NORTHWEST FOREST PLAN
The First 15 Years (1994–2008)

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

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Abstract

Moeur, Melinda; Ohmann, Janet L.; Kennedy, Robert E.; Cohen, Warren B.; Gregory, Matthew J.; Yang, Zhiqiang; Roberts, Heather M.; Spies, Thomas A.; Fiorella, Maria. 2011. Northwest Forest Plan–the first 15 years (1994–2008): status and trends of late-successional and old-growth forests. Gen. Tech. Rep. PNW-GTR-853. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

Late-successional and old-growth (LSOG) monitoring characterizes the status and trends of older forests to answer such questions as: How much older forest is there? Where is it? How much has changed and from what causes? Is the Northwest Forest Plan (the Plan) maintaining or restoring older forest ecosystems to desired conditions on federal lands in the Plan area? This assessment is the second in a continuous monitoring cycle. We initially reported on LSOG status and trends from 1994 to 2003 in the “10-year report.” This document, the mid-cycle “15-year report,” updates the assessment to 2006 in Washington and Oregon and to 2007 in California. The next major assessment will be the 20-year report.

We used maps of forest vegetation and change and regional inventory plot data to assess the distribution and trends of LSOG on federal and other lands in the Plan area over the monitoring periods 1994 to 2007 in California and 1996 to 2006 in Washington and Oregon. We used statistical mapping techniques to develop maps of forest composition and structure at the two monitoring cycle endpoints (“bookend” maps), and yearly maps of forest disturbance. From the two bookend maps we assessed changes in the amount and distribution of LSOG (defined as average diameter of overstory conifers ≥20 in and conifer canopy cover ≥10 percent) over time. We used the disturbance maps to characterize the agents of change (harvest, wildfire, and insects/disease) associated with areas mapped as LSOG loss from the bookend maps. To corroborate the mapped information, we estimated LSOG area from two successive forest inventories from which such data were available (Forest Service and Oregon Bureau of Land Management lands), and compiled the first Plan-wide estimates of LSOG on all ownerships from a regionally consistent inventory design.

The bookend maps suggested a slight net loss (-1.9 percent) of LSOG from federal lands in the Plan area, from 33.2 percent of federal forest to 32.6 percent (from 7.3 to 7.1 million ac). Trends varied by province, but in all cases, the net changes were small relative to the sources of error and uncertainty in the estimates, which limit our ability to estimate the precise amount of LSOG change. Nevertheless, strong evidence suggests that >200,000 ac of LSOG were lost to stand-replacing disturbance (mostly wildfire) on federal lands. Almost 90 percent of the loss of federal LSOG was from reserves.

The losses apparently were roughly balanced by recruitment, although recruitment is much more difficult to estimate than disturbance with available data and technology. Recruitment was most likely through incremental stand growth over the 20-in threshold, or from understory disturbances that eliminated smaller diameter trees and increased average stand diameter. Increases in the area of forests of much larger and older trees are unlikely to occur over the 10- to 14-year monitoring period. Use of a more restrictive definition of LSOG (larger average tree size or denser canopy) likely would increase the estimate of LSOG loss and decrease the estimate of LSOG gain. The small net decrease in LSOG was corroborated by successive forest inventories, but the plot-based estimates of LSOG change were not statistically significant.

The results support the assumption made in the Plan that the primary responsibility for maintaining or restoring LSOG and related habitats in the Pacific Northwest would fall to public lands. Federal lands contained less than half of the total forest land, but the federal share of total LSOG increased from 65 to 67 percent over the monitoring period. Harvesting removed about 13 percent (approximately 491,000 ac) of LSOG on nonfederal lands. Loss of LSOG on federal lands resulting from harvest was less than 0.5 percent (approximately 32,100 ac). Wildfire was the most significant change agent for LSOG on federal lands over the Plan area, and will continue to be a key consideration for policies affecting older forests, associated species, and watershed conditions.

Keywords: Old growth, forest monitoring, Gradient Nearest Neighbor imputation, LandTrendr change detection, Pacific Northwest.

Preface

In 1994, the Northwest Forest Plan (the Plan) record of decision amended 19 national forest and 7 Bureau of Land Management resource plans within the range of the northern spotted owl (*Strix occidentalis caurina*). An interagency effectiveness monitoring framework was implemented to meet requirements for tracking the status and trends of watershed conditions, late-successional and old-growth forests, social and economic conditions, tribal relationships, and the populations and habitats of marbled murrelets (*Brachyramphus marmoratus*) and northern spotted owls. Monitoring results are evaluated and reported in 1- and 5-year intervals. Monitoring results for the first 10 years are documented in a series of general technical reports available online at http://www.fs.fed.us/pnw/publications/gtrs.shtml. This report, and the others in the current series, covers the first 15 years of the Plan.

Contents

Introduction

The Northwest Forest Plan and Effectiveness Monitoring

In the 1980s, public controversy intensified over timber harvesting of late-successional and old-growth (LSOG) forests, declining species populations (e.g., northern spotted owls [*Strix occidentalis caurina*], marbled murrelets [*Brachyramphus marmoratus*], and Pacific salmon), and the role of federal forests in regional and local economies. The 1990 listing of the northern spotted owl as a threatened species was followed shortly thereafter by lawsuits over federal timber sales and injunctions on timber harvests within the range of the owl (Tuchmann et al. 1996). This turmoil over forest management in the region led to a presidential conference in Portland, Oregon, to address the human and environmental needs served by federal forests in Washington, Oregon, and northern California. On July 1, 1993, President Clinton announced his proposed "Forest Plan for a Sustainable Economy and a Sustainable Environment" (Northwest Forest Plan [the Plan]) (Clinton and Gore 1993). Over the next year, environmental analysis was completed and a record of decision (ROD) was signed in 1994, legally adopting a new management direction (USDA and USDI 1994a, 1994b). The ROD amended existing management plans for 19 national forests and 7 Bureau of Land Management (BLM) districts in California, Oregon, and Washington (encompassing 24 million ac of federal land within the 57-million-ac range of the northern spotted owl). The Plan ROD established the following aims with its published standards and guidelines:

- Adopt an ecosystem-management-based, scientifically supported approach to forest management.
- Meet the requirements of existing laws and regulations.
- Maintain a healthy forest ecosystem with habitat that will support populations of native species (particularly those associated with late-successional and old-growth forests), including protection of riparian areas and waters.
- Maintain a sustainable supply of timber and other forest products that will help maintain the stability of local and regional economies on a predictable and long-term basis.

To help meet these intentions, the Plan allocated a network of large reserves to conserve species of concern within the existing pattern of land ownership and location of remaining old-growth forests. The reserve network was embedded in a matrix of "working" forests and was designed to maintain late-successional (mature or old-growth) forests in a well-distributed pattern across federal lands, to protect stream habitats, and to connect old-growth forests with corridors containing old-forest elements, while providing a sustainable level of timber harvest (see sidebar on next page for details of land designations).

The planning direction also called for a comprehensive monitoring program to evaluate progress toward meeting desired outcomes. In 1995, a scientifically based interagency monitoring program was developed (Mulder et al. 1999). Currently composed of six modules, the monitoring program is designed to answer the key questions outlined in the sidebar on page 3.

Between 2005 and 2008, a number of technical reports were published by the USDA Forest Service Pacific Northwest Research Station (PNW) documenting results from the first decade of monitoring (Charnley 2006; Gallo et al. 2005; Haynes et al. 2006; Huff et al. 2006; Lint 2005; Moeur et al. 2005; Stuart and Martine 2005). In 2005, interagency federal executives convened a regional conference to examine the latest science and monitoring results to determine if changes in management direction or monitoring protocols were needed. Over the years, monitoring protocols and methods have been periodically examined and refined based on new science, technology, and lessons learned.

Much has changed since land and resource management plans were amended by the Plan ROD. A wealth of new science informs ecosystem management. Emerging large-scale issues such as climate change, barred owl (*Strix varia*)

Land Use Allocations Under the Northwest Forest Plan (the Plan)

Excerpted from the record of decision, USDA and USDI (1994b)

Congressionally Reserved Areas (7,320,660 ac; 30 percent of the federal land area): Lands reserved by acts of Congress for specific land uses such as wilderness areas, wild and scenic rivers, national parks, and other lands with congressional designations. The Plan cannot and does not alter these lands.

Late-Successional Reserves (7,430,800 ac; 30 percent of the federal land area): These reserves, in combination with the other allocations and standards and guidelines, are designed to restore a functional, interactive, late-successional and old-growth forest ecosystem over time. They are designed to serve as habitat for terrestrial and aquatic species that depend on these old-growth characteristics, including the northern spotted owl. Some silvicultural treatment is allowed to enhance development of old-growth conditions. They include marbled murrelet reserve area (LSR3), spotted owl activity core reserve (LSR4), and managed late-successional area (MLSA).

Managed Late-Successional Areas (102,200 ac; 1 percent of the federal land area): These lands are either mapped to protect areas where spotted owls are known to exist, or they are unmapped protection buffers. Protection buffers are designed to protect certain rare and endemic species.

Adaptive Management Areas (1,521,800 ac; 6 percent of the federal land area): Ten areas were identified to develop and test innovative management approaches to integrate and achieve ecological, economic, and other social and community objectives. Each area has a different emphasis, such as maximizing the amount of late-successional forests, improving riparian conditions through silvicultural treatments, or maintaining a predictable flow of harvestable timber and other forest products. Each area considers learning a principle product of their adaptive management activities. A portion of timber harvest will come from this land.

Administratively Withdrawn Areas (1,477,100 ac; 6 percent of the federal land area): These areas are identified in current forest and district plans and include recreation and visual areas, back country, and other areas where management emphasis does not include scheduled timber harvest.

Riparian Reserves (11 percent of the federal land within the Plan area, estimated at 2,627,500 ac interspersed throughout the matrix): Riparian reserves are areas along all streams, wetlands, ponds, and lakes, and on unstable and potentially unstable lands vital to protecting and enhancing the resources that depend on the unique characteristics of riparian areas. These areas also play a vital role in protecting and enhancing terrestrial species.

Matrix (3,975,300 ac; 16 percent of the federal land area): The matrix includes all federal lands not falling within one of the other categories. Most of the scheduled timber harvested will be from matrix lands. They include nonforested as well as forested areas that may be technically unsuited for timber production.

Six Modules and Key Questions for Northwest Forest Plan (the Plan) Effectiveness Monitoring

Late-successional and old-growth monitoring characterizes the status and trend of older forests to answer the question: Is the Plan maintaining or restoring late-successional and old-growth forest ecosystems to desired conditions on federal lands in the Plan area?

Northern spotted owl monitoring assesses status and trends in northern spotted owl populations and habitat to answer the questions: Will implementing the Plan reverse the downward trend in owl populations? Is the Plan maintaining or restoring owl habitat necessary to support viable owl populations?

Marbled murrelet monitoring assesses status and trends in marbled murrelet populations and nesting habitat to answer the questions: Are the marbled murrelet populations associated with the Plan area stable, increasing, or decreasing? Is the Plan maintaining and restoring marbled murrelet nesting habitat?

Aquatic and riparian monitoring characterizes the ecological conditions of watersheds and aquatic ecosystems to answer the question: Is the Plan maintaining or restoring aquatic and riparian ecosystems to desired conditions on federal lands in the Plan area?

Socioeconomic monitoring characterizes the social and economic impacts of federal forest management on forest-associated communities to answer the questions: Are predictable levels of timber and nontimber resources available and being produced? Are communities and economies experiencing positive or negative changes that may be associated with federal forest management?

Tribal monitoring addresses conditions, trends, and access to resources protected by treaty or of interest to American Indian tribes, the condition of and access to religious and cultural heritage sites, and the quality of the federal government-to-tribal government relationship to answer the questions: How well and to what degree is government-to-government consultation being conducted under the Plan? Have the goals and objectives of the consultation been achieved? Is the consultation occurring because of effects on resources of tribal interest on federal lands or trust resources on tribal lands?

population expansion, and large stand-replacing wildfires have the potential to affect how federal forests are managed in the future. Monitoring will continue to be an essential tool for implementing adaptive management on federal forests in the Pacific Northwest and charting a course for the future.

Overview of Late-Successional and Old-Growth (LSOG) Forest Monitoring for This Report

This report summarizes the assessment of LSOG for federally administered lands ("federal lands") affected by the Plan. Information on other ownerships ("nonfederal lands") is provided for context. This assessment, the "15-year report," provides information for monitoring from 1994 to 2007 in California and from 1996 to 2006 in Washington and Oregon. Previously, the "10-year report" (Moeur et al. 2005) provided information on LSOG status and trends between 1994 and 2003. As in the 10-year report, we followed the basic monitoring approaches and protocols established by Hemstrom et al. (1998). Although the conceptual approach is the same, most of the major information sources have been updated to use the most current technologies and data available. For this reason, the status and trends results in the 15-year and 10-year reports are not directly comparable, and the current estimates are considered more reliable and up-to-date.

As was done for the 10-year report, for the current report we developed maps of forest structure, composition, and change based on satellite imagery, field plot data from regional inventories, and other spatial data from statistical models. We also developed sample-based estimates of older forest based on the regional inventory plots. Most plots used to generate statistical estimates for federal lands have now been measured twice. We report estimates of LSOG amount (acres and percentage of landscape) and distribution (by owner, physiographic province [fig. 1], and land use allocation [LUA]) for the 1994/1996 baseline and for the current (2006/2007) landscape. We also provide estimates of the amount of LSOG potentially affected by wildfire, harvest, or insects and disease since 1994/1996, based on statistical models of Landsat time-series data.

Methods

Overview of Data Sources and Analyses for Assessing Status and Trends

We assessed the amounts, distributions, and trends of LSOG for the monitoring period based on multiple data sources, and by using complementary map-based and sample-based analyses. Map-based analyses provide broad-scale information on landscape patterns developed from statistical models, whereas field-plot-based vegetation inventories provide detailed information on forest characteristics from a probability sample. The map- and plot-based analyses relied on some of the same underlying data sources (fig. 2), which improved the consistency of results among analyses.

Map analyses—
We used forest vegetation maps developed using gradient nearest neighbor (GNN) imputation (Ohmann and Gregory 2002) for the baseline and for the end of the current monitoring period to estimate the amount and distribution of LSOG at the two endpoints ("bookends"). We compared the two bookend maps to summarize net change in LSOG as the difference between gross LSOG losses and gross LSOG gains. The GNN models utilized temporally normalized imagery from the LandTrendr[1] algorithms (see below) as well as plot data from the regional inventories.

We used annual maps of disturbance over the monitoring period developed from LandTrendr (Kennedy et al. 2010) to characterize the agents of disturbance (wildfire, harvest, insects/disease) associated with LSOG loss identified from the two GNN bookend maps. The LandTrendr algorithms also produced temporally normalized imagery for use in GNN modeling. The LandTrendr disturbance maps were validated TimeSync software developed for this project (Cohen et al. 2010).

Plot analyses—
Plot data used in this report came from five inventory programs: Current Vegetation Survey (CVS) (Max et al. 1996; USDA Forest Service 2001) on national forest lands in

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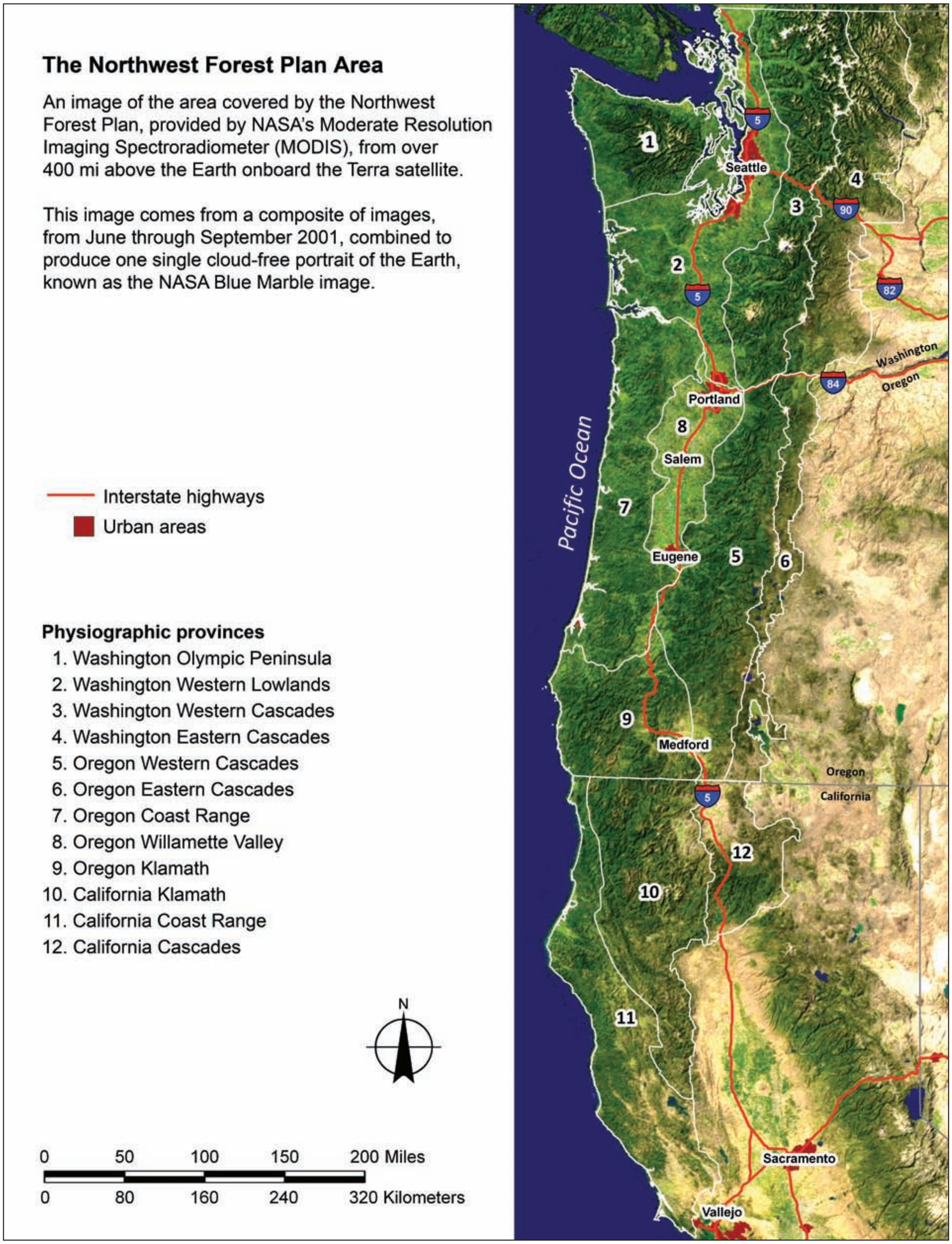
[1] LandTrendr (Landsat-based detection of trends in disturbance and recovery) is a new approach to analysis of annual Landsat satellite imagery that improves the temporal frequency of disturbance maps.



The Northwest Forest Plan Area

An image of the area covered by the Northwest Forest Plan, provided by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), from over 400 mi above the Earth onboard the Terra satellite.

This image comes from a composite of images, from June through September 2001, combined to produce one single cloud-free portrait of the Earth, known as the NASA Blue Marble image.

Physiographic provinces

1. Washington Olympic Peninsula
2. Washington Western Lowlands
3. Washington Western Cascades
4. Washington Eastern Cascades
5. Oregon Western Cascades
6. Oregon Eastern Cascades
7. Oregon Coast Range
8. Oregon Willamette Valley
9. Oregon Klamath
10. California Klamath
11. California Coast Range
12. California Cascades

Figure 1—Physiographic provinces of the Northwest Forest Plan area (from USDA and USDI 1994a).

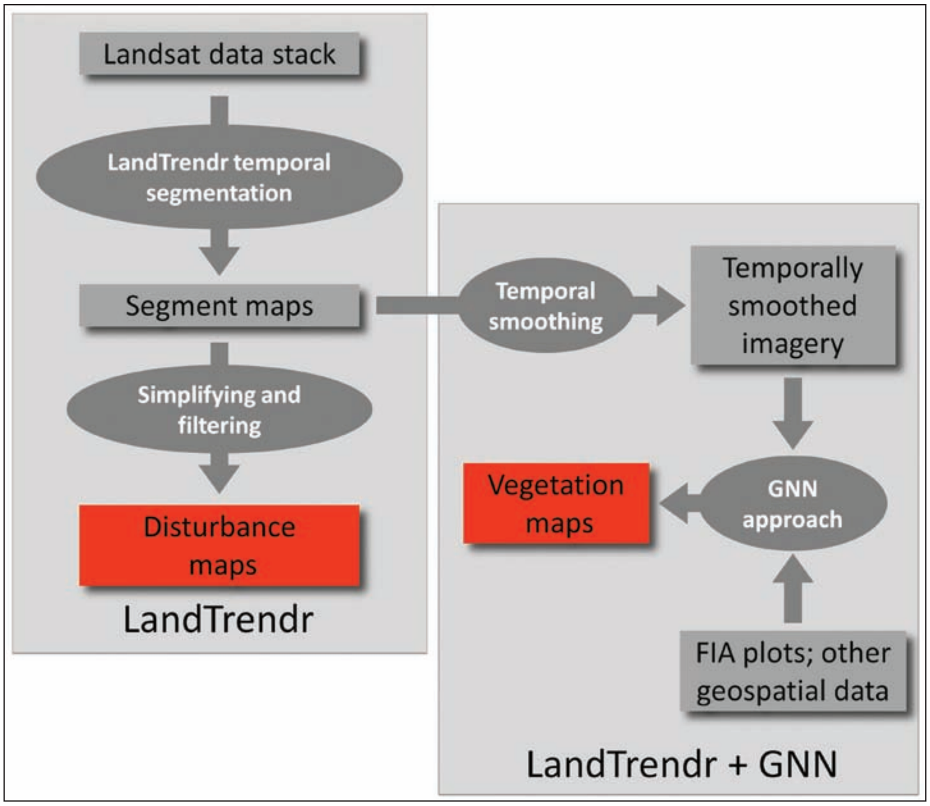


Figure 2—Workflow for LandTrendr and LandTrendr + gradient nearest neighbor (GNN). Temporal segmentation forms the core of both disturbance maps and the imagery needed to apply GNN to multiple years of data. FIA = Forest Inventory and Analysis.

Washington and Oregon, administered by the Forest Service in the Pacific Northwest (Region 6) (CVS-R6); CVS on BLM lands in Oregon, administered by Oregon BLM (CVS-BLM); Forest Inventory and Analysis (FIA) periodic inventories on national forest lands in California, administered by the Forest Service in the Pacific Southwest Region (Region 5) (FIA-R5-periodic) (USDA Forest Service 2000); FIA periodic inventories on nonfederal lands throughout the Plan area, administered by PNW (FIA-PNW-periodic); and the FIA Annual Inventory of all land ownerships throughout the Plan area, administered by PNW (FIA-PNW-Annual). See Moeur et al. (2005) for more information about the inventory programs.

We analyzed plot information from successive CVS-R6 and CVS-BLM inventories, and FIA-R5-periodic and FIA-PNW-Annual inventories in California, as an independent estimate of trends in LSOG area on national forest and Oregon BLM lands. We also acquired sample-based estimates of LSOG area for all ownerships from FIA-PNW-Annual plots measured from 2001 to 2008. The FIA-PNW-Annual plots provide a consistent sample of forest condition over all ownerships and LUAs, but have not yet been remeasured. Only those plots classified as forest-capable were included in the analyses.

Definition of LSOG Used in This Report

For this broad-scale assessment, we used a single, simple definition of LSOG based on the canopy cover and average size of live conifer trees in the overstory, as shown in table 1. We applied the same definition in the analyses of the GNN bookend maps and in the analyses of regional inventory plots. This definition is comparable to the definition of "medium and large older forest," the least restrictive definition of older forest used in the 10-year report (Moeur et al. 2005). It also corresponds closely to the definition of late-successional forests used for mapping purposes by the Forest Ecosystem Management Assessment Team (FEMAT) (FEMAT 1993, Table II-3, p. II-22) and therefore can be used to assess assumptions about the amount and distribution of older forest upon which the Plan was founded.

Table 1—Definition of late-successional and old-growth forest (LSOG) used in this paper, applied to all forest-capable land

Conifer canopy cover[a]	Average conifer tree diameter[b]	Forest class
Percent	*Inches*	
<10	—	Open
10 to 100	0 to 19.9	Young
10 to 100	≥20	LSOG

[a] Percentage of area covered by live crowns of dominant and codominant conifers, corrected for overlap.

[b] Quadratic mean diameter of dominant and codominant live conifers.

The LSOG definition used in this report is quite simplified, compared to ecological definitions based on forest type and live and dead structures, and applies threshold values rather than continuous structural indices, that recognize old-growth as part of a continuum of ecological complexity (Franklin and Spies 1991). Use of a single, simple definition does not recognize the variation in tree size and density attained across gradients in forest type and productivity over the Plan area. In addition, the definition does not equate to habitat for particular species (e.g., the northern spotted owl). The trends and changes in old growth in this report would be different if other definitions were used, but not necessarily more accurate. In particular, the estimated relative amounts of LSOG loss and recruitment would likely change if a more restrictive definition was used (one that emphasized older and larger trees). A comparison of alternative definitions would require a more indepth analysis that is beyond the scope of this paper.

Physiographic Provinces, Land Use Allocations, and Forest-Capable Area

We report monitoring results for forest-capable area within the physiographic provinces and LUAs described in the Plan documents (see sidebar on p. 2), consistent with the 10-year report. Forest-capable area includes all lands potentially capable of supporting forest. The physiographic provinces (fig. 1) are useful for stratifying monitoring findings according to the climatic, topographic, and social gradients across the Plan area that create significant differences in potential natural vegetation, current vegetation, natural disturbance regime, historical land use, and land ownership (Moeur et al. 2005).

Monitoring results also are summarized by the LUA groupings shown in table 2. The Plan ROD divided federal land into seven LUAs (see sidebar on page 2). These allocations were the foundation for establishing an older forest reserve network while maintaining lands designated for scheduled timber harvest. The LUA map layer and Plan boundaries were slightly modified since publication of the 10-year report to correct minor errors and incorporate changes in LUA and federal land boundaries. The difference in total area between the 10-year report and the 15-year report is about 1 percent.

Riparian reserves have never been mapped separately from adaptive management areas and matrix lands for the purpose of the Plan monitoring, but were estimated in the Plan ROD to comprise 2.6 million ac in addition to the other reserves. Therefore, as in the 10-year report, the inclusion of riparian reserves within the nonreserved lands in our analyses results in an overestimate of the amount of LSOG in the nonreserved category, and a conservative estimate of the amount of LSOG in the reserved allocations.

The amount of LSOG was tabulated only for land that is potentially capable of supporting forest. For the map analyses, forest-capable area (table 3) included all areas that are capable of supporting forest and capable of providing habitat for the northern spotted owl and marbled murrelet.

Table 2—Land use allocation groupings used in this paper

Land use allocation	Reserve category
Adaptive management area	Nonreserved
Adaptive management area and late-successional reserve overlapping designation	Reserved
Administratively withdrawn	Reserved
Congressionally reserved	Reserved
Late-successional reserve[a]	Reserved
Matrix or riparian reserve (not mapped separately)[b]	Nonreserved

[a] Includes marbled murrelet reserve areas, spotted owl activity core reserves, and managed late-successional areas.

[b] Includes land labeled as not designated.

Table 3—Distribution of land in the Northwest Forest Plan (NWFP) area by ownership and forest-capable status

State and physiographic province	NWFP federal lands (FS, BLM, NPS)[a]				Other lands[b]				NWFP	
	Total	Forest-capable	Nonforest[c]	Percentage forest-capable	Total	Forest-capable	Nonforest[c]	Percentage forest-capable	Total	Percentage forest-capable
	– – – – – Thousand acres – – – – –			*Percent*	*– – – – –Thousand acres – – – – –*			*Percent*	*Thousand acres*	*Percent*
Washington:										
Olympic Peninsula	1,531.8	1,339.9	192.0	87	1,502.6	1,382.2	120.4	92	3,034.4	90
Western Lowlands	2.4	1.4	1.0	59	6,514.2	4,529.0	1,985.2	70	6,516.6	70
Western Cascades	3,748.6	3,039.3	709.3	81	2,405.2	2,220.2	184.9	92	6,153.8	85
Eastern Cascades	3,547.5	2,608.8	938.7	74	2,144.2	1,605.2	539.0	75	5,691.6	74
Total	8,830.3	6,989.3	1,841.0	79	12,566.1	9,736.7	2,829.5	77	21,396.4	78
Oregon:										
Coast Range	1,417.0	1,392.2	24.9	98	4,409,2	3,836.6	572.6	87	5,826.2	90
Willamette Valley	21.0	17.8	3.3	84	2,645,9	543.9	2,102.0	21	2,666.9	21
Western Cascades	2,125.0	2,102.9	22.1	99	1,881,4	1,519.7	361.7	81	4,006.4	90
Klamath	4,508.9	4,348.6	160.3	96	2,136,7	1,901.4	235.2	89	6,645.6	94
Eastern Cascades	1,628.1	1,449.4	178.7	89	762,4	647.3	115.1	85	2,390.5	88
Total	9,700.0	9,310.9	389.2	96	11,835,6	8,448.9	3,386.6	71	21,535.6	82
California:										
Coast Range	484.0	367.0	116.9	76	5,209,6	3,547.8	1,661.8	68	5,693.6	69
Klamath	4,590.1	4,280.1	310.0	93	1,496,4	1,248.7	247.8	83	6,086.5	91
Cascades	1,124.6	1,013.6	111.0	90	1,378.2	965.0	413.2	70	2,502.8	79
Total	6,198.7	5,660.7	537.9	91	8,084.2	5,761.5	2,322.7	71	14,282.9	80
NWFP total	24,729.0	21,960.9	2,768.1	89	32,486.0	23,947.1	8,538.8	74	57,215.0	80

[a] FS = USDA Forest Service; BLM = Bureau of Land Management; NPS = National Park Service.

[b] Includes all state, tribal, private, and federal lands (USDI Bureau of Reclamation, Department of Defense, U.S. Fish and Wildlife Service) not affected by the NWFP.

[c] Source: Maps of ecological systems developed for the Gap Analysis Program (http://www.gap.uidaho.edu/Portal/DataDownload.html).

Nearest-Neighbor Imputation

Nearest neighbor methods often are used to map detailed forest characteristics across large areas (see review by Eskelson et al. 2009). In nearest-neighbor imputation, forest attributes from ground-based inventory plots are assigned to map locations where plot data are lacking. Usually, there are less expensive predictor variables available for all locations (such as from satellite imagery), but only a sample of locations where more detailed plot data (response variables) are available. Response variables typically are measures such as tree basal area, density, and volume, which come from the sample of field plots or stand exams. The assumption behind nearest-neighbor methods is that two locations with similar predictive variable values should also have similar response variable values. The similarity (or distance) between locations, which is the basis for choosing a nearest-neighbor observation, can be evaluated in different ways. In practice, the distance measure, number of nearest-neighbor plots (*k*), weighting of the plots in the calculations, choice of predictor and response variables, and spatial scale (resolution and extent) all can be varied to produce different variations of nearest-neighbor mapping.

We masked out areas of nonforest based on land class data from the U.S. Geological Survey (USGS) Gap Analysis Program (GAP) (http://gapanalysis.nbii.gov/) and the National Land Cover Data set (NCLD) (http://landcover.usgs.gov/). These included lands above tree line, permanently nonforested lands, water bodies, and other such areas. We used the NLCD “impervious” data to mask out developed open space and GAP data to identify and exclude subalpine and steppe areas. Isolated fragments of less than 2/3 ac were dissolved to their surroundings.

There are more nonforest acres in the current mask, resulting in about 6 percent fewer forested acres than in the 10-year report. Most of these acres are on the margins of forested areas and have very little effect on the estimate of LSOG acres. For the plot analyses, forest land is determined by the classification of the field plot data. The areas by province, ownership, and LUA in table 3 are slightly different than those reported in the 10-year report. In both map and plot analyses, the permanently nonforested areas include administrative sites such as park headquarters and ranger district offices, roads and highways, and naturally nonforested lands such as water, barrens, rocky outcrops, alpine meadows above tree line, etc.

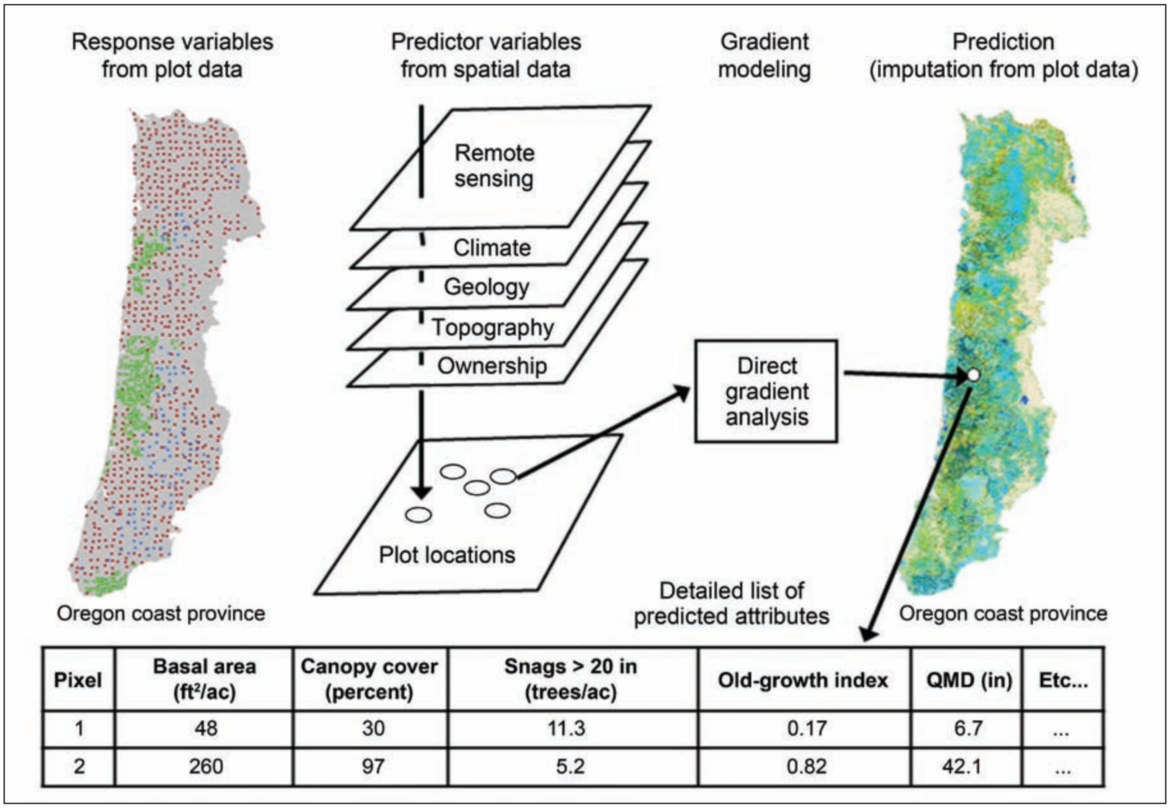
Map Analyses

Gradient Nearest Neighbor “bookend” maps of forest vegetation—

We used the gradient nearest neighbor (GNN) method (Ohmann and Gregory 2002) to map detailed attributes of forest composition and structure for all forest land in the Plan area at two different dates: 1996 and 2006 in Washington and Oregon and 1994 and 2007 in California. The GNN “bookend” maps portray LSOG conditions at the beginning and ending of the Plan monitoring period covered by this report.

GNN imputation (Ohmann and Gregory 2002) is one of many variations of nearest neighbor methods (see sidebar on this page). The GNN method was developed in the Pacific Northwest specifically for applications to landscape analysis and land management planning (e.g., Moeur et al. 2009; Spies et al. 2007). This method has now been applied to broad-scale vegetation mapping across a wide range of forest ecosystems for multiple objectives (Ohmann et al. 2007, 2011; Pierce et al. 2009). However, the vegetation mapping for Plan monitoring marks the first application of GNN to two imagery dates.

In GNN (fig. 3), a single nearest-neighbor plot is identified for each map unit based on weighted Euclidean distance within multivariate gradient space as determined from canonical correspondence analysis (CCA) (ter Braak 1986). All of the inventoried attributes for the nearest-neighbor plot are assigned (or imputed) to the map pixel. This approach maintains the covariance structure of vegetation attributes within each map unit (in other words, no illogical combinations of species or structures will occur). A large suite of diagnostics detailing GNN model reliability and map accuracy is produced as a standard part of GNN modeling. See appendix 1 for more detail about GNN modeling for this report.



Pixel	Basal area (ft²/ac)	Canopy cover (percent)	Snags > 20 in (trees/ac)	Old-growth index	QMD (in)	Etc...
1	48	30	11.3	0.17	6.7	...
2	260	97	5.2	0.82	42.1	...

Figure 3—Schematic of gradient nearest neighbor imputation approach used to develop vegetation maps for the bookend dates (adapted from Ohmann and Gregory 2002). QMD = quadratic mean diameter.

The primary challenge for LSOG monitoring was to develop multidate GNN models (and maps) that reflected real forest changes between dates, by minimizing apparent changes caused by various sources of error. For the bookend models, we implemented two key enhancements to GNN. First, the GNN models used Landsat imagery that had been geometrically rectified and radiometrically normalized through time (i.e., "temporally smoothed") using the LandTrendr algorithms (fig. 2 and fig. 4). This process minimizes uninteresting spectral differences between imagery dates, such that the remaining signal more closely reflects real changes in vegetation. Use of this imagery also improved consistency between the GNN bookend maps and the LandTrendr disturbance maps used in this report. Second, we selected a single set of inventory plots to use in developing a single gradient (statistical) model, which we then applied to each of the two imagery dates. As a result, all differences in forest vegetation between the two bookend maps are associated with changes in the underlying Landsat spectral data; all other spatial predictor variables were held constant.

LandTrendr maps of forest disturbance—

We derived yearly maps of forest disturbance for the Plan using LandTrendr (see footnote 1). Landsat images acquired continuously for the entire conterminous United States (and portions of the world) since 1984 form the basis for many land cover and land cover change maps used in natural resource disciplines (Cohen and Goward 2004; Wulder et al. 2008), including prior studies within the range of the Plan (Cohen et al. 2002; Healey et al. 2005, 2008; Kennedy et al. 2007). LandTrendr leverages more of the satellite archive to improve the temporal frequency of disturbance maps. As a result, we can better detect changes that are difficult to capture when comparing only two images at a time (Kennedy et al. 2010).

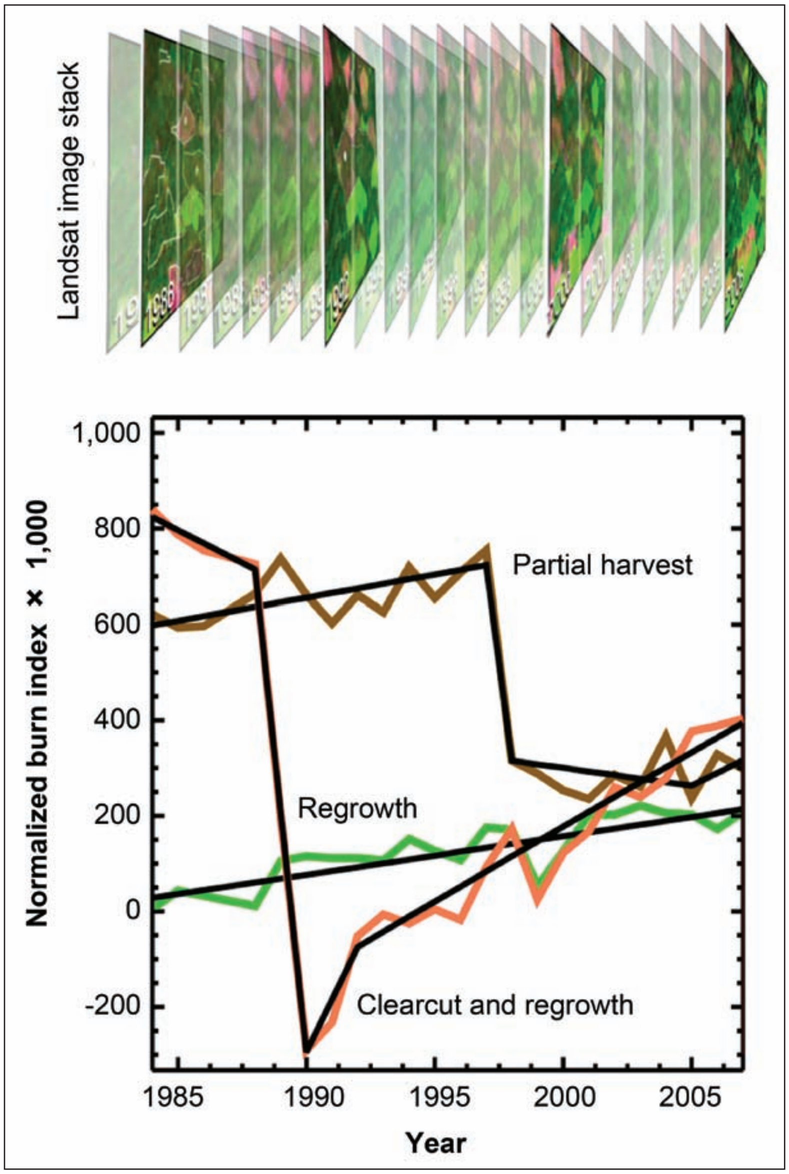


Figure 4—Schematic of LandTrendr trajectory-based change detection approach. Top: a stack of yearly Landsat images is aligned, cleaned, and normalized. Bottom: statistical algorithms fit straight line representations (black lines) of cleaned pixel trajectories (colored traces). When combined across all pixels, maps of disturbance and recovery timing and severity are produced.

LandTrendr uses data-intensive algorithms to assemble and process imagery (figs. 2 and 4; app. 2). Annual time series of Landsat imagery were assembled for the Plan area, atmospherically corrected, and radiometrically normalized. The normalization process reduces much of the year-to-year variability in spectral signal caused by sun angle and phenology. We then extracted the Normalized Burn Ratio (NBR) (van Wagtendonk et al. 2004) spectral index for each 30-m pixel in the time-series, and applied algorithms to identify with straight-line segments the periods of stability and of change in each pixel's annual trajectory (fig. 4). For change segments, we estimated percentage of vegetation cover for the beginning and ending point using a statistical model relating the NBR index to photointerpreted estimates of cover (Cohen et al. 2010), and then calculated a relative magnitude of change (change in cover divided by starting cover). If the relative change was 15 percent or greater, the disturbance map was assigned the year that the disturbance could first be detected, the duration of disturbance (e.g., the length of the segment), and the relative magnitude of change in percentage of cover.

To validate the segmentation results, we compared them against segmentation manually ascribed by an expert interpreter at several hundred plot locations, using TimeSync software developed specifically for this project (Cohen et al. 2010). TimeSync interpretation allows discrimination of very subtle disturbance effects previously unobserved or mapped with satellite imagery. We corroborated the expert interpretation by comparing against observations from other spatial data sets (Cohen et al. 2010). For validation, we grouped the disturbance results into magnitude classes of low (15 to 32 percent relative vegetation loss), medium (33 to 66 percent), or high (>66 percent).

Finally, we grouped pixels into patches to remove small noise events, and used simple rules to separate disturbance agents into three types. See appendix 2 for more detail. Briefly, we grouped adjacent pixels and eliminated those smaller than approximately 2.5 ac. We then used rules related to the duration of the disturbance and alignment with spatial fire databases to assign causes of insect/diseases and fire, and then considered the remaining change patches to be harvest. The latter class is dominated by harvest, but also can contain rare cases of avalanche, landslide, riparian disturbance, and windthrow. Thus, results reported under the "harvest" category must be interpreted with caution.

Combined maps of GNN LSOG change and LandTrendr disturbance—

To develop maps depicting LSOG change, we intersected the two GNN bookend maps and labeled each pixel as one of these four classes:

Classification in 1994/96 GNN data	Classification in 2006/07 GNN data	
	LSOG	Not LSOG
LSOG	LSOG constant	LSOG loss
Not LSOG	LSOG gain	Not LSOG

We computed gross LSOG loss and gross LSOG gain for combinations of physiographic provinces, ownerships, and allocations by simply summing the area represented by all pixels in these LSOG change classes. Net LSOG change was computed as the difference between gross area of LSOG gain and gross area of LSOG loss between the baseline and current maps. For another estimate of forest change, and to characterize the causes of disturbance and potential LSOG loss, we intersected the map of these four GNN LSOG change classes with the LandTrendr disturbance data. Pixels were attributed as disturbed by fire, harvest, or insects/disease, or as not disturbed. Sixteen class combinations were possible after combining the bookends and disturbance map.

Inventory Plot Analyses

Trends of LSOG from successive inventories on Forest Service and Oregon BLM lands—

We analyzed data from inventory plots on federal lands where two sampling occasions were available: CVS-R6 and CVS-BLM on Forest Service and Oregon BLM lands, and FIA-R5-periodic and FIA-PNW-Annual plots on national forests in California (table 4). No data were available for national parks nor for BLM lands outside Oregon. The plot analyses were done independently from GNN and used a different subset of the regional inventory plots.

We used the entire plot sample from both measurement occasions to compile the estimates, including plots that had not been remeasured. Most plots from the first sampling occasion were measured from 1993 to 2001 (table 5), approximating the baseline (near the beginning of the Plan). Plots from the second sampling occasion were measured from 1996 to 2007, and generally are representative of current conditions. Compiling the plot data by measurement date (1980 to 2000 and 2001 to 2007), rather than by measurement occasion, made very little difference in the resulting estimates.

From the plot data we estimated amounts (percentage of area) of LSOG by applying the same LSOG definition used in GNN (table 1) to the inventoried tree lists, and summing the area represented by the plots. We calculated 90-percent confidence intervals around the percentage estimates based on a normal approximation to the binomial distribution, applicable when estimating percentages using two classes (LSOG or not LSOG).

Table 4—Distribution of inventory plots[a] in the Northwest Forest Plan (NWFP) area by physiographic province

State and physiographic province	First sample occasion		Second sample occasion	
	Number of plots	Area sampled	Number of plots	Area sampled
		Thousand acres		*Thousand acres*
Washington:				
Olympic Peninsula	298	631.3	298	631.3
Western Lowlands	0	0.0	0	0.0
Western Cascades	1,242	2,992.3	1,204	2,990.6
Eastern Cascades	1,270	3,467.9	1,243	3,465.3
Total	2,810	7,091.5	2,745	7,087.2
Oregon:				
Coast Range	789	1,414.8	433	1,404.1
Willamette Valley	10	18.6	3	23.0
Western Cascades	2,164	4,390.2	1,838	4,375.6
Klamath	1,084	2,102.5	699	2,108.9
Eastern Cascades	660	1,552.5	633	1,566.8
Total	4,707	9,478.6	3,606	9,478.4
California:				
Coast Range	10	83.5	12	72.5
Klamath	528	4,362.9	715	4,329.5
Cascades	128	1,112.9	178	1,129.2
Total	666	5,559.3	905	5,531.2
NWFP total	8,183	22,129.4	7,256	22,096.8

[a] All current vegetation survey plots falling on Forest Service Pacific Northwest Region and Oregon Bureau of Land Management lands, and Forest Inventory and Analysis plots falling on Forest Service Pacific Southwest Region lands, were analyzed.

Table 5—Distribution of plots on Forest Service and Bureau of Land Management (BLM) lands in the Northwest Forest Plan (NWFP) area by measurement year, inventory program, and measurement occasion

	CVS occasion 1		CVS occasion 2		FIA periodic		FIA Annual	
Year	Number of plots	Area sampled	Number of plots	Area sampled	Number of plots	Area sampled	Number of plots	Area sampled
		Thousand acres		*Thousand acres*		*Thousand acres*		*Thousand acres*
1980					3	27		
1993	405	914						
1994	969	2,834			2	26		
1995	1,936	4,903			7	59		
1996	2,469	4,883	4	7	315	2,684		
1997	637	1,175	786	1,501	133	1,199		
1998	9	15	622	1,140	157	1,405		
1999	127	224	634	1,210	8	71		
2000	560	952	288	513				
2001	368	597	477	899			82	514
2002	30	80	851	3,609			89	561
2003	15	24	854	2,675			161	1,008
2004	7	13	654	2,306			92	578
2005	7	12	522	1.118			72	451
2006	5	10	436	809			278	1,734
2007	13	24	457	866			97	600

CVS = Current Vegetation Survey, on the Forest Service Pacific Northwest Region and Oregon BLM lands. FIA is Forest Inventory and Analysis on Forest Service Pacific Southwest Region lands.

The estimate of LSOG percentage of forest-capable area for the first measurement occasion in California (FIA-R5-periodic plots, ~40 percent) was significantly greater than the estimate for the second occasion (from FIA-PNW-Annual plots, ~30 percent), as well as from the GNN estimates for 1994 and 2007 (~34 percent). Because we do not think the first occasion estimate is credible, these results are not discussed further in this report.

Current LSOG estimates from FIA-PNW-Annual Inventory of all lands—

We also estimated LSOG area for all ownerships in the Plan area, based on FIA-PNW-Annual Inventory plots measured from 2001 to 2008. The FIA-PNW-Annual plots provide the most reliable sample-based estimates of forest conditions in the current landscape, covering all ownerships and allocations based on a consistent plot design, but remeasurement data are not yet available. These data were less complete at the time of the 10-year report.

Results

Reliability of LandTrendr Disturbance and GNN Vegetation Maps

From the TimeSync validation process, allowing for slight mismatch in timing of segmentation (typically ± 1 year for harvest and fire), the LandTrendr segmentation algorithms were found to capture and correctly time 89 percent and 82 percent of the high-severity harvest and fire events, respectively. Medium-severity harvest and fire were also captured with high accuracy (78 percent and 82 percent). The algorithms were not as sensitive at detecting low levels of cover loss (42 percent and 61 percent). Other disturbance agents (insects/disease) were captured less reliably (67 percent of high severity, 48 percent of medium, and 16 percent of low). For all disturbance intensities and agents over the Plan area, the data we used in this report, 82 percent were captured correctly. The TimeSync validation did not evaluate the attribution of agent of disturbance (harvest, fire, or insects/disease).

Local-scale accuracy of the GNN bookend maps for LSOG over the entire Plan area, which was assessed at plot locations using cross-validation, was 80 percent, and the kappa coefficient of agreement (Cohen 1960) was 0.49 (app. 1). At the province level, accuracy ranged from 72 to 89 percent correct and kappas ranged from 0.13 to 0.71. The kappas were positively correlated with LSOG prevalence, and the lowest kappas (the Western Lowlands in Washington and the Willamette Valley in Oregon) were for the two provinces with very little federal land. Additional map diagnostics are presented in appendix 1.

Across all ownerships in the Plan area, the GNN model-based estimate of current (2006/2007) LSOG area was within the standard error of the FIA Annual sample-based estimates for 2001–2008 (fig. 5). However, the GNN estimate was less than FIA for federal lands and greater than FIA for nonfederal lands. At the province level, the GNN estimates of LSOG area on federal lands in 2006/2007 were within the FIA standard error for all but the Washington Western Cascades and Washington Eastern Cascades. At the state level for all ownerships, the GNN estimate was within the FIA standard error for California but not for the other two states. The GNN and FIA estimates of LSOG area for all provinces and ownerships are shown in appendix 1. Variance estimators are not yet available for the GNN estimates of LSOG area. Variance estimators for nearest-neighbor models are still under statistical development (e.g, see Magnussen et al. 2010; McRoberts et al. 2007) and have not yet been implemented over large study areas like ours.

Distribution and Trends of LSOG From the Vegetation and Disturbance Maps

Trends of LSOG on all ownerships—

At the 1994/1996 baseline, 65 percent of the total LSOG throughout the Plan area was on federal lands, and 35 percent was on nonfederal lands (tables 6 and 7; figs. 5 and 6). By the end of the monitoring period, the federal share of total LSOG increased to 67 percent and the nonfederal share decreased to 33 percent. Over all ownerships Plan-wide, the GNN bookend estimates indicated a net loss of 4.7 percent of the baseline LSOG over the monitoring period, with most of the loss from nonfederal lands (table 7, fig. 5). The LSOG losses and gains were distributed across all of the Plan area, but large patches of LSOG loss corresponding to large wildfires are visible in the southern and eastern parts of the Plan area (fig. 7).

Trends of LSOG on federal lands and reserves—

On federal lands Plan-wide, approximately 7,286 thousand ac, or 33.2 percent of the federal forest-capable area (table 3), were classified as LSOG at the baseline (table 6). Most of the federal LSOG was in Oregon, followed by Washington and California. As a percentage of the forest landscape, the eastern provinces (Washington Eastern Cascades, California Cascades, and Oregon Eastern Cascades) had the least LSOG (<20 percent), the Olympic Peninsula had the most (>50 percent), and the other provinces ranged from about 25 percent (California Coast Range) to >40 percent (Oregon Western Cascades).

The federal LSOG area decreased by an estimated 1.9 percent Plan-wide over the monitoring period, computed as net change in LSOG area estimates for the two GNN bookend maps relative to the baseline LSOG area (table 6). Net LSOG change was positive in some provinces and negative in others. However, because of uncertainty in the GNN maps, the small magnitude of change, and the short time period, we cannot conclusively state the direction and magnitude of change.

Areas where LSOG losses from the GNN bookend maps coincided with disturbances of all severities mapped by LandTrendr amounted to 217,000 ac, or 3.0 percent of the baseline LSOG (table 6). (See app. 3 for complete results of the spatial intersection of the GNN and LandTrendr maps.) Most of the LSOG losses (184,000 ac) were associated with wildfire, including several very large fire events in the Oregon Klamath (2002 Biscuit Fire), California Klamath (1999 Megram Fire), Oregon Western Cascades (2003 B&B Fire), Oregon Eastern Cascades (2003 B&B and Davis Fires), and Washington Eastern Cascades (2005 Chelan County Fire) (fig. 7). Only a very small amount of LSOG loss (32,100 ac, or <0.5 percent) on federal lands was associated with the harvest class, and was distributed across the provinces. Because the harvest class also included rare cases of windthrow, avalanche, landslide, and riparian disturbance,

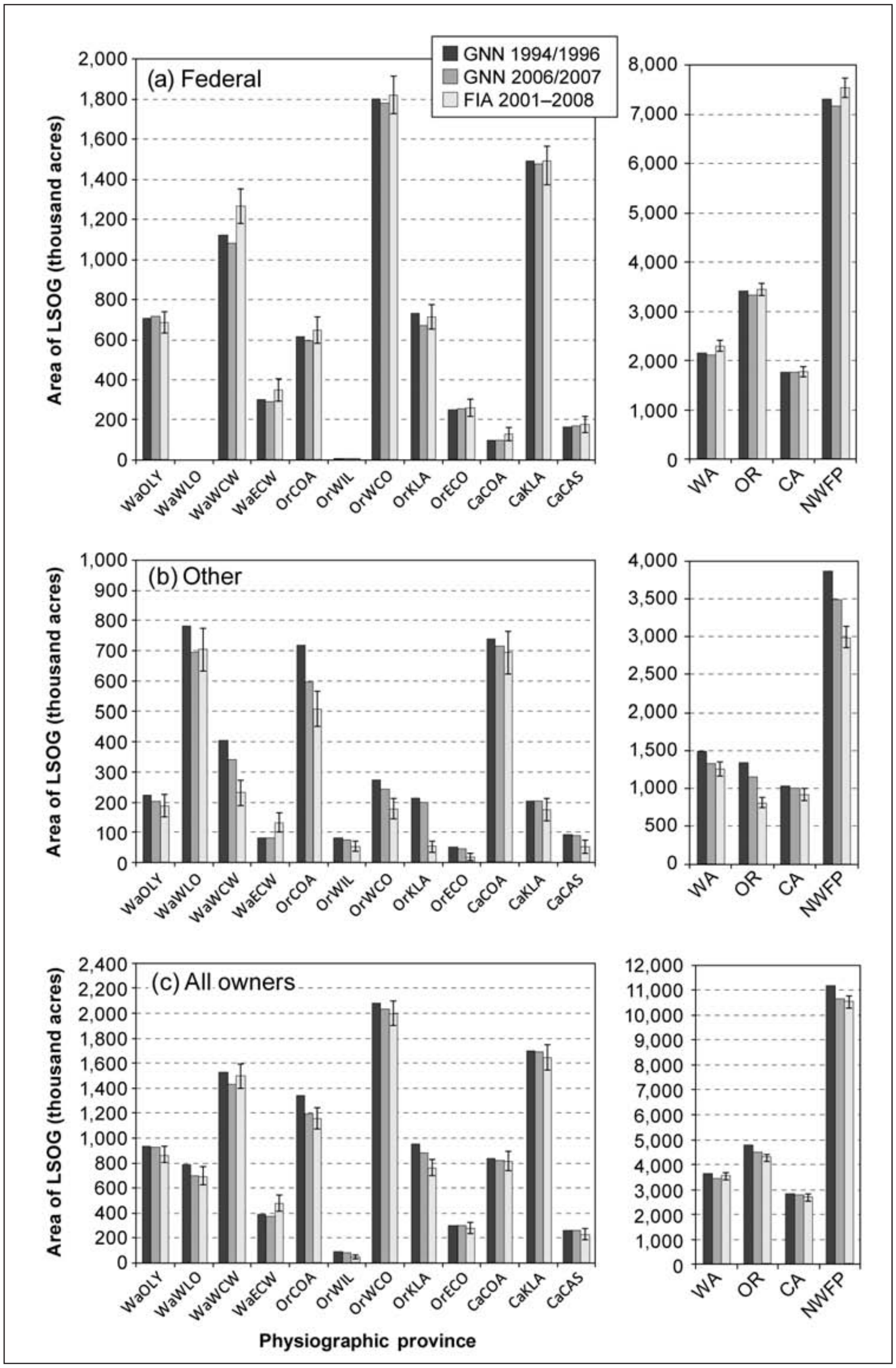


Figure 5—Area of late-successional and old-growth forest (LSOG) from gradient nearest neighbor (GNN) bookend maps (1994 and 2007 in California, and 1996 and 2006 in Washington and Oregon) and from Forest Inventory and Analysis (FIA) Annual Inventory plots measured between 2001 and 2008. The FIA estimates show ± the standard area of the estimate. Area of LSOG is shown for (a) Northwest Forest Plan (NWFP) federal lands, (b) other (nonfederal) ownerships, and (c) all ownerships. Abbreviations for physiographic provinces are in table 3. WA = Washington, OR = Oregon, and CA = California.

Table 6—Area of late-successional and old-growth forest (LSOG) on Northwest Forest Plan federal lands (Forest Service, Bureau of Land Management, and National Park Service) from the gradient nearest neighbor (GNN) bookend maps (left), and intersected with the LandTrendr disturbance map (right)

	LSOG area from GNN bookend maps						LandTrendr disturbance assignment for GNN gross losses					
State and physiographic province	LSOG in 1994/1996 (baseline)	LSOG in 2006/2007 (current)	Gross LSOG loss	Gross LSOG gain	Net LSOG change	Net LSOG change	Harvest[a]	Insects and disease	Wildfire	No disturbance	Total explained losses	Percentage loss from baseline
	Thousand acres					*Percent*	*Thousand acres*					*Percent*
Washington:												
Olympic Peninsula	708.4	716.4	46.2	54.2	8.0	1.1	-0.4	0.0	-0.1	45.7	-0.5	-0.1
Western Lowlands	0.3	0.4	0.0	0.1	0.1	33.3	0.0	0.0	0.0	0.0	0.0	0.0
Western Cascades	1,120.1	1084.5	176.0	140.4	-35.6	-11.8	-2.4	-0.3	-0.7	172.6	-3.4	-0.3
Eastern Cascades	302.3	291.2	69.3	58.2	-11.1	-1.0	-2.6	-0.7	-5.7	60.3	-9.0	-3.0
Total	2,131.1	2,092.5	291.5	252.9	-38.6	-1.8	-5.4	-1.0	-6.5	278.6	-12.9	-0.6
Oregon:												
Coast Range	615.1	596.8	91.8	73.5	-18.3	-3.0	-2.3	0.0	0.0	89.5	-2.3	-0.4
Willamette Valley	4.2	4.6	0.6	1.0	0.4	9.5	0.0	0.0	0.0	0.6	0.0	0.0
Western Cascades	1,800.6	1,780.5	258.2	238.1	-20.1	-1.1	-8.1	0.0	-20.1	230.0	-28.2	-1.6
Klamath	730.1	672.6	207.7	150.2	-57.5	-7.9	-4.5	0.0	-80.2	123.0	-84.7	-11.6
Eastern Cascades	249.9	254.4	64.7	69.2	4.5	1.8	-2.6	0.0	-5.8	56.3	-8.4	-3.4
Total	3,399.9	3,308.9	628.4	532.0	-91.0	-2.7	-17.5	0.0	-106.1	499.4	-123.6	-3.6
California:												
Coast Range	96.4	98.8	19.8	22.2	2.4	2.5	-0.3	0.0	-1.5	18.0	-1.8	-1.9
Klamath	1,493.4	1,480.4	355.9	342.9	-13.0	-0.9	-5.5	-0.1	-68.1	282.2	-73.7	-4.9
Cascades	164.8	167.7	39.3	42.2	2.9	1.7	-3.4	-0.1	-1.6	34.2	-5.1	-3.1
Total	1,754.6	1,746.9	415.0	407.3	-7.7	-0.4	-9.2	-0.2	-71.2	334.4	-80.6	-4.6
NWFP total	7,285.6	7,148.3	1,329.5	1,192.2	-137.3	-1.9	-32.1	-1.2	-183.8	1,112.4	-217.1	-3.0

[a] Can contain rare cases of avalanche, landslide, riparian disturbance, and windthrow.

Note: Gross gain and loss are from spatial intersection of the bookend maps. Net change is the difference in LSOG area between the bookends maps compared to the baseline LSOG area.

NWFP = Northwest Forest Plan.

Table 7—Area of late-successional and old-growth forest (LSOG) on other (nonfederal) ownerships from the gradient nearest neighbor (GNN) bookend maps (left), and intersected with the LandTrendr disturbance map (right)

	LSOG area from GNN bookend maps						LandTrendr disturbance assignment for GNN gross losses					
State and physiographic province	LSOG in 1994/1996 (baseline)	LSOG in 2006/2007 (current)	Gross LSOG loss	Gross LSOG gain	Net LSOG change	Net LSOG change	Harvest[a]	Insects and disease	Wildfire	No disturbance	Total explained losses	Percentage loss from baseline
	– – – – – – – – – – – – – Thousand acres – – – – – – – – – – – – –					*Percent*	*– – – – – – – – – – – – Thousand acres – – – – – – – – – – – –*					*Percent*
Washington:												
Olympic Peninsula	224.1	204.3	98.6	78.8	-19.8	-8.8	-32.0	-0.8	0.0	65.8	-32.8	-14.6
Western Lowlands	783.1	694.1	387.2	298.2	-89.0	-11.4	-112.7	-1.3	0.0	273.2	-114.0	-14.6
Western Cascades	406.1	341.8	171.7	107.4	-64.3	-15.8	-40.6	-0.2	-0.2	130.7	-41.0	-10.1
Eastern Cascades	82.4	82.5	25.3	25.4	0.1	0.1	-6.1	-0.1	-0.2	18.9	-6.4	-7.8
Total	1,495.7	1,322.7	682.8	509.8	-173.0	-11.6	-191.4	-2.4	-0.4	488.6	-194.2	-13.0
Oregon:												
Coast Range	719.0	595.9	362.5	239.4	-123.1	-17.1	-139.7	-0.6	-0.1	222.1	-140.4	-19.5
Willamette Valley	83.4	74.1	29.2	19.9	-9.3	-11.2	-9.5	0.0	0.0	19.7	-9.5	-11.4
Western Cascades	274.9	245.1	125.9	96.1	-29.8	-10.8	-55.2	-0.1	-1,8	68.8	-57.1	-20.8
Klamath	214.6	200.3	103.9	89.6	-14.3	-6.7	-30.2	0.0	-0.9	72.8	-31.1	-14.5
Eastern Cascades	50.8	44.4	26.4	20.0	-6.4	-12.6	-6.2	-0.1	-0.4	19.7	-6.7	-13.2
Total	1,342.7	1,159.8	647.9	465.0	-182.9	-13.6	-240.8	-0.8	-3.2	403.1	-244.8	-18.2
California:												
Coast Range	738.2	715.7	259.0	236.5	-22.5	-3.0	-36.7	-0.3	-2.2	219.8	-39.2	-5.3
Klamath	202.9	204.3	79.9	81.3	1.4	0.7	-13.5	-0.1	-1.8	64.5	-15.4	-7.6
Cascades	93.7	89.1	39.0	34.4	-4.6	-4.9	-8.3	-0.1	-0.7	29.9	-9.1	-9.7
Total	1,034.8	1,009.1	377.9	352.2	-25.7	-2.5	-58.5	-0.5	-4.7	314.2	-63.7	-6.2
NWFP total	3,873.2	3,491.6	1,708.6	1,327.0	-381.6	-9.9	-490.7	-3.7	-8.3	1,205.9	-502.7	-13.0

[a] Can contain rare cases of avalanche, landslide, riparian disturbance, and windthrow.

Note: Gross gain and loss are from spatial intersection of the bookend maps. Net change is the difference in LSOG area between the bookends maps compared to the baseline LSOG area.

NWFP = Northwest Forest Plan.

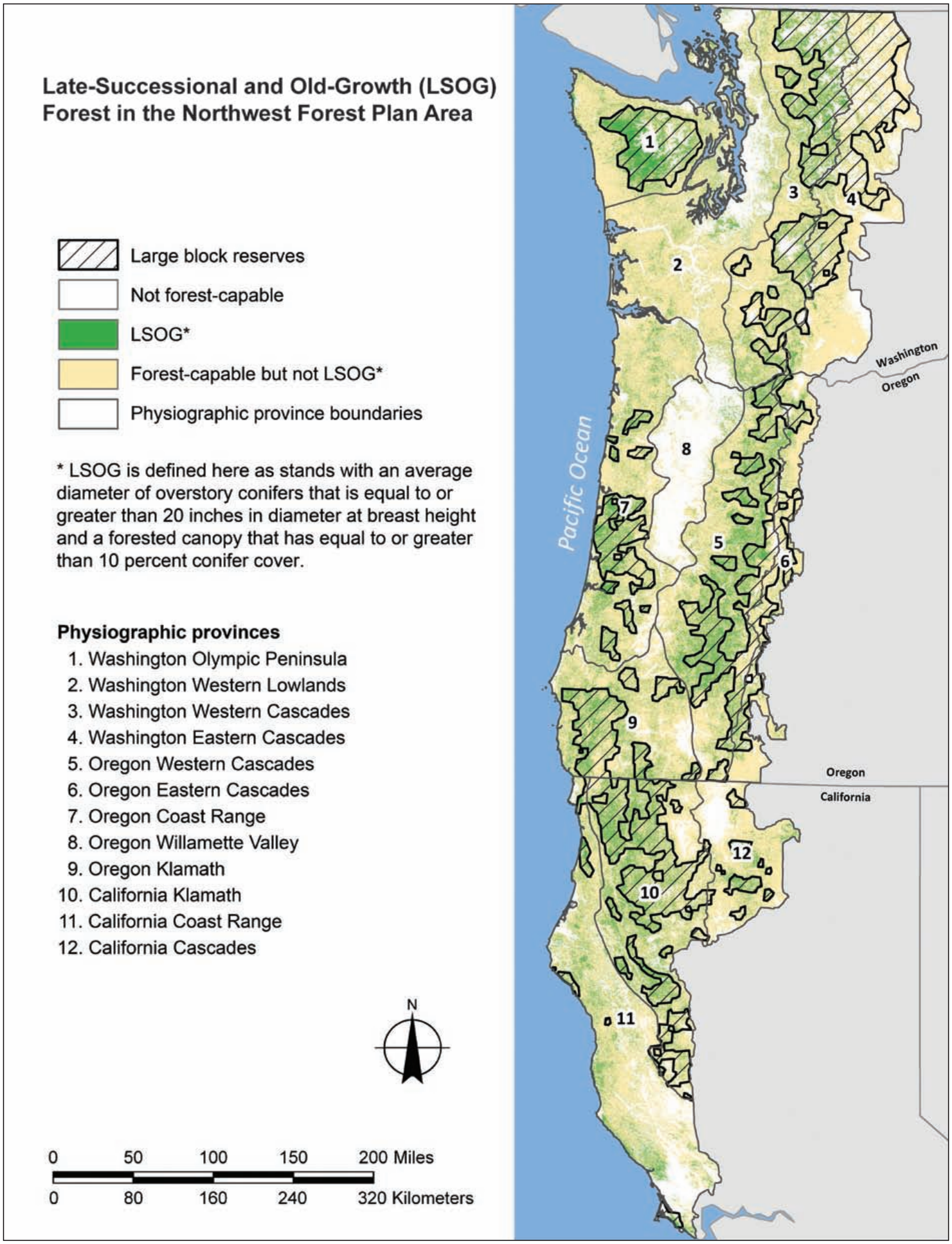


Figure 6—The distribution of late-successional and old-growth forest (LSOG) in the Northwest Forest Plan area in 2006 (Washington and Oregon) and 2007 (California), from gradient nearest neighbor vegetation maps. Data shown here were filtered to eliminate isolated pixels using a two-pass clump/eliminate process employing the four-neighbor PostFilter4 in ERDAS Imagine 9.1. Resulting patches have a minimum mapping unit of about 2.5 acres (11 pixels).

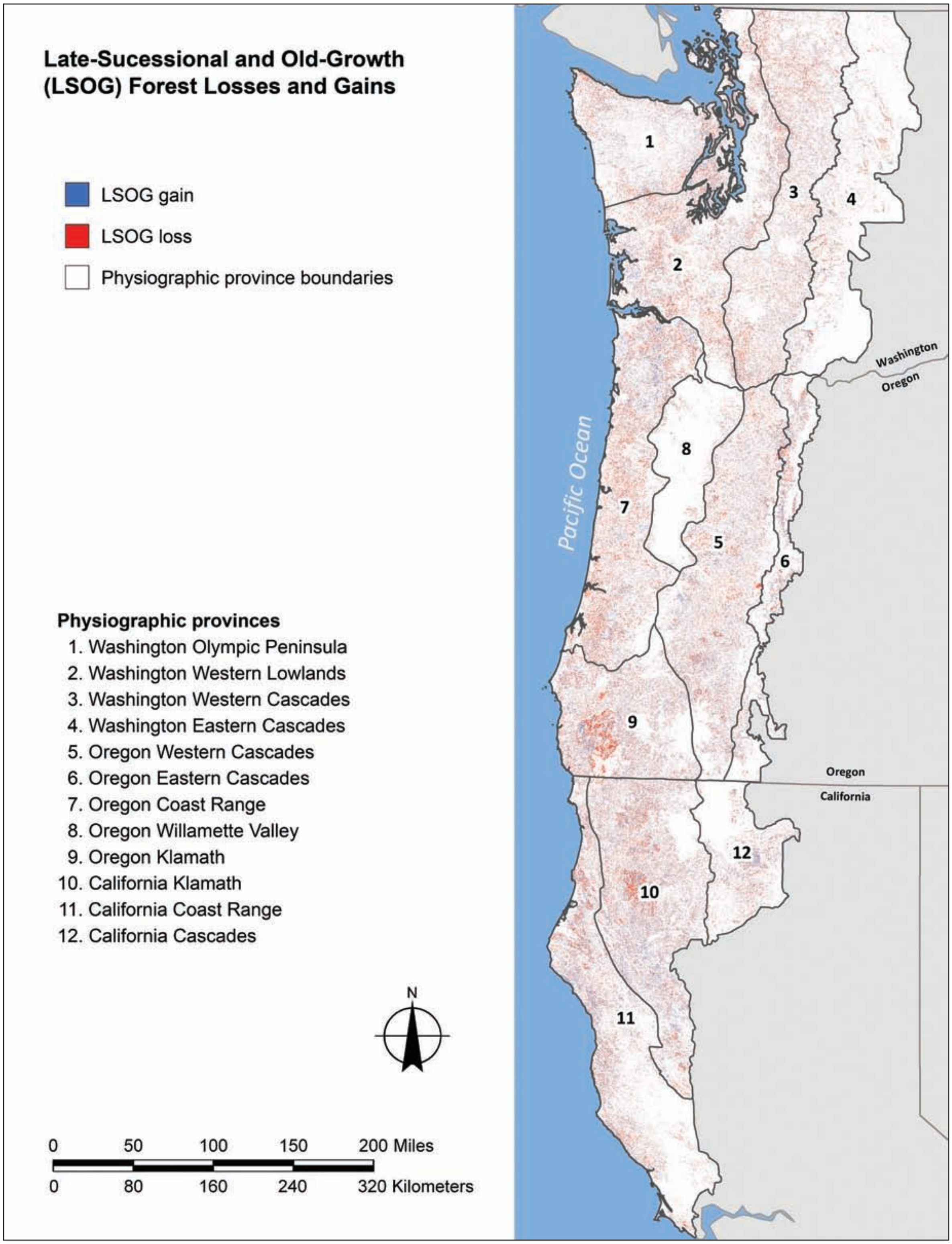


Figure 7—Areas of late-successional and old-growth forest (LSOG) gain and LSOG loss, as determined by differencing the gradient nearest neighbor vegetation maps for the two bookend dates, 1994 and 2007 in California and 1996 and 2006 in Washington and Oregon. Data shown here were filtered to eliminate isolated pixels using a two-pass clump/eliminate process employing the four-neighbor PostFilter4 in ERDAS Imagine 9.1. Resulting patches have a minimum mapping unit of about 2.5 acres (11 pixels).

the actual amount of LSOG lost to harvest on federal lands was likely even lower. Only about 1,000 ac of LSOG loss were associated with insects/disease disturbance.

Total LSOG area, as well as mapped LSOG losses, were proportionately higher in reserved LUAs than in nonreserved lands (fig. 8). Although reserved lands make up about two-thirds of the federal area, about three-fourths of the total LSOG occurred in reserves. Most of the LSOG loss on federal lands was from reserves (fig. 8), and almost 90 percent of the losses were associated with wildfire (table 6).

Trends of LSOG on other (nonfederal) lands—
Other ownerships (nonfederal lands) accounted for slightly more than half of the total forest-capable acres in the Plan area (table 3), but a much smaller percentage of nonfederal forest (16 percent, or 3,873,200 ac) met the LSOG definition compared to federal lands (table 7). Most of the nonfederal LSOG was in Washington, followed by Oregon and California. Nonfederal lands accounted for about 35 percent of the total baseline LSOG, which decreased to 33 percent of the total LSOG by the end of the monitoring period (table 7). The LSOG area on nonfederal lands decreased by an estimated 9.9 percent relative to the baseline LSOG area. In contrast to federal ownerships, losses associated with wildfire were negligible, whereas timber harvest accounted for almost a half million acres of LSOG loss, mostly concentrated in the Oregon Coast Range and Washington Lowlands provinces.

Forest diameter class distributions and potential LSOG recruitment—
On federal lands, the biggest change in forest diameter class distributions over the monitoring period was an increase in the 10- to 19.9-in class (fig. 9), which represents potential recruitment acres into the LSOG class. The largest changes on nonfederal lands were an increase in the 0 to 9.9-in class and a decrease in the 20+ in class, with very little change in the open and 10- to 19.9-in classes. These shifts in forest

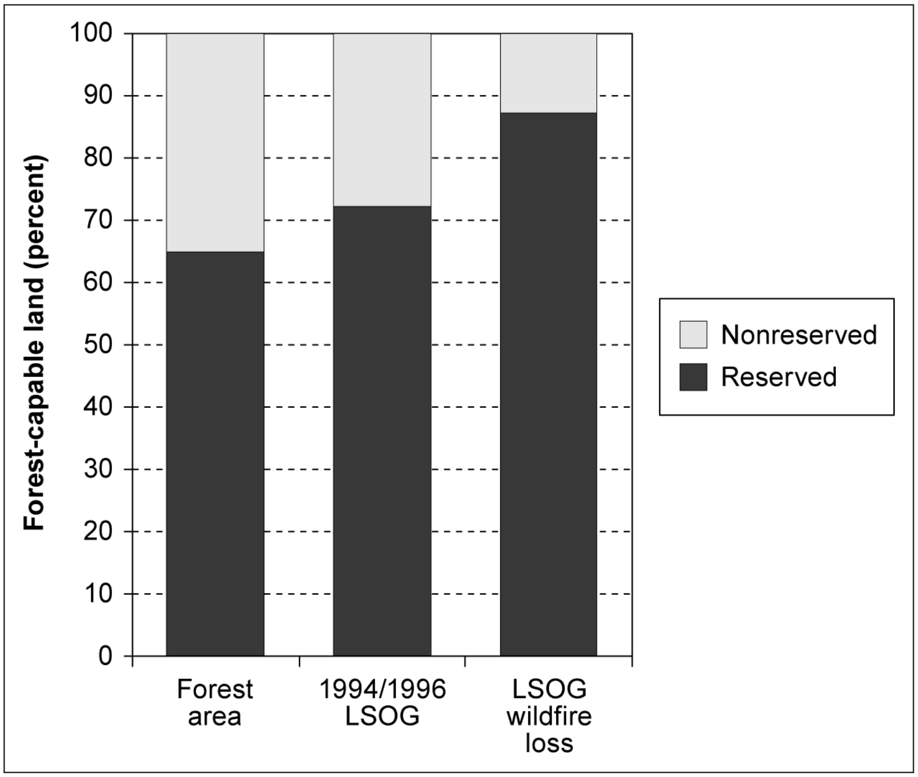


Figure 8—Distribution of forest-capable land (table 3) classified as late-successional and old-growth forest (LSOG) at baseline (1994/1996) from gradient nearest neighbor and LSOG lost to wildfire on federal land (table 6) by reserve status. Reserves include late-successional reserves, administratively withdrawn, Congressionally reserved; nonreserved includes matrix, adaptive management areas, and unmapped riparian reserves.

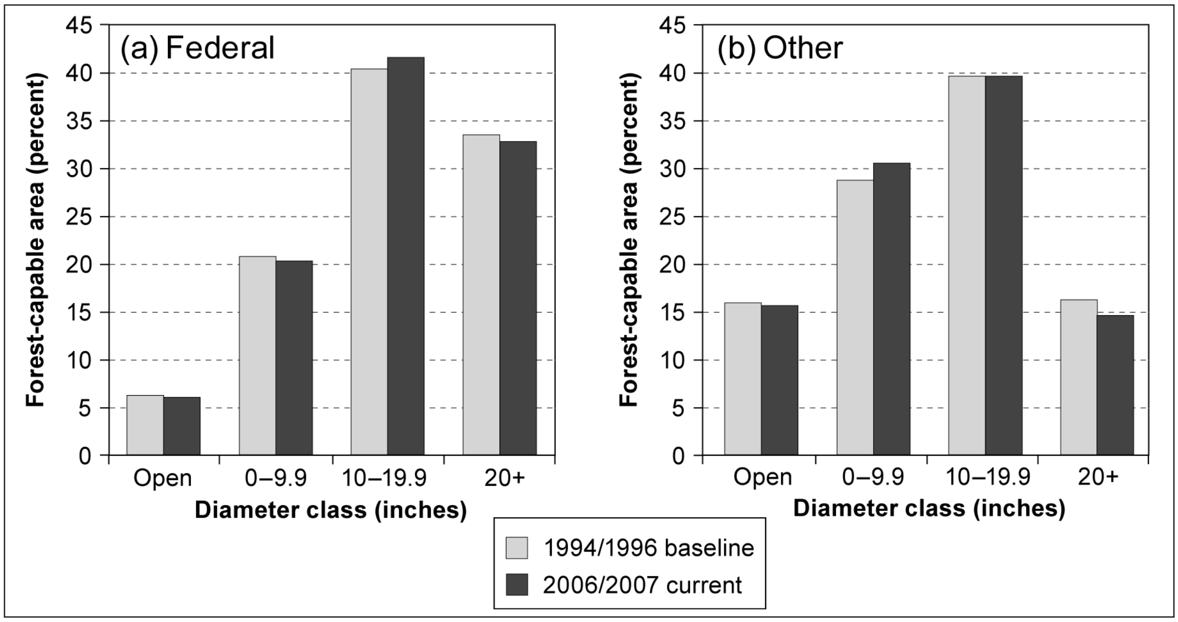


Figure 9—Distribution of forest-capable area by diameter class in the Northwest Forest Plan (NWFP) area from gradient nearest neighbor bookend maps: (a) NWFP federal lands, and (b) all other (nonfederal) lands. Diameter classes are defined by the quadratic mean diameter of live dominant and codominant conifers. Open is forest with <10 percent cover of live conifers.

distribution are consistent with a higher rate of harvest from the two larger size classes, with harvested acres transitioning into the smaller diameter classes.

Trends of LSOG on Forest Service and Oregon BLM Lands From Successive Inventories

Estimates of LSOG area from two successive inventories of Forest Service and Oregon BLM lands outside California showed a very slight increase (0.1 percent) in Washington, a slight decrease (-1.9 percent) in Oregon, and an overall decrease of 1.2 percent (table 8, fig. 10). The differences between the two occasions were not statistically significant (90-percent confidence level) at the state level nor for any of the provinces (fig. 11). The GNN map estimates were within the plot sampling error for all states (table 9, fig. 10).

Estimates of LSOG for All Ownerships From FIA Annual Inventory

Estimates of LSOG area from the FIA Annual Inventory are shown in figure 5, and tabular summaries are shown in appendix 1.

Discussion

Interpreting LSOG Change From Multiple Data Sources

Interpreting changes in LSOG over the monitoring period involves considering multiple sources of information, each subject to different kinds of error and uncertainty. Because methods for assessing uncertainty differ among the map- and sample-based estimates of LSOG area and change, a formal statistical comparison of the estimates is not possible. Because the true LSOG population totals and dynamics cannot be known with certainty, conclusions must rely on level of consistency among the map- and sample-based estimates.

Limitations of the regional inventory plots—Although the plot data from regional forest inventories have increased substantially over what was available for the 10-year report, there still exists no single, regionally consistent sample of all land ownerships and allocations that provides repeat measurements. This information eventually will be

Table 8—Estimates of late-successional and old-growth area on Forest Service and Oregon Bureau of Land Management lands from two sampling occasions of FIA and CVS plots (see tables 4 and 5) in Washington and Oregon

State	Occasion 1		Occasion 2		Change	
	Thousand acres	*Percent*	*Thousand acres*	*Percent*	*Thousand acres*	*Percent*
Washington	1,585.4	25.8	1,587.2	26.6	+1.8	+0.1
Oregon	3,507.4	37.9	3,442.4	37.1	-64.9	-1.9
Total	5,092.8	33.0	5,029.6	33.0	-63.2	-1.2

Note: Percentages are of all forest-capable land, and change acres are a percentage of acres at occasion 1.
FIA = Forest Inventory and Analysis; CVS = Current Vegetation Survey.

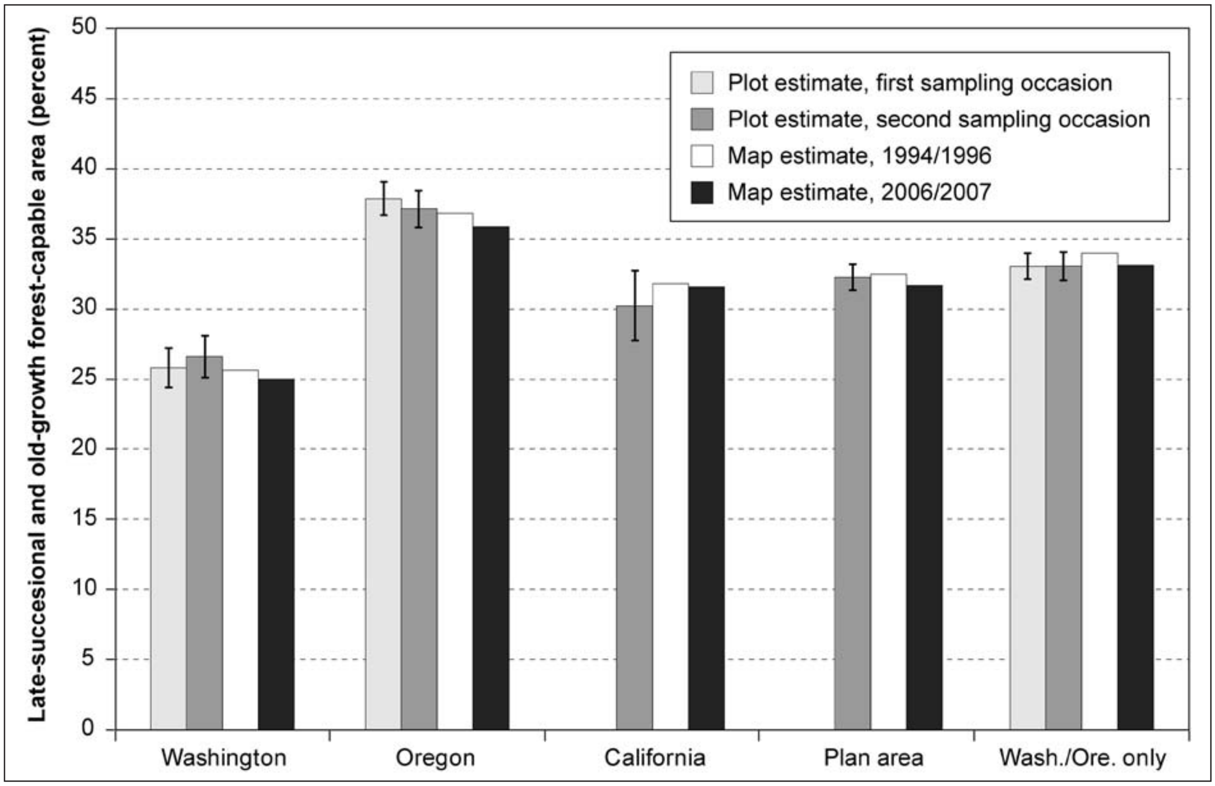


Figure 10—Estimated area of late-successional and old-growth forest on Forest Service and Oregon Bureau of Land Management lands from plots measured in successive inventories and from the gradient nearest neighbor bookend maps. For California and Northwest Forest Plan area total (which includes California), the first sampling occasion is not shown. Note: Wash./Ore. only = Plan area without California. Error bars indicate a 90-percent confidence interval.

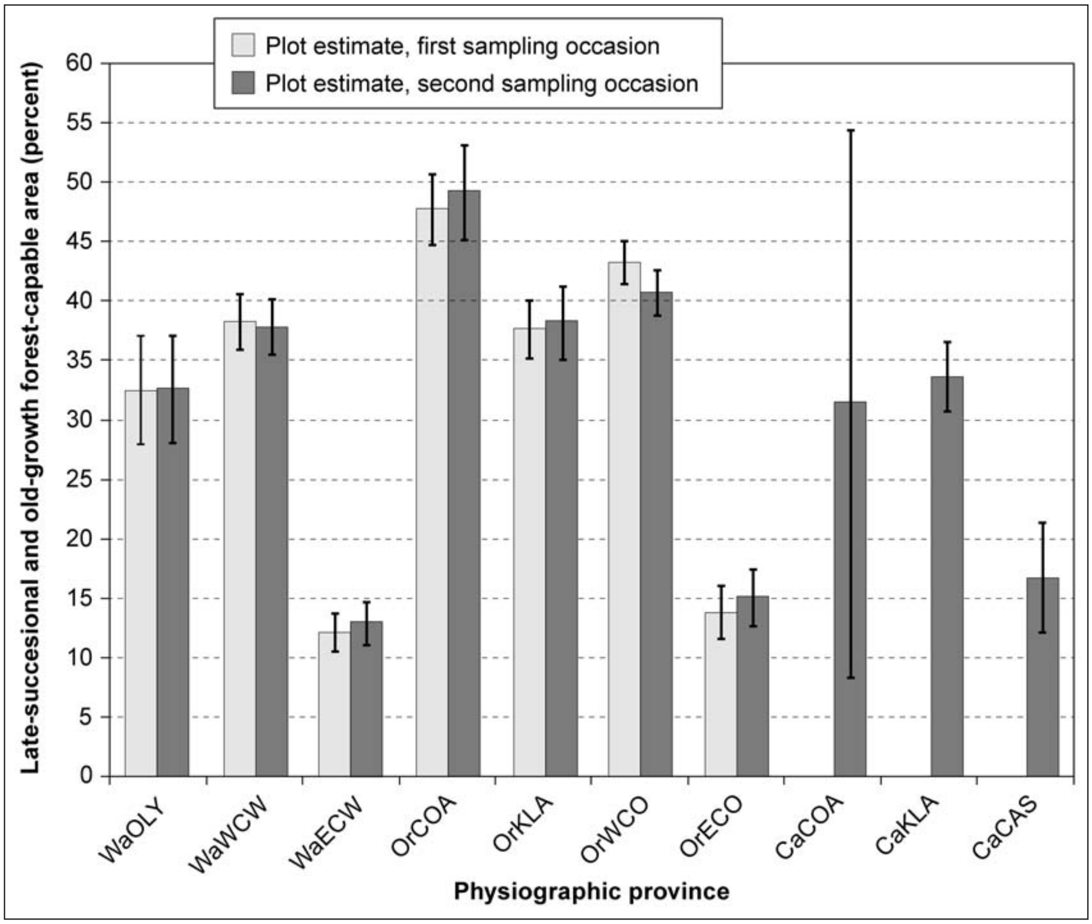


Figure 11—Late-successional and old-growth forest percentage estimated from analysis of plot data from successive Current Vegetation Survey inventories on Forest Service and Oregon Bureau of Land Management lands (first occasion not shown for California). Error bars indicated a 90-percent confidence interval. Abbreviations for physiographic provinces are in table 3.

Table 9—Estimates of area of late-successional and old-growth forest on forest land in the Northwest Forest Plan area from the gradient nearest neighbor (GNN) bookend models (baseline and current) and from Forest Inventory and Analysis (FIA) Annual plots measured from 2001 to 2008, by location and ownership

State and physiographic province	Federal				Other				All ownerships				
	GNN 94/96	GNN 06/07	FIA	(SE)	GNN 94/96	GNN 06/07	FIA	(SE)	GNN 94/96	GNN 06/07	FIA	(SE)	Unsampled area
	Thousand acres												*Percent*
Washington:													
Olympic Peninsula	708	716	688	(54)	224	204	190	(37)	932	920	878	(65)	9.1
Western Lowlands	0	0	0	—	783	694	704	(71)	783	694	704	(71)	7.0
Western Cascades	1,120	1,084	1,270	(88)	406	342	232	(41)	1,526	1,426	1,502	(97)	10.1
Eastern Cascades	302	291	351	(56)	82	83	135	(33)	384	374	486	(65)	10.5
Total	2,131	2,092	2,309	(113)	1,496	1,323	1,260	(92)	3,627	3,415	3,569	(145)	9.1
Oregon:													
Coast Range	615	597	649	(66)	719	596	511	(57)	1,334	1,193	1,160	(86)	5.1
Willamette Valley	4	5	0	—	83	74	55	(17)	87	79	55	(17)	8.4
Western Cascades	1,801	1,780	1,824	(93)	275	245	180	(35)	2,076	2,025	2,004	(99)	3.6
Klamath	730	673	717	(63)	215	200	53	(18)	945	873	771	(65)	8.7
Eastern Cascades	250	254	264	(42)	51	44	20	(12)	301	298	284	(44)	1.5
Total	3,400	3,309	3,454	(121)	1,343	1,160	821	(71)	4,743	4,469	4,275	(138)	5.3
California:													
Coast Range	96	99	129	(33)	738	716	695	(71)	834	815	824	(76)	14.9
Klamath	1,493	1,480	1,472	(96)	203	204	176	(38)	1,696	1,684	1,648	(102)	6.5
Cascades	165	168	180	(39)	94	89	53	(21)	259	257	233	(44)	5.7
Total	1,755	1,747	1,781	(105)	1,035	1,009	924	(81)	2,790	2,756	2,705	(130)	9.7
NWFP total	7,286	7,148	7,544	(196)	3,873	3,491	3,006	(141)	11,159	10,639	10,550	(239)	7.8

Note: Percentage of area unsampled is calculated based on simple rather than double sampling.

NWFP = Northwest Forest Plan.

SE = standard error.

available following full implementation and remeasurement of the FIA Annual Inventory plots, which is expected by 2020. The FIA Annual Inventory provides a statistically rigorous estimate of LSOG area for the period the plots were measured (2001–2008) (fig. 5), but no comparable data are available for the baseline. Where remeasurement data are available following the same sample design (CVS-R6 and CVS-BLM plots on Forest Service and Oregon BLM lands), the measurement dates do not neatly coincide with the Plan baseline year nor with the end of the monitoring period covered by this report (table 5), but the data still can be used to assess trend direction. However, given the short timeframe and the apparently small amount of change, the sampling precision was not sufficient to detect statistically significant differences in LSOG area (figs. 10 and 11).

Uncertainty in estimates of LSOG change from two GNN models—

We provide several diagnostics of GNN model reliability at the local scale from cross-validation in this report (app. 1) and online (http://www.fsl.orst.edu/lemma/nwfp). The LSOG area estimates from the two GNN bookend maps are not independent, and error estimates from cross-validation apply to both maps equally. Variance estimators for nearest-neighbors techniques where *k*=1, as in this application of GNN, which would allow us to place confidence intervals on the GNN estimates, have not yet been reported in the literature. Bootstrap methods for variance estimation (e.g., Magnussen et al. 2010; McRoberts et al. 2007) appear promising but have not been tested for large regions and sample sizes such as ours. Although the current state of the science does not allow us to place “error bars” on the province-scale estimates of LSOG area in figure 5, it is reasonable to expect that the province, state, and Plan-wide estimates are substantially more reliable than are predictions at the local site level (80-percent correct over the entire Plan area, app. 1). Riemann et al. (2010) demonstrated empirically that GNN estimates converge towards FIA plot-based estimates as the geographic extent of the area-of-interest increases.

Although it is not possible to state the statistical significance of differences between two GNN bookend maps, it is plausible that the area of LSOG may have slightly decreased (from 33.2 percent to 32.6 percent of federal lands), given evidence from the other data sources: potential LSOG losses from recent large wildfires corroborated by the LandTrendr disturbance data (table 6), and the small amount of LSOG recruitment from tree growth that would be expected over such a short period of time. In addition, the GNN estimates of LSOG area generally are corroborated by sample-based estimates from the regional inventories (figs. 5 and 10). For federal lands in all provinces and states, the magnitude of change (gain or loss) from the GNN bookend maps was less than the standard error of the FIA sample-based estimate (fig. 5). In Washington and Oregon, the differences in LSOG area on FS and Oregon BLM lands between two inventory occasions were not significant, and the GNN estimates for both years were within the confidence intervals of the plot estimates (fig. 10).

Differences between the GNN and FIA Annual estimates—

The forest inventories provide plot-based estimates of LSOG area that complement the model-based estimates from GNN (fig. 5). Although there are many valid reasons to expect area estimates from these two fundamentally different approaches to differ, it is difficult to quantify these effects. Where the sample- and model-based estimates do differ, it cannot be assumed which of the estimates is more reliable, given the different sources of error and uncertainty. Plot-based estimates are subject to measurement error and sampling error, which also contribute to uncertainty in the GNN estimates.

The FIA estimates are based on a probabilistic sample from a stratified random design. Compared to GNN, the FIA stratification is based on a slightly different total gross area, a different map of nonforest area, and a different ownership/allocation layer, all of which contribute to differing estimates of forest area and its distribution among ownerships.

There also are temporal differences between the FIA and GNN estimates. The FIA plots sample equally across the years 2001 to 2008. The timing of FIA plot measurement relative to major disturbance events (before or after a wildfire, for example) can affect LSOG area estimates. In contrast, the 2006/2007 GNN model was based on plots measured over the same range of years, but the effective date of the GNN area estimates is the 2006/2007 date of the Landsat imagery.

Whereas the FIA estimates are from the complete sample of FIA-PNW-Annual plots only, GNN is based on a subset of plots from FIA-PNW-Annual and other regional inventories, with outliers removed. In addition, the FIA estimates are calculated at the condition-class level (plots can contain multiple forest conditions), whereas the GNN models use the total forested portion of a plot.

For the FIA estimates, the area represented by plots that were unsampled owing to hazardous conditions or to which access was denied by landowners is proportioned among the other plots in the same stratum, based on the untested assumption that the unsampled plots sample the same forest conditions as the plots that were installed. This affects the FIA estimates of area by forest/nonforest and by federal/nonfederal ownerships. The unsampled area can be quite substantial, accounting for as much as 15 percent of total area at the physiographic province level (table 9).

Uncertainty associated with the LSOG definition— We used a single, relatively simple definition of LSOG (table 1) for the plot and GNN analyses reported here, and applied the same definition throughout the Plan area. We chose this definition to be consistent with "medium and large older forest," the least restrictive definition of older forest used in the 10-year report (Moeur et al. 2005), and because it corresponds closely to the definition of older forests used in FEMAT (FEMAT 1993).

Because the canopy cover threshold (10 percent) is so unrestrictive, most changes in LSOG between the two GNN bookend maps, and between the inventory measurement occasions, were associated with changes in average tree size (quadratic mean diameter [QMD] of dominant and codominant conifers). Very little of the federal forest landscape was in an open-canopy condition at either end of the monitoring period (fig. 9). Because QMD is computed as a mean of individual tree diameters, differences in just one or a few trees on a plot can affect its LSOG classification. The QMD can increase because the upper canopy trees grow larger, or because thinning or fire kills smaller diameter trees, thereby increasing the mean diameter of the stand. Consequently, and perhaps counter-intuitively, disturbance can result in gain, loss, or no change in the LSOG classification of a plot.

In the GNN maps, plots were imputed to pixels based on the spatial predictors, and changes in a pixel's LSOG classification between the two bookend maps could only occur where changes in the Landsat spectral data had taken place. Because there is quite a wide range of natural variability in forest conditions associated with any given Landsat spectral signature, very slight pixel-level differences in the Landsat imagery between dates can result in choosing a different nearest-neighbor plot for the pixel. This fine-scale variability in nearest-neighbor plot selection interacts with the LSOG definition, which is sensitive to minor differences in the tree list, to result in lots of fine-scale, pixel-level change in LSOG. Much of the "gross gain" and "gross loss" in LSOG area (tables 6 and 7) is explained by this phenomenon. This fine-scale "noisiness" in the two GNN maps is manifested as change in a spatial intersection of the two maps. Even where real change has occurred, such as in areas of high-severity wildfire corroborated by the LandTrendr disturbance map, LSOG can be gained, lost, or unchanged.

Use of a different LSOG definition would result in estimates of LSOG area and trends that are different but not necessarily more accurate. Nevertheless, it is reasonable to expect that a more restrictive definition of LSOG (e.g., larger threshold values for QMD and canopy cover) would result in less LSOG gain. The large amount of federal forest land in the 10- to 19.9-in size class (fig. 9) would be less likely to grow to LSOG status within the short monitoring period. Similarly, wildfires would be more likely to result in LSOG loss owing to associated decreases in live canopy, rather than LSOG gain or no change, if a greater canopy cover threshold was applied.

One advantage of the GNN- and plot-based analyses in this report is that the same LSOG definition was consistently applied to all plots, which also were used in the GNN imputations. For comparisons of the GNN and plot-based estimates, this removes much of the uncertainty associated with use of different definitions. Unfortunately, the relationship between LandTrendr disturbance severity and agent and LSOG changes cannot be quantified using the same definitional terms. Given the 10 percent canopy threshold in the LSOG definition, we can speculate that only the most intense disturbances would result in sufficient loss of live canopy to cause a change from LSOG to not-LSOG.

Comparing map data from GNN and LandTrendr— All three map data sets (1994/1996 GNN, 2006/2007 GNN, and LandTrendr disturbance) contain error. Of the 16 map classes that result from combining all three maps (app. 3), some combinations that seem illogical are, in fact, explainable, whereas others can result from errors in any of the individual maps. Conversely, logical combinations may occur in places where errors exist in the component maps. This is the result of interactions among the different kinds of error in the GNN and LandTrendr data and the definition of LSOG as discussed above. Furthermore, the relationship between the LandTrendr disturbance classes and LSOG has not been quantified. For example, the "LSOG loss/No disturbance" class can occur simply because two different inventory plots are chosen by the GNN model at either of the bookends endpoints based on their similar spectral signals, one with a list of inventoried trees meeting the LSOG size definition, and the other not. This is perfectly plausible because either plot would be reasonable GNN imputation choices for the general composition, size, and structure at the site. The combinations "LSOG gain/Harvest" and "LSOG gain/Fire" are also explainable. Low- and medium-severity disturbances in areas classified as young forest in the baseline GNN map are likely to result in the loss of smaller diameter trees, resulting in a postdisturbance QMD that exceeds the 20-in diameter threshold for LSOG.

Regardless of any apparent inconsistencies among maps and their causes, there did not appear to be a bias toward LSOG loss or LSOG gain from the GNN bookends data. This is demonstrated by the small difference in the "LSOG loss/No disturbance" and "LSOG gain/No disturbance" totals for federal lands (app. 3) (1,112,400 and 1,089,900 ac, respectively, for a total difference of 22,500 ac or 0.3 percent of the total LSOG).

Consistency between the GNN bookend maps and the LandTrendr disturbance map was greatly enhanced by GNN using imagery based on the same LandTrendr segmented maps used to map disturbance (fig. 2). However, the segmented maps were temporally smoothed for use in GNN, but additional processing steps were applied for mapping disturbance. Pixels with <15 percent relative cover change and disturbance patches of <2.5 ac (11 adjacent pixels) were removed from the disturbance maps, but likely would show up as change in the GNN models.

Estimates of LSOG from successive inventories— Plot-based estimates of LSOG area from successive inventories on Forest Service and Oregon BLM lands showed slightly different trends from the GNN bookend estimates at the state level (fig. 10). Plot estimates for Washington showed a very small increase in LSOG, whereas all other plot and GNN estimates showed slight decreases in LSOG. However, we caution against a literal interpretation of trends because of error and uncertainty in both the plot- and map-based estimates. The plot-based estimates are subject to measurement error and sampling error, none of the differences in LSOG estimates for the two inventory occasions were statistically significant, and all GNN estimates were within the plot sampling error (figs. 10 and 11).

Challenges to Mapping LSOG Recruitment

Much of the LSOG loss mapped from the GNN bookends could be verified by the LandTrendr disturbance maps. Although the losses apparently were roughly balanced by recruitment, recruitment is much more difficult to map with remote sensing technology, and no independent data are available for map validation. Small changes in average tree diameter within mid-successional and older conifer forests are difficult if not impossible to detect with Landsat imagery (Cohen et al. 1995). In addition, mid-successional forest that has been thinned contains canopy gaps and shadows that can be confused spectrally with much older forest in Landsat imagery. Consequently, it currently is impossible to say how much of the gross LSOG increase from the bookend analysis resulted from incremental stand growth into the lower end of the LSOG diameter class (e.g., from 19 to 20 in average diameter), or from understory disturbances (e.g., thinning or surface fire) that eliminated smaller diameter trees and increased average stand diameter without increasing the diameter or number of large trees in the stand. Given the shortness of the monitoring period (10 or 14 years), we would not expect much, if any, increase in the amount of multistoried stands with many very large trees (e.g., >40 in).

The LSOG losses from disturbance are mapped with greater certainty than are the LSOG gains, and the mapped losses are more likely to affect the amount of well-developed stands of LSOG than are incremental gains into the lower end of the LSOG diameter class, which are exceedingly difficult to capture. Recruitment of LSOG as defined in this report does not necessarily equate to habitat for other late-successional species. Different definitions and use of different forest-type strata (e.g., separating out high-elevation forests) could reveal different trends.

Differences From the 10-Year Report

There are major differences in the vegetation and disturbance mapping approaches used for the 15-year and 10-year assessments. In addition, the regional inventories are much more complete now than they were for the 10-year report, including the first regionally consistent sample of all land ownerships, and remeasurement data for much of the federal land base. Furthermore, the current approach achieved much greater integration among the map- and plot-based data and analyses, reducing inconsistencies in the results. Finally, the 10-year report summarized LSOG status and trends only on federally administered lands affected by the Plan, whereas in this report we describe LSOG on all ownerships to provide context for federal lands. Collectively, these differences represent significant improvements in monitoring methods, and they are described in detail in appendix 4.

Comparison of LSOG baseline estimates for federal lands—
The map-based estimates of LSOG area for federal lands for the 1994/1996 baseline for the two assessments are:

	10-year report	15-year report	Difference
	Thousand acres (percentage of forest-capable)		
Washington	2,130.7 (26)	2,131.1 (31)	+0.4 (+5)
Oregon	3,379.3 (36)	3,399.9 (37)	+20.5 (+1)
California	2,357.9 (42)	1,754.6 (31)	-603.4 (-11)
Plan-wide	7,867.9 (34)	7,285.6 (33)	-582.4 (-1)

For federal lands Plan-wide, the current baseline estimate from GNN of 33 percent of forest-capable land is within 1 percent of the 10-year estimate of 34 percent. Forest-capable estimates for the 10-year report were derived from Interagency Vegetation Mapping Project (IVMP) data in Washington and Oregon, and Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG) data for California. Almost all of the differences between the two reports are between the GNN data used for this assessment and the CALVEG data used for the last assessment. The 10-year report (Moeur et al. 2005, p. 73, fig. 21a) showed that, for Forest Service lands in California, the CALVEG map-based estimate was greater than the plot-based estimate with a 90-percent confidence interval, with the most pronounced differences in the Klamath province, lending evidence that CALVEG may have overestimated the amount of LSOG. Although different nonforest masks were used for all three map estimates (GNN, IVMP, and CALVEG), the differences should be concentrated in the forest/nonforest margins and have little effect on areas mapped as LSOG. However, the LSOG percentages of the total landscape will differ with changes in the relative amounts of forest-capable and nonforest acres. In summary, although there is no independent information available to say which estimate is more accurate, it appears that the original LSOG value based on CALVEG was overestimated. In contrast, IVMP and GNN estimates in Washington and Oregon appear to corroborate each other. Because the newer GNN technology was applied consistently over all three states, it is reasonable to conclude that we have achieved improved estimates across the Plan area.

The LSOG loss over the monitoring period estimated from the combined GNN/LandTrendr analysis (table 6) (through 2006/2007) is greater than the loss reported in the 10-year assessment (through 2002/2003) (Moeur et al. 2005, tables 14 and 15). State-level estimates of LSOG lost to wildfire on federal lands from the two reports are:

	10-year report	15-year report
	Thousand acres	
Washington	4.0	6.5
Oregon	68.1	106.1
California	30.4	71.2
Plan-wide	102.5	183.8

The greater loss to wildfire in this report can be explained by the longer timeframe that encompassed several large wildfires from 2003 to 2007, and the greater sensitivity of LandTrendr methods to partial disturbance (although the relationship between disturbance severity and the LSOG classification has not been quantified). We also show more LSOG loss to harvest on federal lands in the current report (31,400 ac vs. 16,900 ac previously), which may be attributed to the same factors.

Comparison of plot analyses—
In the 10-year assessment, we reported strong LSOG gains (recruitment) since the mid-1990s using incomplete remeasured plot data (Moeur et al. 2005). The more complete data available for the 15-year report do not support that finding. We cautioned that less than half of the original plot sample had been remeasured at the time of the 10-year assessment, and that the sample size was too low to make province-level estimates of LSOG recruitment. The 15-year assessment was based on a much larger sample of remeasured plots, but the data are still incomplete. Nearly all of the CVS-R6 plots have been measured twice, but only one quarter of the CVS-BLM plots have been remeasured.

Monitoring Design Considerations

We successfully applied new map-based monitoring proto cols, based on integrating LandTrendr and GNN, to produce the data required for monitoring older forest (app. 4), as well as for northern spotted owl (Davis and Dugger, in press) and marbled murrelet habitat (Raphael et al., in press), and the vegetation component of watershed condition (Lanigan et al., in press). Incremental improvements to the current methods could yield substantial improvements to the reliability of the monitoring data. For GNN modeling, matching inventory plots to LandTrendr imagery of the same year as plot measurement would greatly reduce error caused by temporal mismatches between field data and spectral data (as much as 6 years in the current data). The historical context of disturbance and growth from the LandTrendr time-series could be incorporated directly as spatial predictors in the GNN models. Further refinement of the LandTrendr algorithms could improve their reliability for mapping regrowth in addition to disturbance. New bootstrap or alternative variance estimators for nearest-neighbor imputation need to be tested, which would allow us to place confidence intervals around the GNN area estimates. Remeasured plot data from regional forest inventories will continue to be an essential component of the monitoring program, and support for these programs should be continued.

The richness of the forest attributes from GNN, as well as nuanced information about forest disturbance and successional processes provided by LandTrendr, set the stage for much more indepth analysis of forest dynamics across the region. We recommend that future analyses encompass a holistic view of forest structure and dynamics through application of a more ecological definition of older forest that recognizes regional gradients in forest composition, structure, and productivity. The GNN vegetation maps provide flexibility to apply multiple definitions, including those that are compatible with previous analyses and publications.

Estimates of future expected recruitment of LSOG in FEMAT (FEMAT 1993; fig. IV-2) provided only rough approximations of relative differences among the FEMAT options, and were not meant to be used to set precise benchmarks against which to evaluate LSOG trends under the Plan. These curves were based on reserve allocations only and very simple expectations of transitions between size classes and overall losses to stand-replacing disturbance. We recommend that a new effort be made to estimate future trends in LSOG using inventory plots, growth and succession models, more ecologically based definitions, and assumptions about future disturbance regimes.

Conclusions

Periodic analysis and interpretation of monitoring data is essential to completing the monitoring task, a critical component of the adaptive management cycle. This important step was described in the overall monitoring strategy (Mulder et al. 1999) and approved by the Regional Interagency Executive Committee. The 10-year report (Moeur et al. 2005) was the first comprehensive analysis, and this 15-year report represents the second monitoring assessment.

Using two "bookend" maps of vegetation for the baseline and end of the monitoring period, we assessed the amount and distribution of forest classified as LSOG in the Plan area: between 1996 and 2006 in Washington and Oregon, and between 1994 and 2007 in California. Areas of LSOG change between the two bookend maps, intersected with the map of disturbances over the period, allowed us to describe potential causes of LSOG loss. To corroborate the mapped information, we also developed estimates of LSOG area from two successive forest inventories where data were available (Forest Service and Oregon BLM lands), and estimated LSOG area for all ownerships from inventory plots measured from 2001 to 2008.

The two bookend maps suggested a slight net loss of LSOG over the Plan area, from 33.2 percent of federal forest in 1994/1996 to 32.6 percent in 2006/2007 (from 7.3 to 7.1 million ac). The difference between the two map estimates was small relative to the sources of error and uncertainty in the estimates, and it is not possible to state that there has been a statistically significant net increase or net decrease in the amount of LSOG. Nevertheless, the small decrease in LSOG suggested by the bookend maps was corroborated by estimates from successive inventories where available, although the estimated differences were not statistically significant. In addition, the mapped vegetation and disturbance data together provide strong evidence that >200,000 ac of LSOG were lost to stand-replacing disturbance (mostly wildfire) on federal lands.

The LSOG losses associated with wildfire on federal lands apparently were roughly balanced by recruitment, but recruitment is much more difficult to map reliably with available data and technology. Given the shortness of the monitoring period (10 or 14 years), LSOG recruitment was likely from incremental stand growth over the 20-in diameter threshold, or from understory disturbances that removed smaller diameter trees and raised the average stand diameter above the threshold, rather than from an increase in forests of much larger and older trees.

Our results support the assumption made in the Plan that federal lands would play the primary role in maintaining or restoring LSOG and related habitats in the Pacific Northwest. Federal lands contained less than half of the total forest land, but about two-thirds of the total LSOG. Harvesting removed about 13 percent (approximately 491,000 ac) of LSOG on nonfederal lands. Loss of LSOG on federal land resulting from harvest was less than 0.5 percent (approximately 32,100 ac).

As was concluded in the 10-year report, wildfire was the most significant change agent for LSOG over the Plan area. Our findings indicate that the risk of loss of LSOG to wildfire will continue to be a critical consideration for policies affecting late-successional forests, old-growth-dependent species, and watershed conditions. The Plan projected that, over a time horizon of 100 years, the area of late-successional and old-growth forest that was depleted from logging could be restored and maintained at or near historical levels. In the 15 years since the Plan was implemented there appears to be a slight overall net loss of LSOG. This trend may not be repeated in the next 10 years as large acreages of smaller diameter forest grow larger, or as disturbances from fire or insects or from silvicultural treatments such as thinning increase or decrease.

Several ongoing improvements to the monitoring data and analysis methods should reduce the amount of error and uncertainty in future estimates of LSOG change. In addition, confidence in the sample-based estimates of change should increase as additional inventory plots are remeasured.

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Metric Equivalents

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

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Appendix 1: Gradient Nearest Neighbor (GNN) Imputation for Late-Successional and Old-Growth (LSOG) Change

For LSOG monitoring, we mapped detailed attributes of forest vegetation over all forest land in the Northwest Forest Plan (the Plan) area using gradient nearest neighbor (GNN) imputation (Ohmann and Gregory 2002). The GNN maps used in this report are available for download from http://www.fsl.orst.edu/lemma/nwfp.

Spatial and Plot Data Used in GNN Models

Spatial predictor variables were tasseled cap indices (Crist and Cicone 1984) from the Landsat satellite imagery that was "temporally smoothed" using the LandTrendr algorithms (app. 2). We used imagery mosaics from the LandTrendr "stack" for 1996 and 2006 in Washington and Oregon and 1994 and 2007 in California. We also used climate variables derived from parameter elevated regression on independent slope models (PRISM) (Daly et al. 2008), topographic and solar radiation variables derived from a digital elevation model, and soil parent materials where available. To avoid the appearance of bias, land ownership and allocation were not used as spatial predictors.

Primary plot data sets used in GNN were from the Current Vegetation Survey (CVS) from the Forest Service Pacific Northwest Region (CVS-R6) and Oregon Bureau of Land Management (CVS-BLM). Forest Inventory and Analysis (FIA) data was also used from the Pacific Southwest Region (FIA-R5-periodic) and the Pacific Northwest Research Station (FIA-PNW-periodic, FIA-PNW-Annual), with additional plots used opportunistically where available. As many as three plots had been measured at each plot location. Some were remeasurements based on the same design (CVS-R6 and CVS-BLM), but others were FIA-PNW-Annual plots established at the same location as FIA-PNW-periodic, FIA-R5-periodic, or CVS-R6 plots, with different plot layouts and measurement protocols. For gradient modeling, we selected a single plot from each plot location, to achieve geographic representation over the Plan area while minimizing effects of changing plot measurement protocols on resulting models. For each location where at least one plot was measured, we identified the single plot that was measured closest to either of the bookend imagery dates. Plots measured in 2001 or later were matched to 2006 or 2007 imagery, and plots measured in 2000 or earlier were matched to 1994 or 1996 imagery. This constrained the temporal difference between imagery and plot measurement to no more than 6 years. The plot selected at each location was attributed with the LandTrendr spectral data from the imagery date to which it was matched.

We excluded plots from modeling when the field-collected data did not match the forest conditions in the satellite imagery. This could be caused by disturbance between plot measurement and imagery, inaccurate plot locations (X and Y coordinates), a distinct boundary in forest conditions (caused by disturbance or topography) within the plot footprint, or clouds, snow, or shadows in the imagery. We screened plots by flagging model outliers and comparing the field plot data and narrative descriptions to the Landsat imagery and high-resolution National Agriculture Imagery Program (NAIP) imagery (USDA Aerial Photography Field Office 2009).

Gradient Model Development and Imputation

The GNN models were developed for the same regions used in habitat modeling for the northern spotted owl (*Strix occidentalis caurina*) (Davis and Dugger, in press), which partially coincide with the physiographic provinces (fig. 12). We included a 10-km (6.2 mi) buffer around each province to minimize artificial boundaries with adjacent modeling regions. All selected plots, with associated vegetation and spatial predictor data, were combined and used in developing a single gradient model, using canonical correspondence analysis (CCA) for each modeling region. Response variables in gradient model development were basal area by tree species and size class.

The single gradient model was then used for imputation (spatial prediction) for both bookend model dates. This means that plots matched to the later imagery date could be used as neighbors in the earlier model, and vice versa. The validity of this approach relies on the assumption that the spectral values between images for the bookend dates are normalized through time, e.g., the same spectral value

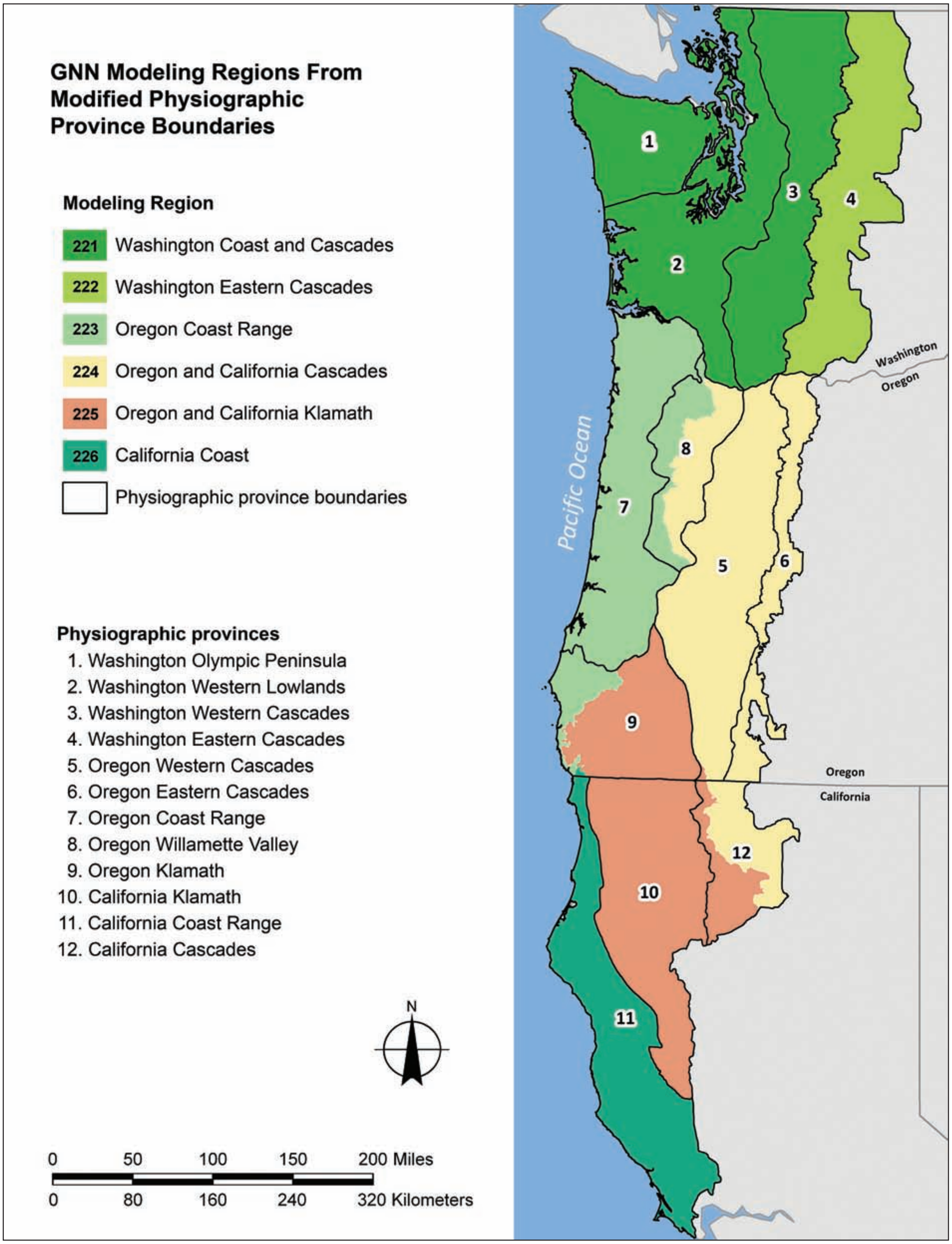

Figure 12—Modeling regions used for gradient nearest neighbor (GNN) modeling, shown in color.

means the same thing in both image years. All modeling and mapping was conducted at 30-m (98.4 ft) spatial resolution. The models were then clipped to the province boundaries and mosaicked to create a single coverage for each bookend date. In the resulting GNN maps, each 30-m pixel is assigned all of the attributes from the nearest-neighbor plot based on the gradient analysis. This allows generation of thematic maps, such as LSOG, for any detailed attribute (or combination of attributes) of forest composition or structure measured on the plots.

GNN Model Evaluation

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

Cross-validation diagnostics were computed for the regions for which the GNN models were developed (fig. 12). To quantify LSOG map accuracy for the physiographic provinces used in this report, we restratified and summarized the cross-validation data (predicted-observed pairs) by province. To assess local-scale map accuracy for LSOG, we compared each plot's observed LSOG classification to an independent GNN prediction at the plot's location and constructed a simply binary error. A field plot (observed value) was considered LSOG if it met the definition in table 1 (conifer canopy closure ≥10 percent and average diameter of dominant and codominant conifers ≥ 20 in) based on the tally trees. The predicted (mapped) value was calculated as an average of the conifer cover and size values for the 30-m pixels within a "window" approximating the field plot configuration. We constructed a binary error matrix of observed (plot) and predicted (mapped) LSOG designations to derive several map diagnostics (table 10).

To assess areal representation of LSOG by GNN, we compared the distribution of LSOG area from the GNN bookend models to sample-based estimates from the FIA Annual Inventory plots at the province, state, and Plan-wide levels. Estimates of LSOG area from GNN and from the FIA Annual Inventory are shown in table 9 and figure 5.

Results from cross-validation for LSOG are shown in table 10. Map accuracy as a percentage correct is the percentage of plots where the observed and predicted agree (either LSOG present or LSOG absent). Sensitivity is based on the percentage of field plots where the map correctly predicted LSOG presence, and specificity is the percentage of plots where the map correctly predicted LSOG absence.

The kappa statistic takes into account the agreement occurring by chance (Cohen 1960), but still is not independent of prevalence (kappas tend to be lower where LSOG comprises a smaller percentage of the forest landscape). The assessment of "overall map agreement" in table 10 is a subjective classification of Kappa by Landis and Koch (1977).

Overall, the LSOG map had moderate agreement at the state and Plan-wide levels, with the exception of California, which had fair agreement. At the province level, the best kappas were in the coastal provinces in Washington and Oregon (Washington Olympic Peninsula and the Oregon Coast Range), followed by the western Cascades provinces in Washington and Oregon. These also were the areas of greatest LSOG prevalence. Kappas were lowest in the Washington Western Lowlands and the Willamette Valley of Oregon, where sample size was low and there was very little federal forest. In general, GNN tends to perform less well in distinguishing tree size in forest with a large broadleaf component, and where canopies are more sparse and stands are uneven-aged (Ohmann et al. 2007). This likely explains the lower LSOG accuracy in southwest Oregon, California, and the eastern Cascades provinces (table 10).

Table 10—Diagnostics for gradient nearest neighbor (GNN) maps of late-successional and old-growth (LSOG) forest

State and physiographic province	Number of plots	LSOG prevalence	Accuracy	Sensitivity	Specificity	Kappa	Overall map agreement
			Percentage correct				
Washington:							
Olympic Peninsula	358	0.35	84.4	0.79	0.88	0.66	Substantial
Western Lowlands	355	0.15	82.5	0.19	0.93	0.15	Slight
Western Cascades	1,052	0.30	79.8	0.65	0.86	0.52	Moderate
Eastern Cascades	1,108	0.10	88.7	0.22	0.96	0.22	Fair
Statewide	2,873	0.21	84.2	0.56	0.92	0.50	Moderate
Oregon:							
Coast Range	1,003	0.31	87.1	0.83	0.89	0.71	Substantial
Willamette Valley	59	0.15	79.7	0.22	0.90	0.13	Slight
Western Cascades	1,892	0.38	77.9	0.72	0.81	0.53	Moderate
Klamath	1,423	0.26	76.0	0.53	0.84	0.37	Fair
Eastern Cascades	635	0.14	82.8	0.38	0.89	0.24	Fair
Statewide	5,015	0.30	79.8	0.67	0.85	0.52	Moderate
California:							
Coast Range	445	0.22	77.3	0.36	0.89	0.27	Fair
Klamath	1,080	0.30	72.2	0.59	0.78	0.36	Fair
Cascades	430	0.12	84.9	0.29	0.93	0.23	Fair
Statewide	1,952	0.24	76.2	0.51	0.84	0.35	Fair
Plan-wide	9,840	0.26	80.4	0.61	0.87	0.49	Moderate

Appendix 2: LandTrendr Maps of Forest Disturbance

LandTrendr uses data-intensive algorithms to both assemble and process imagery (figs. 2 and 4). Annual time series of Landsat imagery were assembled for the entire Northwest Forest Plan area, atmospherically corrected using the COST approach (Chavez 1996), and radiometrically normalized using the MADCAL algorithms (Canty et al. 2004). A semiautomated cloud-screening approach was conducted with human supervision. The normalization process reduces much of the year-to-year variability in spectral signal caused by sun angle and phenology, and thus provides a relatively stable mapping basis over multiple years. After image preparation, the Normalized Burn Ratio (NBR) (van Wagtendonk et al. 2004) spectral index was extracted for each 30-m pixel in the time-series, and temporal segmentation algorithms were applied to identify periods of both stability and change in each pixel's annual trajectory. The segmentation approach utilizes information from nearly every year in the satellite record (with occasional gaps caused by persistent cloud cover), thereby increasing the signal-to-noise ratio of the data and improving the ability to distinguish subtle change from random noise. Analysis of the NBR time-series enables detection of long-term trends, such as those caused by insect-related mortality in forests, and abrupt events, such as fire or harvest. The segmentation phase of analysis (fig. 4) forms the core of all further analysis.

Disturbance maps were created by evaluating each pixel's NBR segmentation results. Disturbed areas were identified as those experiencing declines in NBR over time. We predicted pre- and postdisturbance percentage of vegetation cover using a statistical model developed from photointerpreted plots (Cohen et al. 2010). Relative cover loss was calculated as the change in cover during disturbance divided by predisturbance cover. Year-to-year variation in sun angle, atmospheric contamination, and phenological state can introduce short-duration spikes in the signal that are falsely ascribed as real change. Typically abrupt and of low magnitude, these effects were filtered by removing pixels showing <15 percent relative cover loss within a 1-year-duration disturbance. Insect-related disturbances also can be of low magnitude, but typically show consistent multiyear signals robust to the types of noise evident with short-term disturbance. Therefore, to avoid unnecessary removal of these real signals, disturbances lasting 20 years were filtered at a less aggressive threshold (10 percent relative cover loss), and disturbances with intermediate durations were filtered at intermediate thresholds (linearly interpolated between 15 and 10 percent for 1 and 20 years, respectively). All other disturbed pixels were assigned a disturbance severity low (15 to 32 percent relative vegetation loss), medium (33 to 66 percent), or high (>66). Pixels were grouped, using an eight-neighbor rule to define adjacent pixels, if the year of detected disturbance in adjacent pixels was identical. Polygons smaller in size than 2.5 ha (6.2 ac) were removed.

Using a minimum mapped patch size of at least 2.5 ac (11 adjacent pixels), each remaining pixel in a disturbance patch was labeled with the magnitude of change (percentage of cover change relative to the starting cover), duration of the disturbance (years), year of disturbance onset, and likely cause of the disturbance (fire, harvest, or insect mortality). Up to three multiple disturbances, such as fires occurring during different years, were also captured for each pixel and labeled as primary (as determined by greatest magnitude of change), secondary (second-greatest magnitude), or tertiary (third-greatest magnitude).

Each disturbance patch also was labeled with the likely cause of the disturbance. Assignment of likely disturbance agent is a nascent science, and was done here in three steps. First, we separated disturbances with duration greater than 10 years into a separate class labeled insects/disease. This assignment was based on comparison with field and aerial survey data (Meigs et al., in press), where we have so far found that long-duration disturbance signals are always associated with insect-related mortality processes. We expected assignment of this class to have very low error rate. Of the remaining patches (with duration <10 years), we identified those matching the year and general location of a reference fire polygon and labeled them “fire.” Reference fire polygons were from the Monitoring Trends in Burn Severity project (Eidenshink et al. 2007), which only include fires larger than 1,000 ac, and from Ray Davis (northern spotted owl monitoring program lead, personal communication), which included smaller fires. Finally, we labeled all remaining patches as “Harvest.” Anecdotal examination of thousands of disturbance polygons in this category has shown us that nearly all are indeed harvest, but that it includes a very small number and area of rare natural disturbances such as avalanches, riparian disturbance, and windthrow, as well as some insect-related mortality with duration less than 10 years. Thus, although most of this class membership is indeed harvest, interpretation of results must consider that some nonharvest may contribute.

Appendix 3: Intersection of GNN Bookends With LandTrendr Disturbance Map

Table 11—Complete results of intersection of gradient nearest neighbor (GNN) map bookends (four late-successional and old-growth (LSOG) change classes) with LandTrendr disturbance map, for all forest-capable land, by ownership and physiographic province

	LSOG constant[a]					LSOG gain[a]				
Federal lands	**No disturbance**	**Wildfire**	**Harvest[b]**	**Insects and disease**	**Total**	**No disturbance**	**Wildfire**	**Harvest[b]**	**Insects and disease**	**Total**
					Thousand acres					
Washington:										
Olympic Peninsula	661.5	0.0	0.5	0.0	662.0	53.6	0.0	0.6	0.0	54.2
Western Lowlands	0.3	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.1
Western Cascades	942.8	0.1	1.0	0.1	944.0	139.6	0.1	0.6	0.1	140.4
Eastern Cascades	228.6	2.4	1.7	0.4	233.1	52.2	3.8	1.9	0.3	58.2
Total	1,833.2	2.5	3.2	0.5	1,839.4	245.5	3.9	3.1	0.4	252.9
Oregon:										
Coast Range	520.6	0.0	2.7	0.0	523.3	69.1	0.0	4.4	0.0	73.5
Willamette Valley	3.5	0.0	0.0	0.0	3.5	0.9	0.0	0.1	0.0	1.0
Western Cascades	1,511.7	23.8	6.7	0.1	1,542.3	221.3	9.9	6.8	0.1	238.1
Klamath	488.0	32.1	2.3	0.0	522.4	121.6	26.1	2.5	0.0	150.2
Eastern Cascades	182.1	2.0	1.0	0.0	185.1	62.3	5.3	1.6	0.0	69.2
Total	2,705.9	57.9	12.7	0.1	2,776.6	475.2	41.3	15.4	0.1	532.0
California:										
Coast Range	74.6	1.7	0.2	0.0	76.5	19.0	2.9	0.3	0.0	22.2
Klamath	1,093.9	40.2	3.3	0.1	1,137.5	311.4	28.5	3.0	0.0	342.9
Cascades	124.0	0.2	1.3	0.0	125.5	38.7	0.4	3.0	0.1	42.2
Total	1,292.5	42.1	4.8	0.1	1,339.5	369.1	31.8	6.3	0.1	407.3
NWFP total	5,831.6	102.5	20.7	0.7	5,955.5	1,089.8	77.0	24.8	0.6	1,192.2

Table 11—Complete results of intersection of gradient nearest neighbor (GNN) map bookends (four late-successional and old-growth (LSOG) change classes) with LandTrendr disturbance map, for all forest-capable land, by ownership and physiographic province (continued)

	LSOG loss[a]					Not LSOG[a]				
Federal lands	**No disturbance**	**Wildfire**	**Harvest[b]**	**Insects and disease**	**Total**	**No disturbance**	**Wildfire**	**Harvest[b]**	**Insects and disease**	**Total**
					Thousand acres					
Washington:										
Olympic Peninsula	45.7	0.1	0.4	0.0	46.2	574.6	0.3	2.2	0.1	577.2
Western Lowlands	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
Western Cascades	172.6	0.7	2.4	0.3	176.0	1,767.9	0.9	9.4	0.7	1,778.9
Eastern Cascades	60.3	5.7	2.6	0.7	69.3	2,097.5	114.0	32.6	4.2	2,248.3
Total	278.6	6.5	5.4	1.0	291.5	4,441.0	115.2	44.2	5.0	4,605.4
Oregon:										
Coast Range	89.5	0.0	2.3	0.0	91.8	694.3	0.1	9.1	0.0	703.5
Willamette Valley	0.6	0.0	0.0	0.0	0.6	12.3	0.0	0.2	0.0	12.5
Western Cascades	230.0	20.1	8.1	0.0	258.2	2,250.9	36.5	22.3	0.2	2,309.9
Klamath	123.0	80.2	4.5	0.0	207.7	1,014.5	189.6	18.4	0.2	1,222.7
Eastern Cascades	56.3	5.8	2.6	0.0	64.7	1,052.4	50.4	26.6	0.9	1,130.3
Total	499.4	106.1	17.5	0.0	623.0	5,024.4	276.6	76.6	1.3	5,378.9
California:										
Coast Range	18.0	1.5	0.3	0.0	19.8	239.3	6.9	2.1	0.0	248.3
Klamath	282.2	68.1	5.5	0.1	355.9	2,282.7	137.2	23.8	0.3	2,443.0
Cascades	34.2	1.6	3.4	0.1	39.3	754.5	13.7	36.8	1.7	806.7
Total	334.4	71.2	9.2	0.2	415.0	3,276.5	157.8	62.7	2.0	3,499.0
NWFP total	1,112.4	183.8	32.1	1.2	1,329.5	12,741.9	549.6	183.5	8.3	13,483.3

Table 11—Complete results of intersection of gradient nearest neighbor (GNN) map bookends (four late-successional and old-growth (LSOG) change classes) with LandTrendr disturbance map, for all forest-capable land, by ownership and physiographic province (continued)

	LSOG constant[a]					LSOG gain[a]				
Nonfederal lands	No disturbance	Wildfire	Harvest[b]	Insects and disease	Total	No disturbance	Wildfire	Harvest[b]	Insects and disease	Total
	Thousand acres									
Washington:										
Olympic Peninsula	121.2	0.0	4.2	0.1	125.5	67.8	0.0	10.8	0.2	78.8
Western Lowlands	379.8	0.0	15.7	0.2	395.7	250.4	0.0	47.0	0.8	298.2
Western Cascades	225.5	0.1	8.6	0.1	234.3	92.9	0.1	14.3	0.1	107.4
Eastern Cascades	55.3	0.2	1.5	0.1	57.1	20.7	0.5	4.1	0.1	25.4
Total	781.8	0.3	30.0	0.5	812.6	431.8	0.6	76.2	1.2	509.8
Oregon:										
Coast Range	337.6	0.0	18.5	0.2	356.3	209.4	0.0	29.4	0.6	239.4
Willamette Valley	53.2	0.0	1.1	0.0	54.3	18.8	0.0	1.1	0.0	19.9
Western Cascades	141.2	0.3	7.4	0.0	148.9	85.2	0.5	10.3	0.1	96.1
Klamath	106.6	0.1	4.1	0.0	110.8	82.0	0.1	7.5	0.0	89.6
Eastern Cascades	22.7	0.3	1.5	0.0	24.5	16.6	0.4	3.0	0.0	20.0
Total	661.3	0.7	32.6	0.2	694.8	412.0	1.0	51.3	0.7	465.0
California:										
Coast Range	461.7	1.1	16.1	0.2	479.1	208.9	0.9	26.4	0.3	236.5
Klamath	117.9	0.4	4.6	0.1	123.0	76.3	0.5	4.4	0.1	81.3
Cascades	52.2	0.0	2.4	0.0	54.6	30.6	0.3	3.4	0.1	34.4
Total	631.8	1.5	23.1	0.3	656.7	315.8	1.7	34.2	0.5	352.2
NWFP total	2,074.9	2.5	85.7	1.0	2,164.1	1,159.6	3.3	161.7	2.4	1,327.0

Table 11—Complete results of intersection of gradient nearest neighbor (GNN) map bookends (four late-successional and old-growth (LSOG) change classes) with LandTrendr disturbance map, for all forest-capable land, by ownership and physiographic province (continued)

	LSOG loss[a]					Not LSOG[a]				
Nonfederal lands	No disturbance	Wildfire	Harvest[b]	Insects and disease	Total	No disturbance	Wildfire	Harvest[b]	Insects and disease	Total
					Thousand acres					
Washington:										
Olympic Peninsula	65.8	0.0	32.0	0.8	98.6	957.4	0.0	119.2	2.7	1,079.3
Western Lowlands	273.2	0.0	112.7	1.3	387.2	3,004.3	0.0	436.4	7.1	3,447.8
Western Cascades	130.7	0.2	40.6	0.2	171.7	1,514.6	0.3	190.8	1.1	1,706.8
Eastern Cascades	18.9	0.2	6.1	0.1	25.3	1,302.4	8.2	185.2	1.8	1,497.6
Total	488.6	0.4	191.4	2.4	682.8	6,778.7	8.5	931.6	12.7	7,731.5
Oregon:										
Coast Range	222.1	0.1	139.7	0.6	362.5	2,450.4	0.3	424.6	3.1	2,878.4
Willamette Valley	19.7	0.0	9.5	0.0	29.2	397.0	0.0	43.1	0.5	440.6
Western Cascades	68.8	1.8	55.2	0.1	125.9	1,310.8	8.3	210.7	0.7	1,530.5
Klamath	72.8	0.9	30.2	0.0	103.9	1,093.5	4.5	117.2	0.4	1,215.6
Eastern Cascades	19.7	0.4	6.2	0.1	26.4	473.8	3.9	97.5	1.3	576.5
Total	403.1	3.2	240.8	0.8	647.9	5,725.5	17.0	893.1	6.0	6,641.6
California:										
Coast Range	219.8	2.2	36.7	0.3	259.0	2,433.2	7.7	130.6	1.6	2,573.1
Klamath	64.5	1.8	13.5	0.1	79.9	893.6	11.1	59.1	0.8	964.6
Cascades	29.9	0.7	8.3	0.1	39.0	747.9	8.7	79.0	1.4	837.0
Total	314.2	4.7	58.5	0.5	377.9	4,074.7	27.5	268.7	3.8	4,374.7
NWFP total	1,205.9	8.3	490.7	3.7	1,708.6	16,578.9	53.0	2,093.4	22.5	18,747.8

[a] Can contain rare cases of avalanche, landslide, riparian disturbance, and windthrow.

[b] "LSOG constant" is LSOG in both baseline and current maps. "LSOG gain" is open or young forest in baseline map and LSOG in current map. "LSOG loss" is LSOG in baseline map and open or young forest in current map. "Not LSOG" is open or young forest in both baseline and current maps. Baseline is 1994 in California and 1996 in Washington and Oregon; current map is 2007 in California and 2006 in Washington and Oregon.

NWFP = Northwest Forest Plan.

Appendix 4: Improvements to Northwest Forest Plan Effectiveness Monitoring Protocol

There are major differences between the forest vegetation maps created for the 15-year and 10-year assessments, and between the disturbance mapping approaches used in the two reports. In addition, the regional inventories are much more complete now than they were for the 10-year report, including the first regionally consistent sample of all land ownerships, and remeasurement data for much of the federal land base. The 10-year report (Moeur et al. 2005) summarized late-successional and old-growth (LSOG) status and trends only on the federally administered lands affected by the Northwest Forest Plan (the Plan). In this report, we also summarize the condition of LSOG on all other ownerships to provide context to the overall regional picture of LSOG status and trends and context for federal lands. Collectively, these differences represent significant improvements over the initial monitoring approaches taken in the 10-year report.

The gradient nearest neighbor (GNN) bookend approach provides capability to develop maps from multiple imagery dates using the same methodology and data. Contrary to the prediction in the 10-year report, developing a revised baseline map with the new methods is not “onerous” (Moeur et al. 2005), but becomes almost trivial. In the 10-year assessment, we had only a baseline map depicting LSOG at or near the beginning of the Plan, plus a disturbance layer for estimating LSOG losses, but no updated map was developed and therefore LSOG ingrowth was not evaluated.

For this report, we applied consistent methods for mapping both vegetation and disturbance across the entire Plan area. The 10-year assessment relied upon a piecemeal approach resulting from different mapping projects in Forest Service Pacific Southwest and Pacific Northwest Regions (Regions 5 and 6): the Interagency Vegetation Mapping Project (IVMP) in Oregon and Washington (Browning et al. 2002a, 2002b; Fassnacht et al. 2006) and the Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG) project in California (USDA Forest Service 2000). The two projects provided map data that differed in spatial, temporal, and attribute resolution, and had different map quality statistics. The data incompatibilities limited confidence in some of the initial monitoring results. The LSOG map accuracy from GNN used in this report were substantially improved over the IVMP results (Moeur et al. 2005, p. 124–125), by an average of 6.4 percent for provinces in Washington and Oregon. The GNN accuracy statistics could not be directly compared to CALVEG for the California provinces because of differences in methods.

In the IVMP and CALVEG map products, map attributes were limited to thematic classifications of canopy cover, average size of the overstory trees, and canopy layering (single- or multistoried). With GNN, all of the inventoried plot data are imputed to each map pixel, resulting in a rich suite of attributes. This allowed for additional attributes to be included in models of habitat quality for the northern spotted owl (*Strix occidentalis caurina*) (Davis and Dugger, in press) and marbled murrelet (*Brachyramphus marmoratus*) (Raphael et al., 2011), and the assessment of watershed condition (Lanigan et al., in press). We also used the additional forest attributes from GNN to explore alternative LSOG definitions, although ultimately we chose to apply one of the same definitions used in the 10-year report.

In this monitoring cycle, the same methods for mapping disturbance were applied consistently across the entire Plan area. For the 10-year assessment, disturbance was mapped by two independent projects in California (Levien et al. 1998, 2003a, 2003b) and in Washington and Oregon (Cohen et al. 1998, 2002; Healey et al. 2008). As a result, in the 10-year assessment, the two maps differed in spatial, temporal, and attribute resolution. This limited analyses to the lowest common denominator of attributes shared by both maps. For example, the California product mapped change as classes of decrease and increase, while the Washington/Oregon project mapped only stand-replacing disturbances (loss of at least 70 percent vegetation cover). Thus, only stand-replacing changes could be assessed over the Plan area. In addition, disturbance patches of less than 5 ac were eliminated from the California map to be consistent with the lower mapping resolution in Washington and Oregon. The LandTrendr technology provides maps of change in vegetation cover on a continuous scale, which allow mapping of disturbances over a range of intensities. Algorithms are applied at the individual pixel scale, providing flexibility to postfilter using different standards.

In the 10-year assessment, change was mapped for periods ranging from 3 to 5 years. Consequently, disturbances occurring several years prior to mapping could be masked by vegetation recovery and missed by the maps. Use of annual imagery stacks by LandTrendr results in more disturbances detected more often. LandTrendr also tracks the duration of disturbance, which is useful for distinguishing disturbance cause (e.g., short-duration change such as harvest or wildfire vs. long-duration change such as chronic insect mortality).

Lastly, the map- and plot-based methods applied in this report achieve much greater integration, and therefore consistency among the various estimates, by being based on much of the same underlying data. The same segment maps developed from the LandTrendr algorithms were used to produce the temporally smoothed imagery for the GNN bookend models as well as the maps of forest disturbance (fig. 2). This improved the consistency between the vegetation and disturbance maps compared to using two independent mapping processes as in the 10-year report. Although GNN uses model-based estimation to develop maps of forest composition, the models rely on many of the same inventory plots we use to develop sample-based estimates.

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