelmann et al. 2001). It attempts to exclude urbanized areas, major roads, agricultural areas, water, lands above tree line, snow, rock, and other nonforested features.

Forest Disturbance Maps

Annual forest disturbance maps for forest-capable lands from 1986 to 2017 were produced by the Laboratory for Applications of Remote Sensing in Ecology using ensemble LandTrendr methodology described in Cohen et al. (2018). These maps are part of a larger national dataset produced by the Landscape Change Monitoring System (LCMS), updating, and replacing the maps used in the NWFP 20-year monitoring report (Davis et al. 2015).

These maps show the year, magnitude, duration, and cause of historical fires, harvest, and other disturbances. They represent an evolution in the use of Landsat satellite data (available since 1972) in NWFP monitoring. Kennedy et al. (2012) improved upon earlier maps of regional disturbance (Healey et al. 2008) by using a time series analysis built into an algorithm called LandTrendr to allow detection of more subtle disturbances. Here, the current maps take advantage of a finding that an ensemble of LandTrendr maps, each operating on a different spectral band of forest surface reflectance, greatly increases change detection sensitivity and accuracy (Cohen et al. 2018, Healey et al. 2018). This process, detailed below, can cut both omission (false negatives) and commission (false positives) error in half (Healey et al. 2018).

The mapping method has four components: (1) preprocessing; (2) LandTrendr segmentation; (3) ensemble classification; and (4) postprocess enhancements, including labeling cause of change. The mapping process was carried out in Google Earth Engine™ (GEE)[1] (Gorelick et al. 2017), a cloud-based platform that provides easy access to the Landsat archive, a programming interface, and massively parallel computing power. Images were atmospherically corrected to surface reflectance using the Landsat Ecosystem Disturbance Adaptive Processing System methodology (Masek et al. 2008). A medoid composite image was developed for each year using the cloud-free

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

pixel values that were acquired between June 1 and September 30; clouds and cloud shadows were screened using the f-mask method (Zhu and Woodcock 2012).

We submitted each Landsat reflectance band, plus common indices such as the normalized burn ratio (NBR), to LandTrendr for temporal segmentation in GEE. The GEE implementation of LandTrendr has been shown to be comparable to earlier versions used in previous NWFP monitoring efforts (Kennedy et al. 2018). Modeling details are described by Cohen et al. (2018).

The ensemble model method chosen for integrating the many LandTrendr outputs was "stacking" (Healey et al. 2018, Wolpert 1992), a process where a reference dataset allows a secondary model to integrate the outputs of several different algorithms (or "base learners"). In this case, reference data came from 7,200 clustered random samples (Cohen et al. 2016) of forest disturbance/no-disturbance observations collected using an image interpretation tool called TimeSync (Cohen et al. 2010). TimeSync allows users to access historical Landsat imagery to be compared with any available historical aerial image for interpretation of disturbance. Through TimeSync, each sample was divided into temporal segments corresponding to observed forest disturbance events. The output of the stacking process was a percentage likelihood of disturbance produced by a random forests model (Breiman 2001) that used all band/index-wise LandTrendr outputs as inputs and was calibrated with TimeSync data. Three types of annual forest disturbance maps were then produced from this process:

- Year of detection—the image year of change detection. This year does not always represent the "year of disturbance." Often, vegetation change caused by a disturbance was detected the following year but sometimes in less than 1 year depending on Landsat image availability and other factors. Usually, disturbance was detected within 2 years of the disturbance event.
- Duration of disturbance—based on the duration (number of years) of consecutive disturbance segments. Short-duration (usually 1-year) disturbances are associated with events that quickly remove or alter forest vegetation cover (e.g., wildfire, timber harvest, forest clearing, wind, floods, etc.). Disturbances lasting multiple years represent slow forest change and loss of cover caused by insects, disease, or other physiological stressors (Cohen et al. 2016).
- Severity of disturbance—the relativized difference in the normalized burn ratio (RdNBR) (Miller and Thode 2007) was used as our index of disturbance severity. We classified disturbance severity using class thresholds (low, moderate, high) identified by Reilly et al. (2017) that correlated RdNBR with tree mortality (percentage of live-tree basal area change) from pre- and postfire forest inventory plots. High-severity disturbances were later used in postprocessing of old-forest maps to exclude unrealistic model outputs for those maps. Areas within mapped wildfire perimeters that may have experienced a light surface burn under a closed canopy (thus no difference in NBR) or were islands of unburned areas were assigned to the low-severity class.

The last step in disturbance mapping was to assign a causal agent (wildfire, timber harvest, insect/disease, and other) for each disturbance signal for each year. This was a technical advancement from the last monitoring report (Davis et al. 2015) where only the highest magnitude (severity) disturbance was used across all years. This new procedure captured multiple disturbances that occurred in the same area (pixel) over the course of time. Assignment of causal agent was based on interpretation of the duration of the disturbance; its location in relationship to federal LUAs; relationship to aerial detection survey maps for insects and disease (Coleman et al. 2018, Johnson 2016); spatial relationship to mapped wildfire perimeters (e.g., GeoMAC, NIFC, MTBS); and, when inside wildfire perimeters, the year of detection 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 (e.g., insects or timber harvest). We classified disturbance casual agents into four general classes using the rules below:

- Timber harvest—Represents timber harvesting including thinning and regeneration. Classified as abrupt disturbances (duration <4 years) outside of congressionally reserved (CR) lands (e.g., wilderness areas) where timber harvesting is not allowed in the reserved area's management plan. During our monitoring time period, new CRs have been designated by Congress. For these, harvest attribution applied only to disturbances prior to the year of designation. Abrupt disturbances within wildfire perimeters were attributed to harvesting if they occurred prior to the fire year.

- Wildfire—with a duration of 1 year that occurred the same year or the year following the fire year within a mapped wildfire perimeter.
- Insect and disease—disturbances with long durations (≥4 years, persistent) or with more than four (chronic) disturbances detected. This also includes small, shorter duration disturbances (patch size < nine pixels) when they occurred with a "potential insect/disease area." The potential insect/disease area was generated using a focal mean analysis on a binary map of pixels exhibiting persistent or chronic disturbance signals (duration ≥4 years, or more than four years disturbance events). A focal mean using a 1-km radius (equivalent to a 776-ac area, comparable to the range of sizes of mapped aerial detection survey polygons for the region) was used to identify a mapping threshold to represent potential insect/disease areas. We observed that when at least 10 percent of this area contained persistent/chronic disturbance signals, it matched well with the aerial detection survey data.
- Other disturbance—all detected disturbances not assigned above, including blowdown, floods, landslides, etc.

Forest Vegetation Maps

Annual forest vegetation structure and composition maps for forest-capable lands from 1986 to 2017 were generated using the GNN imputation modeling and mapping methodology. GNN is a multivariate, nonparametric modeling and mapping framework that imputes forest inventory data to individual 30-m pixels based on Landsat multispectral forest surface reflectance and environmental similarity in the gradient space (Ohmann and Gregory 2002). The NWFP effectiveness monitoring program (Mulder et al. 1999) helped develop and has been using GNN maps to track changes in forest and wildlife habitat conditions through time since the NWFP 15-year report (e.g., Moeur et al. 2011). These maps update and replace those used in the NWFP 20-year monitoring reports (Davis et al. 2015, 2016; Falxa and Raphael 2016; Miller et al. 2017).

The modeling/mapping framework uses canonical correspondence analysis, a method of constrained ordination (direct gradient analysis) (ter Braak 1986), to define a multivariate feature space of environmental gradients based on tree or forest attributes measured on forest inventory plots and a set of predictor variables. Weighted Euclidean distances between plots and map pixels in that multivariate feature space are calculated such that the *k*-nearest neighbors for every pixel can be identified as those plots that minimize the distance to the pixel in question. For mapping, forest attributes are imputed to pixels based on some function of those nearest neighbors, such as the mean. Differing values of *k* can be selected based on the objectives of the user. For example, using only the nearest neighbor (e.g., $k = 1$) may help to maintain more realistic combinations of variables (e.g., species lists) by imputing only those combinations that were actually observed in the forest inventory (Ohmann et al. 2014). Conversely, using multiple neighbors ($k > 1$) may reduce some types of mapping errors and allows for the estimation of prediction uncertainties (Bell et al. 2015a, McRoberts 2012).

We used FIA plot data from California, Oregon, and Washington with at least 50 percent forested conditions as the source of our forest attribute data. For each plot, per-hectare, or per-acre forest attribute values that described the forested portion of the plot were calculated based on tree-level data from the forested portions of subplots. We assumed that forest attributes were homogenous for the forested portion of each plot (e.g., variation amongst subplots was not described). Thus, nonforest portions of plots were not accounted for in our modeling.

Spatial predictors upon which GNN modeling was based included relatively static variables, such as topography and climate to more frequently changing variables, such as forest surface reflectance (e.g., tasseled-cap transformations of brightness, greenness, and wetness [Crist and Cicone 1984] and the NBR [Key and Benson 2006]). Previous research indicated that modeling based on a 3-by-3 pixel (0.81-ha) footprint and the measurements across all four subplots performed better in terms of R^2 and root mean square deviations than models using the single pixel overlapping the central subplot (Zald et al. 2016). Thus, spatial predictors were extracted for each plot using a

3-by-3 pixel "plot footprint" that encompassed the outer extent of the field plot. We intersected the plot footprint with each spatial predictor and generated means within it. From the medoid composite Landsat images produced to map forest disturbances, we extracted data for the same year as plot measurement to avoid temporal mismatches between ground conditions and imagery. Note that while the models were fit to these 3-by-3 pixel composites, the mapping occurred at the 30-m pixel scale. Methodological changes since the 20-year report include the following:

- Revised plot pools—the pool of forest inventory plots used for modeling was modified in two ways. First, we used only plots conforming to the annual FIA plot design (Bechtold and Patterson 2005) (e.g., not periodic plot measurements prior to 2001) and not current vegetation survey plots (Max et al. 1996) as in the 20-year report (Davis et al. 2015). This decision was based on our assessment of unrealistic temporal trends in certain forest attributes that could only be explained by changes in sample designs. Second, we incorporated five additional years of plot measurements (2012–2016), resulting in plot data that spanned 2001–2016. All plots were screened for outliers using various algorithms and visual inspection of predictions, Landsat imagery, and aerial photography (as described in Davis et al. 2015). The most common outliers were associated with inhomogeneous plots (e.g., plots straddling a timber harvest boundary), clearly incorrect global position system coordinates, or apparent disturbances occurring between the time of plot measurement and the availability of satellite imagery. Although there were no consistent changes in the number of plots per modeling region since the previous report (Davis et al. 2015), the increased consistency in input data minimizes impacts of forest attribute change artifacts owing solely to sampling design.
- Ensemble LandTrendr imagery—for previous reports, we used the fitted imagery provided by an implementation of the LandTrendr algorithm on a single spectral band (NBR). Here, we used temporally fitted imagery derived from the ensemble LandTrendr methodology described in the previous section, using all bands and several derived indices.
- Imagery stabilization—early examination of multispectral data and subsequent vegetation maps produced by GNN highlighted low magnitude, multidecadal shifts in several multispectral indices. Such changes were often associated with mature or old-growth forests that appeared stable based on aerial photography, but GNN predicted declines in live-tree basal area and OGSI. Similar patterns have been previously observed in GNN mapping, motivating the stabilization (e.g., use of multiyear mean spectral indices rather than the trends from LandTrendr) when forests were deemed to be stable (e.g., not disturbed or recovering from disturbance) (Davis et al. 2015, Kennedy et al. 2018a). Such issues may arise as a result of spectral saturation, whereby the sensitivity of spectral reflectance decreases as forest age and biomass increase (Foody et al. 2003; Lu et al. 2012, 2016), meaning that small changes owing to "imagery noise" can drive shifts in forest attribute predictions from the modeling. Other potential drivers of multidecadal shifts in spectral indices include orbital drift for the Landsat 5 satellite, causing a decrease in the normalized difference vegetation index (Zhang and Roy 2016) or increasing exposure of nonleaf material in older forest, such as lichen and bark (Cohen and Spies 1992).

Here, we adopted an imagery stabilization method intended to minimize errors associated with slow spectral changes in older forests lacking any observed disturbance or recovery signal. We identified stable pixels as locations where ensemble LandTrendr had a single segment (e.g., no evidence of disturbance or recovery) from 1986 to 2017 and classified as OGSI 80 in 1993 using GNN predictions based on unstable imagery. We then stabilized imagery for those pixels by replacing the temporally smoothed indices from LandTrendr with the mean value across years for each band or index.

Previous stabilization methods held spectral indices constant across years for all pixels that did not experience disturbance or recovery (e.g., Kennedy et al. 2018), meaning that the primary mode of change was disturbance (e.g., loss of older forest), which may bias results by underrepresenting gains in older forests. In contrast, our current imagery stabilization method minimizes unreasonable modeled changes in older forests while still allowing for the transition of young stands into mature forest conditions. Whereas the forest area stabilized in the previous 20-year report was 15.7 million ha (43.1 percent of total forest area), stabilization in these models only accounted for 9.9 million ha (27.1 percent).

- Bootstrap approximation—Previous reports used k = 1 GNN (e.g., imputing the nearest neighbor only) as the basis of mapping in order to avoid the mapping of unrealistic forest conditions. However, pixel-level uncertainties can be large (Bell et al. 2015b, Loehle et al. 2015), especially when examining rare forest conditions, such as high-elevation forests recovering from wildfire (Bell et al. 2015a, Reilly et al. 2018). Such uncertainties vary substantially, depending on the forest attribute being considered (Bell et al. 2015a), indicating that maps of predicted means and uncertainties (e.g., standard deviations) are both needed for the utilization of forest attribute maps; traditional accuracy assessments (Ohmann and Gregory 2002) may not be sufficient for assessing map utility. To minimize the potential for unrealistic combinations of predictions, allow for the mapping of model precision across the study area, and dampen uncertainties related to rare forest conditions, we adopted an approximation of a bootstrap sampling approach for k = 1 GNN (Bell et al. 2015a). The bootstrap approximation utilized multiple neighbors (k = 7) and applied a weighted mean with weights proportional to the probability that a bootstrap sample would result in that plot being the nearest neighbor for a pixel. Resulting predictions from the bootstrap approximation for aboveground forest biomass in California and western Oregon were highly correlated to k = 1 predictions but with smaller root mean square deviations (Battles et al. 2018). The current report uses continuous forest structural attributes for identifying old-growth forest, making the distinctions between k = 1 and the bootstrap approximation relatively minor. However, if mapping tree species composition was the primary goal for a project, k = 1 would be a more appropriate choice.

GEE—As stated earlier, GEE is a cloud platform for massively parallel spatial analysis and computation and has provided many benefits in model development in terms of rapid comparison, visualization, and attribute calculation. As such, it facilitated on-the-fly, bootstrap approximations of the continuous OGSI stand attributes using the first k = 7 neighbor rasters and cross walking them to the OGSI class threshold scores used for binary mapping. The OGSI large, live-tree qualifier (see Davis et al. 2016: 17, table 5) used k = 1 because when using k > 1 it, was possible to have at least one neighbor (of seven nearest neighbor plots) meet this condition, thus producing large commission errors (false positives). The same would hold true for species presence/absence or richness. Annual maps of older forest were produced in GEE by applying the OGSI class thresholds specific to each forest vegetation zone.

High-Severity Disturbance Mask

The use of Landsat time series data to conduct forest monitoring is relatively new and a rapidly developing field of applied science (Banskota et al. 2014). Currently, abrupt forest changes are more easily and accurately detected; whereas gradual changes are more subtle and difficult to measure (Davis et al. 2011, Kennedy et al. 2010). The GNN maps produced for our monitoring relied on spectral variables, and forest change was prone to errors caused solely by changes in surface reflectance of the forest. To reduce errors in our time series of old-forest maps, we used a masking procedure to prevent OGSI 80 and 200 pixels from quickly returning back into those classes after a high-severity disturbance (e.g., stand-replacing event), given the relatively short temporal span of this monitoring (less than 80 years). Put simply, once a pixel of old forest was stand-replaced, it could not return to an old-forest condition in such a short amount of time. Observed causes for this included rapid green up of ground vegetation after high-severity wildfires that resulted in rapid (5- to 10-year) recovery of NBR (Bright et al. 2019), sometimes causing erroneous assignments of old-forest plots to pixels where this signal occurred. The masking of high-severity disturbance included the entire Landsat archive dating back to 1972 (Healey et al. 2008).

Morphological Spatial Pattern Analysis

We analyzed spatial patterns of our older forest maps (OGSI 80 and 200) using the software package GUIDOS (Graphical User Interface for the Description of image Objects and their Shapes) v2.2, which was developed for analyzing morphological spatial patterns from satellite images (Soille and Vogt 2009, Vogt and Riitters 2017). GUIDOS assigned each older forest map 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 combined these classes into five general morphological spatial pattern classes (fig. 5):

- Core: 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 a group of older forest pixels large enough to contain at least one core pixel. Given the resolution of our 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 ac (the approximate size of a forest inventory plot).
- Finger: stringers of older forest pixels that bridge two patches or are connected to 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 pixels that are too small (<2 ac) to contain core pixels and do not connect to any patches of older forest.

Contiguous older forest consists of patches and the fingers connected to those patches. The interior portion of a patch (core) is greater than 30 m (98.5 ft) from an edge and typically has a milder microclimate during the summer with lower windspeed and temperature, and higher humidity (Chen et al. 1995). Forest patches as small as 2.47 ac can have microclimates similar to larger intact forest conditions (Heithecker and Halpern 2007). The finger and scatter map classes, when combined, represent fragmented older forest patterns. As a younger forest patch redevelops into an older forest patch, the scatter class begins to appear and form fingers that eventually coalesce to form the patch classes (core and edges).

Trend and Bookend Analyses

In previous monitoring reports, bookend analyses (e.g., analyses occurring between two specific points in time) were performed to assess the amount of older forest at the beginning of the NWFP (1993) and the end of the

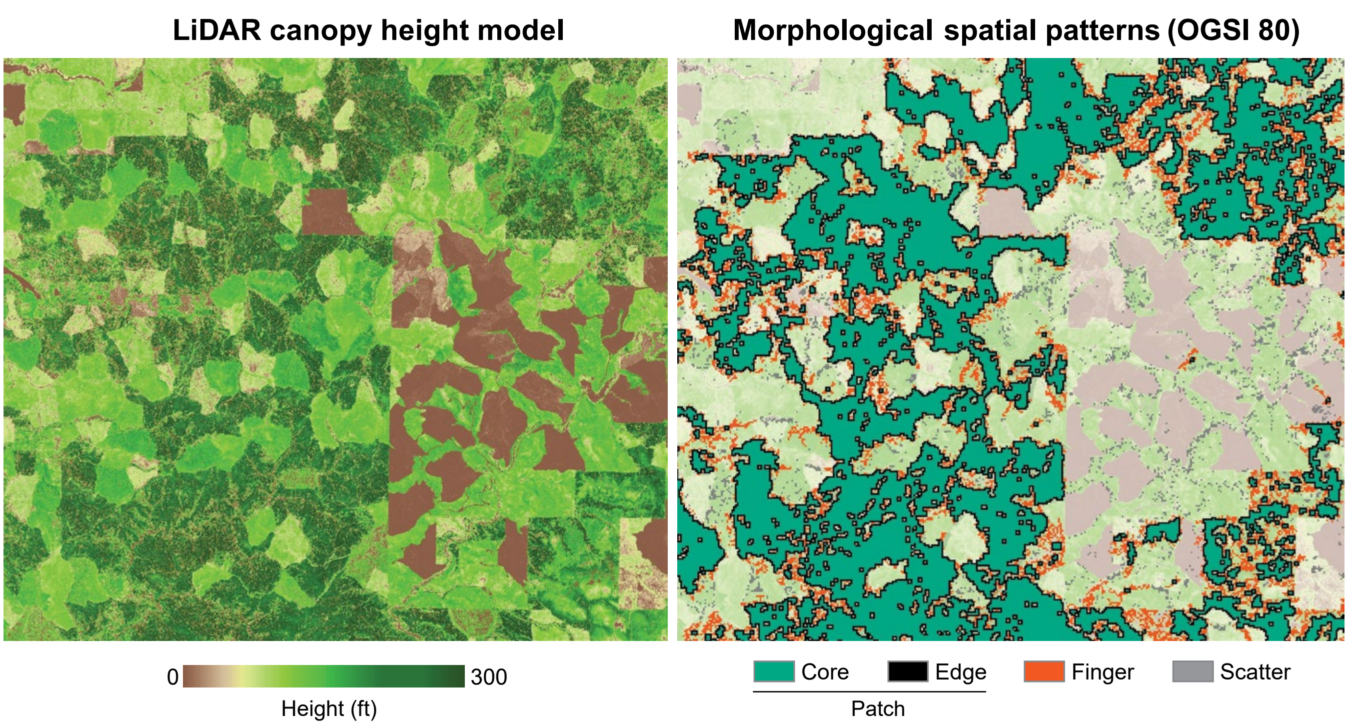

Figure 5—Example of morphological spatial pattern analysis map classes produced for this report compared to a map of tree heights produced by light detection and ranging (LiDAR) data. OGSI 80 = old-growth structure index ≥80 years.

monitoring period. Here, we used new annual time series maps to produce trend lines in the years preceding the NWFP (1986) to the end of this monitoring period (2017). This allowed us to observe the effect of the NWFP on old-forest trends preceding the NWFP and improved our interpretation of old-forest trends since its implementation. Annual mapping also allowed us to estimate annual rates of change. Trend lines were produced for pixels that were classified as "contiguous" GUIDOS described in the previous section. A 5-year moving average (with first and last 2 years using 3- and 4-year averages, respectively) was used to smooth the trend lines. Bookend analyses were still conducted using unsmoothed mapped estimates (disturbance-masked, including all spatial pattern classes) for the standard reporting scales based on physiographic provinces, states, and range.

Outcome Analyses

As in the previous report (Davis et al. 2015), we gauged NWFP effectiveness in achieving its goal (outcomes 1 or 2 below) for abundance, distribution, and connectivity of older forest (tables 2 and 3). This evaluation was based on (1) the total federal area covered by older forest, (2) the federal area covered by large patches of older forest as represented by core and core-edges only (>1,000 ac), (3) the average distance between these large patches, and (4) the federal area covered by contiguous older forest as represented by patches and fingers only (>2.47 ac).

- Outcome 1: at levels near or above the long-term average that occurred prior to logging and extensive fire suppression
- Outcome 2: within the estimated natural range
- Outcome 3: below the estimated natural range
- Outcome 4: very low

We used 30-km (18.6-mi) hexagons (center to center) to represent "relatively large areas" (each hexagon covered about 192,000 ac) as described in FEMAT (1993: IV–50). Using zonal statistics in GEE, 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 Euclidean distance to large patches of older forest. These statistics were based on the entire area of the hexagon, and not just the forest-capable portions within

Table 2—Thresholds for measuring success in achieving older forest abundance and diversity outcomes

Outcome	Federal land covered by older forest	Federal area covered by large patches of older forest as represented by core and core edges (>1,000 ac)	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

Table 3—Thresholds for measuring success in achieving older forest connectivity outcomes

Outcome	Average distance between large patches (>1,000 ac) of older forest as represented by core and core edges	Federal area covered by contiguous older forest as represented by patches and fingers	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

them. Thus, they were comparable between all hexagons across the NWFP area. Only hexagons that contained at least 10 percent of federally managed forest lands (or about 19,200 ac, which is roughly equivalent to the mean area of one sixth-field watershed) were attributed with outcomes outlined in tables 2 and 3 for each time period. We differenced the time periods to determine if the trend was toward improving or degrading these outcomes. Finally, we determined which hexagons met the threshold criteria for outcomes 1 or 2 for abundance and diversity (table 2) as well as connectivity (table 3) for each time period.

Results

Forest Inventory Plots

Of the 44.8 million ac of forest land in the NWFP area, 18.6 ± 0.64 million ac (42 percent) met the criteria for estimated OGSI of a ≥80-year-old stand for a vegetation zone (OGSI 80) in the 2010s (± value is the 95-percent confidence interval, or 1.96 times the standard error) (fig. 6). The change in OGSI 80 was estimated to increase by 392,000 ± 403,000 ac from the 2000s, or 39,000 ac per year; however, this estimate is not significantly different from zero. Seventy-two percent of the OGSI 80 area in the 2010s was on NWFP federal lands (fig. 6). Of the 5.12 million ac of OGSI 80 in nonfederal ownership (fig. 6), 21 percent was on state lands, 33 percent was on private corporate lands, and 41 percent was on private noncorporate (including American Indian tribal) lands.

The area meeting the estimated OGSI of a ≥200-year-old stand for a vegetation zone (OGSI 200) criteria in the 2010s was 8.6 ± 0.46 million ac, or 19 percent of the total forested area (fig. 7). The change in OGSI 200 was estimated to increase by 500,000 ± 325,000 ac from the 2000s, or 50,000 ac per year, which was significantly greater than zero. Eighty-seven percent of the OGSI 200 area in the 2010s was on NWFP federal lands (fig. 7). Of the 1.1 million ac of OGSI 200 in nonfederal ownership (fig. 7), 31 percent was on state lands, 20 percent was on private corporate lands, and 44 percent was on private noncorporate (including American Indian tribal) lands.

The physiographic provinces with the greatest proportion of federal forest classified as OGSI 80 were the California Klamath and Oregon Western Cascades; all except the Washington Eastern Cascades (48.5 percent) had more than 50 percent of their forest in OGSI 80. The California Cascades, California Klamath, Oregon Western Cascades, Washington Olympic, and Washington Western Cascades had more than 60 percent of federal forest as OGSI 80. None of the changes in OGSI 80 acreage by province were significant, although there was a tendency toward small increases in most provinces.

As with OGSI 80, the physiographic provinces with the greatest amount of federal forest classified as OGSI 200 were the California Klamath and Oregon Western Cascades. Washington Olympic had 49 percent of its federal forest land classified as OGSI 200, with Washington Western Cascades, at 42 percent, being the only other province with more than 40 percent. The rest of the provinces had at least 20 percent of federal forest in OGSI 200, except for the California Coast Range, which had 18 percent. A tendency toward increases was evident in most provinces, with significant increases seen in the Washington Eastern and Western Cascades.

Trend and Bookend Analyses

In the few years preceding the NWFP, map estimates showed mostly negative annual rates of change on federally managed forests in both OGSI 80 and OSGI 200 (fig. 8). Annual rates of change became positive shortly after the listing of the northern spotted owl (1990) and the subsequent timber injunction of 1991 and remained positive, except for large wildfire years (e.g., 1996, 2002, 2008, and 2015). These results imply that during years with few wildfires, annual rates of change for OGSI 80 and OGSI 200 have been 0.1–0.3 percent and 0.0–0.6 percent, respectively (fig. 8), showing that older forest development and recruitment after forest disturbances occur slowly, but steadily. In contrast, large wildfire years can offset those gains relatively quickly.

Since 1993, the amount of older forest estimated from maps on all lands within the NWFP boundary has decreased by 0.7 percent (OGSI 80) (fig. 6) and by 2.0 percent (OGSI 200) (fig. 7) between 1993 and 2017. On federal lands, the trend and net change for OGSI 80 was fairly stable (-0.3 percent) (fig. 6) and +0.3 percent for OGSI 200 (fig. 7). On the surrounding nonfederal lands, the amounts of older forest decreased by 2.9 (fig. 6) and 8.7 percent (fig. 7) for OGSI 80 and 200, respectively.

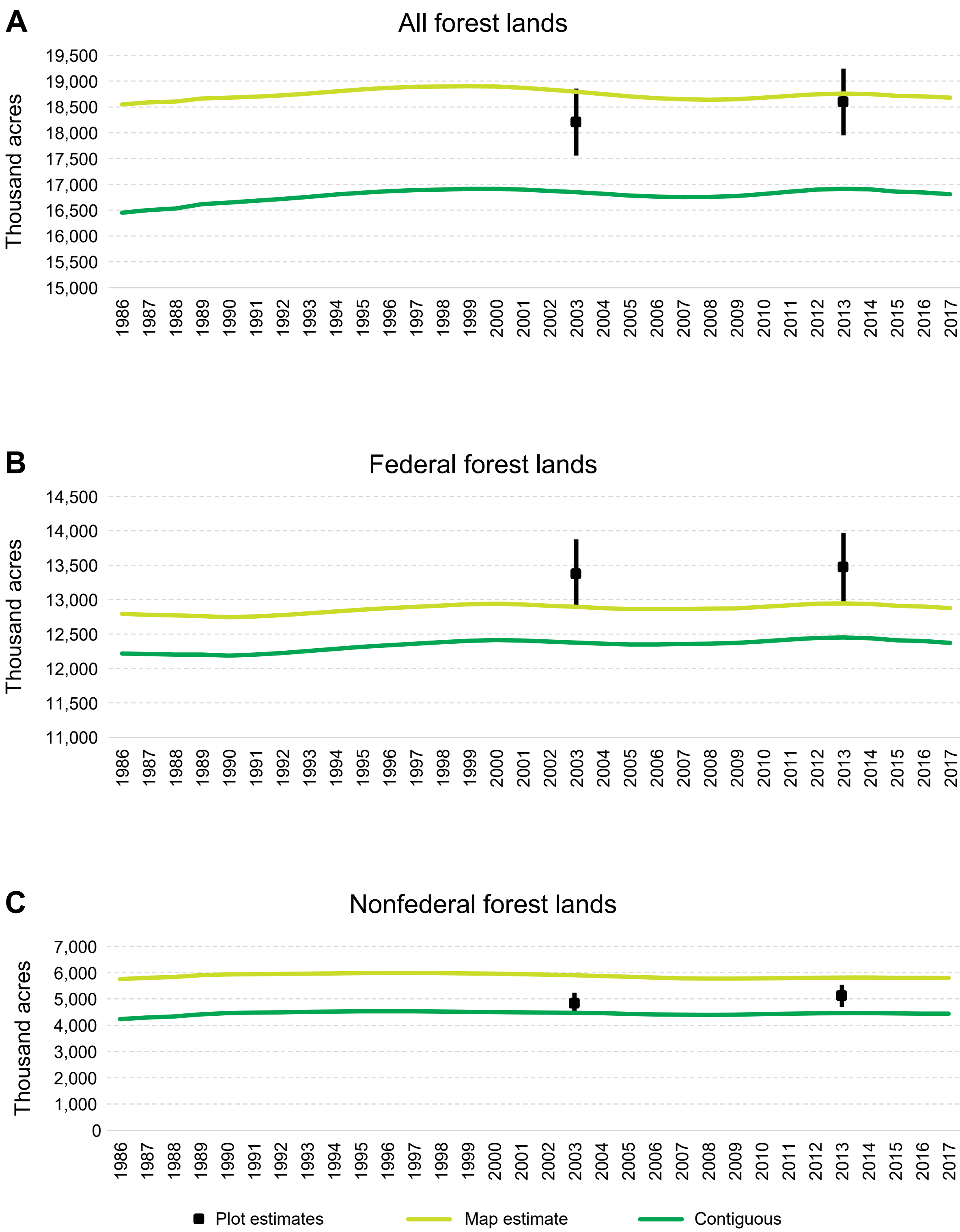

Figure 6—Trend lines for old-growth structure index 80 classification, including plot estimates with 95-percent confidence intervals.

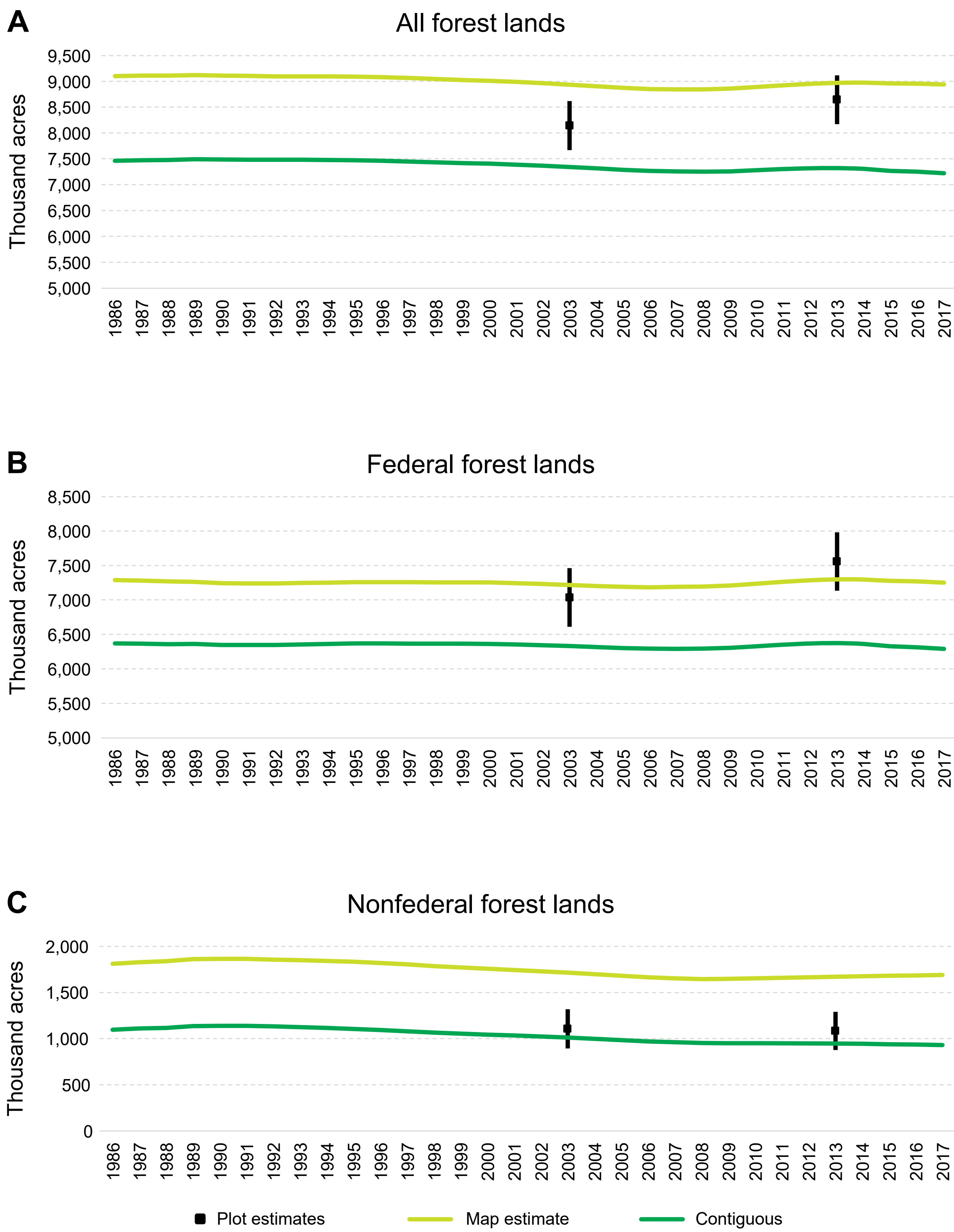

Figure 7—Trend lines for old-growth structure index 200 classification, including plot estimates with 95-percent confidence intervals.

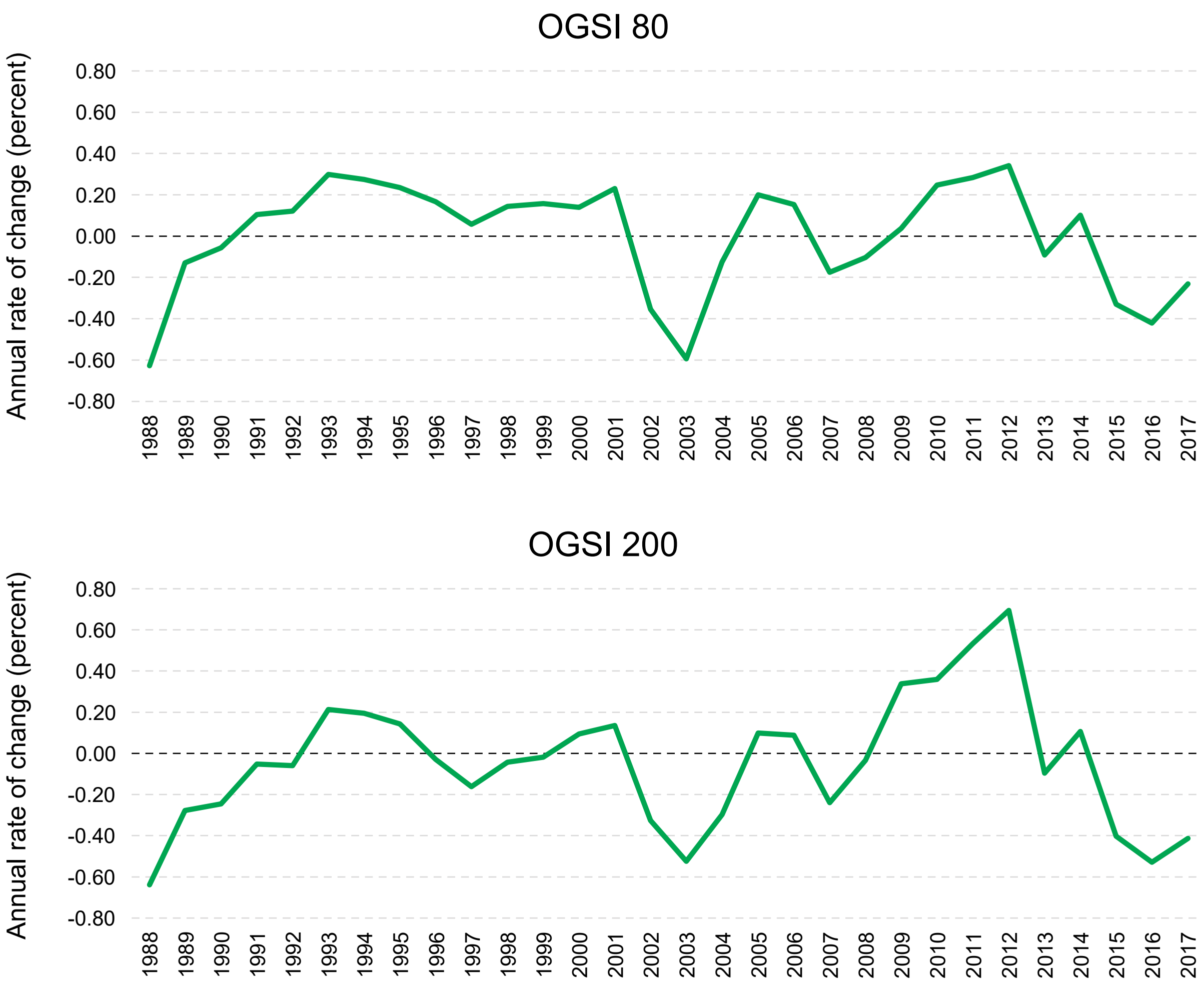

Figure 8—Estimated annual rates of change in older forests based on map differences. OGSI = old-growth structure index.

Although the overall amount of older forest on federally managed lands has remained fairly stable as a whole, it has become slightly more fragmented. Within reserved allocations, the amount of fragmented OGSI 80 (finger and scatter) increased by 4.5 percent, while patches (core and edge) decreased by 3.1 percent. For reserved OGSI 200, fingers and scatter (combined) increased by 3.2 percent, while patch area decreased by 4.4 percent. These changes were mainly due to large wildfires within reserved LUAs; however, some of these losses occurred prior to the area being designated as reserved. Within the nonreserved LUAs, OGSI 80 became slightly more contiguous, with patch area increasing by 6.5 percent and fingers/scatter decreasing by 5.5 percent. Conversely, OGSI 200 became slightly more fragmented, with patch area decreasing by 0.9 percent and fingers/scatter increasing by 10.9 percent. Some of the increase in fragmentation is due to younger forests from historical large wildfire or other disturbance events coalescing back into patches of older forests, mostly OGSI 80 (fig. 9).

The distribution of reserved forest is concentrated on federal land (fig. 10), and higher amounts of older forest in 1993 and 2017 (figs. 11 and 12) reflect the distribution of federal land ownerships. This relationship reflects the history and geography of the forest reserves established between 1891 and 1907 (Davis et al. 2017) and a shorter history of timber harvesting with a higher focus on old-forest conservation than the surrounding nonfederal lands. Similarly, ownership distributions appear strongly related to regional patterns of forest disturbance. Whereas timber harvesting was concentrated on nonfederal forest lands, natural disturbances, such as wildfire, insect, and disease occurred mostly on federal forest lands (see fig. 13 in relation to fig. 10). Interestingly, we note accumulations of older forests in the Coast Range (Oregon) (figs. 11 and 12) that are not easily explained by recent disturbance or ownership patterns (fig. 10). We speculate that this may be due to long-term fire exclusion along the margins of the Willamette Valley where open oak woodlands were historically maintained by frequent human-ignited fire.

Outcome Analyses

At the implementation of the NWFP, 74.1 percent of hexagons (that contained 10 percent or more federal forest lands) met older forest (OGSI 80) abundance and diversity outcomes 1 or 2 (figs. 14 and 15, respectively) and 60.9 percent met connectivity outcomes 1 or 2 (figs. 16 and 17). We observed net increases in all abundance, diversity, and connectivity outcomes (table 4). Overall, the federally managed forests of the NWFP area that met the abundance and diversity outcome objective (fig. 18) increased by 3.6 percent (from 74.1 to 77.7 percent), and by 4.5 percent (from 60.9 to 65.5 percent) for areas meeting the connectivity outcome objective (fig. 19). However, there were net decreases in the drier forest physiographic provinces (Eastern Cascades and Klamath) owing to multiple large wildfires since 1993.

Older forests represented by OGSI 200 covered a smaller proportion of the NWFP area in 1993, and only 16.4 percent of the hexagons met the desired abundance

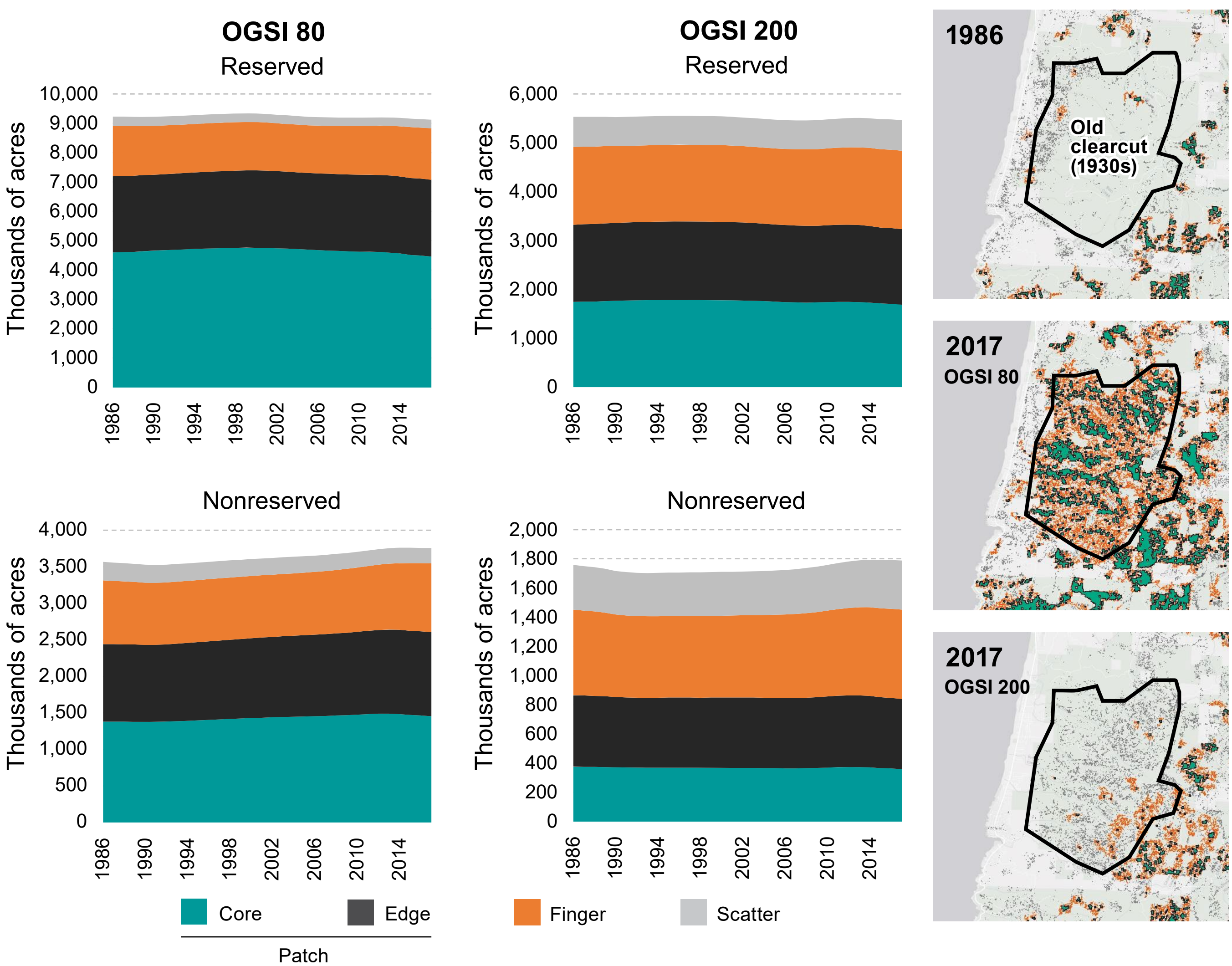

Figure 9—Trends in morphological spatial patterns of older forest on federal lands (left) and an example of older forest cohesion as a 1930s clearcut (black outline) redevelops back into older forest (right). OGSI = old-growth structure index.

and diversity outcome (figs. 20 and 21, respectively). Even less (5.5 percent) met the desired connectivity outcomes (figs. 22 and 23). Between 1993 and 2017, we observed net decreases in all abundance, diversity, and connectivity outcomes except for the percentage of federal lands covered by older forest (table 4). Although this percentage increased (+2.7 percent), the percentage of "contiguous" older forests decreased (-2.3 percent). Overall, the federal portions of the NWFP area that met the abundance and diversity outcome objective (fig. 24) increased slightly by 0.4 percent (from 16.4 to 16.8 percent). However, the federal forests decreased by 2.3 percent (from 5.5 to 3.2 percent) for meeting the connectivity outcome objective (fig. 25) owing to large wildfires in the drier fire-prone physiographic provinces; this decreased to 3.2 percent (-2.3 percent) by 2017.

Most of the increases in NWFP outcomes occurred in the moister forest physiographic provinces (e.g., Washington Olympic Peninsula and Coast Ranges of Oregon and California) but also where historical large wildfires from the late 1800s and early 1900s had created patches of early-successional forests that are now beginning to transition into older forest types (fig. 26). Most of the degradation (decrease from expected outcomes) occurred in the fire-prone areas (Davis et al. 2015: 50).

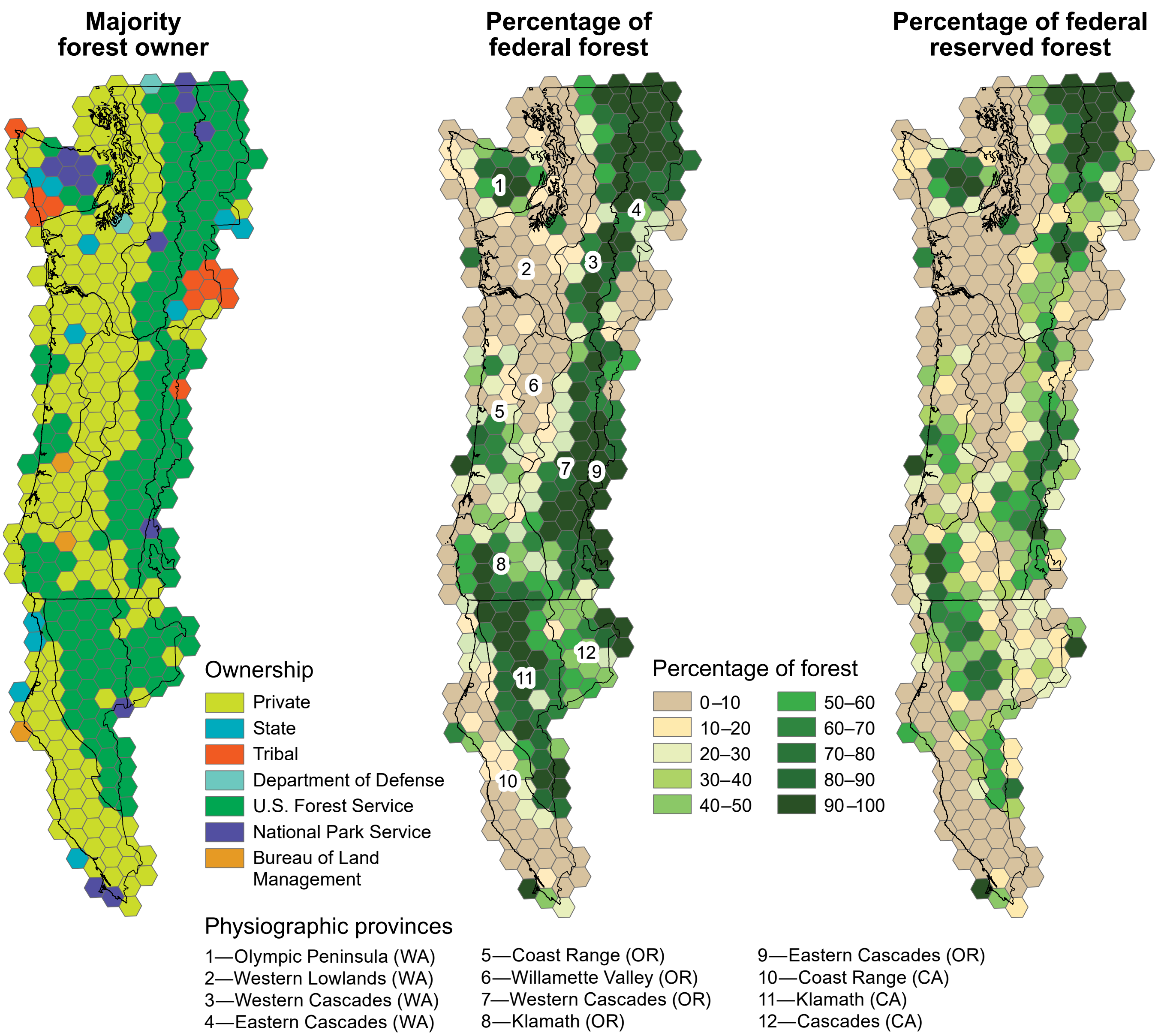

Figure 10—Geographical patterns of forest ownership and percentage of federal forest using 30-km (18.6-mi) hexagons.

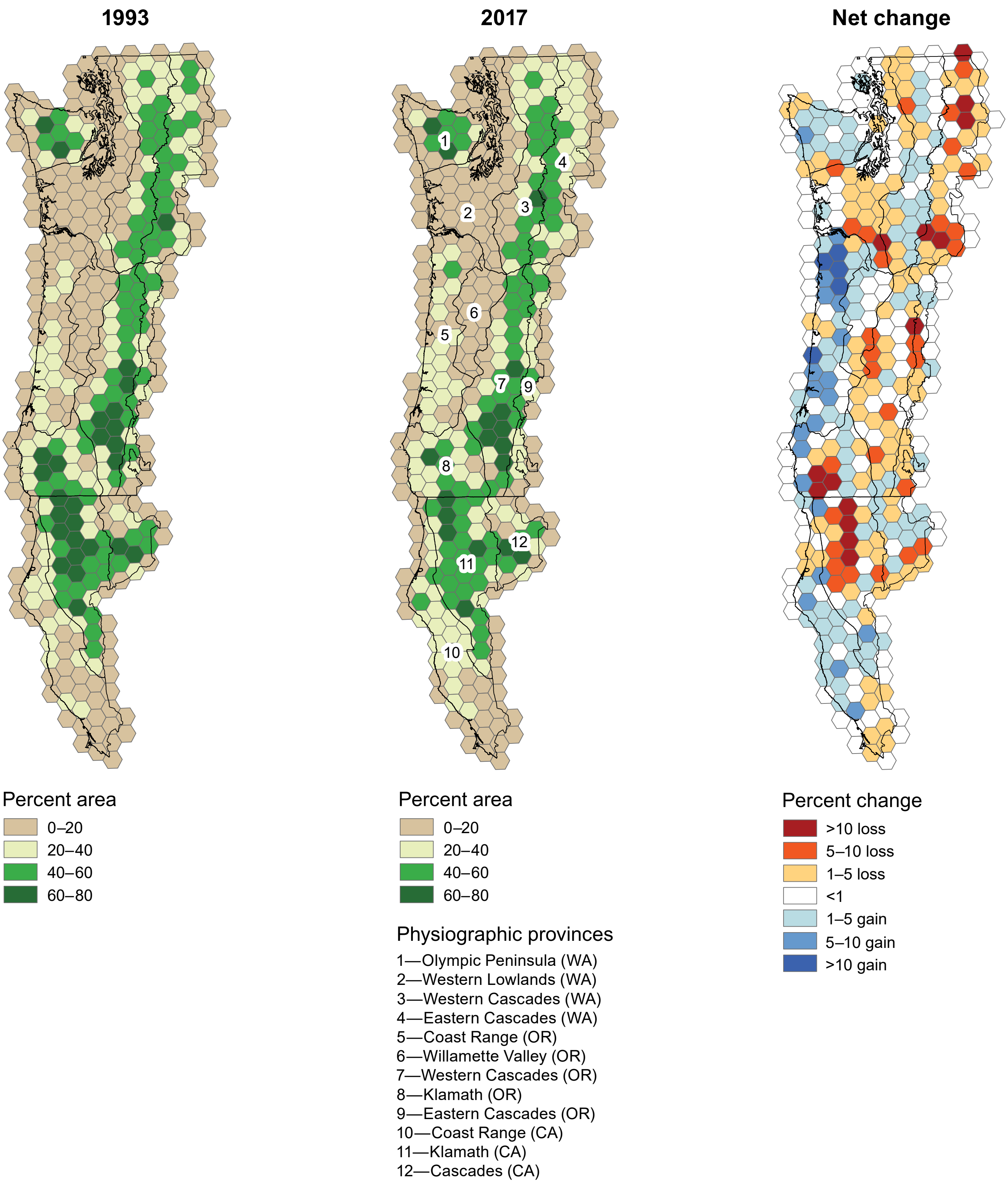

Figure 11—Geographical patterns of status and change between 1993 and 2017 for older forest (old-growth structure index 80) on all lands.

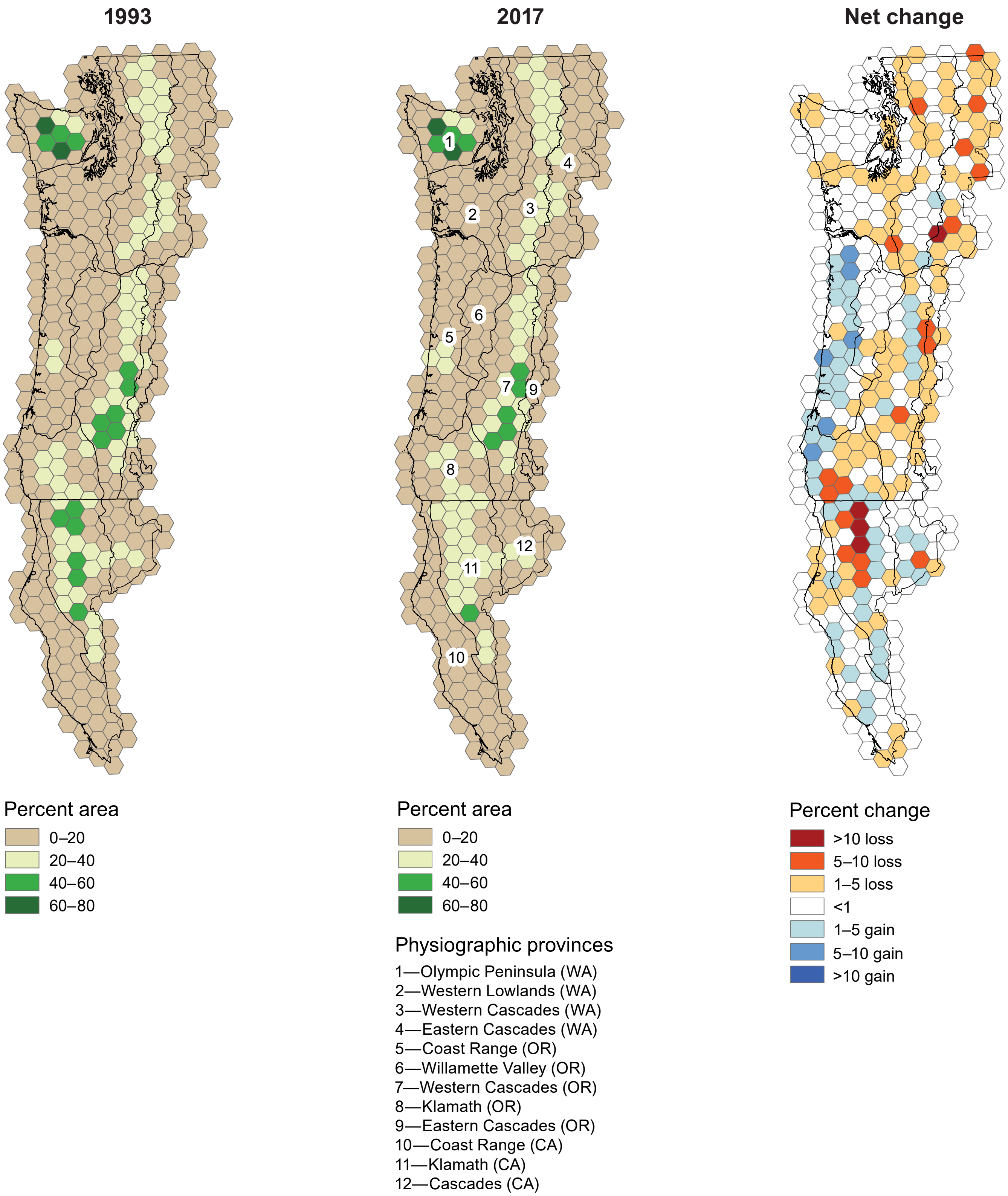

Figure 12—Geographical patterns of status and change between 1993 and 2017 for older forest (old-growth structure index 200) on all lands.

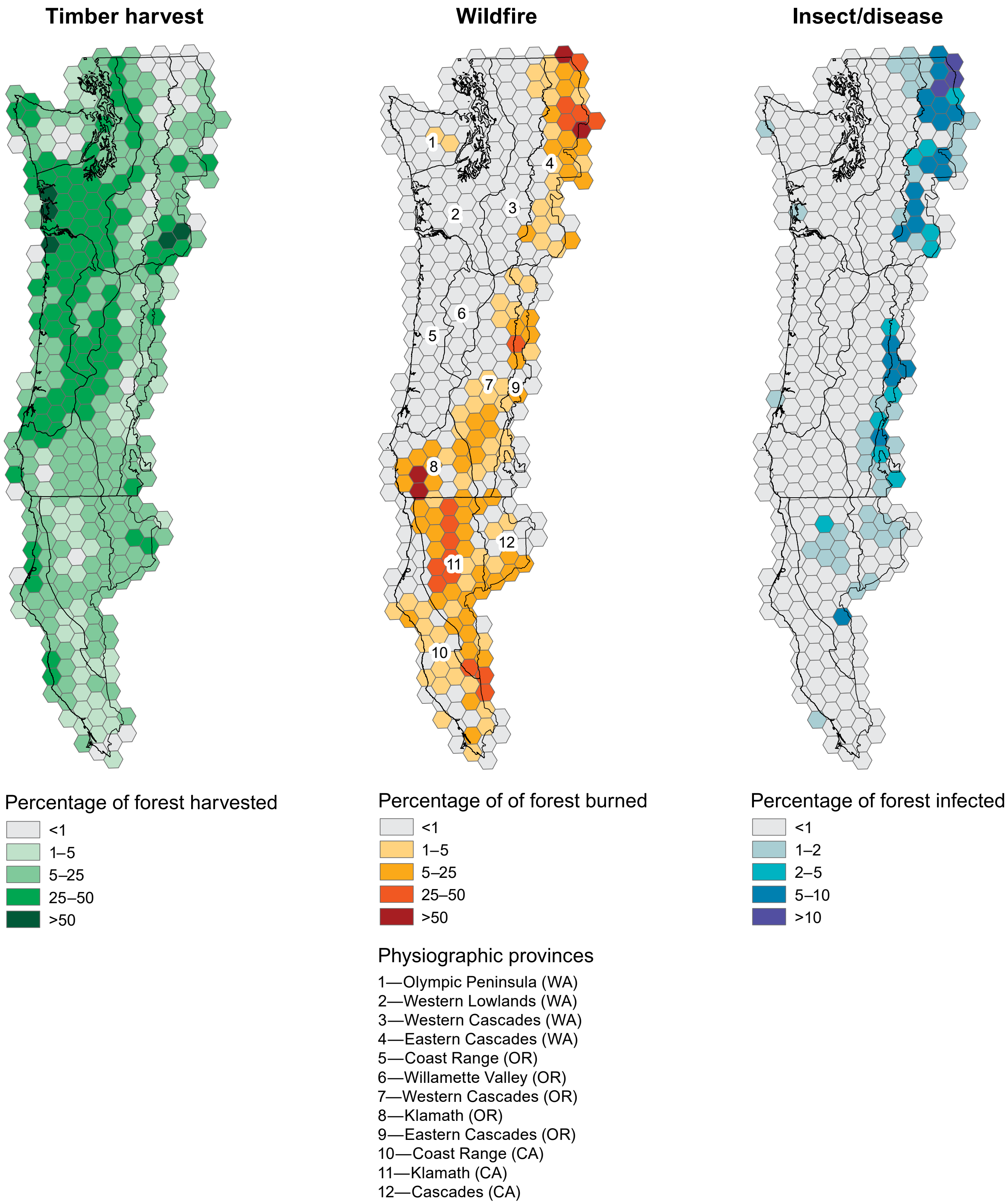

Figure 13—Geographical patterns of major forest disturbances between 1993 and 2017 on all lands.

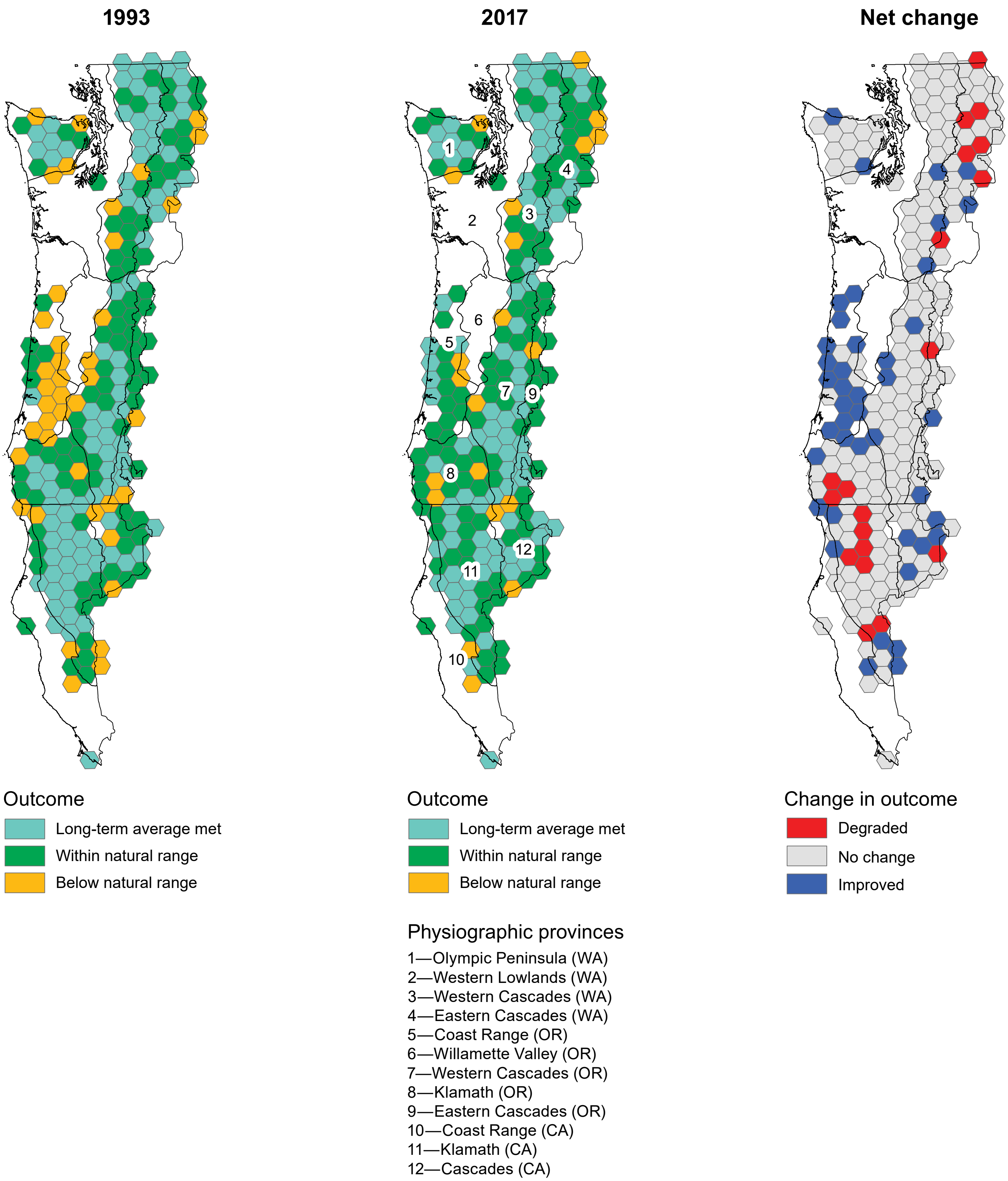

Figure 14—Geographical patterns of abundance as percentage of federal land covered by older forest (old-growth structure index 80).

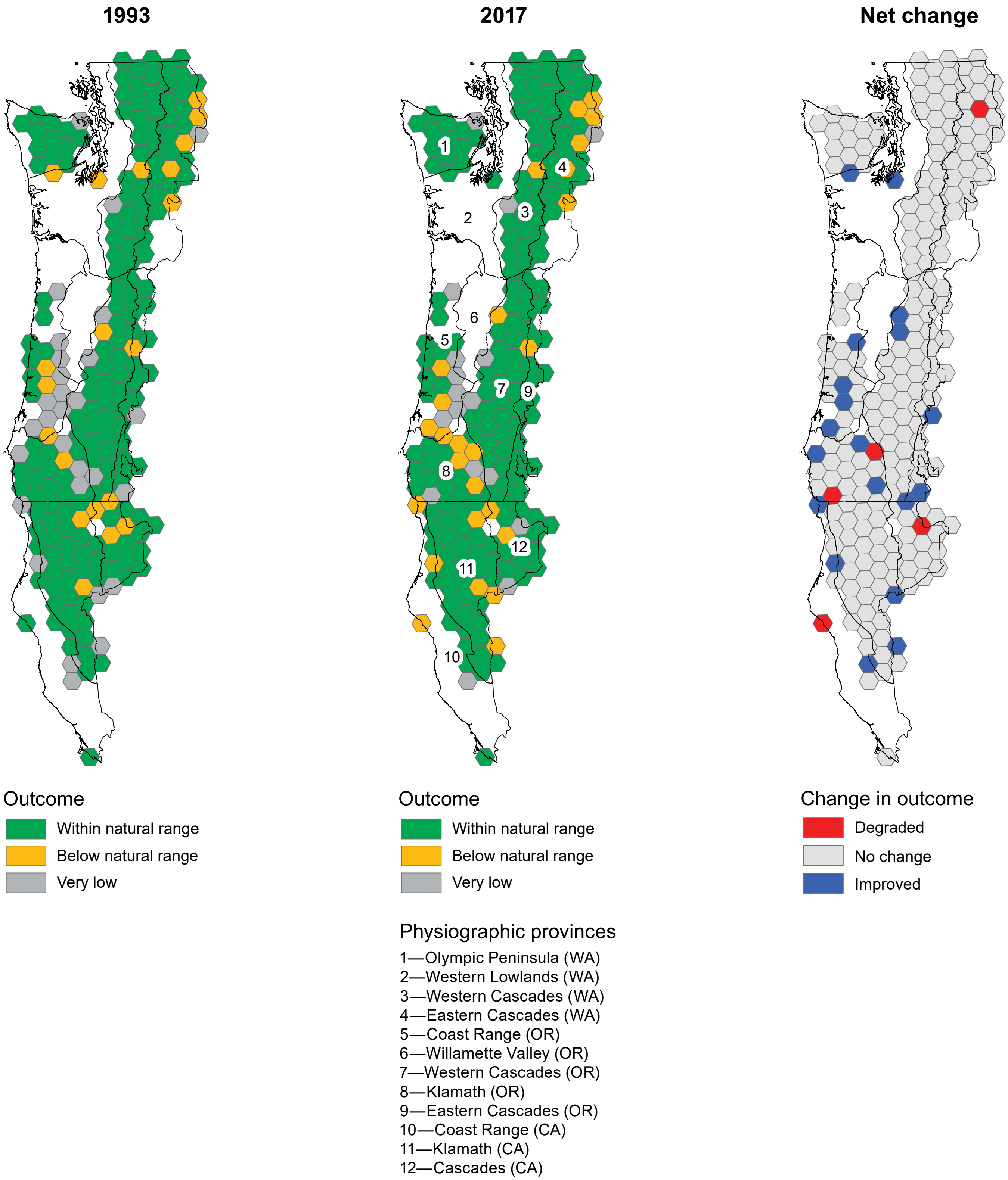

Figure 15—Geographical patterns of diversity as percentage of federal land in older forest (old-growth structure index 80) stands >1,000 ac in patch size.

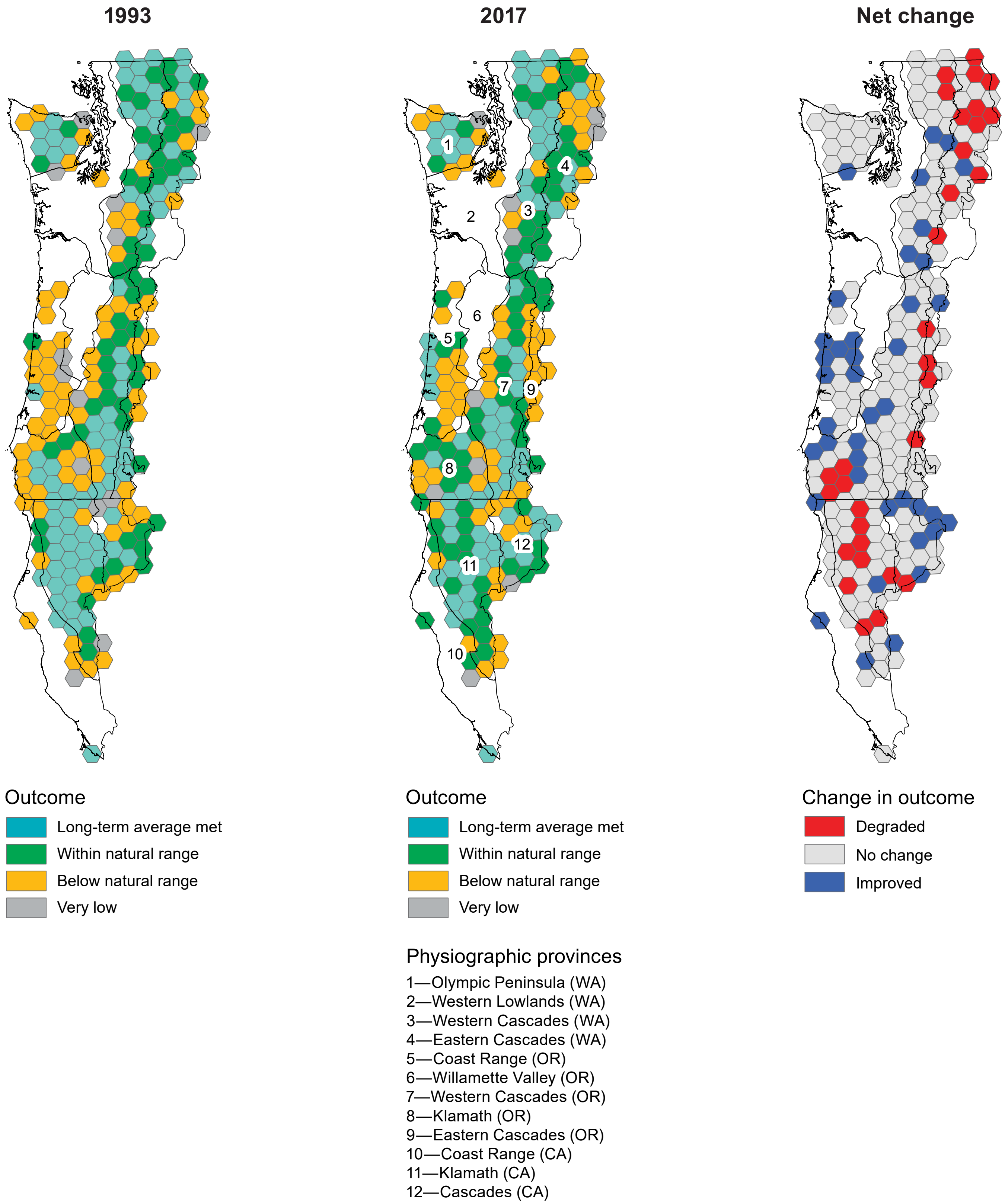

Figure 16—Geographical patterns of connectivity as average distance between old-forest stands >1,000 ac (old-growth structure index 80).

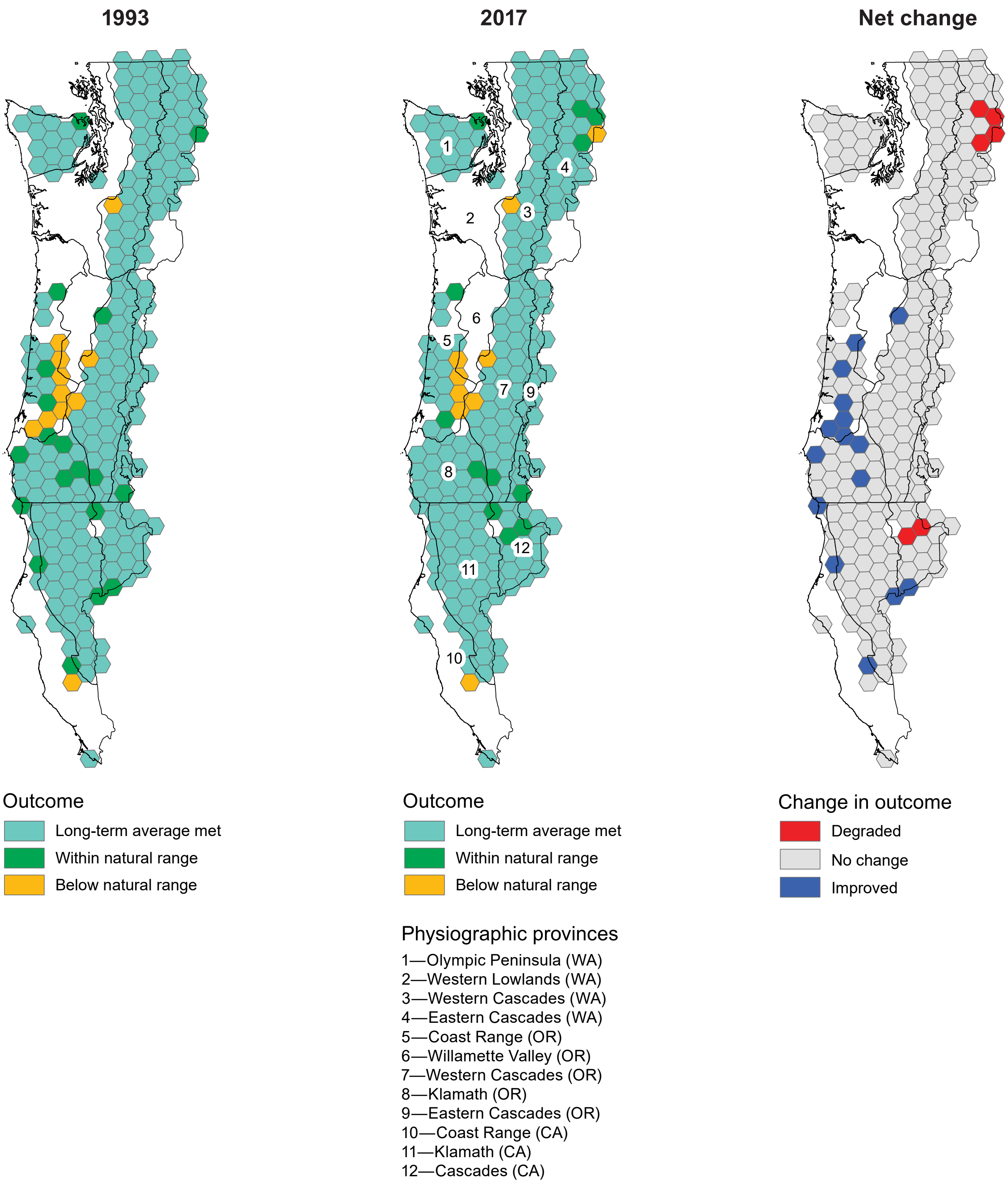

Figure 17—Geographical patterns of connectivity as percentage of federal land covered by old-forest stands (old-growth structure index 80).

Table 4—Summary of outcome analyses for the 1993–2017 monitoring period

	Abundance and diversity outcomes		Connectivity outcomes		Outcomes 1 or 2 achieved	
	Federal land covered by older forest	Federal land covered by large patches (>1,000 ac) of older forest as core and core edges	Average distance between large patches (>1,000 ac) of older forest as core and core edges	Federal area covered by connected older forest as patches and fingers	Abundance and diversity	Connectivity
	Percentage of hexagons					
OGSI 80:						
Improved (+)	18.6	6.4	5.9	16.8	6.4	10.0
Degraded (-)	7.7	1.8	2.7	12.3	2.7	5.5
Change	+10.9	+4.5	+3.2	+4.5	+3.6	+4.5
OGSI 200:						
Improved (+)	7.7	5.0	8.2	4.5	3.6	0.0
Degraded (-)	5.0	7.3	10.0	6.8	3.2	2.3
Change	+2.7	-2.3	-1.8	-2.3	+0.4	-2.3

OGSI = old-growth structure index.

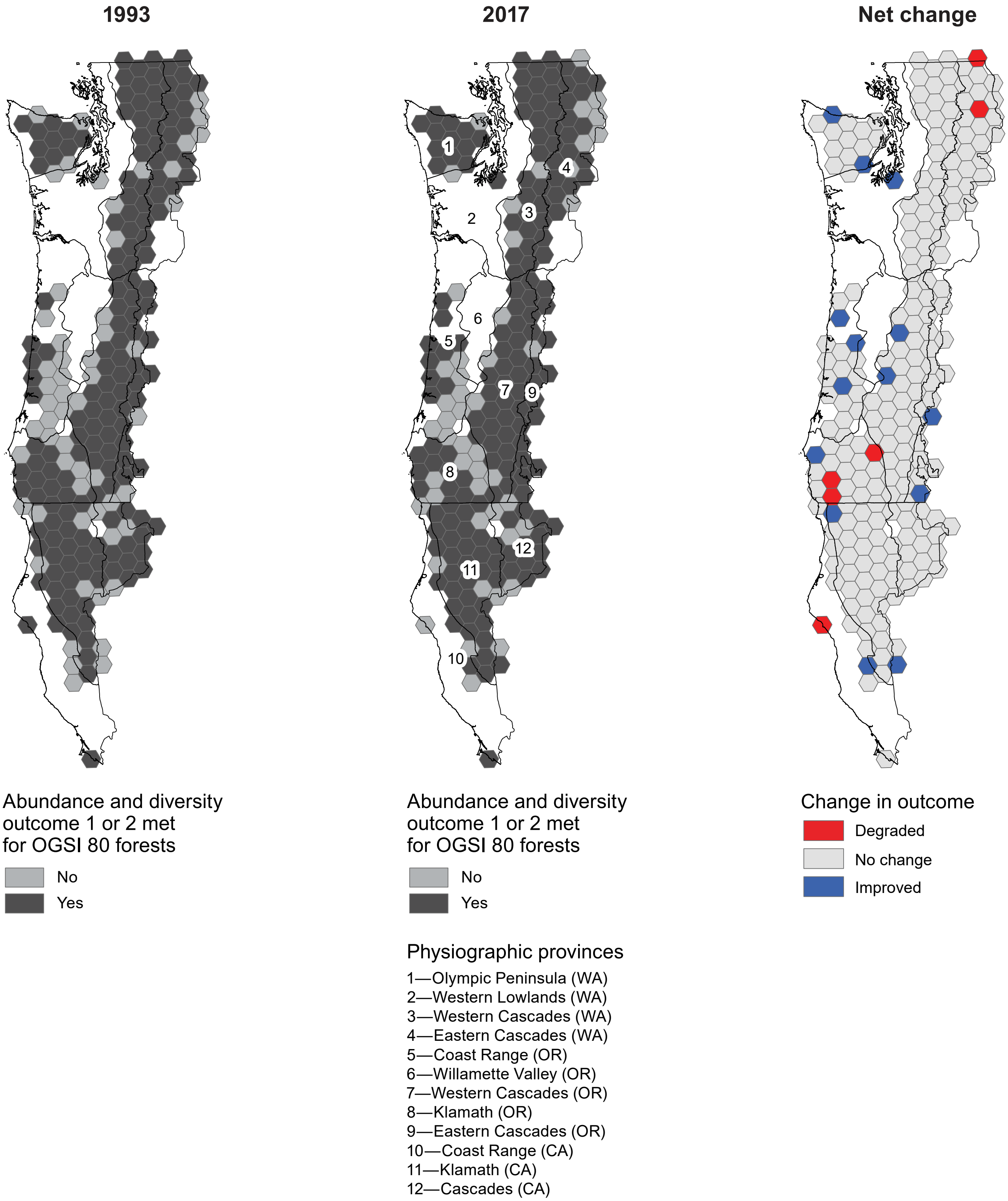

Figure 18—Geographical patterns of status and change for older forest (old-growth structure index [OGSI] 80) abundance and diversity outcome objectives.

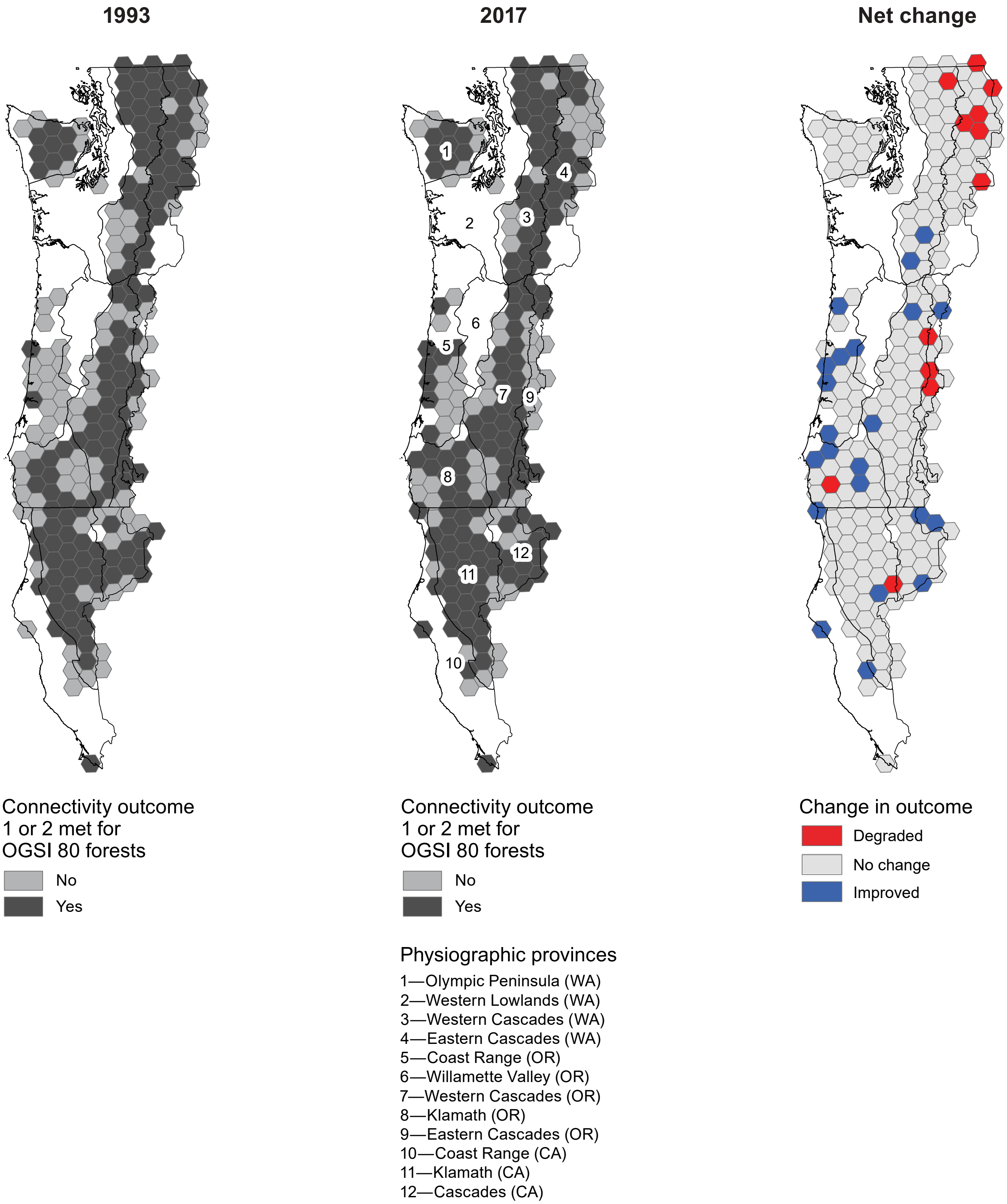

Figure 19—Geographical patterns of status and change for older forest (old-growth structure index [OGSI] 80) connectivity outcome objectives.

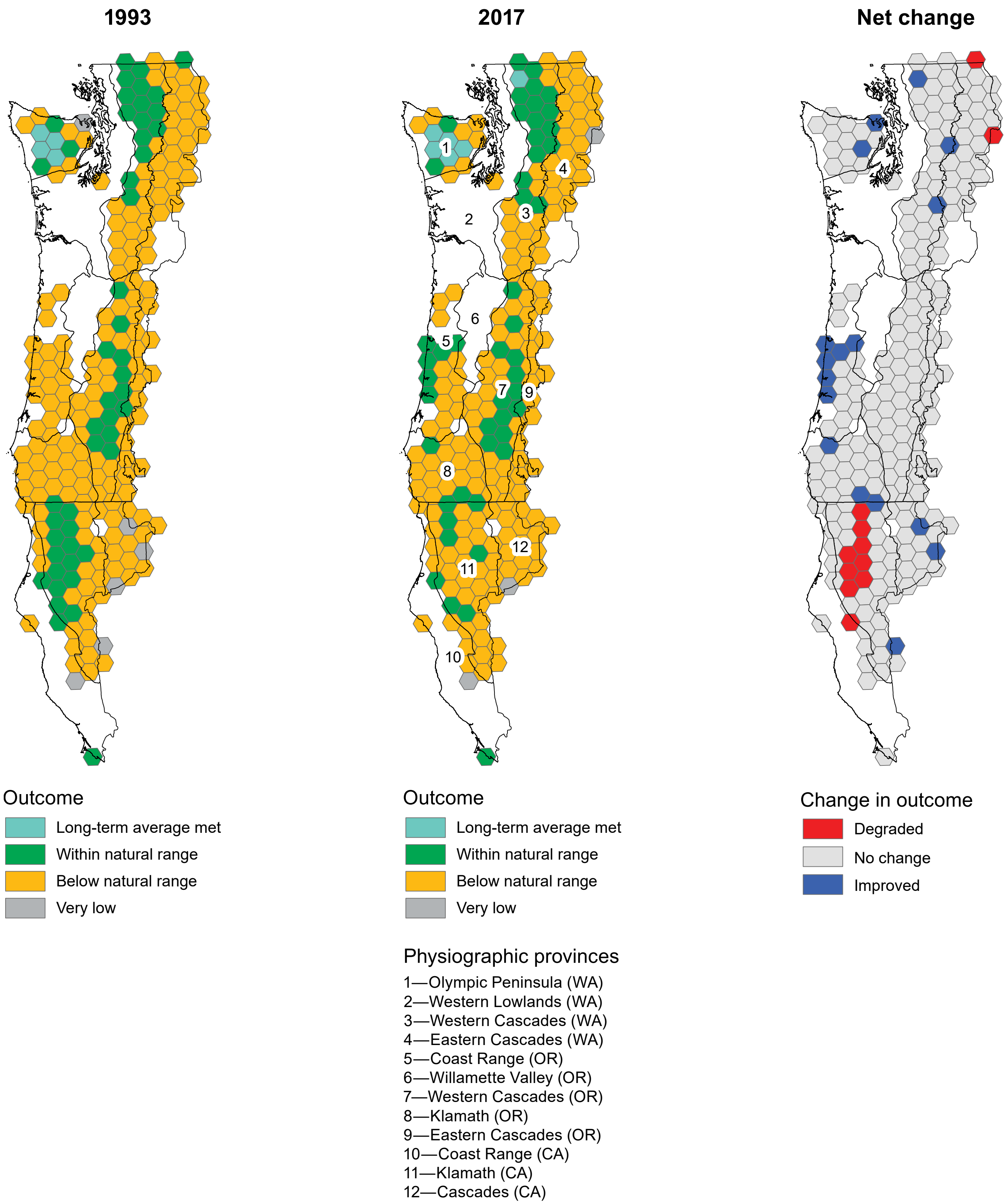

Figure 20—Geographical patterns of abundance as percentage of federal land covered by older forest (old-growth structure index 200).

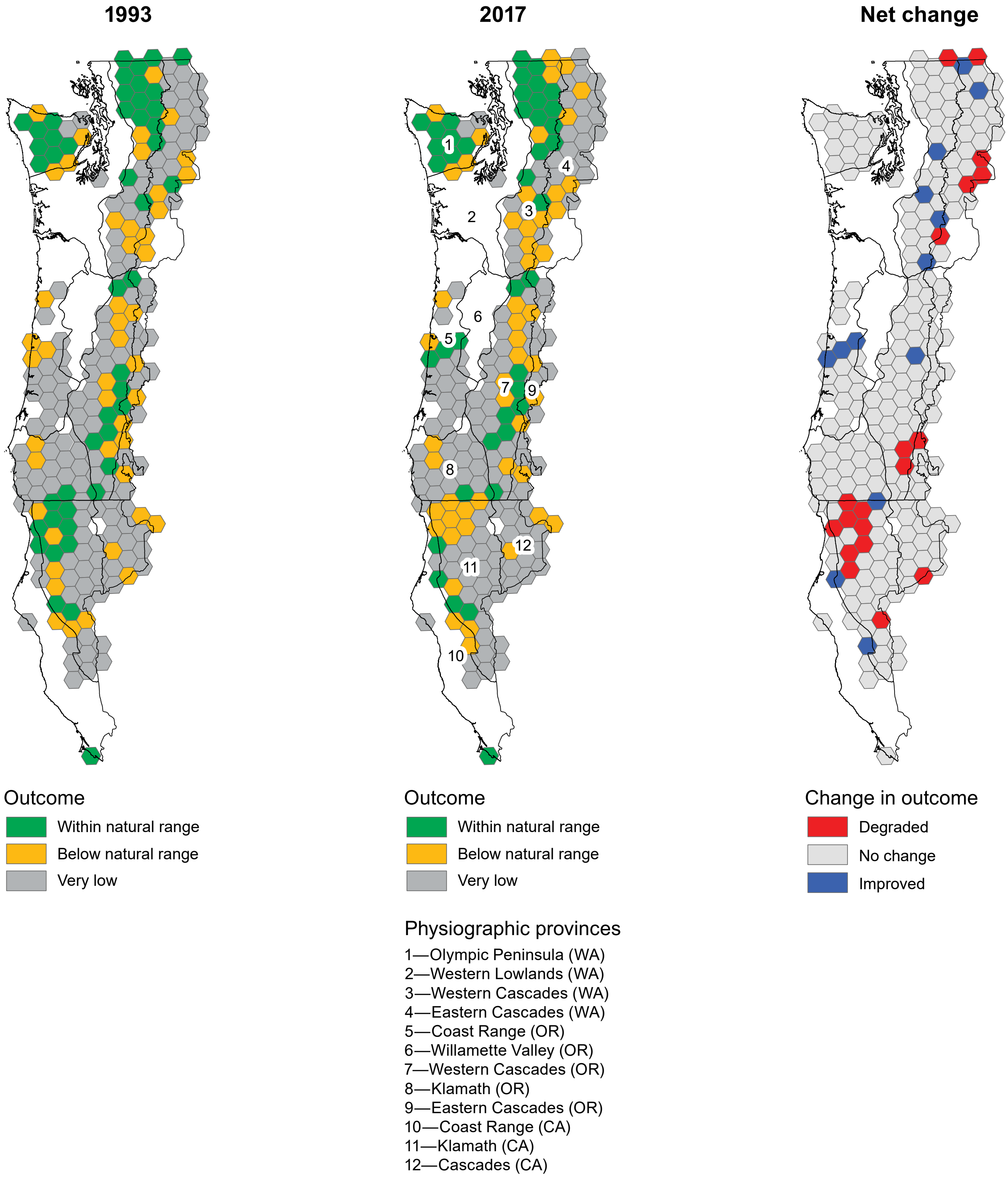

Figure 21—Geographical patterns of diversity as percentage of federal land in older forest (old-growth structure index 200) stands >1,000 ac in patch size.

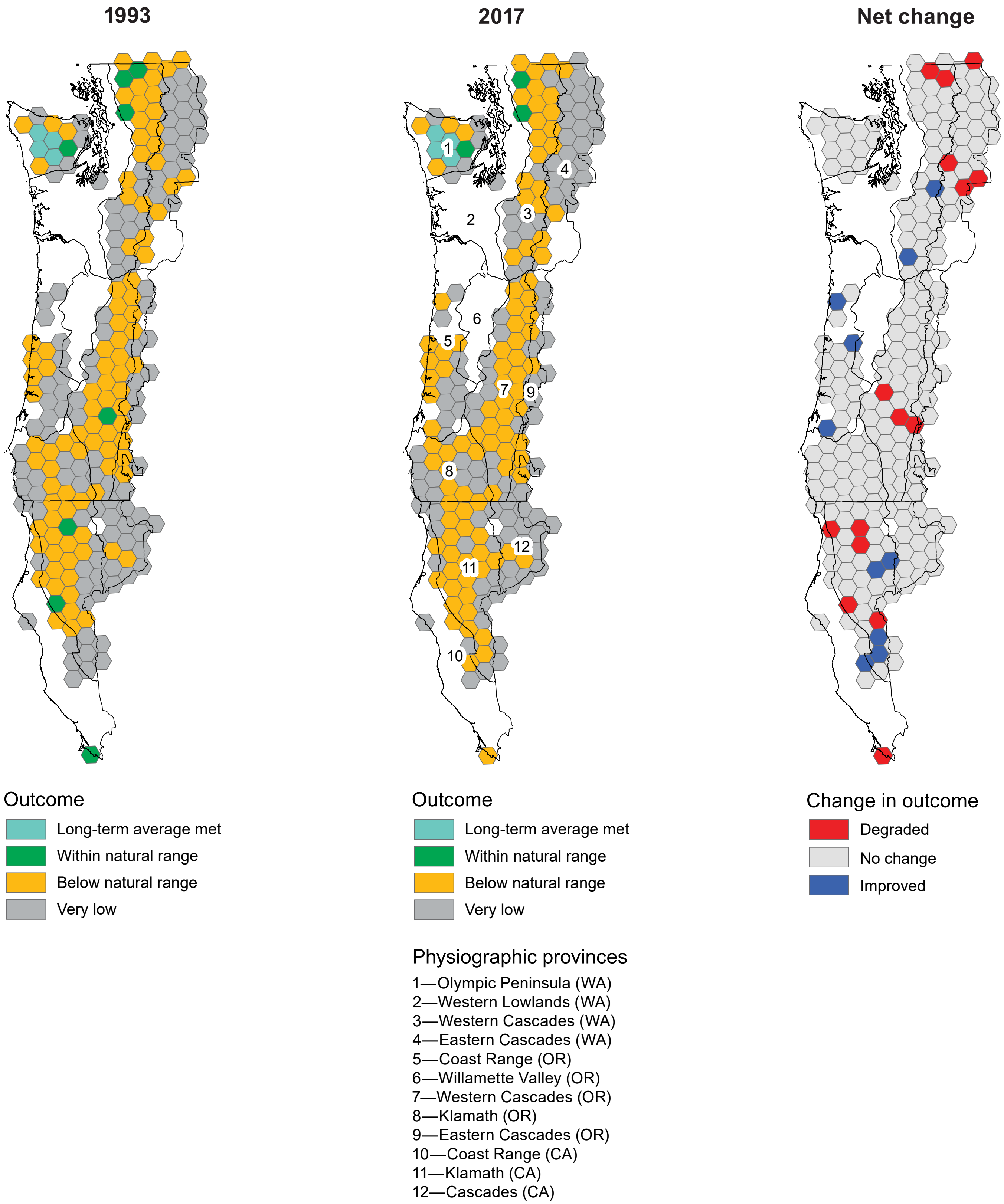

Figure 22—Geographical patterns of connectivity as average distance between old-forest stands of >1,000 ac (old-growth structure index 200).

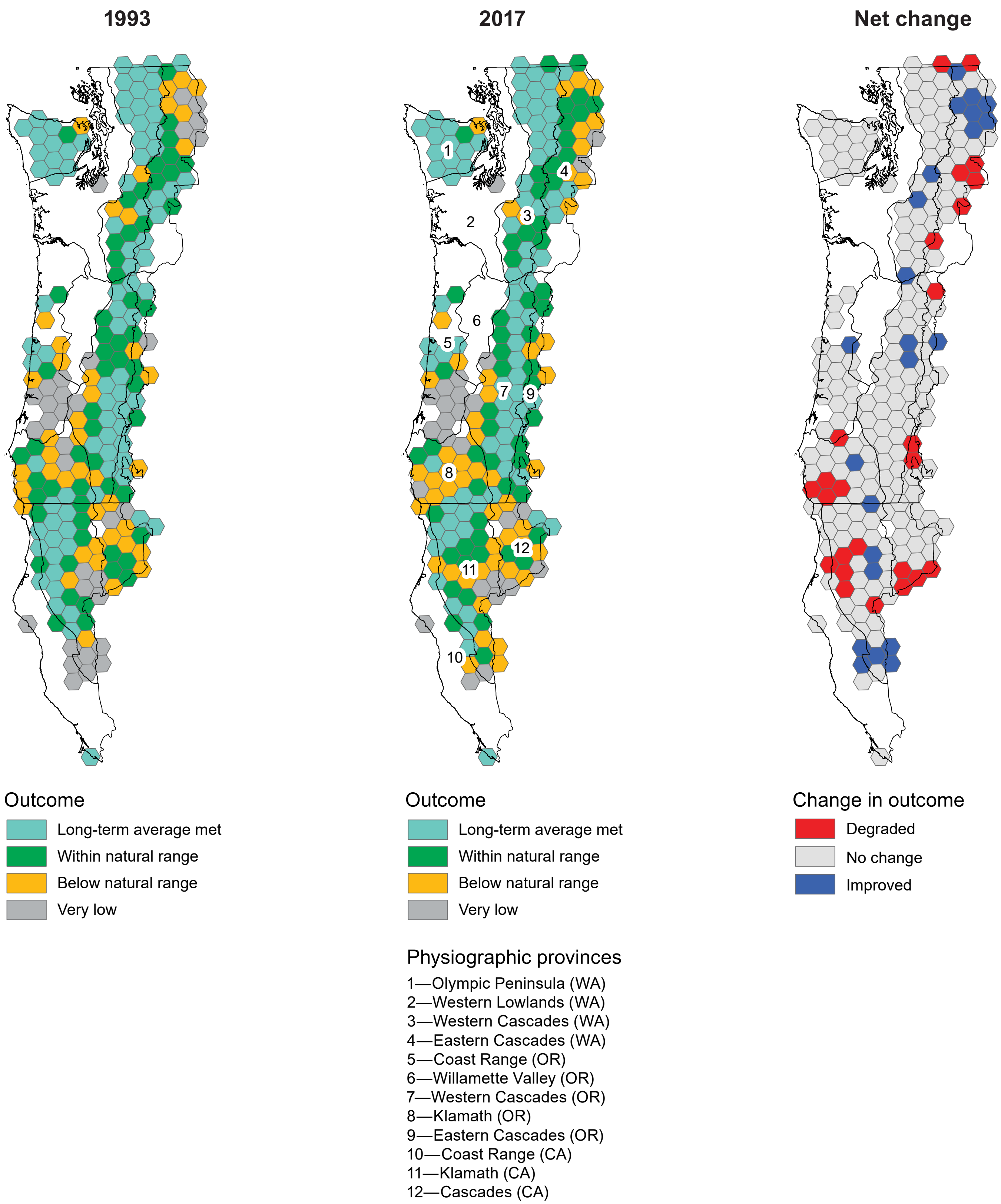

Figure 23—Geographical patterns of connectivity as percentage of federal land covered by old-forest stands (old-growth structure index 200).

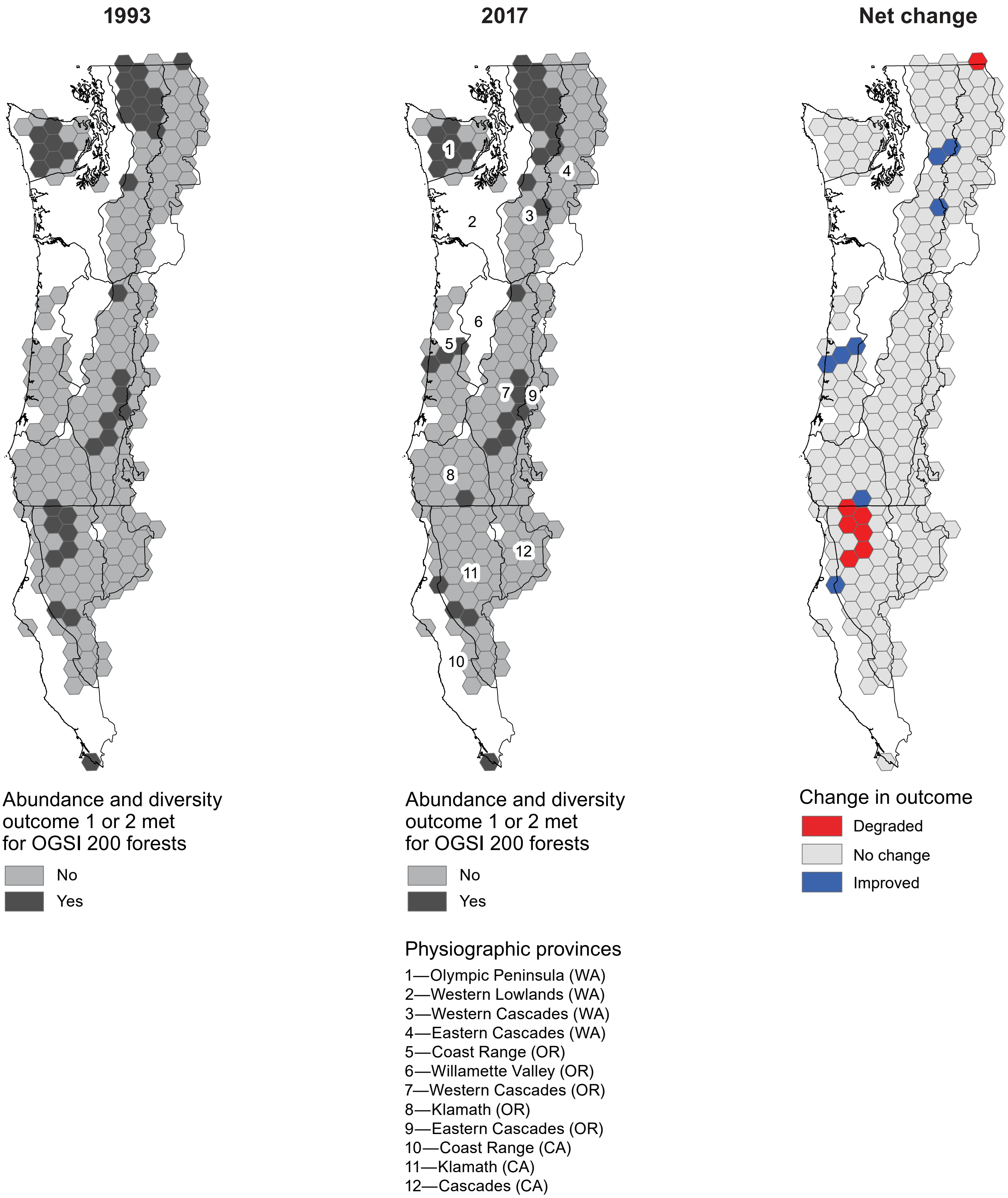

Figure 24—Geographical patterns of status and change for older forest (old-growth structure index [OGSI] 200) abundance and diversity outcome objectives.

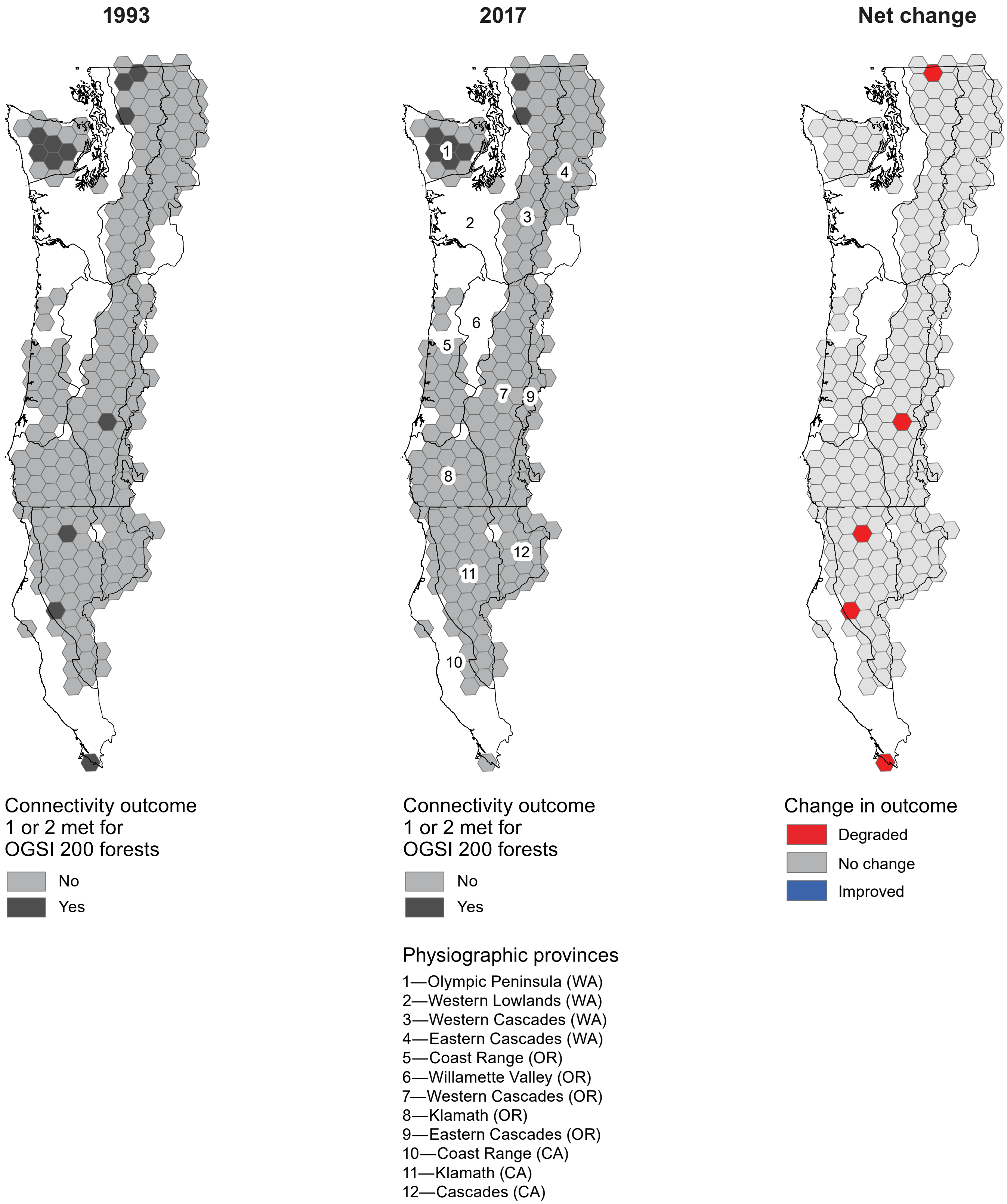

Figure 25—Geographical patterns of status and change for older forest (old-growth structure index [OGSI] 200) connectivity outcome objectives.

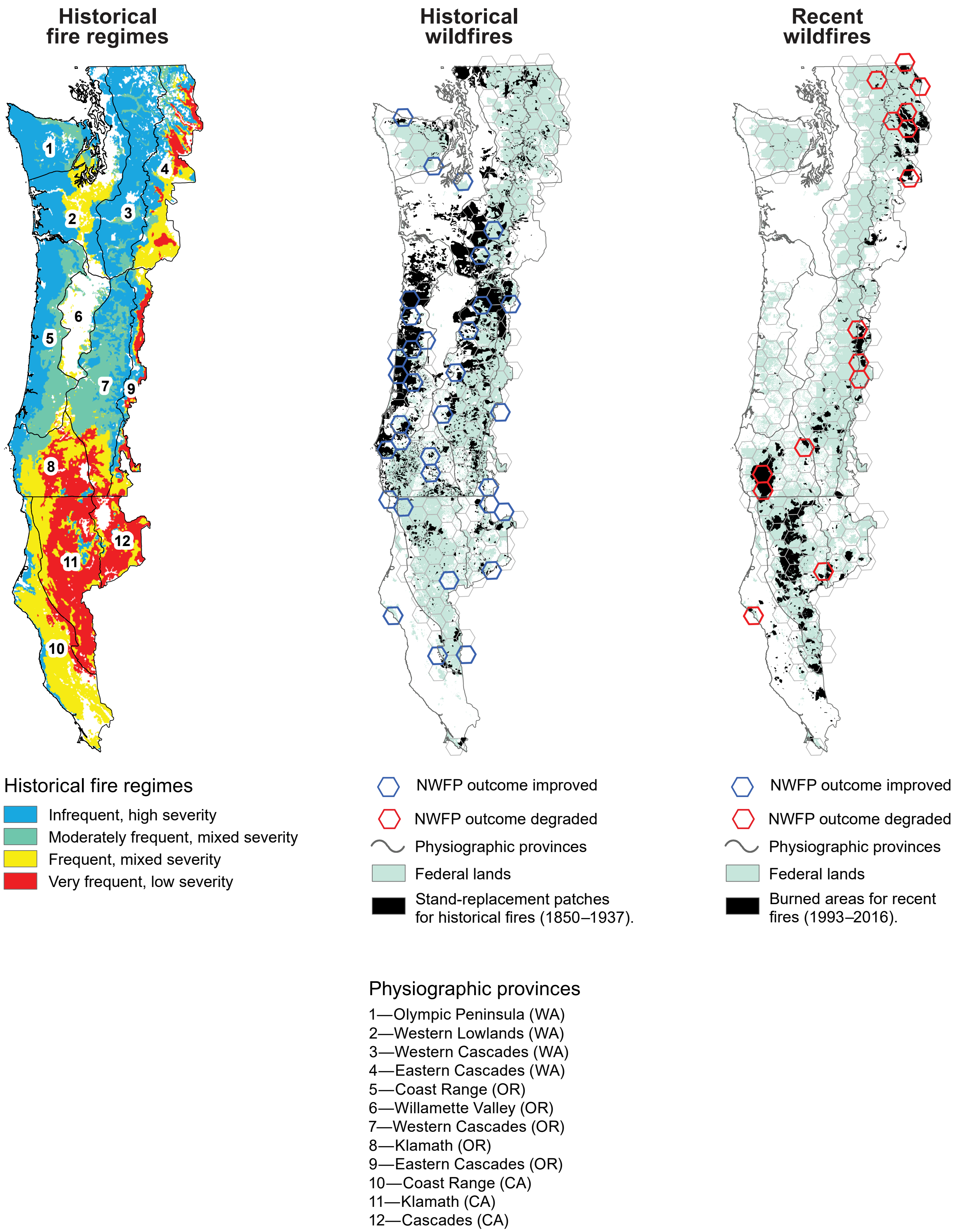

Figure 26—Patterns of change in older forest (old-growth structure index 80) abundance, diversity, or connectivity outcomes between 1993 and 2017 in relation to historical fire regimes, historical wildfires (late 1800s to early 1900s), and current wildfires (1993 to 2016). NWFP = Northwest Forest Plan.

Discussion

One of the goals of the NWFP is to maintain a functional older forest ecosystem on federally managed lands. Functionality was described in terms of abundance and diversity of older forest patches and their distribution across the region, such that they provide for well-distributed populations of older forest-dependent species and connectivity to maintain genetic flow between them (FEMAT 1993). Ecological processes that lead to the development and maintenance of this ecosystem, and those that set it back, were acknowledged. Two major NWFP geographic areas were recognized: (1) the moist provinces where forests grow faster and fires are less frequent, and (2) the dry provinces where forests grow slower and wildfires are more common. During the first quarter-century of NWFP implementation, monitoring indicated that, at the scale of the NWFP, abundance and diversity of older forests on federally managed lands increased slightly for mature and old-growth forests combined (OGSI 80), with a 3.6-percent net increase in the number of hexagons achieving this outcome, but remained relatively stable for old-growth forests (OGSI 200), showing a slight increase (+0.4 percent). The distribution and connectivity of mature and old-growth forests improved somewhat (4.5-percent net increase in hexagons achieving the connectivity outcome), but connectivity of old-growth forests (OGSI 200) decreased (2.3-percent net decrease in hexagons) as shown in table 4.

The rangewide story is one of losses in one geographic area being balanced by gains in another. In general, this pattern fits historical fire regimes for the NWFP area (Spies et al. 2018: chapter 3) and the two geographic regions described above (fig. 26). Most improved landscape-scale outcomes occurred within the western moister physiographic provinces and fire regimes with infrequent to moderately frequent historical fire regimes. Degraded outcomes were mainly observed in the eastern and southern dry provinces where wildfire occurrence is more frequent and historically more resistant to high-severity fires. However, contemporary wildfires in these fire regimes appear to be uncharacteristic of historical landscape dynamics, with increased areas of high-severity fire (Reilly et al. 2017, Spies et al. 2018). The NWFP acknowledged potential losses to wildfires in this area and designed LSRs to be large enough to incur wildfire effects and maintain functionality. Much of the improvement in these landscape indices (outcomes) occurred within the Oregon Coast Range physiographic province (and other areas) where federal forests had experienced large, stand-replacing wildfires from the mid-19th and early-20th centuries. Landscape conditions moving away from these desired outcomes are closely related to where contemporary, large wildfires have occurred (and continue to occur).

As we noted in the previous monitoring report (Davis et al. 2015), wildfire remained the leading cause for older forest losses on federal lands, accounting for about 70 percent of all losses since 1993 (fig. 27). Timber harvest was the second-largest cause of loss on federal lands and remained the primary cause of older forest losses on nonfederal lands. Insect, disease, and other disturbances (e.g., wind, floods, etc.) accounted for less than 10 percent of old-forest losses since 1993. The largest combined losses (all disturbances) occurred in Eastern Cascades and Klamath physiographic provinces and the southern half of the Oregon Western Cascades (fig. 28). Losses were offset by older forest recruitment in all physiographic provinces, but particularly in the moister provinces resulting in net gains of older forests. The Western Cascades of Oregon province occurs largely in the middle of the two regions

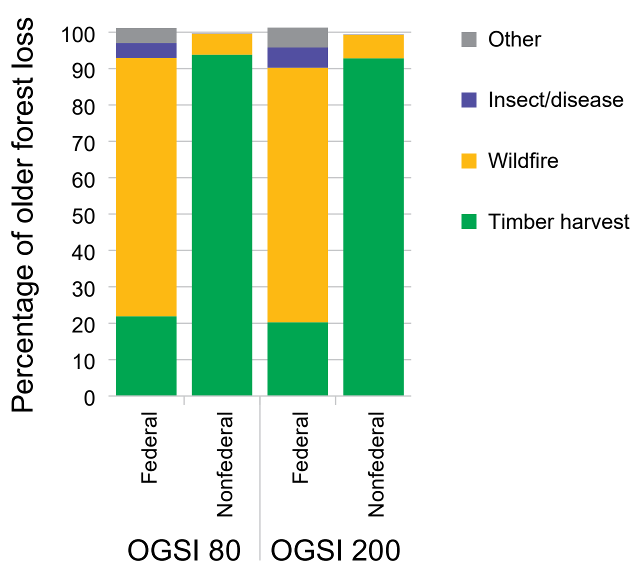

Figure 27—Landscape Change and Monitoring System-explained causes for losses of older forests between 1993 and 2017. OGSI = old-growth structure index.

described as “moist” and “dry.” It has qualities of both and falls mainly in the moderately frequent/mixed-severity fire regime. It incurred the fourth-largest gross loss of older forests from wildfire, yet had the second- to third-highest amount of older forest recruitment, resulting in a slight positive net change in OGSI 80 (+1.2 percent) and essentially no net change in OGSI 200 (fig. 28).

Losses of older forest caused by timber harvest prior to the NWFP have mainly been replaced by losses from wildfires (fig. 29). The annual amount of older forest losses from timber harvest on federal forests declined to 11 to 13 percent of what it was in 1988 and has remained fairly stable at about 5,000 to 10,000 ac per year, depending on the older forest definition. The frequency of large wildfire events that result in ≥75,000 ac of old-forest losses has increased during the last half of this monitoring cycle (fig. 29). Older forest losses on federal lands owing to insect and disease were usually <2,500 ac per year and appeared to increase and peak during the 1996 to 2008 time period (fig. 29). Other disturbances accounted (on average) for <2,000 ac of annual losses.

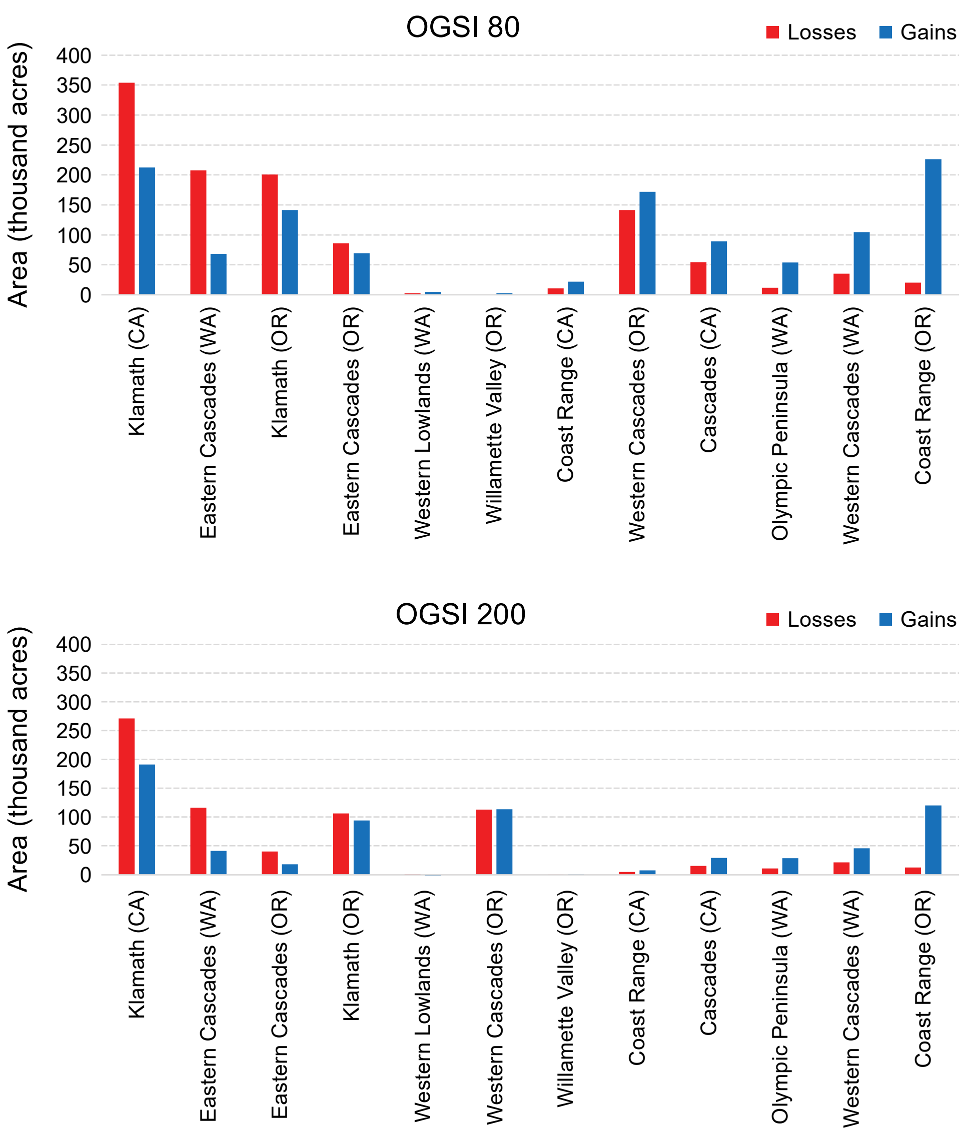

Figure 28—Losses (explained by the Landscape Change and Monitoring System) and gains in older forests on federally managed lands. Physiographic provinces are sorted by net change in ascending order (largest net losses on the left to largest net gains on the right). OGSI = old-growth structure index.

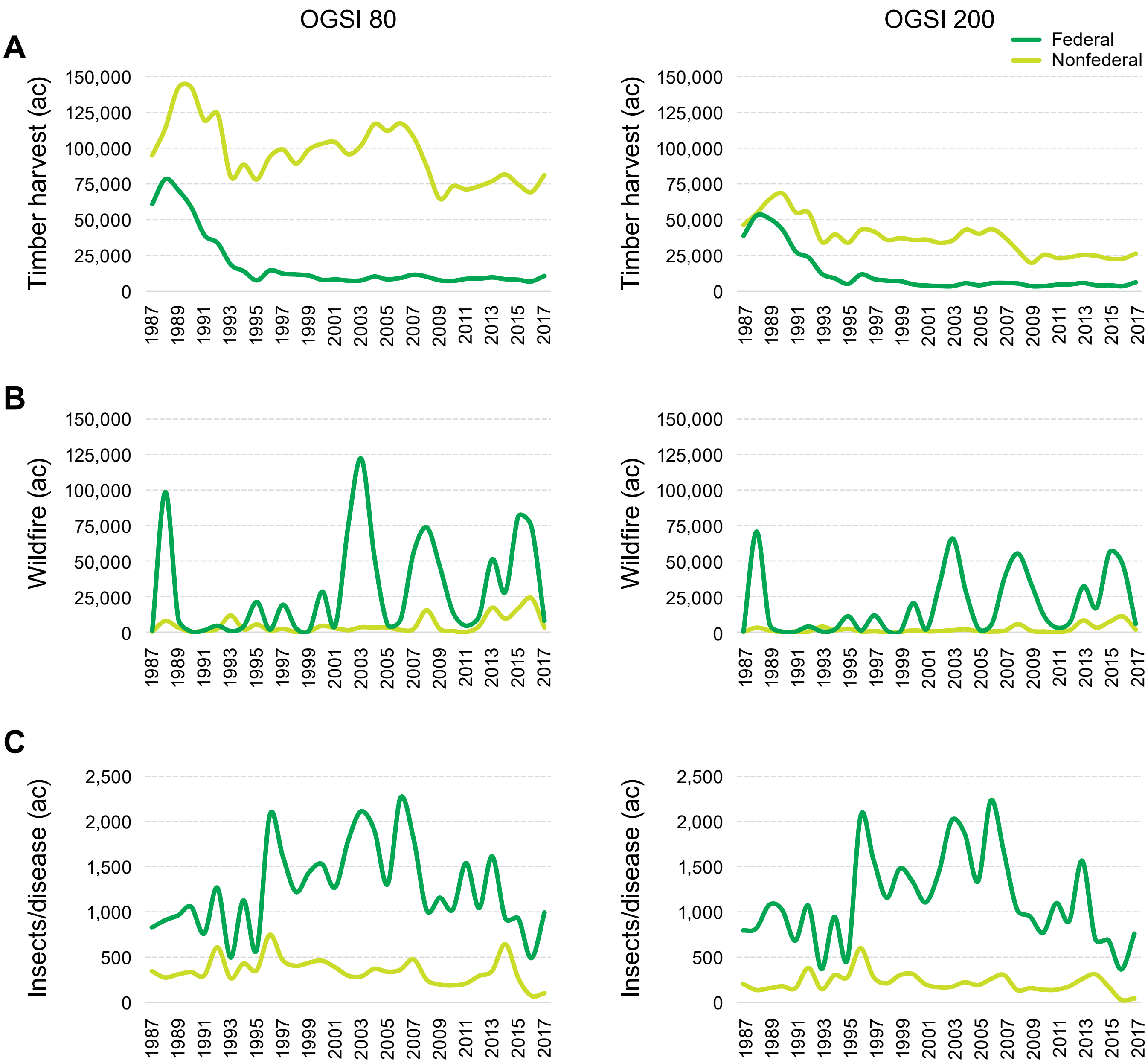

Figure 29—Trends in older forest mapped losses on federal and nonfederal forest lands by, wildfire, timber harvest, and insects and disease. OGSI = old-growth structure index.

Trends in severity (severity in terms of live-tree basal area removed) (see Reilly et al. 2017) of older forest disturbances on federally managed lands varied between disturbance agent (fig. 30). For all disturbance types, moderate and high severity account for most of the older forest losses. Low to moderate disturbances modify stand structure but do not always equate to losses. There was no apparent trend over time in wildfire severity in older forests, where high severity accounted for 35 ± 4 percent of the annual area burned (95-percent confidence intervals), moderate severity 47 ± 3 percent, and low severity 18 ± 3 percent across the study period (fig. 30). Timber harvest showed a rapid decrease in high severity (e.g., regeneration harvesting) between 1986 and 1994, and a concurrent increase in proportion of low severity (e.g., light thinning). Since 1996, the trend in light thinning has been slightly decreasing, and most current harvesting appears to be evenly split between light and moderate thinning, with

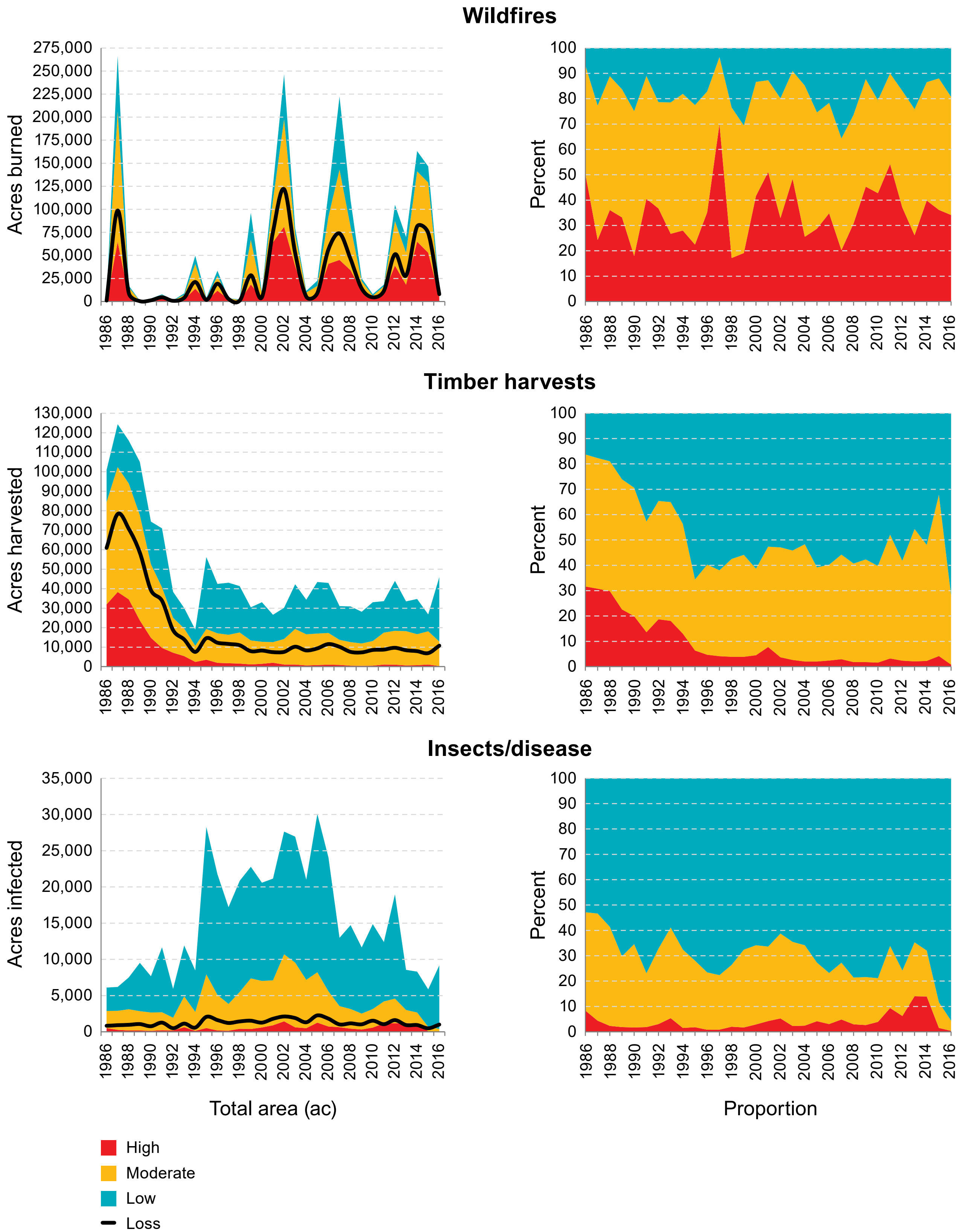

Figure 30—Explained losses of older forest (old-growth structure index 80) on federal lands in relationship to disturbance severity.

some high severity, likely in the form of small gaps. Insect and disease disturbance is mainly of low to moderate severity and showed an increasing proportion of older forest disturbed by low severity through time.

The effectiveness monitoring plan (Hemstrom et al. 1998) called for two perspectives of older forests, one from remotely sensed data at the landscape scale and one from plot data at the stand scale. The former now allows for producing annual maps to detect changes in amounts and spatial patterns, and the latter for understanding the components of change in forest structure and composition over a 10-year period (app. 2). For our bookend analyses, because the plot data only date back to 2001 (2002 in Washington), we relied on our map estimates to account for the complete trend (1986–2017) in the amounts of older forest. However, because we produced annual maps, we compared mapped estimates with plot estimates for the mid-point years for the “2000s” plot measurement period (2003) and the “2010s” plot measurement period (2013).

Map estimates for OGSI 200 on federal forests were on average within 55,000 to 90,000 ac of plot estimates at the state and physiographic province scales (app. 1, table A1-1). For OGSI 80 on federal forests, map estimates were on average about 50,000 ac from plot estimates at the physiographic province scale, but around 170,000 ac at the state scale. In all cases, these map estimates were within the margin of error from plot estimates (app. 1). These results are consistent with previous research showing that GNN maps produce similar estimates of classified areas at physiographic province scales (Pierce et al. 2009). Map estimates for older forests on nonfederal lands were less frequently within plot error bounds, but we note that the contiguous mapped estimates were closer to plot estimates in these forest lands, where older forests are less abundant and more fragmented.

The close similarities between mapped vs. plot estimates at two different time periods provided assurance that the mapped surfaces used in this report allowed for a realistic (e.g., mapped conditions match ground conditions) look back in time and across the NWFP area landscape that would not be possible with only plot-based estimates. This achieves the multiperspective monitoring objective outlined by Hemstrom et al. (1998).

Uncertainty

Using remotely sensed vegetation maps and forest inventory data as the basis for monitoring requires a clear understanding of their inherent uncertainties, as discussed in previous NWFP monitoring reports. Vegetation maps are produced using statistical models based on, in part, remote sensing and forest inventory data, both of which include their own errors. Some of those errors are well documented, such as the spectral saturation associated with relating Landsat multispectral imagery to forest biomass measurements (Foody et al. 2003) or the estimation of forest biomass based on tree diameters (Clough et al. 2016). Here, we focus on two areas of uncertainty particularly important for monitoring: temporal consistency and mapping change.

As a basis for monitoring, data need to be consistent through time (e.g., related to patterns and drivers in the same way, regardless of year) to minimize the role of methodological artifacts in driving changes. Our use of temporally smoothed spectral indices generated by LCMS addresses temporal consistency because we used the trends in spectral indices, rather than the raw data, to build our vegetation models, making year-to-year variation in vegetation mapping a more reasonable representation of reality (Kennedy et al. 2018). Furthermore, the use of only FIA annual plots in our imputation process minimized mapped changes through time because of changes in forest inventory plot design. However, limiting our analysis to these plots also limited the time frame used for model fitting (2001–2016). As a result, we assumed that the relationships of remote sensing and environmental predictor variables with forest inventory response variables was stationary through time to map conditions prior to 2001. We could not account for potential errors caused by subtle shifts in spectral data, such as those observed for Landsat 5 as gradual changes in the satellite’s orbital path have caused erroneous detections of vegetation “browning” and underestimations of “greening” (Zhang and Roy 2016). However, in forested ecosystems, the impact of shifting spectral indices may be minimized by imagery stabilization procedures, such as the one used here (Schleeweis et al. 2016). Thus, though uncertainties associated with the construction of a time series of vegetation mapping data remain, we have taken several steps to maximize the temporal consistency of those maps.

Other previously noted sources of error or uncertainty include regeneration harvest edges, which often have substantial shadowing, sometimes resulting in erroneous gains or losses of older forest along disturbance margins (Davis et al. 2015). We have also observed a tendency for GNN to predict increasing older forest characteristics after forest thinning disturbances. In many cases, this may be a result of the elevated frequency of canopy gaps and shadows generating confusing remote sensing signals instead of an actual increase in old-growth structure. Likewise, we have observed that rapid ground vegetation reestablishment (green up) in forest stand-replacement events (e.g., high-severity fire) can also result in apparent rapid gains in older forest. For this monitoring report, we used high-severity disturbance maps to mask out these rapid-recovery events. In other words, once a stand-replacing event affected a pixel, it could not be tallied as "older forest" following the disturbance event, given that it takes more than three decades (the temporal span of our imagery) for a regenerated stand to redevelop into older forest.

For remotely sensed vegetation mapping to be used as a component in monitoring activities, changes in those vegetation maps should be accurate and coherent. Our imagery stabilization and integrated disturbance and vegetation mapping framework was explicitly designed to ensure that changes in forest attributes were consistent with disturbance and recovery processes occurring on the landscape (Kennedy et al. 2018, Ohmann et al. 2014). The fitted satellite imagery explicitly considers disturbance history for a given pixel, providing trends in spectral indices upon which vegetation mapping is generated, but does not preclude errors in the mapping of change. For example, aboveground live biomass change in California and Oregon was most accurate for disturbance with recovering forests exhibiting moderate accuracy and stable forests exhibiting little accuracy in change predictions (Battles et al. 2018). Furthermore, local-scale (e.g., tens to hundreds of hectares) map estimates can be quite error prone (Bell et al. 2015b), and one should be skeptical of forest vegetation changes that do not make ecological sense for plot- to stand-level areas of interest.

The image stabilization procedures used in this study were implemented to reduce temporal variation in the spectral characteristics of old forests, presumably reducing uncertainties in large-scale monitoring of older forests. However, stabilization may bias maps toward lesser accumulation of older forests because we applied stabilization to forests classified as OGSI 80 without observed disturbance. Therefore, OGSI 80 forests were unlikely to transition to OGSI 200 because their spectral data through time was stabilized. To gauge for that potential, we included both map- and plot-based estimations for comparison in this report, as we did in previous NWFP monitoring reports.

Conclusion

In the first quarter-century of the NWFP, the trend in older forests on federally managed lands was stable for the NWFP area on aggregate. However, this does not equate to a stable forested landscape as is evident in our maps of forest change and disturbances (figs. 10 through 12). The losses in drier, more fire-prone forests have been balanced by gains in moister forests, particularly where large, high-severity wildfires occurred more than a century ago. To date, the NWFP has been successful in maintaining and restoring the abundance, diversity, and connectivity of mature older forests (OGSI 80) on federal lands, but for older forests (OGSI 200) this has not been the case. With the exception of a 2.7-percent increase in the landscape-scale abundance outcome index (percentage of federal lands covered by older forest), the remaining outcomes were slightly degraded from what they were when the NWFP was implemented, but we are only one-quarter of the way through a 100-year objective. There were certainly many more forests having structure associated with 55- to 79-year-old stands than 175- to 199-year-old stands a quarter-century ago. As mean forest ages increase, despite reverses in areas sustaining stand-replacing fires, it stands to reason that gains in OGSI 200 should become more apparent. Thus, it is not surprising that we should see the restoration signal in the OGSI 80 class prior to the OGSI 200 class, which will take more time.

As reported in previous monitoring cycles, indications remain that the increasing occurrence of large wildfires on federal forests will pose a challenge to both maintenance and restoration of older forests. Although the status and trend was stable at the scale of the NWFP area, we noted negative provincial scale trends in older forest in the areas identified as "dry" largely because of wildfire, but we also note the same area has experienced most of the insect/disease-related losses. This should not come as a surprise to federal land managers, as the NWFP identified this area as having a lower likelihood of achieving the NWFP goal of well-distributed and connected older forests because of the risks of wildfire and insect outbreaks (USDA FS and USDI BLM 1994: B-5). The NWFP even included standards and guidelines that allowed for active forest management in LSRs of this region designed to aid in achieving this goal (USDA FS and USDI BLM 1994: app. B-6 and B-7).

Technical advances since the previous monitoring cycle have made it possible to produce improved maps of older forests, not just for the bookend years, but for all years since 1986, providing better context of old-forest trends preceding the NWFP. The amount of data produced in this latest monitoring effort was significantly larger than in prior efforts. This report is only a summary of those data. To make these data more useful for forest managers, regulatory agencies, and the public, we have produced Web-based applications that allow users to view, interpret, and access the data (https://www.fs.usda.gov/r6/reo/monitoring). These data should prove valuable for researchers in their exploration of the forest and disturbance ecology of the Pacific Northwest.

Acknowledgments

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Acres (ac)	0.405	Hectares (ha)
Miles (mi)	1.61	Kilometers

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Appendix 1: Differences Between Forest Inventory Plot and Remotely Sensed Map Estimates

Table A1-1—Summary of differences between map and plot estimates (e.g., map area minus plot area)

	OGSI 80						OGSI 200					
	2003			2013			2003			2013		
Geographic area	Fed	Nonfed	All	Fed	Nonfed	All	Fed	Nonfed	All	Fed	Nonfed	All
	Thousand acres											
Northwest Forest Plan	-517.6	1,080.3	**562.7**	-519.6	689.5	**169.9**	**166.7**	**-90.3**	-782.1	**-251.0**	**-139.5**	**-331.1**
Washington	**-195.9**	272.5	**76.7**	**-174.8**	**186.5**	**11.7**	**88.1**	**-88.0**	**-176.1**	**-149.0**	-16.6	**132.4**
Oregon	**-113.4**	525.9	412.5	**-129.3**	342.4	**213.1**	**60.0**	308.7	368.8	**8.6**	309.5	318.1
California	**-208.4**	282.0	**73.6**	**-215.5**	**160.7**	**-54.8**	**18.6**	218.7	**237.2**	**-110.6**	256.0	**145.4**
Washington Olympic Peninsula	**-35.1**	**31.5**	**-3.6**	**-21.6**	**2.3**	**-19.3**	**12.1**	**23.9**	**35.9**	**46.4**	**20.1**	**66.5**
Washington Western Cascades	**-60.5**	150.1	**89.6**	**-73.3**	**99.4**	**26.1**	**52.5**	95.1	**42.6**	**152.2**	**52.4**	**-99.7**
Washington Eastern Cascades	**-105.3**	**-6.8**	**-112.1**	**-71.4**	**58.1**	**-13.3**	**121.6**	**-12.5**	**109.1**	**-43.8**	**-36.9**	**-80.6**
Oregon Coast Range	**-90.4**	149.5	**59.1**	**-50.0**	**121.0**	**71.0**	**-29.6**	102.9	**73.3**	**-32.7**	100.1	**67.3**
Oregon Western Cascades	**17.1**	**48.8**	**163.4**	**-11.7**	**53.7**	**130.7**	**111.2**	57.9	**169.0**	**65.1**	84.6	**149.7**
Oregon Klamath	**2.0**	178.7	180.7	**5.8**	**68.9**	**74.7**	**45.3**	129.1	174.4	**63.6**	124.0	187.6
Oregon Eastern Cascades	**-48.5**	**7.9**	**-40.7**	**-80.6**	**19.3**	**-61.2**	**-68.2**	**-1.5**	**-69.7**	**-88.9**	**-7.2**	**-96.0**
California Coast Range	**-49.5**	**123.5**	**74.0**	**-45.9**	**3.1**	**-42.8**	**25.8**	**67.4**	**93.2**	**3.0**	**83.6**	**86.6**
California Klamath	**-58.4**	**24.4**	**-34.1**	**-40.8**	**69.9**	**29.0**	**73.1**	**62.7**	**135.8**	**-10.5**	113.5	**102.9**
California Cascades	**-100.5**	134.1	**33.6**	**-128.8**	**87.7**	**-41.1**	**-80.3**	88.5	**8.2**	**-103.0**	58.9	**-44.1**

Bold numbers indicate that mapped estimates were within the 95-percent confidence intervals of plot estimates. Fed = federal; nonfed = nonfederal. OGSI = Old-growth structure index.

Appendix 2: Components of Change in Remeasured Forest Inventory Plots

Forest inventory ground plot remeasurement data provide some insight into understanding mechanisms of forest successional change from younger forest stages into late-successional and old-growth characteristics. However, given the length of time (decades to centuries) needed for younger forests to develop into older forests and the current short interval between plot measurements in place, we are currently limited to those stands that structurally existed at the margins of the thresholds that separate the two.

Methods

The plot-based analysis used Forest Inventory and Analysis (FIA) plots installed on forestland across all ownerships using standard national and regional field procedures. Plots were installed beginning in 2001 across the Northwest Forest Plan (NWFP) area and remeasured starting in 2011. We analyzed the subset of plots that had been installed and remeasured using the same procedures. For California and Oregon, this consisted of plots installed in 2001–2006 and remeasured in 2011–2016; for Washington, it consisted of plots installed in 2002–2006 and remeasured in 2012–2016 (the new inventory was started a year later in Washington). In the results, the first measurement is referred to as "2000s" and the second measurement is referred to as "2010s." There were 5,920 FIA plots that sampled forestland and were installed and remeasured within the NWFP area between 2001 and 2016.

The core national FIA plot density is one plot per 6,000 ac, measured over a 10-year period in the West. Our analysis therefore uses six-tenths of the plots in California and Oregon, and five-tenths (one-half) of the plots in Washington. However, the same procedures were also used on a spatially intensified grid of plots on National Forest System lands outside wilderness (one plot per 1,580 ac) in the U.S. Department of Agriculture (USDA), Forest Service's Pacific Northwest Region, so the remeasured subset (six-tenths and one-half) were used for Oregon and Washington, respectively.

The FIA inventory uses poststratification to improve precision. We adjusted the post-stratification to match the total acres in each federal ownership within the NWFP area using the land use allocation (LUA) layer. Federal owners within NWFP LUAs consisted of the U.S. Department of the Interior (USDI), Bureau of Land Management in California and Oregon; the USDA Forest Service Pacific Northwest and Pacific Southwest Regions; and the USDI National Park Service. Some results are presented for all lands, which include other owners: state, local government, and private.

Results

Changes in old-growth structure index (OGSI) results from both forest succession and forest disturbances. The majority (70 percent) of plots on federal forests had no disturbance agent recorded, the remaining (30 percent) recorded some type of human or natural disturbance area between the 2000s and 2010s, for a disturbance rate of 3 percent per year (table A2-1). Federal forests overall experienced timber harvest at a higher rate than the subsets that were classified as OGSI 80 and OGSI 200 (stand ages ≥80 and ≥200, respectively) in the 2000s (see fig. 5). On the other hand, fire and insects and disease tended to be more common on the OGSI forests. Timber harvest had little effect on OGSI status, with the OGSI 80 area remaining the same and only a 3,000-ac net loss in the OGSI 200 class. The effects of fire were relatively modest and reduced the area of OGSI 80 by 21 percent and the area of OGSI 200 by 12 percent. In contrast, insects and disease resulted in 1 percent more area in OGSI 80 and 18 percent more area in OGSI 200.

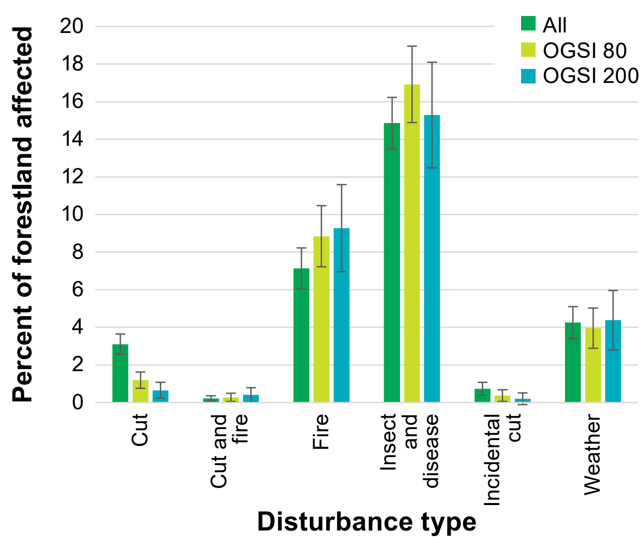

Figure A2-1—Percentage of forest land in different old-growth structure index (OGSI) categories in the 2000s that experienced different disturbances by the 2010s. Bars are 95-percent confidence intervals.

Table A2-1—Area of federal forest affected by disturbance and changes in old-growth structure index (OGSI) category 80 and OGSI 200

			OGSI 80				OGSI 200			
Disturbance	**Forest**	**Nonforest**	**2000s**	**SE**	**2010s**	**SE**	**2000s**	**SE**	**2010s**	**SE**
					Thousand acres					
None	15,845	2,015	9,032	222	9,489	226	4,819	179	5,414	186
Timber harvest	706	11	180	34	180	33	42	15	39	11
Fire	1,622	35	1,157	108	914	95	567	77	498	73
Timber harvest and fire	51	0	35	14	34	14	26	14	9	5
Incidental cut	167	3	49	21	68	25	14	11	27	16
Insect and disease	3,380	13	2,230	138	2,251	137	1,070	100	1,267	109
Weather	968	64	514	72	539	73	285	55	306	52

SE = standard error.

Table A2-2—Mean changes in old-growth structure index (OGSI) component scores by change in OGSI 200 status

OGSI 200 threshold met		Mean change in OGSI and component scores				
2000s	**2010s**	**OGSI**	**Live tree**	**Snags**	**CWD**	**DDI**
N	N	1.7	1.8	1.9	-1.6	4.5
Y	N	-20.6	-13.3	-15.0	-35.6	-12.2
N	Y	28.6	22.0	36.2	37.4	13.8
Y	Y	1.0	1.3	2.9	-0.5	0.3

CWD = coarse woody debris; DDI = diameter diversity index.

Table A2-3—Matrix of change between old-growth structure index (OGSI) classes in millions of acres

OGSI class in 2000s	OGSI class in 2010s				
	<80	80	120	160	200
<80	24.2	1.6	0.8	0.3	0.2
80	0.9	1.4	0.9	0.3	0.2
120	0.6	0.6	1.1	0.7	0.7
160	0.2	0.1	0.3	1.0	0.9
200	0.3	0.1	0.2	0.6	6.7

No change
Loss of older forest
Gain in older forest
Transition from one older forest to another

The majority (75 percent) of older forest losses occurred in the OGSI 80 and 120 classes. Likewise, the majority (83 percent) of gains occurred in the same classes.

Federal forest lands that qualified as OGSI 200 in the 2000s and did not in the 2010s lost 21 points (out of 100) in the OGSI on average; scores declined across all components and for the coarse woody debris (CWD) component in particular (table A2-2). Lands that did not qualify as OGSI 200 in the 2000s and did in the 2010s gained 29 points in the OGSI on average; gains were seen in all components and for the snag and CWD components in particular.

The OGSI scores are based on equal weighting of four different stand structure components that in turn are based on plot-based samples of finite areas. Although in theory relatively undisturbed stands should increase steadily in OGSI score and class, small or large disturbances do occur, and stands that are near a threshold between one class and another can move in either direction based on the loss or gain of a small number of snags or logs on the sample plot. Although there were instances of large changes in OGSI status (e.g., 200,000 ac that changed from OSGI 80 in the 2000s to OGSI 200 in the 2010s), most of the time, the majority of acres in a class were either in the class previously or changed from the next closest class (table A2-3).

The majority (75 percent) of older forest losses occurred in the OGSI 80 and 120 classes. Likewise, the majority (83 percent) of gains occurred in the same classes.

Appendix 3: Bookend Analysis Summary Tables

Table A3-1—Bookend map area estimates of old forests (OGSI 80) on federal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	865.8	907.8	42.0	4.9	3.0	3.3	0.4	5.2	11.8	-1.4
Western Lowlands	30.4	32.4	2.0	6.6	2.7	0.0	0.0	0.0	2.7	-8.9
Western Cascades	1,765.2	1,834.5	69.3	3.9	14.2	6.2	2.7	12.1	35.2	-2.0
Eastern Cascades	1,556.5	1,416.9	-139.6	-9.0	27.9	154.0	14.7	11.3	207.9	-13.4
Total	4,217.9	4,191.6	-26.3	-0.6	47.8	163.5	17.8	28.6	257.7	-6.1
Oregon:										
Coast Range	532.3	738.7	206.4	38.8	19.7	0.2	0.0	0.0	20.0	-3.8
Willamette Valley	5.7	8.0	2.3	40.4	0.5	0.0	0.0	0.0	0.5	-8.8
Western Cascades	2,593.7	2,624.6	30.9	1.2	53.4	79.1	3.7	5.0	141.2	-5.4
Klamath	1,174.3	1,115.0	-59.3	-5.0	28.6	171.1	0.2	1.0	200.7	-17.1
Eastern Cascades	792.0	775.2	-16.8	-2.1	29.0	45.7	7.8	3.5	86.1	-10.9
Total	5,098.0	5,261.5	163.5	3.2	131.2	296.1	11.6	9.5	448.5	-8.8
California:										
Coast Range	158.9	169.9	11.0	6.9	2.5	8.0	0.0	0.2	10.7	-6.8
Klamath	2,751.1	2,609.8	-141.3	-5.1	31.4	311.8	2.8	7.9	354.0	-12.9
Cascades	572.8	607.8	35.0	6.1	33.8	19.2	1.1	0.2	54.2	-9.5
Total	3,482.8	3,387.5	-95.3	-2.7	67.7	339.0	3.9	8.3	418.9	-12.0
NWFP total	12,798.7	12,840.6	41.9	0.3	246.7	798.7	33.3	46.4	1,125.1	-8.8

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Table A3-2— Bookend map area estimates of old forests (OGSI 80) on reserved federal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	840.5	870.3	29.7	3.5	2.0	3.3	0.4	5.2	10.9	-1.3
Western Lowlands	30.2	32.2	2.0	6.5	2.7	0.0	0.0	0.0	2.7	-9.0
Western Cascades	1,488.8	1,522.9	34.1	2.3	6.9	6.2	2.6	12.1	27.9	-1.9
Eastern Cascades	1,238.3	1,098.3	-140.0	-11.3	13.1	135.3	12.6	11.2	172.2	-13.9
Total	3,597.8	3,523.7	-74.2	-2.1	24.8	144.8	15.7	28.4	213.7	-5.9
Oregon:										
Coast Range	468.4	618.5	150.1	32.0	12.6	0.2	0.0	0.0	12.8	-2.7
Willamette Valley	1.5	2.1	0.6	38.1	0.1	0.0	0.0	0.0	0.1	-7.9
Western Cascades	1,628.3	1,603.1	-25.1	-1.5	13.9	64.6	3.0	4.8	86.3	-5.3
Klamath	835.4	765.7	-69.7	-8.3	12.4	144.6	0.1	0.9	157.9	-18.9
Eastern Cascades	536.8	508.9	-27.9	-5.2	9.0	34.4	5.4	3.2	52.1	-9.7
Total	3,470.4	3,498.3	27.9	0.8	48.0	243.7	8.4	9.0	309.1	-8.9
California:										
Coast Range	129.4	138.8	9.5	7.3	1.6	6.5	0.0	0.2	8.3	-6.4
Klamath	1,819.1	1,676.6	-142.5	-7.8	9.4	216.2	2.4	7.8	235.9	-13.0
Cascades	248.7	254.3	5.6	2.2	5.4	8.7	0.4	0.1	14.7	-5.9
Total	2,197.2	2,069.7	-127.5	-5.8	16.4	231.4	2.8	8.2	258.8	-11.8
NWFP total	9,265.4	9,091.7	-173.7	-1.9	89.2	619.9	26.9	45.6	781.7	-8.4

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Table A3-3— Bookend map area estimates of old forests (OGSI 80) on nonfederal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

State and physiographic province	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	196.0	211.2	15.2	7.8	105.0	0.0	0.4	0.1	105.5	-53.8
Western Lowlands	574.6	517.4	-57.2	-10.0	347.4	0.0	0.5	0.0	348.0	-60.6
Western Cascades	520.2	462.3	-57.9	-11.1	207.9	0.4	0.3	0.0	208.6	-40.1
Eastern Cascades	743.2	598.7	-144.5	-19.4	191.7	34.5	3.1	0.1	229.4	-30.9
Total	2,034.0	1,789.6	-244.4	-12.0	852.0	35.0	4.3	0.2	891.5	-43.8
Oregon:										
Coast Range	602.3	750.2	147.9	24.6	432.4	0.3	0.5	0.0	433.2	-71.9
Willamette Valley	118.2	125.9	7.7	6.5	52.1	0.0	0.1	0.0	52.2	-44.2
Western Cascades	455.3	330.9	-124.4	-27.3	268.2	2.9	0.3	0.0	271.5	-59.6
Klamath	384.7	383.4	-1.3	-0.3	168.0	10.2	0.3	0.1	178.5	-46.4
Eastern Cascades	247.2	190.2	-57.0	-23.1	88.1	17.9	1.3	0.2	107.5	-43.5
Total	1,807.7	1,780.6	-27.1	-1.5	1,008.9	31.3	2.5	0.3	1,043.0	-57.7
California:										
Coast Range	1,135.9	1,247.1	111.2	9.8	189.0	17.7	0.1	0.0	206.8	-18.2
Klamath	508.8	533.8	25.0	4.9	88.8	29.5	0.5	0.1	118.8	-23.4
Cascades	471.4	432.6	-38.8	-8.2	103.3	25.0	1.3	0.0	129.6	-27.5
Total	2,116.1	2,213.5	97.4	4.6	381.1	72.2	1.9	0.1	455.2	-21.5
NWFP total	5,957.8	5,783.7	-174.1	-2.9	2,242.0	138.4	8.7	0.6	2,389.7	-40.1

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Table A3-4— Bookend map area estimates of old forests (OGSI 80) on all lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

State and physiographic province	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	1,061.8	1,119.0	57.2	5.4	108.0	3.3	0.8	5.2	117.4	-11.1
Western Lowlands	605.0	549.8	-55.2	-9.1	350.1	0.0	0.5	0.0	350.7	-58.0
Western Cascades	2,285.4	2,296.8	11.4	0.5	222.1	6.6	2.9	12.1	243.9	-10.7
Eastern Cascades	2,299.7	2,015.6	-284.1	-12.4	219.6	188.5	17.8	11.4	437.3	-19.0
Total	6,251.9	5,981.2	-270.7	-4.3	899.8	198.5	22.1	28.8	1,149.2	-18.4
Oregon:										
Coast Range	1,134.6	1,488.9	354.3	31.2	452.1	0.5	0.5	0.0	453.2	-39.9
Willamette Valley	123.9	133.9	10.0	8.1	52.6	0.0	0.1	0.0	52.7	-42.5
Western Cascades	3,049.0	2,955.5	-93.5	-3.1	321.6	82.1	4.0	5.0	412.7	-13.5
Klamath	1,559.0	1,498.4	-60.6	-3.9	196.5	181.3	0.4	1.0	379.3	-24.3
Eastern Cascades	1,039.2	965.4	-73.8	-7.1	117.1	63.6	9.1	3.7	193.5	-18.6
Total	6,905.7	7,042.1	136.4	2.0	1,140.1	327.4	14.1	9.8	1,491.5	-21.6
California:										
Coast Range	1,294.8	1,417.0	122.2	9.4	191.5	25.7	0.2	0.2	217.6	-16.8
Klamath	3,259.9	3,143.6	-116.3	-3.6	120.2	341.3	3.3	8.0	472.8	-14.5
Cascades	1,044.2	1,040.4	-3.8	-0.4	137.1	44.2	2.3	0.2	183.8	-17.6
Total	5,598.9	5,601.0	2.1	0.0	448.8	411.2	5.8	8.4	874.1	-15.6
NWFP total	18,756.5	18,624.3	-132.2	-0.7	2,488.7	937.1	42.0	47.0	3,514.8	-18.7

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Table A3-5— Bookend map area estimates of old forests (OGSI 200) on federal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	709.8	727.8	18.0	2.5	2.3	3.0	0.3	4.8	10.5	-1.5
Western Lowlands	8.0	5.5	-2.5	-31.3	0.6	0.0	0.0	0.0	0.6	-7.0
Western Cascades	1,128.1	1,152.5	24.4	2.2	8.9	3.5	1.6	7.4	21.4	-1.9
Eastern Cascades	661.7	586.8	-74.9	-11.3	17.6	74.3	14.4	9.8	116.1	-17.6
Total	2,507.6	2,472.6	-35.0	-1.4	29.3	80.8	16.3	22.1	148.6	-5.9
Oregon:										
Coast Range	354.2	461.7	107.5	30.4	12.3	0.1	0.0	0.0	12.5	-3.5
Willamette Valley	1.3	1.7	0.4	30.8	0.2	0.0	0.0	0.0	0.2	-11.6
Western Cascades	1,640.6	1,640.9	0.3	0.0	40.5	64.8	3.4	4.2	112.9	-6.9
Klamath	621.6	609.4	-12.2	-2.0	19.4	85.8	0.1	0.6	105.9	-17.0
Eastern Cascades	347.4	325.0	-22.4	-6.4	12.1	21.2	4.5	2.5	40.3	-11.6
Total	2,965.1	3,038.7	73.6	2.5	84.5	171.9	8.0	7.2	271.7	-9.2
California:										
Coast Range	66.7	69.2	2.5	3.7	0.8	3.6	0.0	0.1	4.6	-6.9
Klamath	1,550.3	1,470.4	-79.9	-5.2	23.0	233.1	5.1	9.7	270.9	-17.5
Cascades	153.1	167.4	14.3	9.3	6.4	8.0	0.4	0.0	14.8	-9.7
Total	1,770.1	1,707.0	-63.1	-3.6	30.2	244.7	5.5	9.9	290.3	-16.4
NWFP total	7,242.8	7,218.3	-24.5	-0.3	144.0	497.4	29.9	39.3	710.6	-9.8

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Table A3-6— Bookend map area estimates of old forests (OGSI 200) on reserved federal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	697.5	710.6	13.0	1.9	1.9	3.0	0.3	4.8	10.1	-1.4
Western Lowlands	8.0	5.5	-2.5	-31.5	0.6	0.0	0.0	0.0	0.6	-7.0
Western Cascades	981.5	995.8	14.2	1.5	4.7	3.5	1.6	7.4	17.2	-1.8
Eastern Cascades	551.1	477.1	-74.0	-13.4	10.0	68.4	12.7	9.7	100.9	-18.3
Total	2,238.2	2,188.9	-49.3	-2.2	17.2	74.8	14.6	22.0	128.7	-5.8
Oregon:										
Coast Range	323.1	408.3	85.2	26.4	8.5	0.1	0.0	0.0	8.7	-2.7
Willamette Valley	0.5	0.9	0.4	70.8	0.0	0.0	0.0	0.0	0.0	-8.0
Western Cascades	1,064.0	1,040.7	-23.3	-2.2	11.1	53.0	2.8	4.0	70.9	-6.7
Klamath	442.4	426.1	-16.2	-3.7	8.5	72.3	0.1	0.5	81.4	-18.4
Eastern Cascades	267.1	247.8	-19.3	-7.2	3.7	16.5	3.5	2.3	26.0	-9.7
Total	2,097.0	2,123.7	26.7	1.3	31.9	141.9	6.3	6.9	187.1	-8.9
California:										
Coast Range	60.2	62.2	2.0	3.3	0.6	3.5	0.0	0.1	4.2	-7.0
Klamath	1,060.4	970.8	-89.6	-8.5	7.4	166.9	4.5	9.6	188.5	-17.8
Cascades	87.0	92.1	5.1	5.9	2.1	5.6	0.2	0.0	8.0	-9.2
Total	1,207.6	1,125.0	-82.6	-6.8	10.2	176.0	4.7	9.8	200.7	-16.6
NWFP total	5,542.8	5,437.6	-105.1	-1.9	59.4	392.8	25.7	38.7	516.5	-9.3

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Table A3-7— Bookend map area estimates of old forests (OGSI 200) on nonfederal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

State and physiographic province	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	97.5	93.6	-3.9	-4.0	44.1	0.0	0.3	0.0	44.5	-45.6
Western Lowlands	117.5	78.0	-39.5	-33.6	92.0	0.0	0.1	0.0	92.1	-78.4
Western Cascades	220.2	169.2	-51.0	-23.2	83.3	0.2	0.1	0.0	83.7	-38.0
Eastern Cascades	190.5	133.6	-56.9	-29.9	54.2	14.3	2.8	0.1	71.5	-37.5
Total	625.7	474.4	-151.3	-24.2	273.6	14.6	3.4	0.1	291.7	-46.6
Oregon:										
Coast Range	193.1	242.5	49.4	25.6	149.3	0.1	0.2	0.0	149.6	-77.5
Willamette Valley	22.0	23.5	1.5	6.8	11.2	0.0	0.0	0.0	11.2	-51.0
Western Cascades	142.3	97.9	-44.4	-31.2	100.2	1.2	0.2	0.0	101.6	-71.4
Klamath	137.3	127.2	-10.1	-7.4	77.5	3.7	0.1	0.0	81.3	-59.2
Eastern Cascades	66.0	46.6	-19.4	-29.4	22.5	7.9	0.8	0.1	31.3	-47.4
Total	560.7	537.7	-23.0	-4.1	360.7	13.0	1.2	0.2	375.1	-66.9
California:										
Coast Range	379.4	387.0	7.6	2.0	94.1	5.7	0.1	0.0	99.9	-26.3
Klamath	182.6	201.2	18.6	10.2	50.6	14.1	0.4	0.0	65.1	-35.7
Cascades	104.4	92.2	-12.2	-11.7	35.2	9.2	0.5	0.0	44.9	-43.0
Total	666.4	680.4	14.0	2.1	179.9	29.0	0.9	0.1	209.9	-31.5
NWFP total	1,852.8	1,692.5	-160.3	-8.7	814.2	56.6	5.5	0.4	876.7	-47.3

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Table A3-8— Bookend map area estimates of old forests (OGSI 200) on all lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

State and physiographic province	Old-forest area estimates from bookend maps				LCMS disturbance explanation for losses					
	1993	2017	Net area change	Net change	Harvest	Wildfire	Insect	Other	Total explained loss	Loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	807.3	821.4	14.1	1.7	46.4	3.0	0.6	4.9	54.9	-6.8
Western Lowlands	125.5	83.5	-42.0	-33.5	92.5	0.0	0.1	0.0	92.7	-73.8
Western Cascades	1,348.3	1,321.7	-26.6	-2.0	92.2	3.7	1.7	7.5	105.1	-7.8
Eastern Cascades	852.2	720.4	-131.8	-15.5	71.8	88.6	17.3	9.9	187.6	-22.0
Total	3,133.3	2,947.0	-186.3	-5.9	302.9	95.3	19.8	22.3	440.3	-14.1
Oregon:										
Coast Range	547.3	704.2	156.9	28.7	161.6	0.2	0.2	0.0	162.1	-29.6
Willamette Valley	23.3	25.2	1.9	8.2	11.4	0.0	0.0	0.0	11.4	-48.8
Western Cascades	1,782.9	1,738.8	-44.1	-2.5	140.7	66.1	3.6	4.2	214.5	-12.0
Klamath	758.9	736.6	-22.3	-2.9	96.9	89.5	0.2	0.6	187.2	-24.7
Eastern Cascades	413.4	371.6	-41.8	-10.1	34.6	29.1	5.3	2.6	71.6	-17.3
Total	3,525.8	3,576.4	50.6	1.4	445.2	184.9	9.3	7.4	646.8	-18.3
California:										
Coast Range	446.1	456.2	10.1	2.3	94.9	9.4	0.1	0.1	104.5	-23.4
Klamath	1,732.9	1,671.6	-61.3	-3.5	73.6	247.2	5.4	9.8	336.1	-19.4
Cascades	257.5	259.6	2.1	0.8	41.6	17.1	0.9	0.1	59.7	-23.2
Total	2,436.5	2,387.4	-49.1	-2.0	210.1	273.7	6.4	10.0	500.2	-20.5
NWFP total	9,095.6	8,910.8	-184.8	-2.0	958.2	553.9	35.5	39.6	1,587.3	-17.5

OGSI = old-growth structure index; NWFP = Northwest Forest Plan.

Appendix 4: Gradient Nearest Neighbor Older Forest Map Accuracy Report

A large suite of diagnostics detailing Gradient Nearest Neighbor (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-scale (plot-scale) accuracy assessment, we used a modified leave-one-out, cross validation for all plots used in the model (Ohmann and Gregory 2002). The modified leave-one-out, cross validation—where the first independent neighbor (i.e., not the reference plot in question) is used to generate predictions upon which accuracy statistics are based—has been shown to produce equivalent results to traditional cross-validation techniques, but is far less computationally intensive (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 (OGSI 80 and OGSI 200) map accuracy for this report (high-severity masked OGSI), we summarized the cross-validation data (predicted-observed pairs) by GNN model region. For each bookend map, we compared plot-observed, old-forest classification to independent GNN prediction at the plot's location. This was done by extracting plot footprints (3-by-3 pixels) from the corresponding year of plot measurement. If a pixel in the plot footprint was identified as high-severity disturbance, the GNN call for OGSI was overruled. The majority OGSI class of the 9-pixel footprint was used and a binary error matrix of observed (plot) and predicted (mapped) designations was constructed to derive several map diagnostics (tables A4-1 and A4-2).

Map accuracy as a percentage correct is the percentage of plots where the observed and predicted agree (both presence and absence). Sensitivity is based on the percentage of field plots where the map correctly predicted presence, and specificity is the percentage of plots where the map correctly predicted 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 old forest comprises a smaller percentage of the forest landscape). The assessment of "overall map agreement" in tables A3-1 and A3-2 is a subjective classification of kappa by Landis and Koch (1977). Overall, the bookend maps had fair to moderate agreement with the plot data.

Table A4-1—Map versus forest inventory plot accuracy statistics for bookend map 1 (1993)

Model region	OGSI	Number of plots	Prevalence	Percent correct	Sensitivity	Specificity	Kappa	Overall map agreement
221	80	3,084	0.39	0.81	0.74	0.85	0.59	Moderate
	200	3,084	0.21	0.84	0.62	0.90	0.52	Moderate
222	80	2,075	0.48	0.68	0.69	0.67	0.36	Fair
	200	2,075	0.16	0.79	0.39	0.87	0.25	Fair
223	80	1,509	0.35	0.82	0.74	0.85	0.60	Moderate
	200	1,509	0.16	0.87	0.61	0.92	0.53	Moderate
224	80	3,946	0.50	0.72	0.75	0.69	0.44	Moderate
	200	3,946	0.23	0.79	0.53	0.86	0.40	Fair
225	80	2,671	0.52	0.71	0.77	0.64	0.41	Moderate
	200	2,671	0.21	0.77	0.53	0.83	0.34	Fair
226	80	879	0.40	0.67	0.62	0.71	0.33	Fair
	200	879	0.11	0.86	0.37	0.92	0.29	Fair

OGSI = old-growth structure index.

Table A4-2—Map versus forest inventory plot accuracy statistics for bookend map 2 (2017)

Model region	OGSI	Number of plots	Prevalence	Percent correct	Sensitivity	Specificity	Kappa	Overall map agreement
221	80	3084	0.39	80.8	0.74	0.85	0.60	Moderate
	200	3084	0.21	83.5	0.62	0.89	0.51	Moderate
222	80	2075	0.48	68.6	0.70	0.67	0.37	Fair
	200	2075	0.17	78.5	0.39	0.86	0.25	Fair
223	80	1509	0.35	81.6	0.74	0.86	0.60	Moderate
	200	1509	0.16	87.2	0.62	0.92	0.54	Moderate
224	80	3946	0.50	72.3	0.75	0.69	0.45	Moderate
	200	3946	0.23	78.8	0.54	0.86	0.41	Moderate
225	80	2671	0.52	70.9	0.77	0.65	0.42	Moderate
	200	2671	0.22	76.5	0.53	0.83	0.34	Fair
226	80	879	0.40	67.3	0.62	0.71	0.33	Fair
	200	879	0.11	85.9	0.32	0.92	0.25	Fair

OGSI = old-growth structure index.

References

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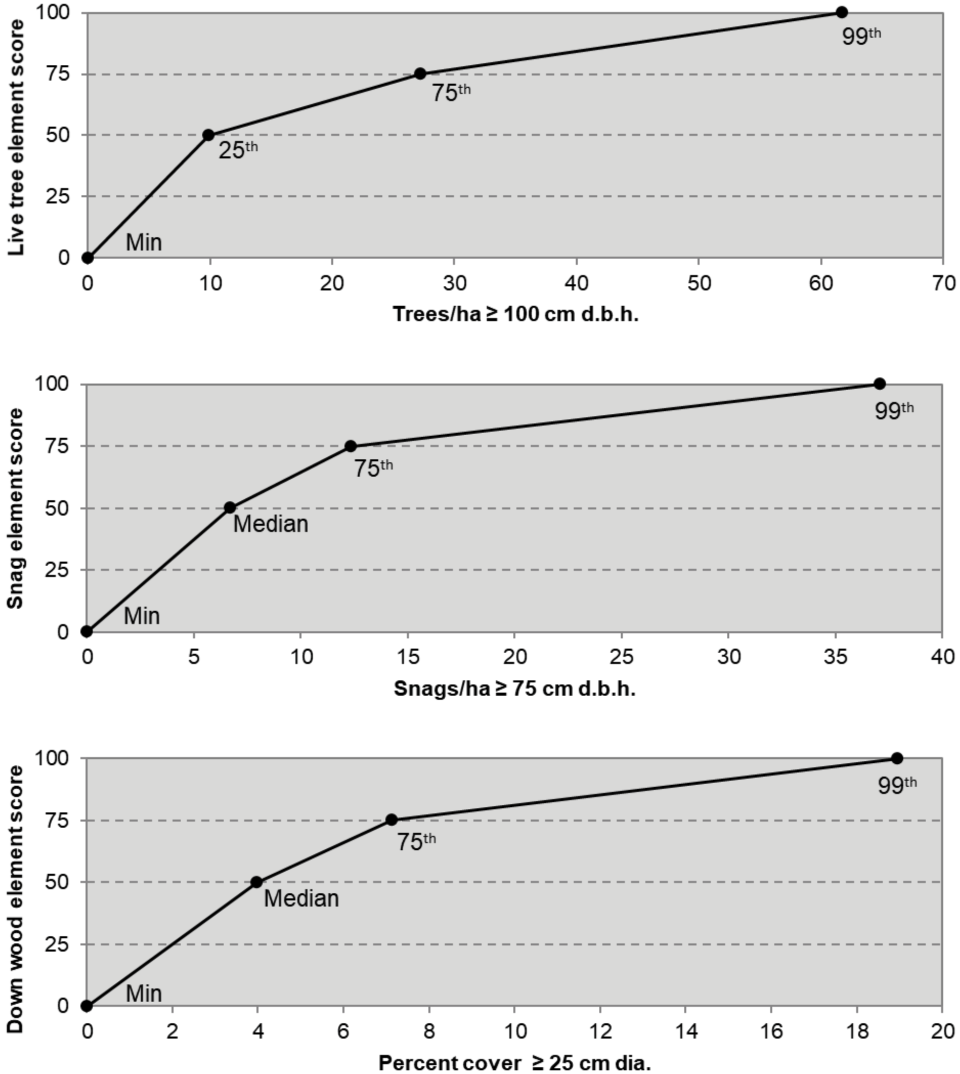
Landis, J.R.; Koch, G.G. 1977. The measurement of observer agreement for categorical data. Biometrics. 33(1): 159–174. https://doi.org/10.2307/2529310.

Ohmann, J.L.; Gregory, M.J. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, U.S.A. Canadian Journal of Forest Research. 32(4): 725–741. https://doi.org/10.1139/x02-011.

Appendix 5: Old-Growth Structure Index Element Curves

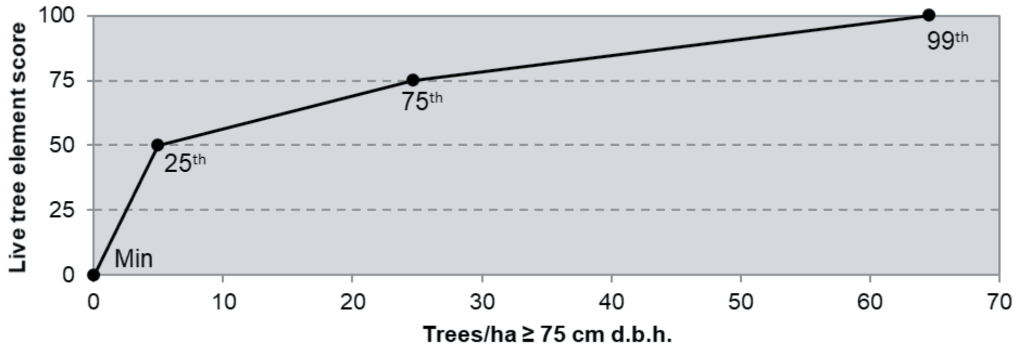


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	9.9	50	5.06	0
75th	27.3	75	1.44	35.79
99th	61.7	100	0.73	55.23

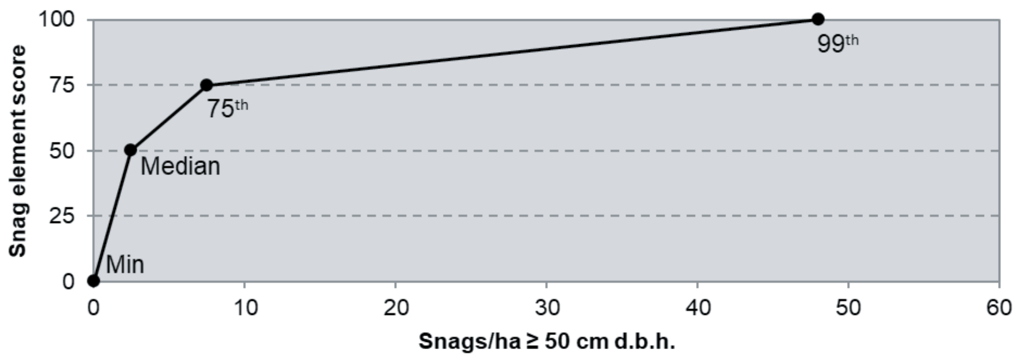
Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	6.7	50	7.45	0.00
75th	12.3	75	4.44	20.22
99th	37.1	100	1.01	62.53

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	4.0	50	12.54	0.00
75th	7.1	75	7.97	18.20
99th	19.0	100	2.11	59.94

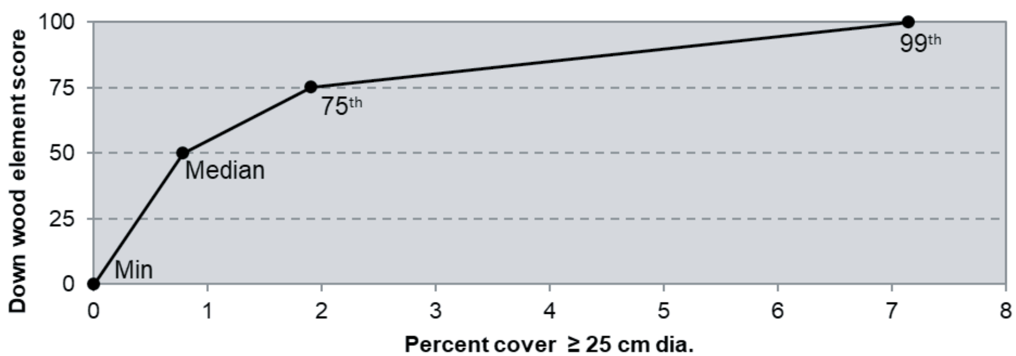
Figure A5-1—Western hemlock curves for stands age ≥200 (n = 801). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	4.9	50	10.13	0
75th	24.7	75	1.27	43.75
99th	64.6	100	0.63	59.53

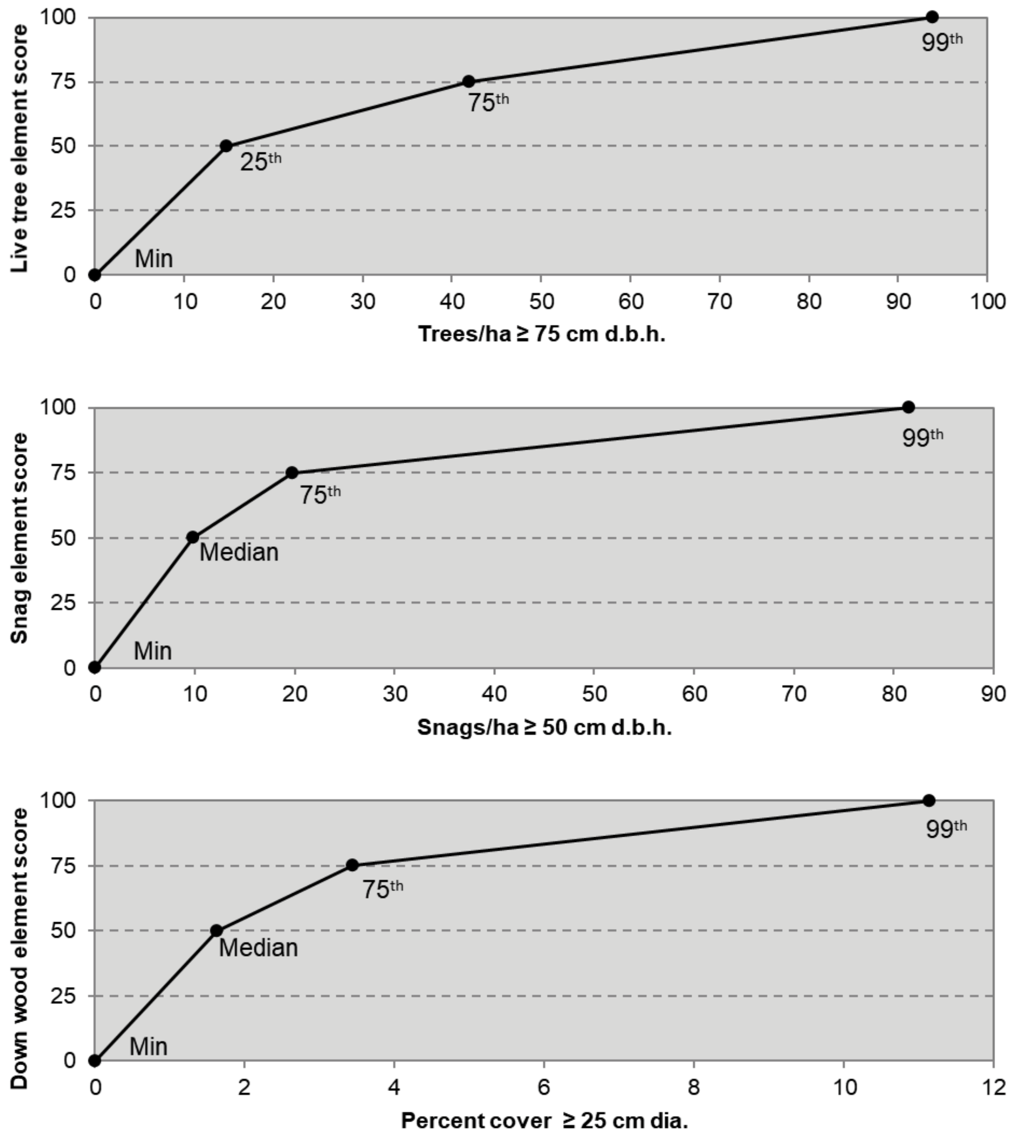


Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	2.5	50	20.25	0
75th	7.5	75	4.96	37.76
99th	48.0	100	0.62	70.37



Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	0.8	50	63.78	0
75th	1.9	75	22.22	32.58
99th	7.1	100	4.77	65.89

Figure A5-2—Douglas-fir curves for stands age ≥150 (n = 785). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

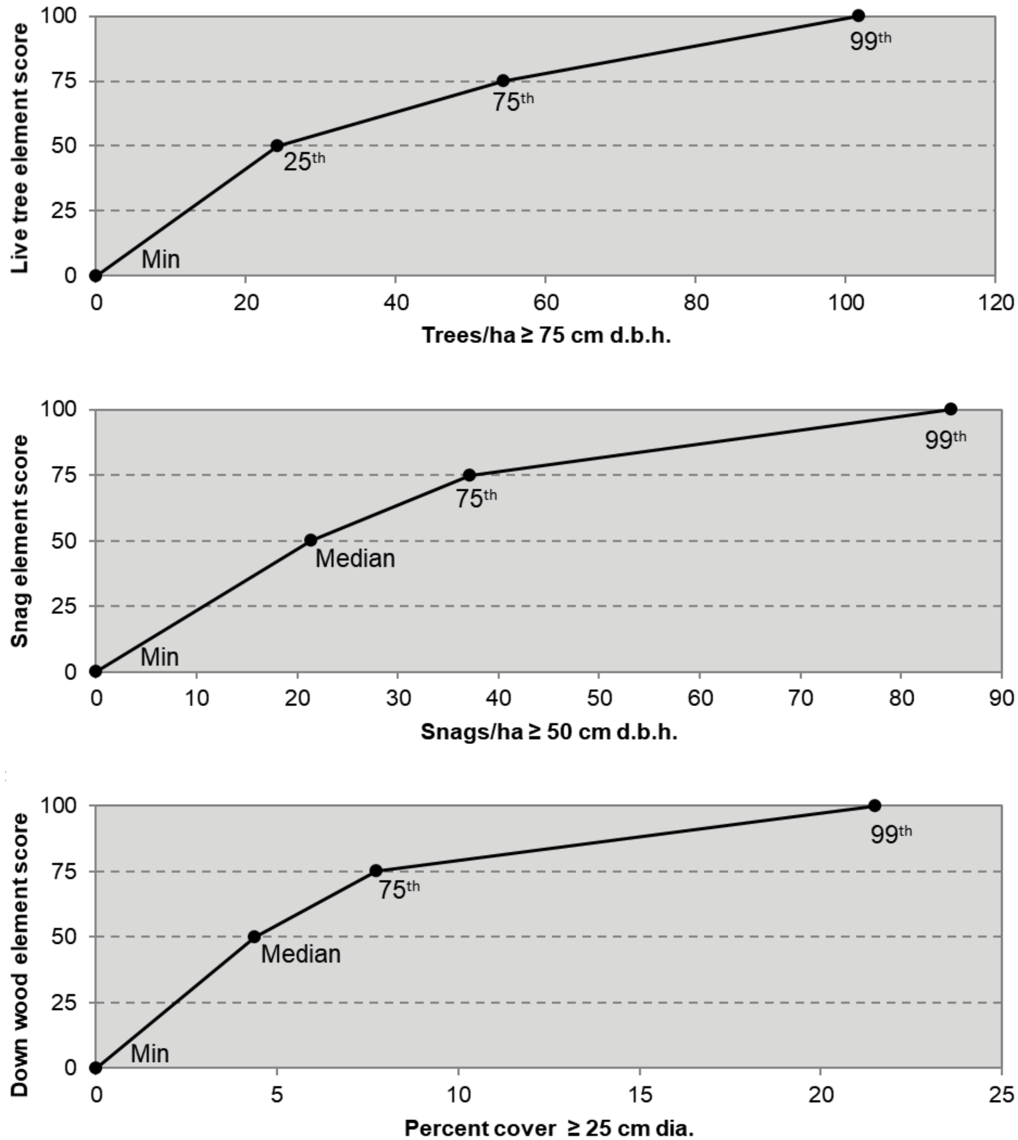


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	14.8	50	3.38	0
75th	42.0	75	0.92	36.36
99th	93.9	100	0.48	54.78

Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	9.9	50	5.06	0
75th	19.8	75	2.52	25.14
99th	81.5	100	0.40	66.98

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	1.6	50	30.72	0
75th	3.4	75	13.77	27.58
99th	11.1	100	3.25	63.82

Figure A5-3—Grand fir/white fir curves for stands age ≥200 (n = 705). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

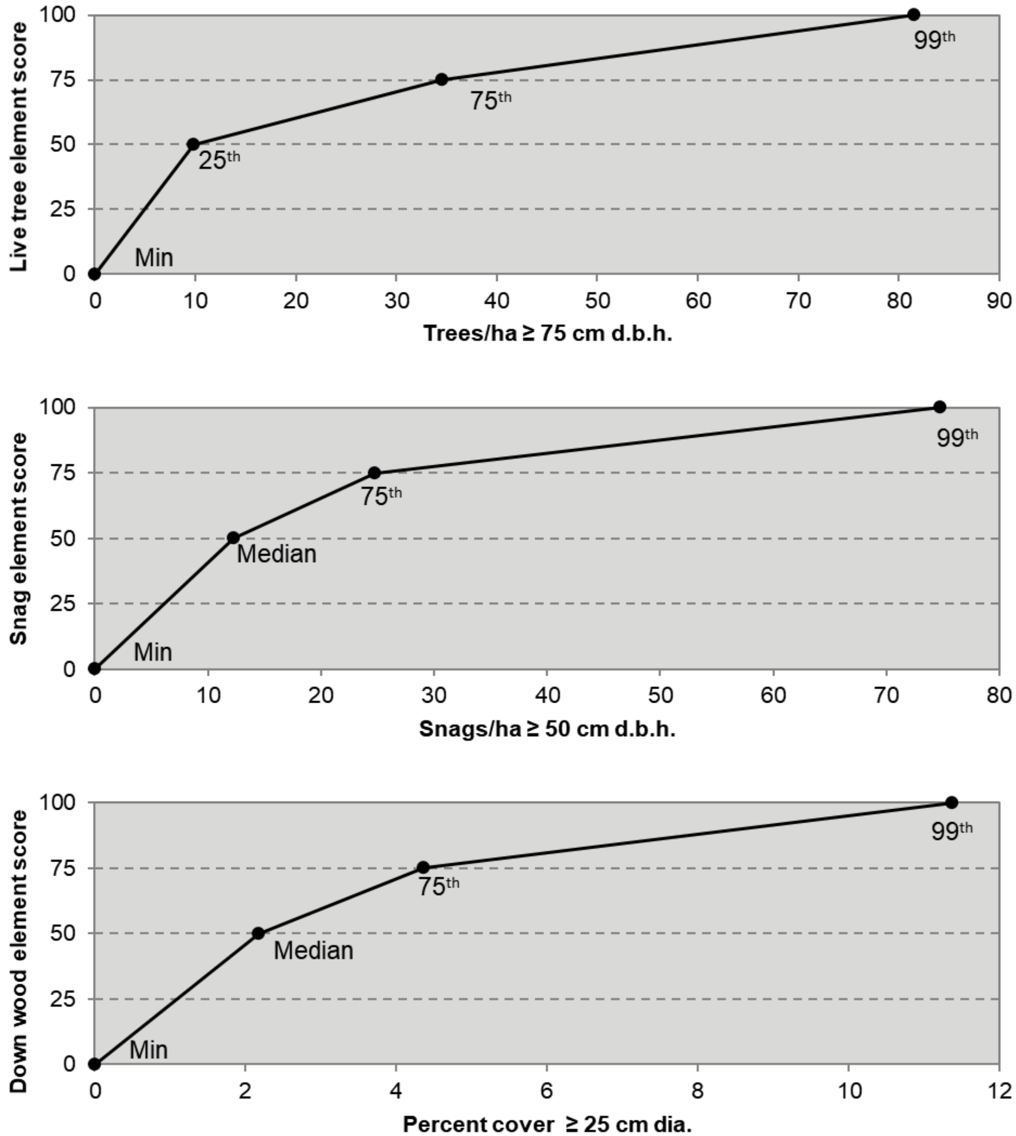


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	24.3	50	2.06	0
75th	54.3	75	0.83	29.81
99th	101.7	100	0.53	46.34

Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	21.4	50	2.33	0
75th	37.2	75	1.59	16
99th	85.0	100	0.52	55.56

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	4.4	50	11.37	0
75th	7.8	75	7.45	17.26
99th	21.5	100	1.82	60.9

Figure A5-4—Pacific silver fir curves for stands age ≥200 (n = 783).Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

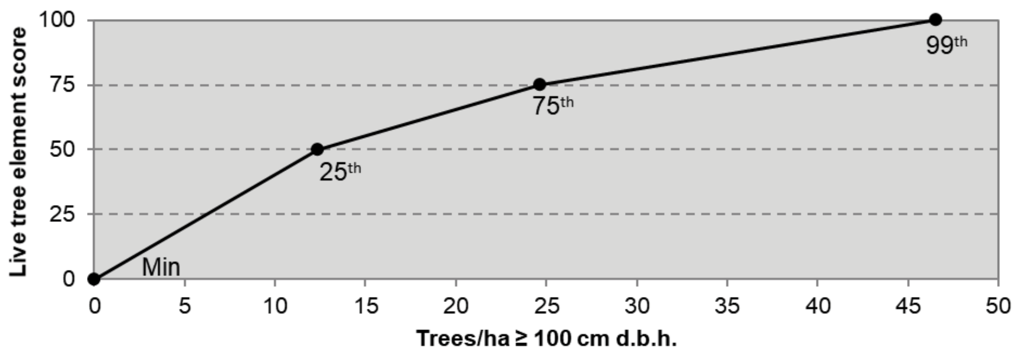


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	9.9	50	5.06	0
75th	34.6	75	1.01	40
99th	81.5	100	0.53	56.6

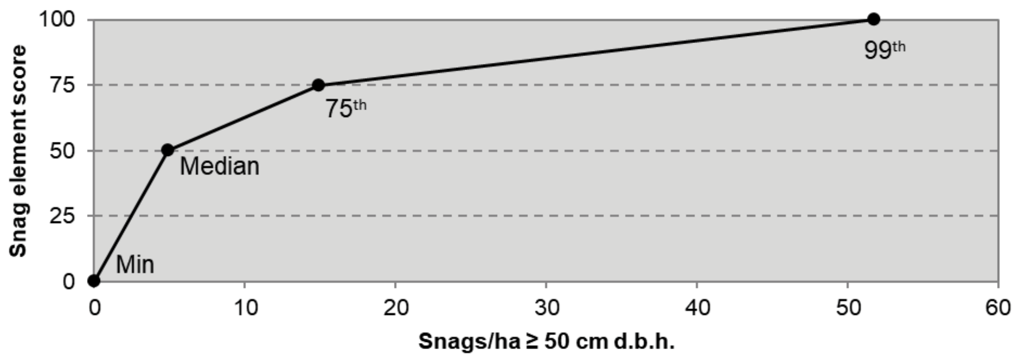
Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	12.3	50	4.05	0
75th	24.7	75	2.02	25.11
99th	74.8	100	0.50	62.63

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	2.2	50	22.92	0
75th	4.4	75	11.46	25
99th	11.4	100	3.57	59.42

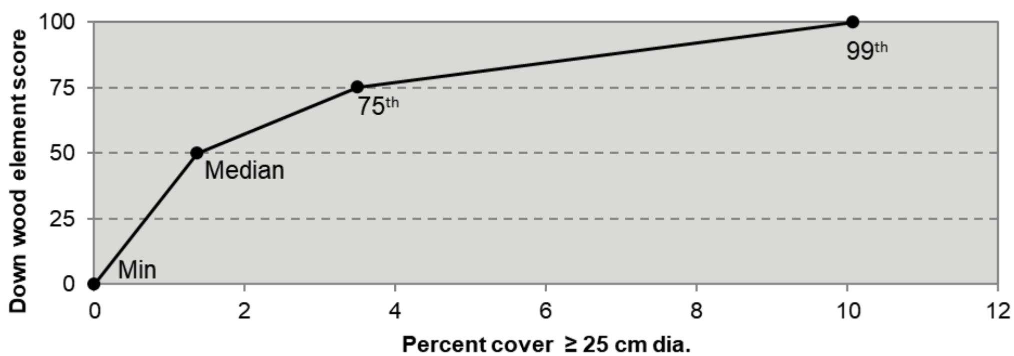
Figure A5-5—Mountain hemlock curves for stands age ≥200 (n = 483). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	12.3	50	4.05	0
75th	24.7	75	2.03	25
99th	46.6	100	1.14	46.78

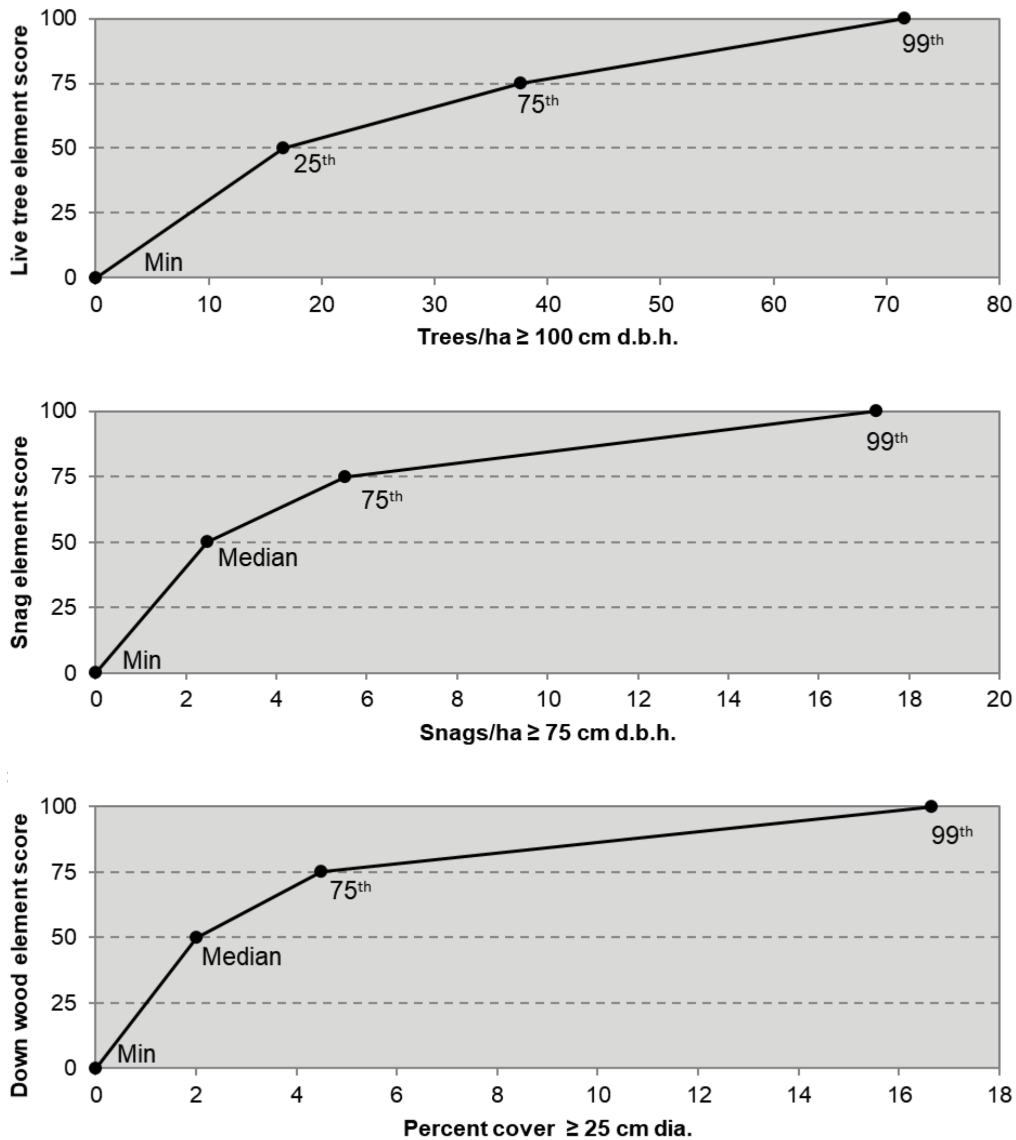


Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	4.9	50	10.13	0
75th	14.9	75	2.5	37.65
99th	51.8	100	0.68	64.86



Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	1.4	50	36.67	0
75th	3.5	75	11.71	34.03
99th	10.1	100	3.80	61.72

Figure A5-6—Tanoak curves for stands age ≥200 (n = 115). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

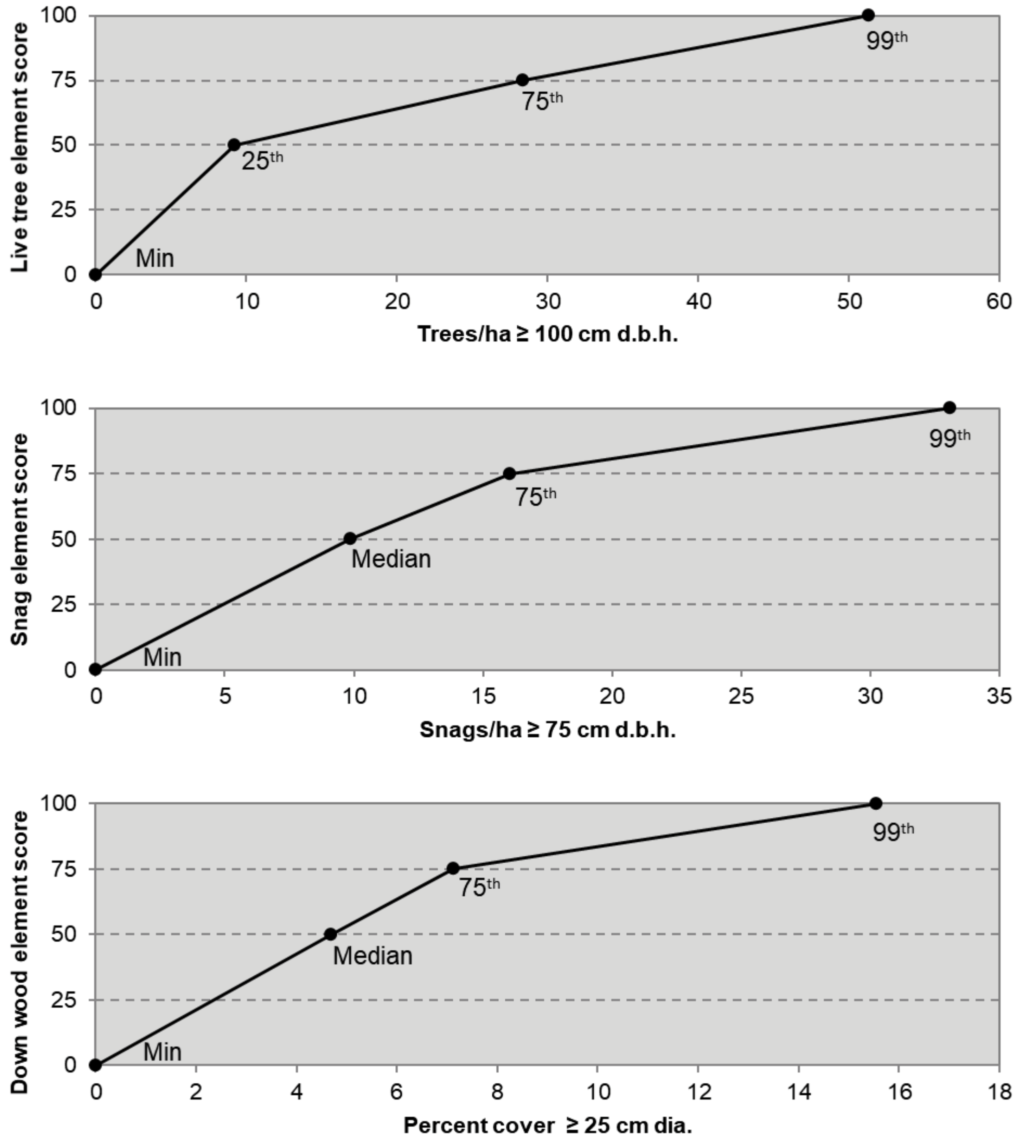


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	16.7	50	3	0
75th	37.7	75	1.19	30.15
99th	71.6	100	0.74	47.27

Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	2.5	50	20.25	0
75th	5.5	75	8.16	29.85
99th	17.3	100	2.13	63.23

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	2	50	24.86	0
75th	4.5	75	10.03	29.84
99th	16.6	100	2.06	65.72

Figure A5-7—Redwood curves for stands age ≥200 (n = 60). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

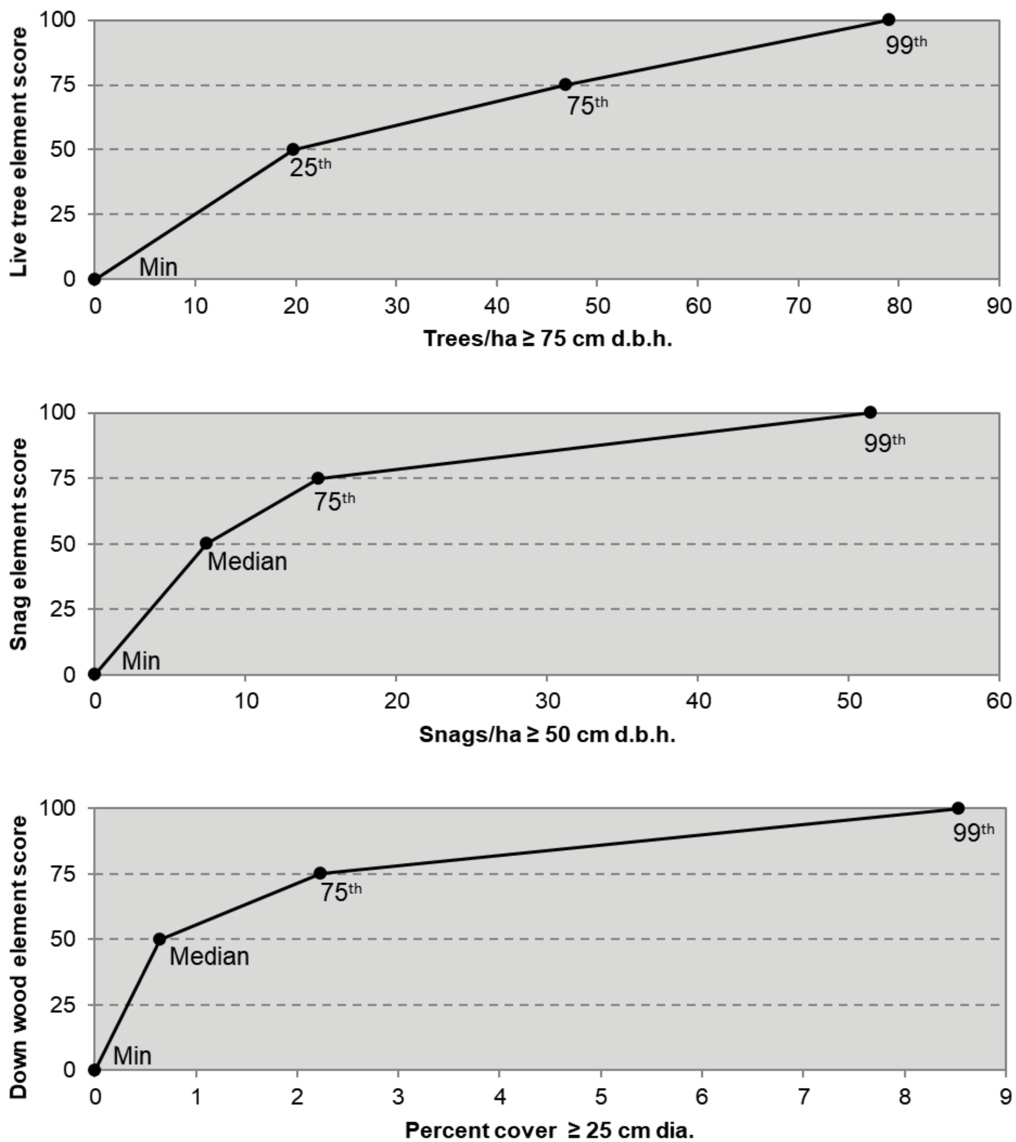


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	9.3	50	5.4	0
75th	28.4	75	1.31	37.9
99th	51.4	100	1.09	44.09

Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	9.9	50	5.06	0
75th	16	75	4.05	10
99th	33.1	100	1.47	51.45

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	4.7	50	10.67	0
75th	7.1	75	10.26	1.92
99th	15.6	100	2.96	53.88

Figure A5-8—Sitka spruce curves for stands age ≥200 (n = 16). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

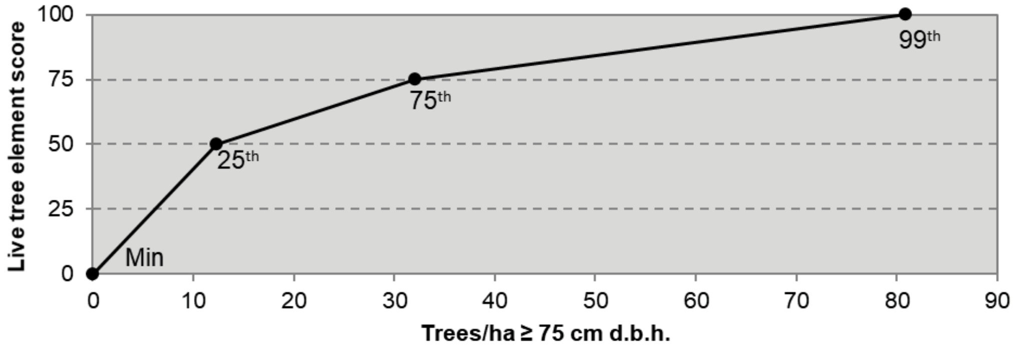


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	19.8	50	2.53	0
75th	46.9	75	0.92	31.82
99th	79.0	100	0.78	38.46

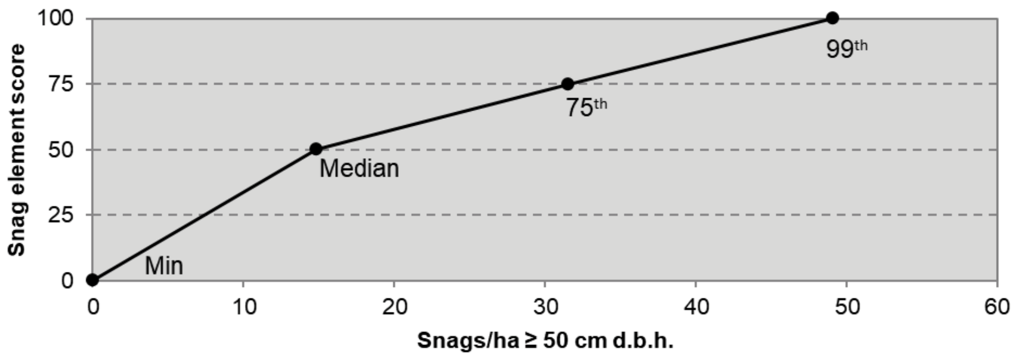
Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	7.4	50	6.75	0
75th	14.8	75	3.38	25
99th	51.4	100	0.68	64.89

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	0.6	50	77.2	0
75th	2.2	75	15.77	39.78
99th	8.5	100	3.97	66.14

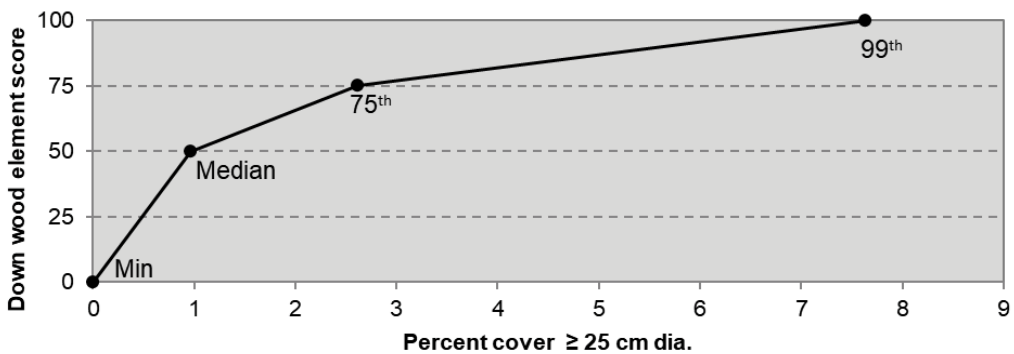
Figure A5-9—Subalpine fir curves for stands ≥150 years of age (n = 314). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	12.3	50	4.05	0
75th	32.1	75	1.27	34.38
99th	80.9	100	0.51	58.56

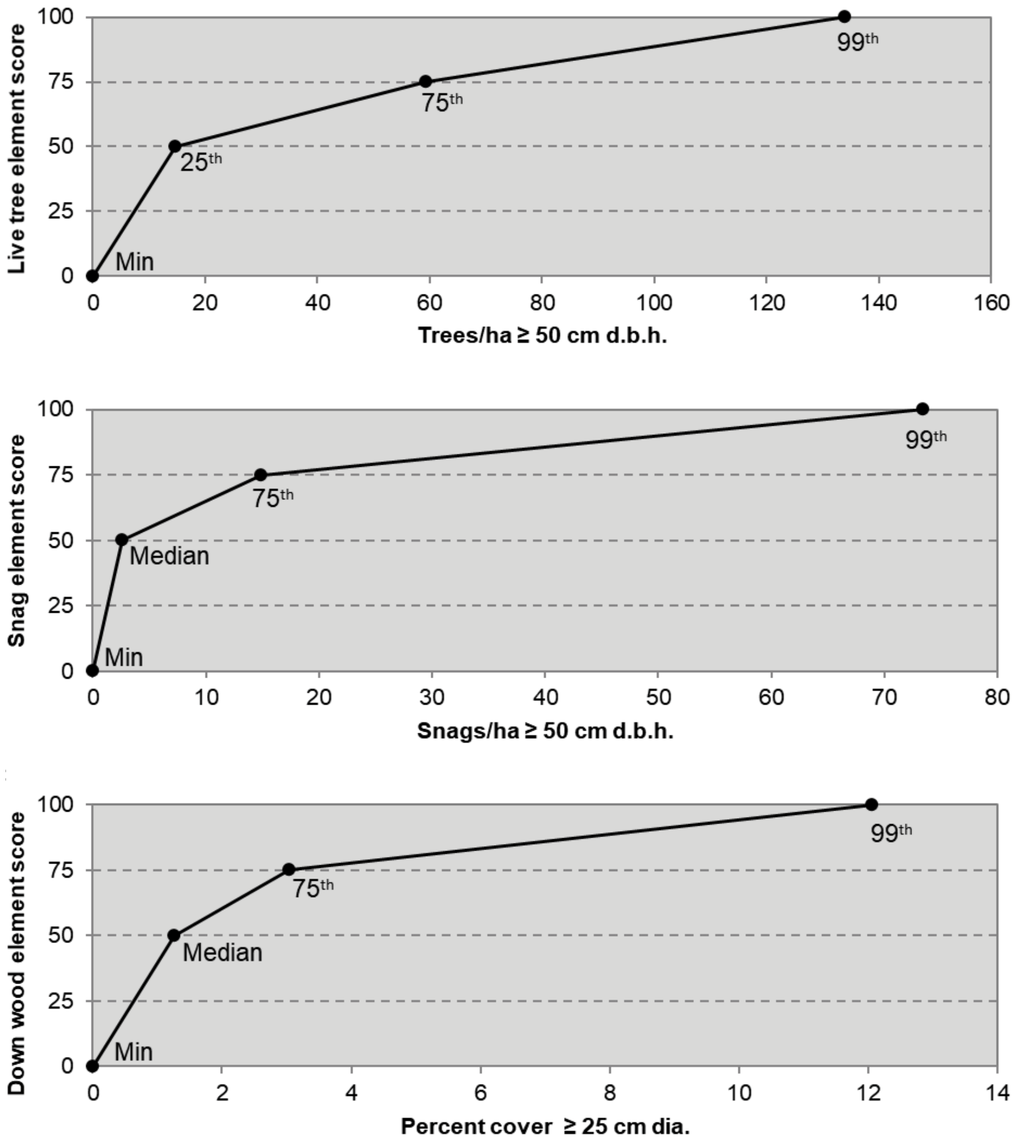


Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	14.9	50	3.36	0
75th	31.5	75	1.50	27.69
99th	49.1	100	1.43	30.04



Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	1	50	51.47	0
75th	2.6	75	15.20	35.23
99th	7.6	100	4.98	61.97

Figure A5-10—Shasta red fir curves for stands age ≥200 (n = 124). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

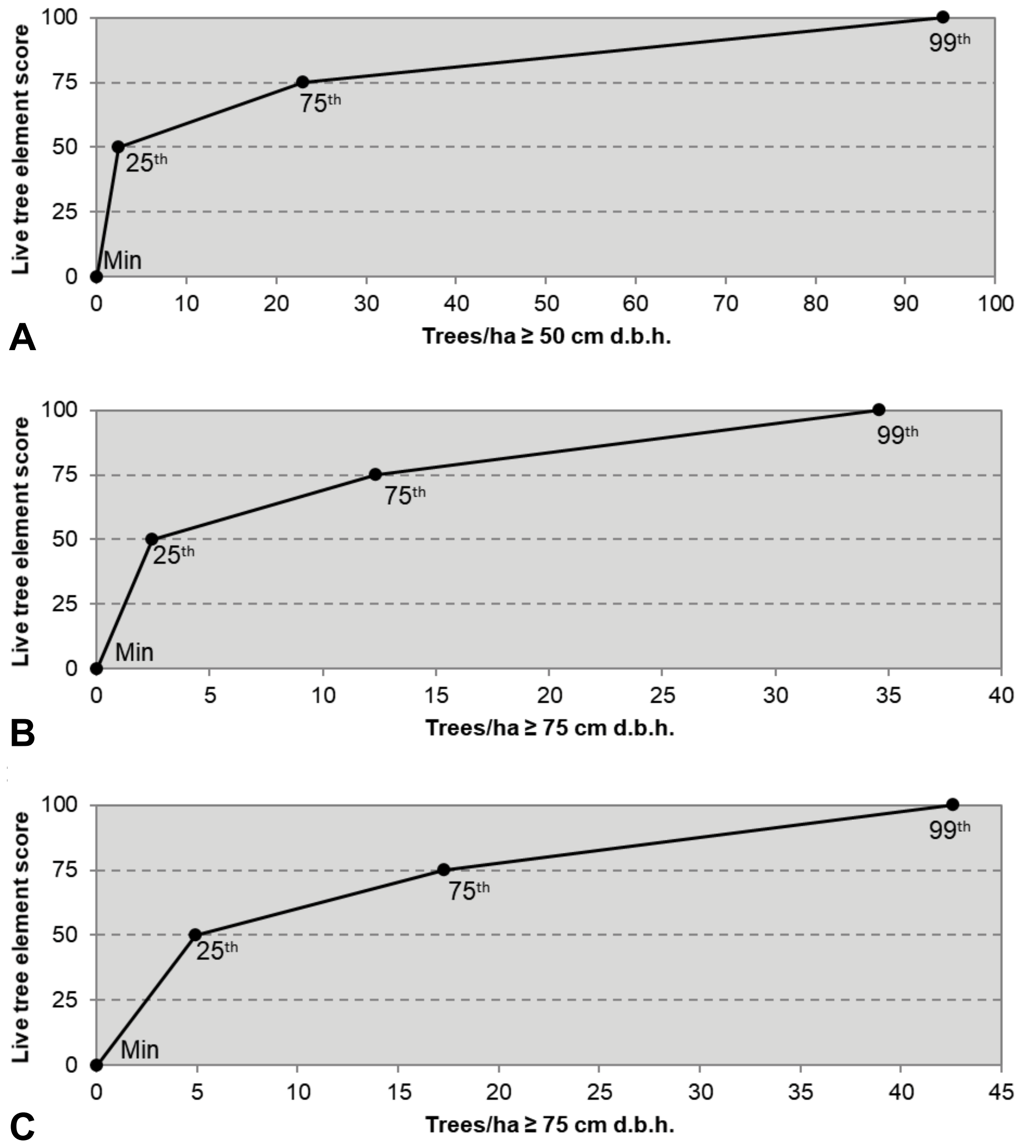


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	14.8	50	3.38	0
75th	59.3	75	0.56	41.68
99th	134	100	0.33	55.14

Plot statistic	SPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	2.6	50	19.09	0
75th	14.9	75	2.04	44.65
99th	73.4	100	0.43	68.65

Plot statistic	COV (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
Median	1.3	50	39.64	0
75th	3.1	75	13.97	32.38
99th	12.1	100	2.77	66.54

Figure A5-11—Port Orford cedar curves for stands age ≥200 (n = 18). Note: d.b.h. = diameter at breast height; dia. = diameter at large end and ≥3 m (10 ft) long; NA = not applicable; COV = percentage of cover; SPH = snags per hectare; TPH = trees per hectare.

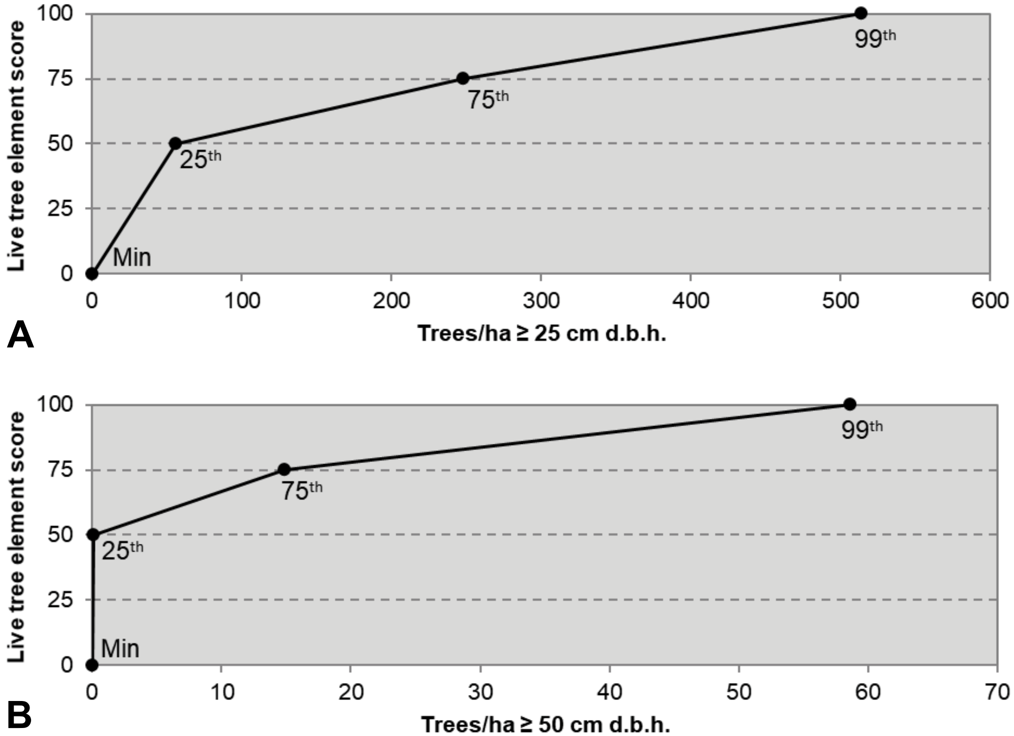


Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	2.5	50	20.25	0
75th	23	75	1.22	47
99th	94.2	100	0.35	66.91

Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	2.5	50	20.25	0
75th	12.3	75	2.53	43.75
99th	34.6	100	1.12	61.14

Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	4.9	50	10.13	0
75th	17.3	75	2.03	40
99th	42.6	100	0.99	57.9

Figure A5-12—(A) Oak woodland, (B) ponderosa pine, and (C) Jeffrey/knobcone pine curves for stands age ≥100 (a and c; n = 253 and 188, respectively) and age ≥150 (b; n = 499). Note: d.b.h. = diameter at breast height; NA = not applicable; TPH = trees per hectare.



Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	56	50	0.89	0
75th	247.8	75	0.13	42.7
99th	514	100	0.09	51.73

Plot statistic	TPH (x-axis)	Score (y-axis)	Slope	Intercept
Minimum	0	0	NA	NA
25th	0.1	50	500	0
75th	14.9	75	1.67	49.83
99th	58.6	100	0.57	66.5

Figure A5-13—(A) Lodgepole pine and (B) juniper woodland curves for stands age ≥100 (n = 101 and 734, respectively). Note: d.b.h. = diameter at breast height; NA = not applicable; TPH = trees per hectare.

Appendix 6: Old-Growth Structure Index Mapping and Analysis Thresholds

Table A6-1—Old-growth structure index (OGSI) mapping thresholds (80, 120, 160, and 200 years) by forest vegetation zone

Vegetation zone	OGSI 80	OGSI 120	OGSI 160	OGSI 200
Western hemlock	21.08	28.72	36.92	44.63
Douglas-fir	19.67	31.81	42.73	50.81
Grand fir/white fir	18.72	30.82	40.96	48.00
Silver fir	18.11	25.67	34.58	43.39
Mountain hemlock	12.24	20.95	31.02	41.34
Tanoak	22.41	30.86	40.17	48.22
Redwood	28.83	37.90	45.63	50.94
Sitka spruce	30.58	43.54	52.73	59.96
Oak woodland	32.00	57.07	62.46	NA
Subalpine	17.42	31.29	40.97	45.08
Ponderosa pine	NA	28.96	55.87	67.95
Jeffrey pine/knobcone pine	6.30	28.69	49.07	61.77
Shasta red fir	21.36	32.59	45.95	52.81
Port Orford cedar	24.85	33.34	41.47	45.01
Lodgepole pine	39.18	57.48	61.46	NA
Juniper	1.55	30.10	63.03	70.95

NA = not applicable.

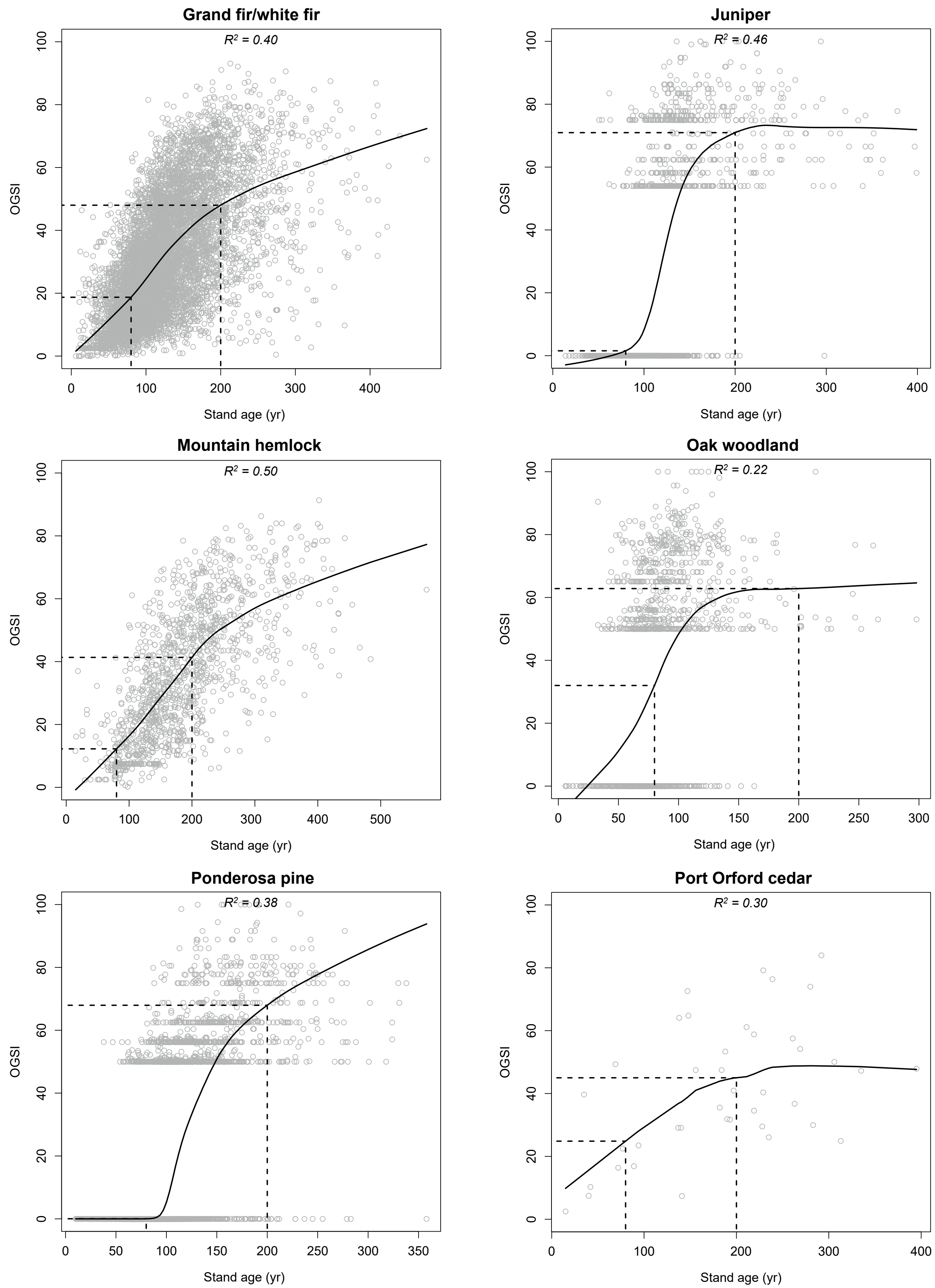


Figure A6-1—Scatter plot of old-growth structure index (OGSI) and stand age for forest inventory plots showing a locally weighted polynomial regression line used to develop mapping thresholds at 80 and 200 years (dashed lines). R² = pseudo R² (see Cleveland 1979 and Schabenberger and Pierce 2002).

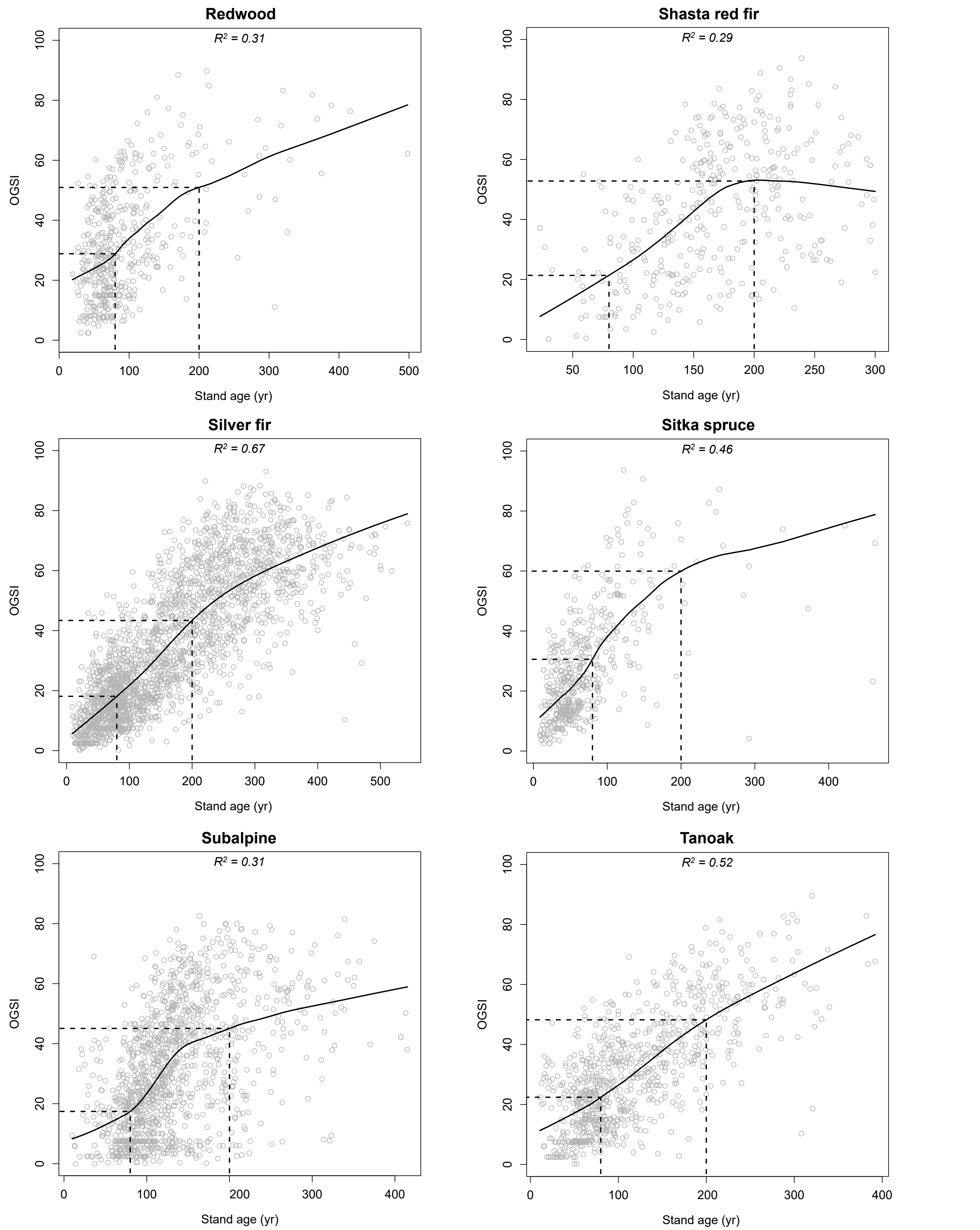


Figure A6-1 continued—Scatter plot of old-growth structure index (OGSI) and stand age for forest inventory plots showing a locally weighted polynomial regression line used to develop mapping thresholds at 80 and 200 years (dashed lines). R^2 = pseudo R^2 (see Cleveland 1979 and Schabenberger and Pierce 2002).

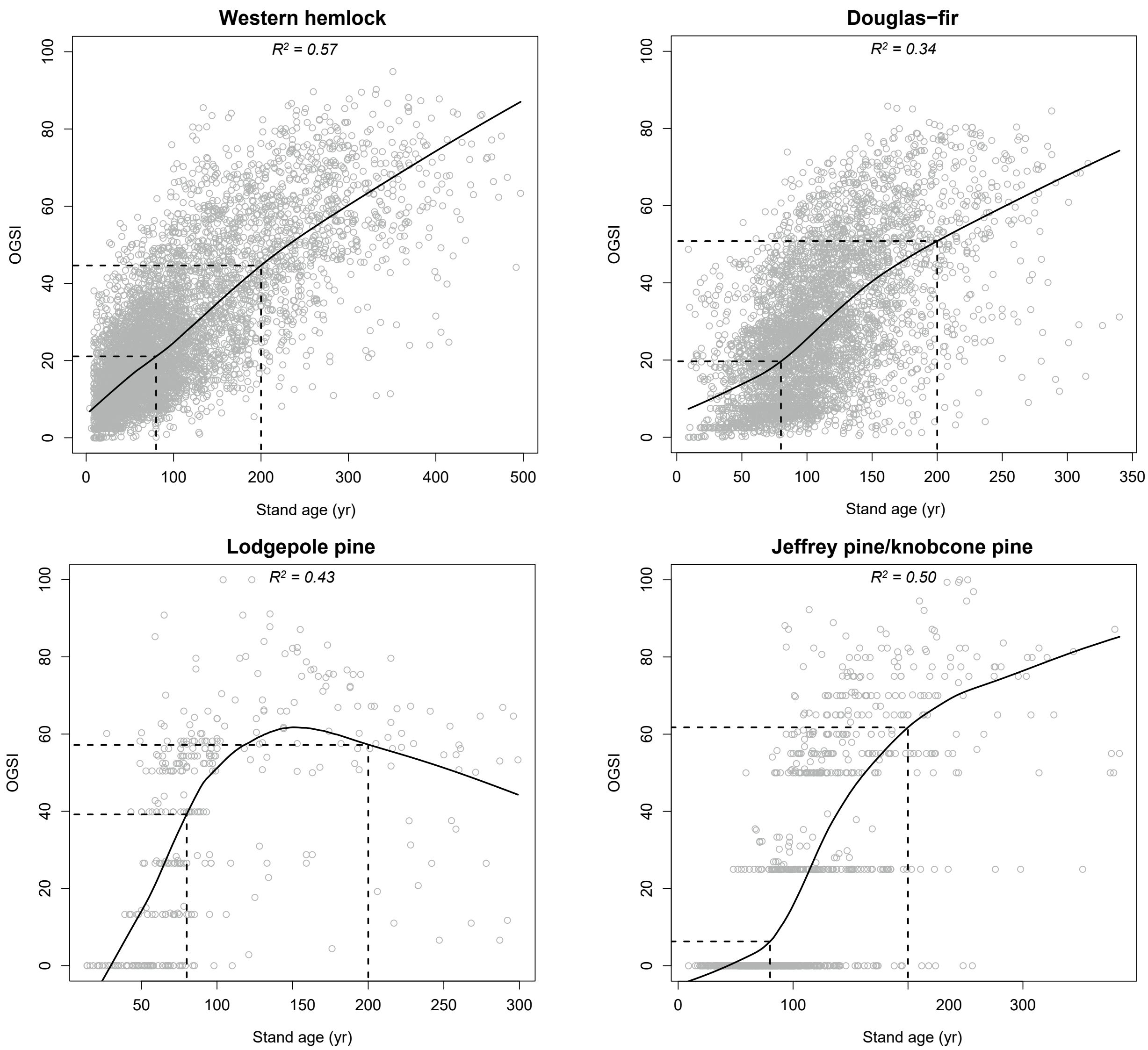


Figure A6-1 continued—Scatter plot of old-growth structure index (OGSI) and stand age for forest inventory plots showing a locally weighted polynomial regression line used to develop mapping thresholds at 80 and 200 years (dashed lines). R^2 = pseudo R^2 (see Cleveland 1979 and Schabenberger and Pierce 2002).

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