NORTHWEST FOREST PLAN
THE FIRST 10 YEARS (1994–2003)

Status and Trend of Late-Successional and Old-Growth Forest

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Abstract

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We monitored the status and trend of late-successional and old-growth forest (older forest) on 24 million ac of land managed by the Forest Service, Bureau of Land Management, and National Park Service in the Northwest Forest Plan (the Plan) area between 1994 and 2003. We developed baseline maps from satellite imagery of older forest conditions at the start of the Plan. We used remotely sensed change detection to track losses of older forests on federally managed lands to stand-replacing harvest and wildfire, and we analyzed the amounts and spatial distribution of older forests by using the mapped data. We also performed statistical analysis on inventory plot information collected on Forest Service and Bureau of Land Management lands. These analyses provided statistically rigorous estimates of older forest acres bracketed by confidence intervals. We analyzed remeasured inventory plots to estimate net change in the amount of older forests on federally managed lands.

We estimated the amount of older forest at the start of the Plan corresponding to three different older forest definitions based on average tree size, canopy layering, canopy closure, and life form. The results ranged from 7.87 million ac (± 1.96 million ac) of federally managed lands with average tree size at least 20 in (medium and large older forest), to 7.04 million ac (± 1.93 million ac) using a definition that recognizes variation in regional forest vegetation (older forest with size indexed to potential natural vegetation zone). We found 2.72 million ac (± 0.35 million ac) were in stands with average tree size 30 in and greater, with multistoried canopies (large, multistoried older forest). At least 1.7 million ac of existing "medium and large" older forest were in fire-adapted vegetation types characterized by high fire frequency and low severity in the Eastern Cascades and Klamath provinces. Up to 1 million additional older forest ac occurred in dry mixed-conifer types in the Western Cascades.

Our data from remeasured inventory plots indicated that the annual net rate of increase of "medium and large" older forest was about 1.9 percent, outpacing losses from all sources. The extrapolated gain in older forest 20 in was between 1.25 million ac and 1.5 million ac in the first decade after the Plan. The gain came primarily from increases in the area of forest at the lower end of the diameter range for older forest. The net increase took into account the older forest removed by stand-replacing harvest, 0.2 percent of the total (about 16,900 ac on all federally managed lands), and the amount burned by stand-replacing wildfire, about 1.3 percent (about 102,500 ac on all federally managed lands). The area mapped as logged or burned had an error estimate of between 7 and 12 percent.

The initial amount, distribution, and arrangement of older forest on federally managed land appears to have met or exceeded Northwest Forest Plan expectations. But the large amount of older forest susceptible to catastrophic wildfire may be a concern for managers. Losses to wildfire in the first decade were in line with assumptions for the Plan area, but rates of loss were highly variable among provinces, with the highest rates of loss occurring in the dry provinces. Loss of older forest to harvest was a fraction of the approximately 230,000 ac of older forest expected to have been harvested. Overall gain was about twice the 600,000 ac expected during the first decade of the Plan.

Older forest maps based on remote sensing allowed for a spatial assessment of landscape patterns, but map accuracy was low in some areas, especially the Eastern Cascades. Remotely sensed change detection was highly accurate for assessing older forest losses to catastrophic disturbance (clearcutting and stand-replacing wildfire). But technological improvements are needed to use remotely sensed data for detecting less severe disturbance from partial harvest or less severe burning. Plot data were not of sufficient resolution to allow for spatial analysis or to identify causes of change. But estimates made from plot data were unbiased, accurate, and precise. Future monitoring work will pursue approaches that tie the plot-based and mapped data sets together more closely.

This document, including high-resolution versions of all the map images it contains, is accessible online (http://www.reo.gov/monitoring/).

Keywords: Northwest Forest Plan, effectiveness monitoring, late-successional and old-growth forests, remote sensing, existing vegetation, change detection, Pacific Northwest, Forest Service, Bureau of Land Management, land use allocations, late-successional reserves, physiographic provinces.

Preface

This report is one of a set of reports produced on this 10-year anniversary of the Northwest Forest Plan (the Plan). The collection of reports attempts to answer questions about the effectiveness of the Plan based on new monitoring and research results. The set includes a series of status and trend reports, a synthesis of all regional monitoring and research results, a report on interagency information management, and a summary report.

The status and trend reports focus on establishing baselines of information from 1994, when the Plan was approved, and reporting change over the 10-year period. The status and trend series includes reports on late-successional and old-growth forest, northern spotted owl population and habitat, marbled murrelet population and habitat, watershed condition, government-to-government tribal relationships, socioeconomic conditions, and monitoring of project implementation under Plan standards and guidelines.

The synthesis report addresses questions about the effectiveness of the Plan by using the status and trend results and new research. It focuses on the validity of the Plan assumptions, differences between expectations and what actually happened, the certainty of the findings, and, finally, considerations for the future. The synthesis report is organized in two parts: Part I–introduction, context, synthesis and summary–and Part II–socioeconomic implications, older forests, species conservation, the aquatic conservation strategy, and adaptive management and monitoring.

The report on interagency information management identifies issues and recommends solutions for resolving data and mapping problems encountered during the preparation of the set of monitoring reports. Information management issues inevitably surface during analyses that require data from multiple agencies covering large geographic areas. The goal of that report is to improve the integration and acquisition of interagency data for the next comprehensive report.

Executive Summary

In this assessment we evaluated three older forest definitions. The definitions used average tree size, canopy layering, canopy closure, and life form as defining attributes. “Medium and large older forest” represents forests with a minimum average tree size of 20 in, and having either single-storied or multistoried canopies. “Older forest with size indexed to potential natural vegetation zone” uses an average-tree-size threshold that varies by potential natural forest vegetation zone, and having either single- or multistoried canopies. “Large, multistoried older forest” represents forests with average tree size 30 in and greater and multistoried canopies. Each of the three definitions was applied to create a set of regional and provincial older forest benchmarks. “Medium and large older forest” corresponds closely to the definition of older forests used in the Northwest Forest Plan Record of Decision, and therefore can be used broadly to assess the assumptions upon which the Plan was founded about the amount of remaining older forest. “Older forest with size indexed to potential natural vegetation zone” is a definition that recognizes regional variation in climate, topography, and natural disturbance regimes. “Large, multistoried older forest” retains minimum structural elements of “classic” Douglas-fir old growth (large live, old-growth trees and multiple canopy layers).

We used maps of existing vegetation created from satellite data to estimate the amount and distribution of older forests at the start of the Plan. Older forests assessed by using the “medium and large” older forest definition occupied 34 percent (7.87 ± 1.96 million ac) of the federal forested landscape at the start of the Plan, ranging from 5 percent in the Eastern Cascades of Washington to 47 percent in the California Coast province. There were fewer acres overall of “older forest with size indexed to potential natural vegetation zone” (7.04 ± 1.93 million ac or 30 percent), and the distribution differed from the “medium and large older forest” estimate across physiographic provinces and potential natural vegetation zones. This definition estimated more acres in higher elevation forests and forest types east of the Cascades, and fewer acres in very productive west-side forest types compared with the “medium and large” older forest definition. The “large, multistoried older forest” definition estimated 2.72 ± 0.35 million ac (12 percent), concentrated in forests west of the Cascade divide.

Estimates of older forest compiled from map and plot data were generally consistent. The number of acres of “medium and large” older forest tallied from maps developed from remote sensing data was contained within 90-percent confidence intervals constructed from plot data at the regional level. The map and plot estimates were equivalent in Oregon and Washington, whereas in California the map estimate was higher than the upper 90-percent confidence boundary for the plot estimate. There was even greater difference between map and plot estimates within physiographic provinces. In particular, map estimates were well below plot estimates in the Eastern Cascades of Washington and Oregon where average size was mapped to lower resolution than in the rest of the range. This comparison can help us identify where the mapping technology and related analyses need the greatest effort to improve the accuracy of results.

Our results confirm the older forest amounts reported in the Northwest Forest Plan Record of Decision. The estimate of 7.87 million ac of “medium and large” older forest is within 10 percent of the 8.55 million ac published in the Plan, which used a similar definition. It appears therefore that the Plan was founded upon valid assumptions about the extent of remaining older forest.

Two-tenths of a percent (about 16,900 ac) of “medium and large” older forest on federal land was removed by clearcutting harvests since the Plan was signed. Another 1.3 percent (about 102,500 ac) was burned by stand-replacing wildfires. The area mapped as logged or burned had an error estimate of between 7 and 12 percent. Local variation in wildfire was huge, with 95 percent of acres lost in a few catastrophic fires. Three-quarters of the total was burned in the Oregon and California Klamath provinces during the 2002 Biscuit Fire.

Gains well outpaced losses from all causes between 1994 and 2003. When we analyzed change rates by using remeasured plot data, we projected an increase of 1.01 million ac of “medium and large” older forest in the first decade after the Plan, just on Forest Service Pacific Southwest and Pacific Northwest Regions nonwilderness land. Likely an additional 0.24 to 0.48 million ac were gained on other federally managed lands, assuming that the rate of change was at least half, but no greater than the rate calculated on sampled lands. This was a net increase after taking into account losses from stand-replacing harvest and wildfire.

About three-quarters of existing older forest is in administratively withdrawn, congressionally reserved, and late-successional reserve federal land allocations. Of the older forest on land allocated to matrix, an unknown proportion is in riparian reserves that have not been spatially differentiated from matrix. Therefore our results underestimated the true proportion of older forest in reserved land allocations. The record of decision estimated that matrix accounted for 4.0 million ac, and riparian reserves interspersed with matrix accounted for 2.6 million ac. Applying the same proportions to our results (that is, assuming the combined class is 60 percent matrix and 40 percent riparian reserve), we estimated that riparian reserves accounted for an additional 11 percent of the total older forest (and matrix 11 percent less).

The report focuses attention on the large amount of existing older forest in fire-adapted ecosystems (that is, characterized by high fire frequency and low severity) in dry physiographic provinces. There are 1.7 million ac of “medium and large” older forest in fire-adapted forest types in the Klamath and Eastern Cascades provinces. Up to 1 million additional older forest ac occur in dry mixed-conifer types in the Western Cascades. Twentieth-century fire-suppression policies and resulting accumulation of fuel has increased the susceptibility of these older forests to catastrophic wildfire. Therefore it will be very important to consider wildfire when evaluating management policies aimed at perpetuating a healthy, functioning older forest ecosystem in the Northwest Forest Plan area.

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Introduction

How much late-successional and old-growth forest existed on federal land at the start of the Northwest Forest Plan (the Plan)? How was it arranged on the landscape? How much was lost and gained in the first decade of the Plan? From what causes? How did the amount and pattern of late-successional and old-growth forest (older forest) differ from the expectations under the Plan? These and other related questions are the focus of this report.

This report summarizes the scientific assessment of the status and trend of late-successional and old-growth forest between 1994 and 2003 on the federal lands affected by the Plan (fig. 1).

In the early 1990s, controversy over harvest of old-growth forest led to sweeping changes in management of federal forests in western Washington and Oregon and northwest California. These changes were prompted by a series of lawsuits in the late 1980s and early 1990s, which effectively shut down federal timber harvest in the Pacific Northwest (Tuchmann and others 1996). In response, President Clinton convened a summit in Portland, Oregon, in 1993. At the summit, President Clinton issued a mandate for federal land management and regulatory agencies to work together to develop a plan to resolve the conflict. The President's guiding principles followed shortly after the summit in his *Forest Plan for a Sustainable Economy and a Sustainable Environment* (Clinton and Gore 1993).

Immediately after the summit, a team of scientists and technical experts were convened to conduct an assessment of options (FEMAT 1993). This assessment provided the scientific basis for the environmental impact statement (USDA and USDI 1994a) and record of decision (USDA and USDI 1994b) to amend Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl (*Strix occidentalis caurina*).

The record of decision, covering 24 million federal ac, put in place a new approach to federal land management. Key components of the record of decision included a new set of land use allocations—late-successional reserves, matrix, riparian reserves, adaptive management areas, and key watersheds. Plan standards and guidelines provided specific management direction regarding how these land use allocations were to be managed (USDA and USDI 1994b). In addition, the Plan put in place a variety of strategies and processes to be implemented. These included adaptive management, an aquatic conservation strategy, late-successional reserve and watershed assessments, a survey and manage program, an interagency organization, social and economic mitigation initiatives, and monitoring.

Monitoring provides a means to address the uncertainty of our predictions and compliance with forest management laws and policy. The record of decision stated that monitoring is essential and is required:

> Monitoring is an essential component of the selected alternative. It ensures that management actions meet the prescribed standards and guidelines and that they comply with applicable laws and policies. Monitoring will provide information to determine if the standards and guidelines are being followed, verify if they are achieving the desired results, and determine if underlying assumptions are sound.

Judge Dwyer reinforced the importance of monitoring in his 1994 decision declaring the Plan legally acceptable (Seattle Audubon Soc. v. Lyons, 871 F.Supp. 1291 [W.D. Wash. 1994]; affirmed Seattle Audubon Soc. v. Moseley, 80 F.3d 1401 [9th Cir. 1996]):

> Monitoring is central to the [Northwest Forest Plan's] validity. If it is not funded, or done for any reason, the plan will have to be reconsidered.

The record of decision monitoring plan provided a very general framework to begin development of an interagency monitoring program. It identified key areas to monitor, initial sets of questions, types and scope of monitoring, the need for common protocols and quality assurance, and the need to develop a common design framework. In 1995, the effectiveness monitoring program plan (Mulder and others 1995) and initial protocols for implementation monitoring (Alegria and others 1995) were approved by the Regional Interagency Executive Committee. Approval of the effectiveness monitoring plan led to the formation of technical teams to develop the overall program strategy and design

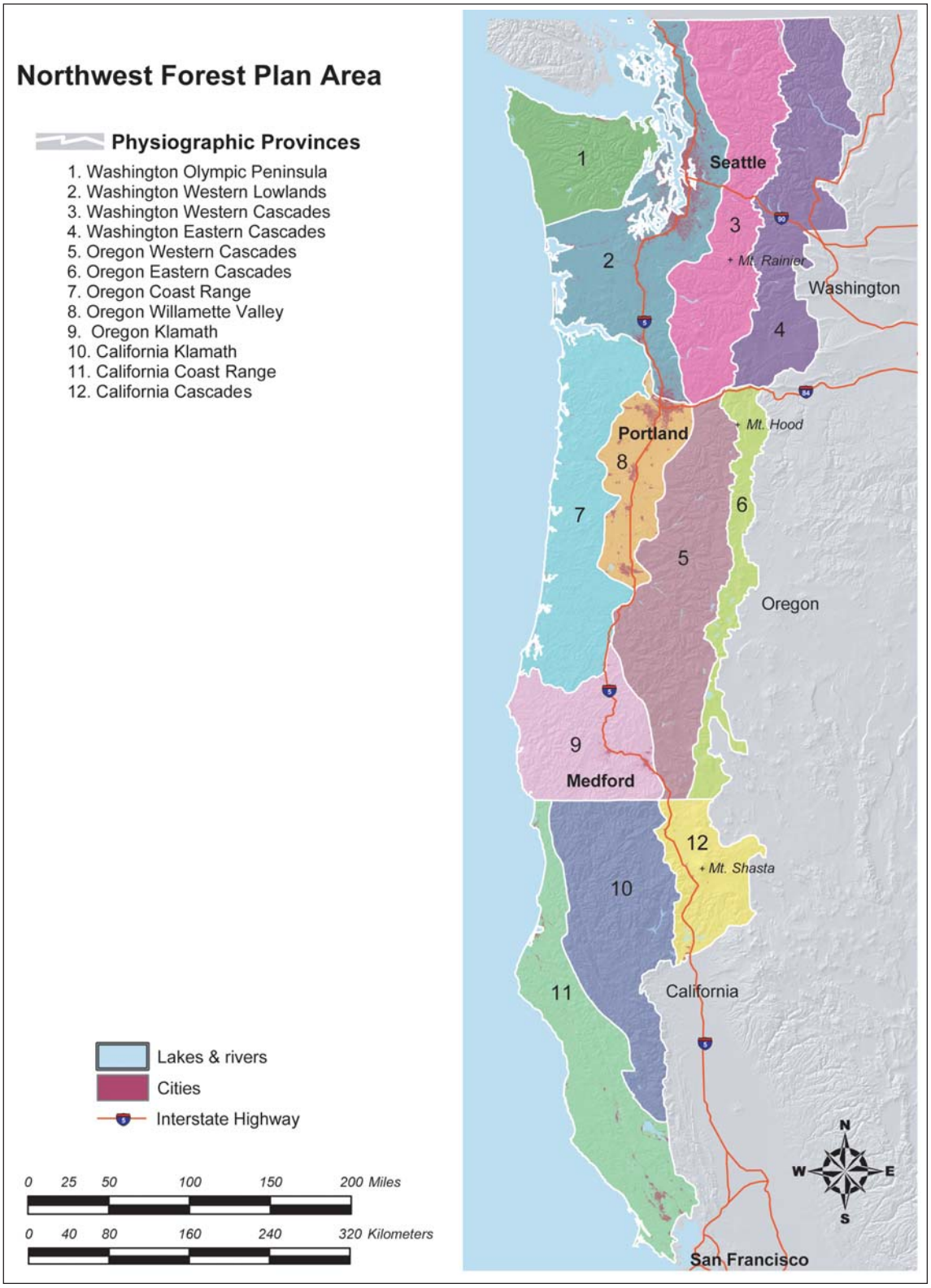

Figure 1—Terrestrial physiographic provinces of the Northwest Forest Plan area (from USDA and USDI 1994a, fig. 3&4-1).

(Mulder and others 1999) and monitoring protocols for late-successional and old-growth forest (Hemstrom and others 1998), northern spotted owls (Lint and others 1999), marbled murrelets (*Brachyramphus marmoratus*) (Madsen and others 1999), tribal concerns (Bown and others 2002), and watershed condition (Reeves and others 2004). Socioeconomic monitoring protocols continue to be tested (Charnley et al., in press).

Periodic analysis and interpretation of monitoring data is essential to completing the monitoring task and critical to completing the adaptive management cycle. This important step was described in the overall monitoring strategy (Mulder and others 1999) and approved by the regional interagency executive committee. This 10-year report is the first comprehensive analysis and interpretation of monitoring data since the record of decision.

The Plan's Expectations

At the very heart of the Northwest Forest Plan was the observation that the amount of older forest on federal land in the Pacific Northwest had declined steeply in the 20th century (see Bolsinger and Waddell 1993), and the assumption was that it would continue to decline unless policies were put in place to halt it. Declining old-growth habitat was also blamed for placing at risk some old-growth-dependent species such as the northern spotted owl and marbled murrelet. The Plan was implemented in hopes of returning older forest to a level more in line with the amount of the historical landscape that was covered by older forest.

The Northwest Forest Plan was developed by expert panel assessments under the direction of the Forest Ecosystem Management Team (FEMAT 1993, USDA and USDI 1994a). Each alternative was evaluated based upon its probable success of achieving historical ranges of older forest abundance and diversity, ecological processes, and landscape arrangement over the life of the Plan. The possible outcomes ranged from high probability of achieving amounts at least as high as the long-term historical average, to the possibility of highly fragmented remnant older forest patches restricted to a few locations and therefore considerably below the low end of the historical range of conditions. The benchmarks were the amounts and variety of plant communities across the range of environments (that is, abundance and ecological diversity), ecological processes such as the balance of successional stages, nutrient and hydrological cycling, and habitat for old-growth-dependent species (that is, processes and functions), and the extent to which the landscape pattern of the ecosystem provides for biological flows that sustain animal and plant populations (that is, landscape patterns and connectivity). Thresholds were set for each of the benchmarks for quantifying the observed outcome relative to the Plan expectation. For example, expert panels estimated there would be a 77-percent likelihood under the Plan of achieving either outcome 1 or 2 (within the historical range of variation) for the abundance and diversity benchmark for moist provinces (and only 63 percent for dry provinces). The actual result could be measured by the total amount of the land base covered by older forest, and the amount covered by large contiguous stands, relative to the stated benchmark amounts.

Comparison of monitoring results with outcomes expected under the Plan gives us a gauge of how well the Plan is working. This concept is covered in much greater detail in subsequent sections. However, it is helpful to note in this introduction some key assumptions of the Plan:

1. The environmental impact statement included an initial estimate of the amount of late-successional and old-growth forest remaining on federal lands at the start of the Plan (8,550,500 ac or 35 percent of the federal landscape—table 3&4-8, USDA and USDI 1994a). Of this amount, about 85 percent was in reserved allocations.
2. The record of decision included estimates of the historical amount of older forest. Under natural disturbance regimes, the long-term average percentage of the regional landscape covered by late-successional and old-growth forest was 60 to 70 percent.
3. The proportion of late-successional and old-growth forest in reserved allocations was expected to increase over time under the Plan, to at least as high as the long-term average in 5 to 10 decades.

Sidebar 1—Plan expectations

Abundance and diversity are the amount and variety of plant communities and environments. **Connectivity** is the extent to which the landscape pattern of the ecosystem provides for biological flows that sustain animal and plant populations. **Processes and functions** are the ecological actions that lead to the development and maintenance of the ecosystem and the values of the ecosystem for species and populations.

Abundance and diversity outcomes and thresholds for late-successional and old-growth forests (LSOG) in the Northwest Forest Plan

Outcome	Land covered by LSOG	Lands in stands of more than 1,000 acres	Provinces meeting both amount and stand size
		Percent	
1	60 to 100	80 to 100	100
2	40 to 60	5 to 80	100
3	5 to 40	1 to 5	50 to 100
4	Less than 5	Less than 1	Less than 50

Outcome 1—Late-successional and old-growth ecosystem abundance and ecological diversity on federal lands are at least as high as the long-term average estimated at 65 percent of the forested landscape prior to logging and extensive fire suppression (FEMAT 1993: 51). Relatively large areas (50,000 to 100,000 ac) would still contain levels of abundance and distribution of late-successional forests that are well below the regional average for long periods. However, within each physiographic province, abundance would be at least as high as province-level long-term averages, which might be higher or lower than the regional long-term average.

Outcome 2—Late-successional and old-growth ecosystem abundance and ecological diversity on federal lands are less than the long-term conditions (prior to logging and extensive fire suppression) but within the typical range of conditions that occurred during previous centuries, assumed to be 40 percent of the forested landscape (FEMAT 1993: 51).

Outcome 3—Late-successional and old-growth abundance and ecological diversity on federal lands are considerably below the typical range of conditions that have occurred during the previous centuries, but in some provinces some older forest (more than 1 percent) would still exist. The ecological diversity (age-class diversity) may be limited to the younger stages of late-successional ecosystems. Late-successional and old-growth communities and ecosystems may be absent from some physiographic provinces and/or occur as scattered remnant patches.

Outcome 4—Late-successional and old-growth ecosystems are very low in abundance and may be restricted to a few physiographic provinces or elevation bands or localities within provinces. Late-successional and old-growth communities and ecosystems are absent from most physiographic provinces or occur only as small remnant patches.

Source: (USDA and USDI 1994a: table 3&4-5).

Connectivity outcomes and thresholds for late-successional and old-growth forest used when ranking land management alternatives considered in the Northwest Forest Plan FSEIS

Outcome	Mean distance between stands of more than 1,000 acres	LSOG cover	LSOG stands less than 1,000 acres	Adjacent provinces connected with large LSOG stands
	– – – Miles – – –	*– – Percent – –*		*– – – Percent – – –*
1	Less than 6	60 to 100	Common	100
2	6 to 12	50 to 60	Common	100
3	12 to 24	25 to 50	Present	Less than 100
4	More than 24	Less than 25	Absent to few	Less than 100

Outcome 1—Connectivity is very strong, characterized by relatively short distances (less than 6 mi on average) between late-successional and old-growth areas. Smaller patches of late-successional and old-growth forest frequently occur (riparian buffers, green-tree retention in harvest units, etc.). The proportion of the landscape covered by late-successional and old-growth conditions of all stand sizes exceeds 60 percent, a threshold when many measures of connectivity increase rapidly. At regional scales, physiographic provinces are connected by the presence of landscapes containing areas of late-successional and old-growth forests.

Outcome 2—Connectivity is strong, characterized by moderate distances (less than 12 mi on average) between large late-successional and old-growth areas. Smaller patches of late-successional forest occur as described in outcome 1. At regional scales, physiographic provinces are connected by the presence of landscapes containing areas of late-successional and old-growth forests. The total proportion of landscape in late-successional and old-growth conditions, including smaller patches, is at least 50 percent, so that the late-successional condition is still the dominant cover type.

Outcome 3—Connectivity is moderate, characterized by distance[s] of 12 to 24 mi between large old-growth areas. There is limited occurrence of smaller patches of late-successional forest in the matrix. The late-successional forest is at least 25 percent of the landscape, and the matrix contains some smaller areas for dispersal habitat.

Outcome 4—Connectivity is weak, characterized by wide distances (greater then 24 mi) between old-growth areas. There is a matrix in which late-successional and old-growth conditions occur as scattered remnants or are completely absent.

Source: (USDA and USDI 1994a: table 3&4-7)

Scope and Context of Effectiveness Monitoring for Older Forests

This report covers only older forest effectiveness monitoring. The monitoring is designed to address questions about older forest status and trend such as, “How much older for-est is there? Where is it? How much has it changed and from what causes?” Hemstrom and others (1998) developed specific effectiveness monitoring questions for late-successional and old-growth forest. Of the monitoring questions listed, the first five are within the scope of status and trend monitoring, and are specifically addressed in this report. They deal with amounts, distributions, and spatial patterns of older forests. Monitoring of older forest processes and functions, such as providing habitat or contributing to watershed health, is not explicitly covered in this report beyond the comparison of observed status and trend with the Plan’s expectations.

The last two questions are beyond the scope of this report. However, they are addressed explicitly in a synthesis report (Haynes and others, in press), in the context of

Sidebar 2—Status and trend monitoring questions

Older forest status and trend monitoring questions (after Hemstrom and others 1998)

What is the current amount and distribution of older forests in the Northwest Forest Plan?
What is the amount and distribution of older forest classes for the Plan area? Within federal ownerships, physiographic provinces, plant communities, and land use allocations? How accurate are these estimates?

What is the spatial arrangement of older forest classes across the Northwest Forest Plan landscape?
What are the spatial distributions of stand sizes, stand interior areas, edges, and interstand distances?

What are the structural and compositional characteristics of older forest classes?
Large tree diameters, canopy structure, snags, and down woody debris? What is the error associated with these estimates?

How is the amount and distribution of older forest classes changing?
How have they changed during the first decade of the Plan? How much are they likely to change in the near-term and long-term future?

What are the stressors causing change in the amount and distribution of older forest classes?
What are the gains from growth and succession? What are the losses from logging, fire, wind, insects, and disease?

What are the effects of silvicultural treatment and salvage on the development of older forest structure and composition?
This question is outside the scope of the status and trend monitoring report but is addressed by Spies (in press).

Are the relationships of forest structure and composition at stand and landscape scales to ecological processes and biological diversity assumed by the Plan, accurate?
This question is outside the scope of the status and trend monitoring report but is addressed by Spies (in press).

scientific findings external to the monitoring program. In his synthesis report chapter, Spies (in press) includes discussion about possible effects of silvicultural practices for restoring ecological diversity or accelerating old-growth development, as well as a section that reevaluates the validity of the Plan's assumptions and approaches. Furthermore, the habitat sections of the status and trend reports for northern spotted owls (Lint 2005) and marbled murrelets (Huff, in press) devote discussion on the subject of how well the old-growth forest ecosystem is providing habitat for those species. Habitat for old-growth-dependent species is one (arguably the foremost) of the functions of older forest that the Northwest Forest Plan was designed to address.

We report monitoring results only for the federally administered lands affected by the Plan: USDA Forest Service Pacific Northwest Region (Forest Service-Region 6) and Pacific Southwest Region (Forest Service-Region 5), U.S. Department of the Interior Bureau of Land Management in Oregon (Bureau of Land Management-Oregon) and California (Bureau of Land Management-California), and U.S. Department of the Interior National Park Service in Washington, Oregon, and California (fig. 2). The Plan does not affect lands administered by other federal agencies, such as Fish and Wildlife Service or Department of Defense (USDA and USDI 1994b), nor is it applicable to any nonfederal lands.

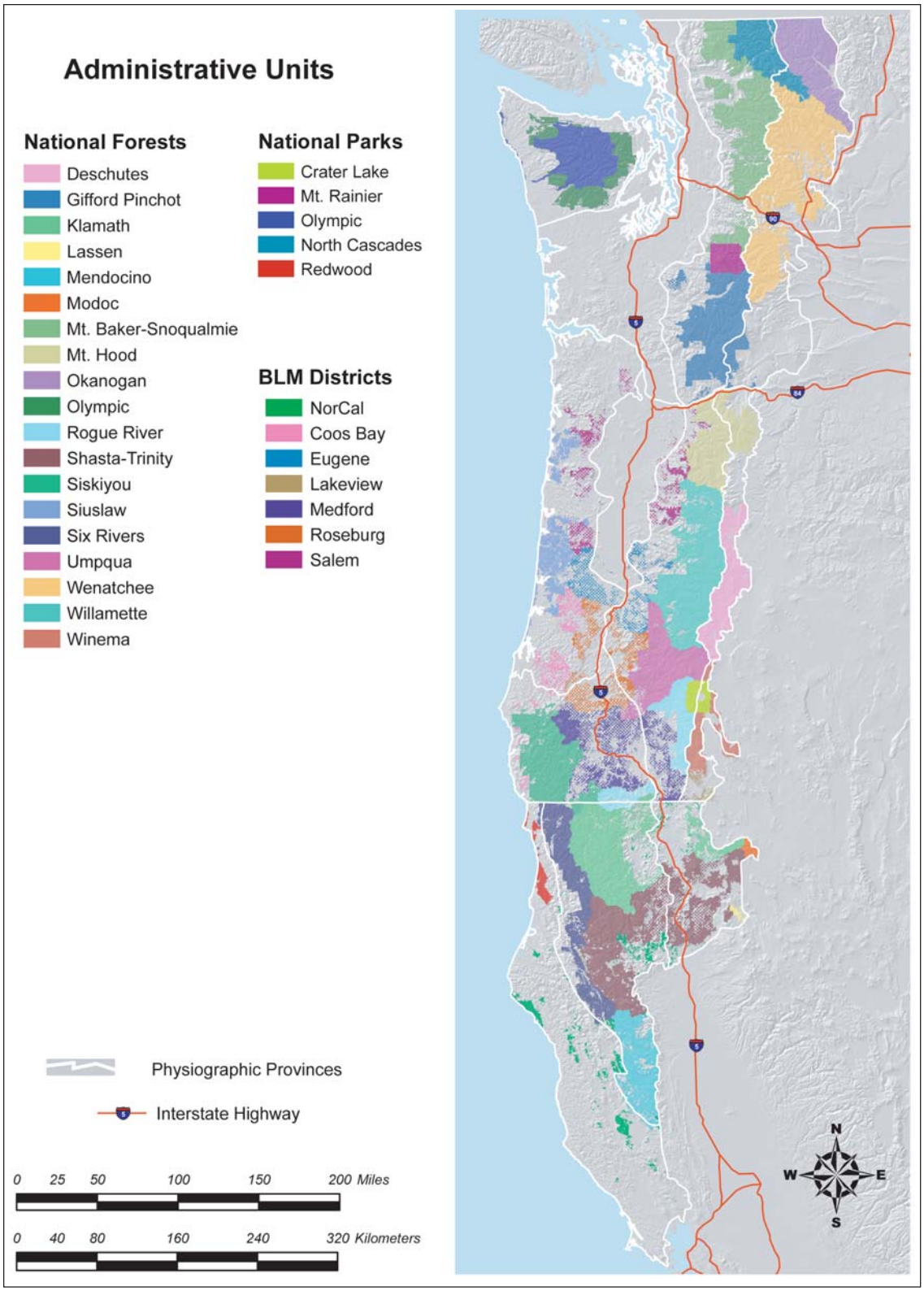

Figure 2–Federal administrative units in the Northwest Forest Plan area.

Status and Trend Monitoring Design for Older Forest

The goal of the monitoring program is to determine the status and trend of older forest, in order to provide information for evaluating the likelihood that the Plan will achieve the stated objectives for maintaining and restoring older forest (Hemstrom and others 1998). The basic monitoring approach is periodic assessment of late-successional and old-growth forest.

This document is the first comprehensive report of the Plan's effect on older forest status and trend. It presents two main findings. First, it establishes initial older forest conditions by using consistent information to approximate a baseline at the beginning of the Plan in 1994. Second, it reports the observed status and trend in older forest during the first decade after implementation of the Plan by using monitoring information to update baseline estimates. It paints a picture of the cumulative changes from 1994 to 2003 and the resultant current forest conditions in the Plan area. It also discusses aspects of the monitoring design, including strengths and limitations. Finally, it lays some groundwork for major phases of future monitoring activities, such as introducing the concepts of trend analysis using landscape modeling (fig. 3).

Three major types of monitoring information went into this report (fig. 3):

1. A map estimating the amount and extent of older forest at the start of the Plan, developed from remote sensing data, ground observations, and modeling techniques.
2. Estimates of older forest amount at the start of the Plan, developed from statistical analysis of ground-based inventory data.
3. Estimates of the amount of change in older forest during the first decade after the Plan, developed from remotely sensed disturbance maps and from remeasured plot data.

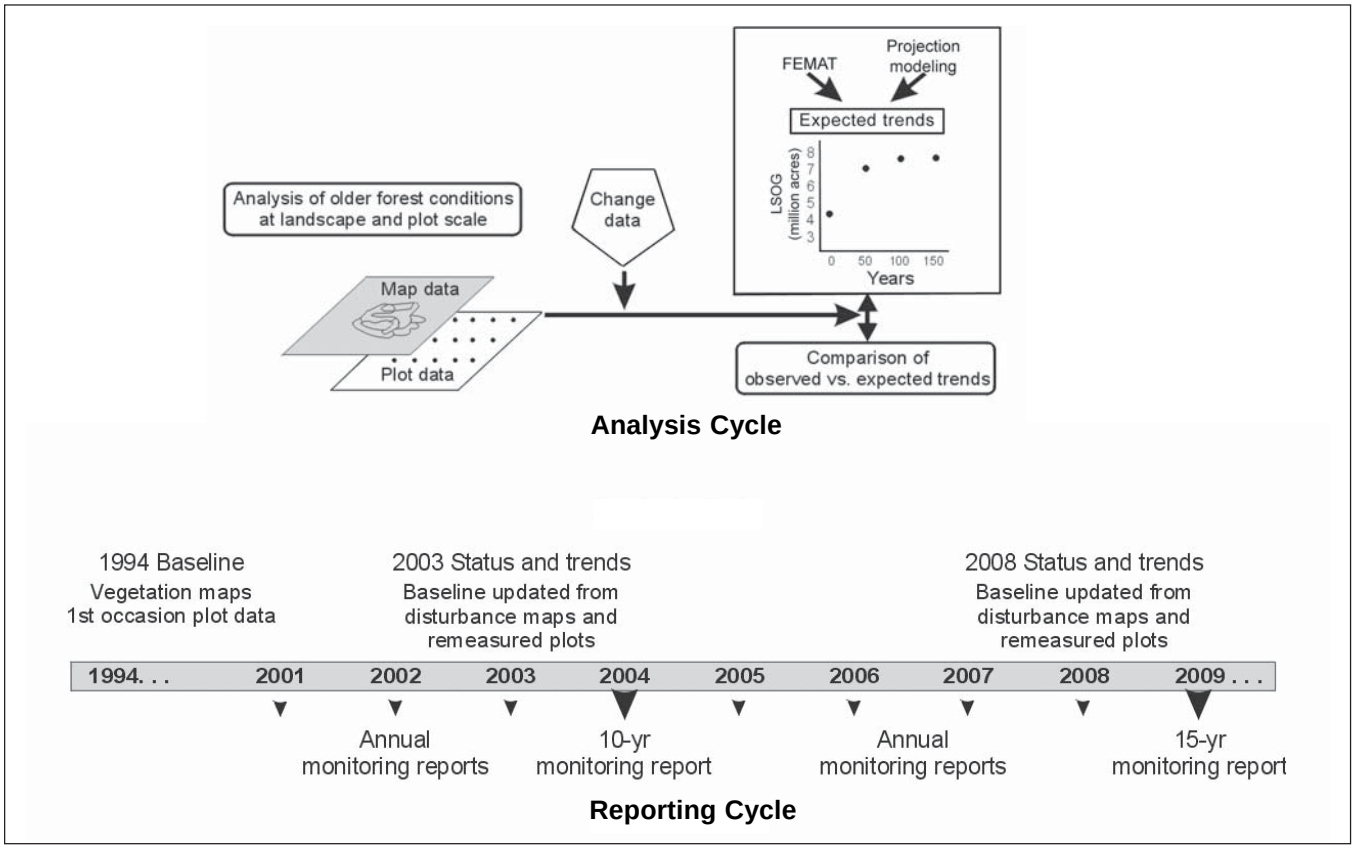

Figure 3—Older forest monitoring activity and reporting cycle.

Older forest maps derived from remote sensing information provide complete and consistent coverage of existing forest vegetation in the Northwest Forest Plan area, at the start of the Plan. Maps are analyzed to evaluate the amount (area) and distribution (size and arrangement) of older forest across the Plan landscape. All lands are mapped, but results on nonfederal lands are not evaluated or discussed in this report. The synthesis report does, however, extend the analysis of map results to nonfederal lands and discusses the contribution of older forest on federal land within the larger regional context (Haynes and others, in press).

Statistical analysis of stand-scale plot data is used to report older forest amounts at provincial and regional scales with a known degree of statistical reliability. Statistical relationships between mapped vegetation attributes and sample-based measurements can be used to describe structural conditions of vegetated landscapes at regional scales by providing information about older forest structural attributes and composition that remote sensing cannot detect.

Monitoring for trend requires establishment of baseline conditions and a subsequent means of tracking changes from the baseline. Change detection tracks losses and gains in forest conditions from a variety of sources—management, natural succession, and disturbances. Remotely sensed change detection is used to track stand-replacing disturbances (clearcut harvest and wildfire). Analysis of stand-scale information on remeasured permanent plots provides a statistical sample reflective of annual changes in forest conditions for the full range of disturbance scales—from stand loss owing to management or natural disturbance, to successional change resulting from growth and mortality.

Organization of This Report

A very large amount of information was analyzed and compiled to write this report. To meet the challenge of presenting the information clearly and effectively, we describe methods and results organized by each major topic: (1) older forest maps developed from remotely sensed data, (2) older forest area estimates from inventory plot information, and (3) analysis of change from remotely sensed data and from remeasured inventory plots. For each topic, we discuss the data sources and methods of analysis in detail, followed by the major findings leading from that topic. When a monitoring approach has been derived from published methodology, we briefly summarize the methods and refer the reader to the original work for additional detail. The discussion section at the report's end synthesizes the findings from the individual topics. Key results and interpretations are reiterated in the conclusions section.

Maps compose much of the information discussed in this report. The key maps are reproduced in this document. In addition, all map images referred to in the report are accessible online as high-resolution graphic images so that the reader may view map detail that cannot be reproduced adequately by the page-size printed maps (http://www.reo.gov/monitoring/).

A Continuum of Older Forest Definitions

Throughout this document we use the term "older forest" interchangeably with the term "late-successional and old-growth forest." Our term is intended to connote greater flexibility inherent to assessing and displaying results based on a variety of definitions.

The concept of "old growth" is laden with social value, and various audiences employ a wide range of language for describing significant unique features of older forest (Marcot and others 1991). Advanced age (or more accurately, time since major disturbance) is an inherent driver leading to ecologically important structural components (such as large trees, snags, down logs, and complex canopy layering) and processes and functions (such as habitat for old-growth-dependent species, carbon storage, hydrologic and nutrient cycling) typically associated with late-successional and old-growth forests (Franklin and others 1981, 1986; Franklin and Spies 1991a, 1991b). Portions of Chapter IV of FEMAT (FEMAT 1993: IV-27-31) and appendix B2 of the environmental impact statement (USDA and USDI 1994a) provide a detailed discussion of older forest elements relevant to the Northwest Forest Plan. They

referred specifically to "late-successional conifer forest" as stands dominated by conifer trees that are 21 to 32 in diameter breast height (d.b.h.), characterized by a single canopy layer (also called "medium/large single-storied conifer") and stands dominated by conifer trees that are greater than 32 in d.b.h., and characterized by two or more canopy layers (also called "medium/large multistoried conifer"). Generally speaking, those reports consider late-successional conditions to develop typically between 80 and 140 years, at least in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands west of the Cascade Range. They also refer to the onset of old-growth conditions typically beginning between 150 and 250 years, and persisting for 300 to 600 years depending on local conditions.

Although forest age is an important defining attribute in most old-forest definitions, age is difficult to determine and may be misleading in complex forest conditions. Tree or stand age is difficult or impossible to infer directly from remotely sensed information. In the field, tree age may be difficult or impossible to measure, especially for large trees, and stand age is not readily characterized when trees of very different ages are present. As a result, we rely on more readily measurable attributes as a substitute for stand age. Average large-tree size is a useful attribute because it is easy to measure and well correlated with age, when local site and stand density factors are controlled for. Large trees are also fundamental to old-forest structure, function, and composition and are the precursor to large snags and down logs. In this assessment, we use tree size as the primary attribute for determining older forest status. Other measures provide additional information about older forest status and condition, but they may be less important than size, or less easy to characterize reliably. We include canopy closure and canopy layering as ancillary older forest attributes, as closed canopies and multilayered canopies are common characteristics of very old forests (Franklin and others 1981, Hemstrom and others 1998).

In this assessment, we chose to evaluate and present maps and acreage estimates corresponding to three points along a continuum of older forest definitions. This approach accomplishes several objectives. First, it recognizes that development of older forests is continuous and complex and that multiple definitions help characterize the diversity of forest development. Second, it accommodates a range of acceptable definitions rather than presenting an estimate based upon a single (and arguably, disputable) definition. And finally, it is our hope that reporting results from multiple acceptable definitions may lead to more flexible decisionmaking when different management objectives are presented.

The basis for our older forest definitions lies in the original monitoring plan. Hemstrom and others (1998) discussed a landscape-scale set of classes to describe existing forest vegetation, defined by average tree size, canopy layering, and species composition. Attributes that define the classes are average size of the topstory trees (computed as the quadratic mean diameter of dominant and codominant trees), percentage of canopy closure, canopy layering (single- or multistoried), and life form (percentage of conifer or hardwood tree canopy cover) (table 1). Classes formed from these attributes were based upon a standard set of vegetation attributes established by the Vegetation Strike Team (Askren and others 1995, 1996) (table 2). Two of the older forest definitions we evaluated correspond directly with groups of classes listed in table 1 based on average tree size and canopy layering. The third incorporates variation in average tree size associated with potential natural vegetation zone. We employed these definitions knowing that an estimate of older forest amount depends on which definition is used. Adding more criteria to the definition will reduce the area of forest meeting the definition. Also, we acknowledge that the definitions are simply "rule sets" designed around coarse-filter structural attributes available in our monitoring data. In that sense, they are not truly "ecological" definitions, especially since they cannot encompass important functional features of older forests, or even fine-filter components of structure and composition. Still, they exploit the available monitoring data to describe forests in terms of attributes important in most ecologically-based definitions of older forests—large trees, dense crown closure, and complex canopy layering.

Table 1— Forest vegetation classes based on canopy cover, average tree size, canopy structure, and species composition

	Class attributes				
Class	**Vegetation class[a]**	**Canopy cover**	**Average tree size**	**Canopy structure**	**Species mix**
		Percent	*Inches*		*Present*
1	PF	<10	NA	NA	NA
2	SS-D	≥10	<10	Any	≥80% deciduous
3	SS-M	≥10	<10	Any	20%-79.9% either
4	SS-C	≥10	<10	Any	≥80% conifer
5	SSS-D	≥10	10-19.9	Simple	≥80% deciduous
6	SSS-M	≥10	10-19.9	Simple	20%-79.9% either
7	SSS-C	≥10	10-19.9	Simple	≥80% conifer
8	SMS-D	≥10	10-19.9	Complex	≥80% deciduous
9	SMS-M	≥10	10-19.9	Complex	20%-79.9% either
10	SMS-C	≥10	10-19.9	Complex	≥80% conifer
11	MSS-D	≥10	20-29.9	Simple	≥80% deciduous
12	MSS-M	≥10	20-29.9	Simple	20%-79.9% either
13	MSS-C	≥10	20-29.9	Simple	≥80% conifer
14	MMS-D	≥10	20-29.9	Complex	≥80% deciduous
15	MMS-M	≥10	20-29.9	Complex	20%-79.9% either
16	MMS-C	≥10	20-29.9	Complex	≥80% conifer
17	LSS-D	≥10	≥30	Simple	≥80% deciduous
18	LSS-M	≥10	≥30	Simple	20%-79.9% either
19	LSS-C	≥10	≥30	Simple	≥80% conifer
20	LMS-D	≥10	≥30	Complex	≥80% deciduous
21	LMS-M	≥10	≥30	Complex	20%-79.9% either
22	LMS-C	≥10	≥30	Complex	≥80% conifer

[a] Key to vegetation class names:

	Species composition		
Size and structure class	Deciduous (D)	Mixed (M)	Conifer (C)
Potentially forested but presently nonstocked (PF)			
Seedling and sapling (SS)	SS-D	SS-M	SS-C
Small single-storied (SSS)	SSS-D	SSS-M	SSS-C
Small multistoried (SMS)	SMS-D	SMS-M	SMS-C
Medium and large single-storied (MSS)	MSS-D	MSS-M	MSS-C
Medium and large multistoried (MMS)	MMS-D	MMS-M	MMS-C
Large single-storied (LSS)	LSS-D	LSS-M	LSS-C
Large multistoried (LMS)	LMS-D	LMS-M	LMS-C

Source: Modified from Hemstrom and others 1998.

Table 2—Vegetation Strike Team standards followed during mapping of existing vegetation attributes in the IVMP and CALVEG projects

Element	Existing vegetation standards
Total tree canopy cover	10-percent classes
Forest canopy structure	Single-layered / Multilayered
Tree overstory size class (inches)	0-4.9, 5-9.9, 10-19.9, 20-29.9, 30-49.9, 50+

Source: Askren and others 1995, 1996.

Older Forest With Medium and Large Trees and Single- or Multistoried Canopies (Medium and Large Older Forest)

Our "medium and large" definition of older forest (medium to large trees with single- or multistoried canopies) is the least restrictive of the three definitions we applied. It establishes only a minimum average tree size (quadratic mean diameter of dominant and codominant trees) of 20 in for any forest type, regardless of canopy layering or location in the environment. "Medium and large" older forest is composed of structure and composition classes 11 through 22 in table 1. The "medium and large older forest" definition is similar to the record of decision (USDA and USDI 1994b) definition of late-successional forest, with the exception that the diameter break is set at 20 inches in accordance with the Vegetation Strike Team standards (Askren and others 1995, 1996) rather than at 21 in as specified in the record of decision. The Plan associated this class with combined late-successional and old-growth stages (80+ years). We used the estimated acres of "medium and large older forest" to validate the values stated in the Plan about the amount and distribution of older forest assumed to be present at the start of the Plan. In applying this definition, we recognized that a one-size-fits-all, 20-in average-tree-size minimum criterion, would tend to overestimate older forest amounts in productive forest types, and underestimate it in less productive types. On balance, though, it would provide a reasonable benchmark at the Plan level. Throughout this document, older forest refers to "medium and large older forest" unless it is specified that a different definition is intended.

Older Forest With Large Trees and Multistoried Canopies (Large, Multistoried Older Forest)

Our "large, multistoried older forest" definition (large trees with multistoried canopies) represents forest with a minimum average tree size (quadratic mean diameter of dominant and codominant trees) of at least 30 in, with multistoried canopies, regardless of location in the environment. "Large, multistoried" older forest is composed of structure and composition classes 20 through 22 in table 1, and is therefore a restricted subset of "medium and large" older forest. These particular size and canopy attributes were chosen because they correspond roughly with primary size and canopy structure characteristics representative of old-growth Douglas-fir developing between 175 and 250 years of age (Franklin and others 1981, 1986; Franklin and Spies 1991b). Whereas "medium and large" older forest sets the upper endpoint, "large, multistoried" older forest sets the lower endpoint for establishing the amount of older forest. In fact, the 30-in average-tree-size minimum criterion is inappropriate for many forest community types where older forests simply do not develop trees as large as 30 in. Still, it is a useful definition for identifying the largest, most "classic" old growth.

Older Forest With Medium and Large Trees Defined by Potential Natural Vegetation Zone (Older Forest With Size Indexed to Potential Natural Vegetation Zone)

Neither "medium and large older forest" nor "large, multistoried older forest" definition recognizes the variability in forest conditions across environmental gradients (for example, temperature, moisture, and soils). Instead, they use "one-size-fits-all" average-tree-size rules to screen for older

forest. An alternative definition was created to partially account for differences in productivity, size, and structural characteristics that depend on the local environment. The "older forest with size indexed to potential natural vegetation zone" definition uses an average-tree-size (quadratic mean diameter of dominant and codominant trees) threshold that varies by potential natural vegetation zone (table 3). In contrast to the "medium and large" or "large, multistoried" older forest definitions, "older forest with size indexed to potential natural vegetation zone" predicts more area of older forest in community types where trees grow slowly or seldom reach 20 in d.b.h. by imposing a diameter threshold less than 20 in (for example, some pine types east of the Cascade divide, or some high-elevation types). In other zones, by using a diameter threshold greater than 20 in, it predicts fewer acres of older forest where trees quickly reach 20 in, such as in the moist, productive Coast Range. We indexed average-tree-diameter thresholds to potential natural vegetation maps (fig. 4). In Washington and Oregon, we used vegetation zone maps compiled from a model of potential natural vegetation (Henderson, n.d.). In California, we indexed potential natural vegetation zone to potential late-seral condition as classified by Society of American Foresters (SAF) type (Eyre 1980). Diameter thresholds for potential natural vegetation zones were based on local older forest definitions (Forest Service-Region 5 and Region 6 old-growth interim definitions [USDA Forest Service 1992, 1993]). This definition represents the midpoint compared with "medium and large" or "large, multistoried" older forest definitions.

Map Analysis Methods

Hemstrom and others (1998) recommended that older forest monitoring be examined from two perspectives. Broad-scale landscape patterns are best determined from maps of existing vegetation and other spatial information, whereas detailed vegetation surveys are needed to determine older forest characteristics at the stand scale. Because these

Table 3—Average tree-size threshold values used to determine if a map unit or plot data met the definition of "older forest with size indexed to vegetation zone"

Minimum quadratic mean diameter	Vegetation zone
Inches	
40	Redwood
32	Port-Orford-cedar, tanoak, Douglas-fir/tanoak/Pacific madrone
31	Sitka spruce, western redcedar (west[a]), western hemlock (west)
24	Douglas-fir (west), Pacific Douglas-fir (west)
22	Pacific silver fir
21	Grand fir, Douglas-fir (east[b]), interior ponderosa pine, Jeffrey pine, mountain hemlock, Pacific Douglas-fir (east), Pacific ponderosa pine, Pacific ponderosa pine/Douglas-fir, ponderosa pine, red fir, subalpine fir (west), western hemlock (east), western redcedar (east), western white pine, white fir
20	Alpine open, blue oak/grey pine, parkland-mountain hemlock, shrub-steppe, western juniper, hardwood types (Oregon white oak, canyon live oak, California black oak, cottonwood, cottonwood/willow, willow)
13	Subalpine fir (east)
12	Lodgepole pine

[a] West–California Coast Range, California Klamath, Oregon Coast Range, Oregon Klamath, Oregon Willamette Valley, Oregon Western Cascades, Washington Olympic Peninsula, Washington Western Lowlands, and Washington Western Cascades.

[b] East–California Cascades, Oregon Eastern Cascades, and Washington Eastern Cascades.

Source: Modified from Forest Service, Pacific Southwest and Pacific Northwest Regions, old-growth interim guidelines (USDA Forest Service 1992, 1993).

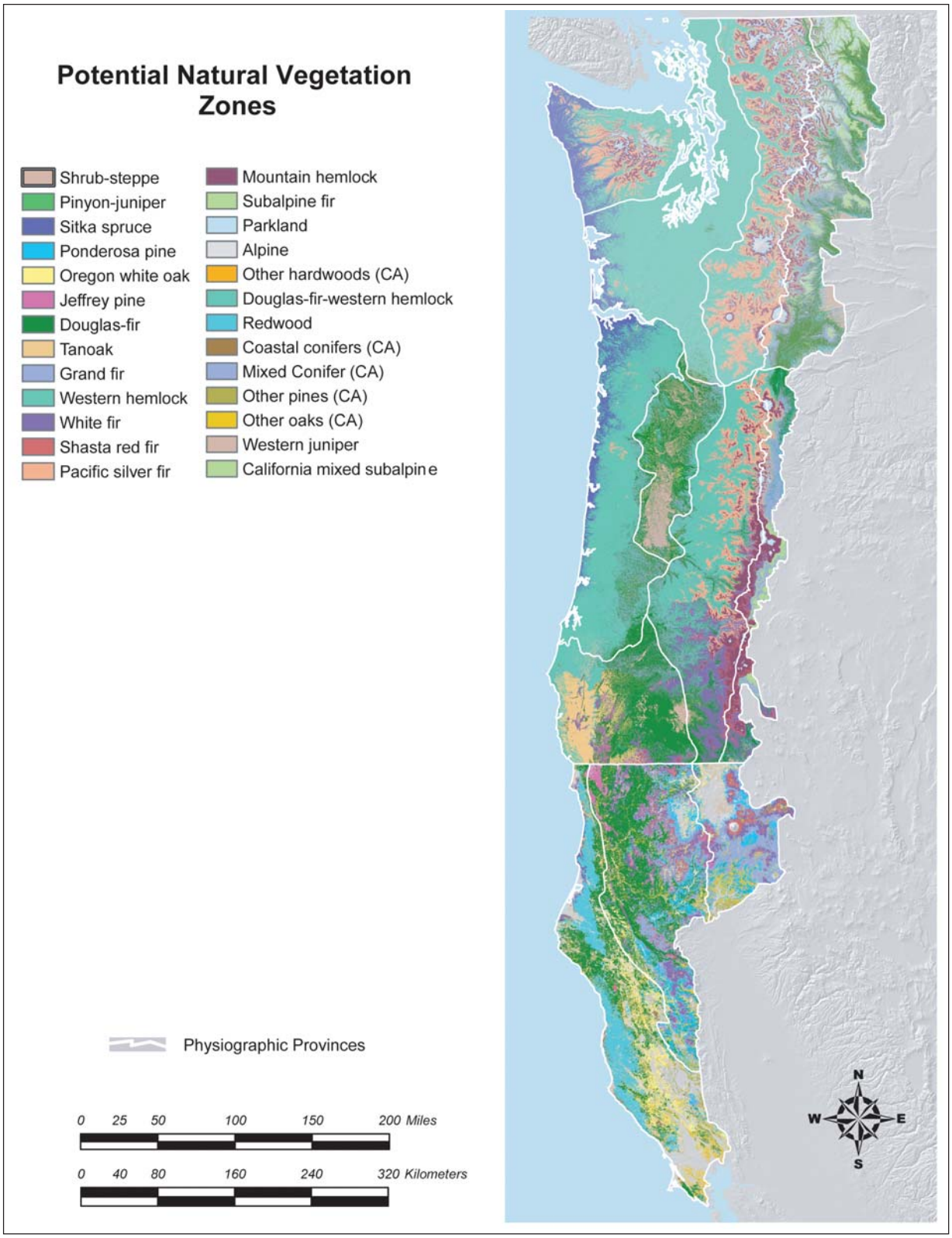

Figure 4—Potential natural vegetation zones for the Northwest Forest Plan area. Vegetation zones in Washington and Oregon are from Henderson (n.d.). In California, vegetation zones are based on Society of American Forester types (Eyre 1980).

perspectives focus on different scales and use different attributes and definitions, analysis of older forest amounts and patterns from vegetation maps and from inventory data are expected to yield different (but complementary) estimates. In this report, vegetation maps primarily were used to examine older forest amounts (percentages of area occupied by older forest) and landscape patterns of older forest elements (their spatial arrangement) relative to other spatial data such as ownerships, land use allocations, and ecological setting. Statistical analysis of inventory plot data primarily was used to estimate the area in acres occupied by older forest, with accompanying confidence intervals, and to estimate net change in older forest amounts by using measurements taken on the same set of plots at two points in time. We summarized the stand-scale characteristics of older forest (density of large trees, snags, and logs, and canopy layering) by using the plot data. We also used the estimates from the plot data, which are considered statistically defensible, to validate the estimates obtained from the map data, whose accuracy and precision are more difficult to quantify.

Federal Lands in the Northwest Forest Plan Area

We mapped existing vegetation on all lands in the Plan area. However, we report results only on federally administered managed lands (see Haynes and others, in press, for results on nonfederal lands). Consequently, we portioned the Plan area into federally managed versus other lands. Other lands include those owned or managed by individuals, corporations, tribes, states, counties, and other agencies (USDA and USDI 1994a). Federal lands include lands managed by the three federal land management agencies represented by the Plan (Forest Service, Bureau of Land Management, and National Park Service), as well as lands managed by other federal agencies (Fish and Wildlife Service and Department of Defense). Although the influences of activities on lands administered by Fish and Wildlife Service and Department of Defense were considered in the Plan's assessment, the record of decision did not adopt new management direction for those lands (USDA and USDI 1994b). We summarize the land area and percentage of area occupied by older forest for lands managed by the Fish and Wildlife Service and Department of Defense but do not include them in subsequent discussions.

The Forest Service, Bureau of Land Management, and National Park Service manage about 24,444,100 ac in the Plan area (table 4). This figure excludes major water bodies and is within one-tenth of a percent of the 24,455,200 ac reported in table 3&4-2 of the environmental impact statement (USDA and USDI 1994a). The discrepancy is accounted for by updates to map boundaries used in 1994 and in 2004, and also by land exchanges in and out of federal ownership since the Plan was signed. All acres reported here were calculated from the Northwest Forest Plan land use allocations 2002 polygon coverage released in April 2004 (www.reo.gov/gis/data/gisdata/index.htm).

Not all federal land is potentially capable of supporting older forest. The permanently nonforest area includes administrative sites such as park headquarters and ranger districts, roads and highways, as well as naturally nonforested land—barrens, rock outcrops, alpine meadows above tree line, etc. We separated the land area managed by the federal agencies into area that is forest-capable versus area that is not capable of growing forest by using thematic data from our remote-sensing mapping projects (discussed in following sections). Of the total federal land area, 23,259,000 ac are forest-capable (or 95 percent of the federal land base), and 1,185,100 ac are not forest-capable (table 4).

Physiographic Provinces

The Northwest Forest Plan area is very diverse in terms of physical, biological, and environmental factors. The environmental impact statement (USDA and USDI 1994a) described the Plan area in terms of 12 terrestrial physiographic provinces (fig. 1). The concept of physiographic provinces is not only useful for describing how topography, soils, and geomorphologic differences shape vegetation, but how vegetation responds to natural disturbance and management. Note that the provinces are arbitrarily cut by state boundaries, so they are not strictly ecological provinces. Nevertheless, we used the 12 individual provinces to stratify the monitoring analysis and for reporting purposes to be consistent with the approach in designing the Plan.

Table 4—Land area in the Northwest Forest Plan area

Province	Federal land: Total	Federal land: Forest capable	Federal land: Not forest capable	Federal land: Percentage of forest-capable	Other land	Province total
	Acres	*Acres*	*Acres*	*Percent*	*Acres*	*Acres*
California:						
Cascades	1,091,300	999,800	91,500	92	1,379,600	2,470,900
Coast Range	503,600	357,800	145,800	71	5,215,900	5,719,500
Klamath	4,520,200	4,221,400	298,800	93	1,530,000	6,050,200
Total	6,115,100	5,579,000	536,100	91	8,125,500	14,240,600
Oregon:						
Coast Range	1,413,300	1,396,200	17,100	99	4,377,300	5,790,600
Eastern Cascades	1,551,800	1,477,500	74,300	95	741,300	2,293,100
Klamath	2,118,200	2,104,400	13,800	99	1,879,600	3,997,800
Western Cascades	4,476,700	4,398,200	78,500	98	2,135,400	6,612,100
Willamette Valley	21,000	18,500	2,500	88	2,643,900	2,664,900
Total	9,581,000	9,394,800	186,200	98	11,777,500	21,358,500
Washington:						
Eastern Cascades	3,502,400	3,347,600	154,800	96	2,130,100	5,632,500
Olympic Peninsula	1,522,300	1,419,300	103,000	93	1,502,000	3,024,300
Western Cascades	3,721,000	3,516,100	204,900	94	2,404,800	6,125,800
Western Lowlands	2,300	2,200	100	96	6,492,300	6,494,600
Total	8,748,000	8,285,200	462,800	95	12,529,200	21,277,200
Northwest Forest Plan area	24,444,100	23,259,000	1,185,100	95	32,432,200	56,876,300

Note: Federal land includes land administered by the Forest Service, Bureau of Land Management, and National Park Service. Other land includes land administered by Department of Defense and Fish and Wildlife Service, and all nonfederal owners.

Strong climatic, topographic, and social gradients across the Plan area create significant differences in the physiographic provinces in terms of potential natural vegetation and current vegetation, natural disturbance regime, historical land use, and land ownership (USDA and USDI 1994a: 14-24, chapters 3&4). Most of the Plan area is dominated by coniferous forests and mountainous terrain, with the exception of some lowland interior valleys and coastal plains. Of the coastal physiographic provinces, the Washington Olympic Peninsula province is dominated by coniferous rain forest on the western slope of the Olympic Mountains, and drier Douglas-fir forest in the rain shadow on the eastern slope. Fire frequency is very low, resulting in some remnant forest hundreds or even thousands of years old. Current vegetation is a mosaic of late-successional and old-growth forest mixed with early-seral stages resulting from extensive forest management. Federally managed lands occupy the interior half of the province, the core being Olympic National Park girded by the Olympic National Forest (fig. 2, table 4). Moist, productive forests in the Oregon Coast Range province are dominated by Douglas-fir, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Donn). The Forest Service and Bureau of Land Management together manage one-quarter of the land in the Oregon Coast Range (fig. 2, table 4). Older forest there is highly fragmented, largely as a result of infrequent but very large wildfires in the 1800s and 1900s, and heavy cutting. Only a

small proportion of area (9 percent) in the California Coast Range province is administered by federal agencies (fig. 2, table 4). Some of the last remaining old-growth redwoods (*Sequoia sempervirens* (D. Don) Endl.) are conserved in Redwoods National Park, and the Bureau of Land Management administers holdings of mixed forests of Douglas-fir and hardwoods. Fire frequency is low compared with the adjacent California and Oregon Klamath provinces.

Along the western slope of the Cascade Range (Washington Western Cascades and Oregon Western Cascades), lower elevation forest dominated by Douglas-fir and western hemlock gives way to Pacific silver fir (*Abies amabilis* ex Forbes) in the middle elevations, and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) and subalpine vegetation at higher elevations. In the southern part of the range, moist lowland vegetation yields to drier, mixed conifer-forest. Historical fire frequencies were low or moderate (100+-year fire-return intervals) in the northern part of the range, and high (0-35-year fire-return intervals) in the south, resulting from a north-to-south moisture gradient. About two-thirds of the area is administered by the Forest Service, Bureau of Land Management, and National Park Service (fig. 2, table 4). Although highly fragmented, numerous areas of late-successional and old-growth forest still exist along the western slopes of the Cascade Range.

The provinces along the eastern slopes of the Cascade Range (Washington Eastern Cascades and Oregon Eastern Cascades) are dominated by mixed-conifer forest and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forest at lower-to-mid elevations, and by true fir (*Abies* spp.) and mountain hemlock at higher elevations. Forest productivity is low in places owing to poor soils and high elevations. Historically, fire frequencies were high (0-35-year fire-return intervals) in the Eastern Cascades. Intensive fire suppression practices since the latter half of the 20th century have resulted in areas with significant accumulations of fuel, and shifts in species composition and stand structure. About two-thirds of the area is federally managed (fig. 2, table 4). Older forest is highly fragmented as a result of both natural factors and management history. The California Cascades province includes the very southern end of the Cascade Range. Similarities to the Eastern Cascades provinces of Washington and Oregon include dominance of mixed-conifer and pine forest in fire-adapted community types. Slightly less than half of the province is federally managed (table 4). Older forest is fragmented as a result of fire, harvest activities, and checkerboard ownership patterns of Forest Service land (fig. 2).

The Oregon Klamath province in southwestern Oregon and the California Klamath province in northwestern California are influenced by geologic conditions unique within the Plan area. Serpentine soils formed by the accretion of rocks onto the continent control the native vegetation, which is dominated by mixed-conifer and mixed-conifer/hardwood forest such as Douglas-fir/tanoak (*Lithocarpus densiflorus* (Hook. & Arn. Rehd.) /Pacific madrone (*Arbutus menziesii* Pursh). The Klamath provinces are characterized by historically high fire frequencies (0-35-year fire-return intervals), and fire suppression has resulted in areas with significant accumulations of fuel, shifts in species composition, and changes in stand structure. Older forest is highly fragmented as a result of dry climate, poor soils, and past harvest practices, as well as ownership patterns, especially on lands administered by the Bureau of Land Management. These parcels are typically intermixed with harvested private lands in a checkerboard pattern of alternating 1-mi sections (fig. 2). National forests cover three-quarters of the land area in the California Klamath province, and slightly over half of the Oregon Klamath province is federally managed (table 4).

There is very little federally managed land in either the Washington Western Lowlands province or the Oregon Willamette Valley province (table 4), and only small parcels of these lands are occupied by older forest. Both provinces include extensive urban and agricultural areas. Both are dominated by wide, glaciated valleys, except for the Willapa Hills in the coastal section of the Washington Western Lowlands. Lowland coniferous forest, deciduous forest, and native prairie were the natural dominant vegetation types.

Land Use Allocations

The Northwest Forest Plan record of decision divided federal land into seven land use allocations. These allocations were the foundation for establishing an older forest reserve network category while maintaining lands designated for scheduled timber harvest.

The 2002 land use allocation map (www.reo.gov/gis/data/gisdata/index.htm) combined or further split some existing allocations (fig. 5, table 5). Late-successional reserve has three mapped components: (1) large-block late-successional reserve, (2) activity centers reserved for northern spotted owls, and (3) marbled murrelet reserved areas. These three categories are grouped together in our analysis. A few areas have more than one land allocation; lands with overlapping late-successional reserve and adaptive management area designation are treated as late-successional reserves. We grouped together administratively withdrawn and congressionally reserved lands for analysis purposes. All national park lands are congressionally reserved. Late-successional reserves, when combined with congressionally reserved lands and the smaller, more fragmented administratively withdrawn lands, form the backbone of the large-block older forest reserve network.

Matrix and adaptive management areas are land allocations where scheduled timber harvest activities may take place. For analysis and reporting purposes, we grouped these categories. Lands that are denoted as "not designated" are lands that were acquired after the Plan was implemented and had no allocation in the 1994 land use allocation map. They are treated as matrix in our analysis.

Riparian reserve allocations have never been mapped separately from matrix at the scale of the Northwest Forest Plan, because riparian reserves are a fine-scale delineation intended for mapping at the project scale. At the Plan scale, riparian reserves could not be reliably distinguished from matrix because of a lack of consistency in defining intermittent stream corridors and varying definitions for riparian buffers. The Plan estimated that riparian reserves may constitute 40 percent of the land area within the matrix/riparian reserve class (see sidebar 3), depending on local variation in stream density and topography (USDA and USDI 1994b). For more discussion of this issue, refer to Gallo and others (2005). We had no way to analyze riparian reserve separately from matrix. We acknowledge that including riparian reserve in matrix in the older forest analysis results in an overestimate of the amount of older forest in the nonreserve category, and a conservative estimate of the amount of older forest in the reserve category.

Our reporting level for most analyses is land use allocation groups or reserve categories within each physiographic province (shown in table 5), totals by province, province results totaled within state, and state values totaled across the Plan area.

Classification of Existing Vegetation

Hemstrom and others (1998) determined that a landscape-scale map of existing forest vegetation created from remotely sensed data was needed to provide a baseline estimate of older forest at the beginning of the Plan from which future changes could be benchmarked. The acquisition or development of an accurate, consistent, and continuous map representing older forest conditions at the start of the Plan over the entire Plan area was key to effectiveness monitoring (Hemstrom and others 1998, Mulder and others 1999). The option of using map products already in existence and covering some or all of the Plan area was evaluated and rejected because existing maps have been created originally to meet a variety of objectives not necessarily compatible with regional-scale monitoring needs, and were mapped to a variety of standards and spatial extents. Instead, consistent maps were developed under the direction of the regional monitoring program.

Existing vegetation mapping for Northwest Forest Plan monitoring was carried out by two independent programs—the Interagency Vegetation Mapping Project (IVMP) in Oregon and Washington and the Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG) project in California. Both CALVEG and IVMP mapped forest vegetation by using satellite imagery from Landsat Thematic Mapper (TM) and other spatial data to classify primary attributes of forest vegetation—life form,

Sidebar 3—Land Use Allocations

Land Use Allocations Under the Northwest Forest Plan

Excerpted from the Record of Decision (USDA and USDI 1994b)

Congressionally Reserved Areas: (7,320,660 ac, 30 percent of the federal land within the Plan 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 within the Plan 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.

Managed Late-Successional Areas: (102,200 ac, 1 percent of the federal land within the Plan 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 within the Plan 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 within the Plan 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 within the Plan 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.

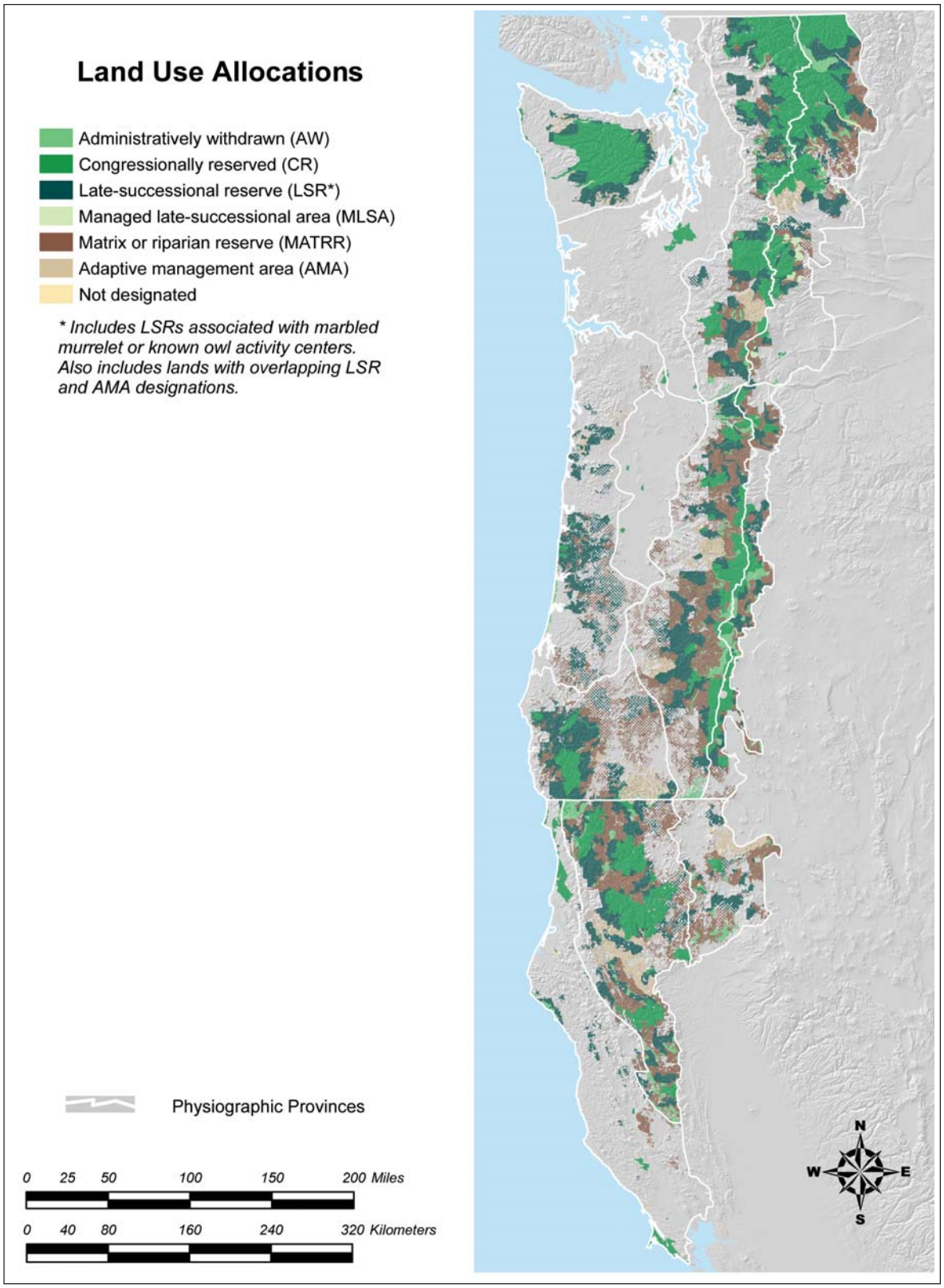

Figure 5—Land use allocations of federally managed lands in the Northwest Forest Plan area. Source: http://www.reo.gov/gis/data/gisdata/index.htm.

Table 5—Mapped land use allocation classes and codes

Land use allocation	Map abbreviation	Land allocation group code	Reserve category
Adaptive management area	AMA	MAT+	Nonreserve
Adaptive management area and late-successional reserve overlapping designation	AMR	LSR+	Reserve
Administratively withdrawn	AW	AW/CR	Reserve
Congressionally reserved	CR	AW/CR	Reserve
Late-successional reserve	LSR	LSR+	Reserve
Marbled murrelet reserve area	LSR3	LSR+	Reserve
Spotted owl activity core reserve	LSR4	LSR+	Reserve
Managed late-successional area	MLSA	LSR+	Reserve
Matrix or riparian reserve (not mapped separately)	MATRR	MAT+	Nonreserve
Not designated	ND	MAT+	Nonreserve

Note: Refer to sidebar 3 for additional description of land allocations.
Source: Northwest Forest Plan Land Use Allocations 2002 http://www.re.gov/gis/data/gisdata/index.htm.

average tree size, canopy density, and canopy layering. Both used inventory plots as reference and validation data to guide the classification. The IVMP and CALVEG together mapped a region of nearly 57 million ac crossing all ownerships in the Plan area, including the approximately 24.4 million ac administered by federal agencies affected by the Plan (table 4).

Although IVMP and CALVEG used different mapping protocols, both projects mapped existing vegetation in compliance with established standards to assure the compatibility of the map products to midscale monitoring (Askren and others 1995, 1996). These standards included average overstory tree size mapped in 10-in classes, with an additional class of 0 to 4.9 in, total tree crown closure mapped in 10-percent classes, and forest canopy layering mapped in two classes (single- and multistoried) (table 2).

Interagency Vegetation Mapping Project—
The IVMP was initiated in 1998 under joint program management and funding by the Bureau of Land Management-Oregon and the Forest Service-Region 6. The project's goal was to provide consistent spatial data for monitoring older forests within the portions of the Plan area in Washington and Oregon. The IVMP mapped existing vegetation in the nine physiographic provinces in Washington (Eastern and Western Cascades, Olympic Peninsula, and Western Lowlands) and Oregon (Eastern and Western Cascades, Coast Range, Willamette Valley, and Klamath Mountains) (fig. 2).

The following description highlights the features of IVMP methods and map products that are most important for understanding their application to Plan monitoring. More detailed discussions are given in Weyermann and Fassnacht (2000) and Fassnacht and others (n.d.). In addition, detailed documentation and metadata accompany the map data for each physiographic province (Browning and others 2002b, 2003e, 2003f, 2003g, 2003h, 2004; O'Neil and others 2001b, 2001d, 2002c). All IVMP map data and supporting documentation are available online at http://www.or.blm.gov/gis/projects/ivmp.asp.

The IVMP modeling approach combined remotely sensed satellite imagery (25-m Landsat TM), digital elevation models, interpreted aerial photos, and inventory information collected on the ground to classify existing vegetation. Landsat scenes used in the IVMP project ranged from fall 1992 through summer 1996. Of the 17 scenes, 2 were acquired in 1992, 1 each in 1994 and 1995, and 13 in 1996 (app. 1). Even though they repre-sented a range of dates around 1994, with most images from 1996, we made the assumption in the monitoring analysis that older forest maps derived from the IVMP data were representative of baseline conditions at or near the start of the Plan. This assumption

would be shown to be invalid if it were determined that a large amount of change had occurred between 1994 (that is, the date of the start of the Plan) and the actual date of the imagery. To assess potential difference in the amount of older forest between 1994 and 1996, we examined stand-replacing harvests detected by remote sensing between 1992 and 1996 (see the later section in this report titled, "Trend Analysis: Forest Disturbance Map Methods"). For the portions of the plan area that were mapped by using 1996 imagery, our disturbance map indicates only about 5,300 ac of older forest were regeneration-harvested between 1992 and 1996. Assuming half the harvest occurred prior to 1994 and half between 1994 and 1996, there is a maximum error of only about 2,600 ac (or 0.03 percent) attributable to mapping older forest in 1996 rather than in 1994. We therefore accepted 1996 data as baseline.

Inventory plot data were used as reference information for IVMP model building and accuracy assessment. Almost 10,000 plots were used for model building and testing, and another 2,800 plots were held out for an independent accuracy assessment. These data came primarily from Current Vegetation Survey (CVS) plots maintained by Forest Service-Region 6 and Bureau of Land Management-Oregon on Forest Service and Bureau of Land Management lands in Washington and Oregon, and from Forest Inventory and Analysis (FIA) plots administered by Pacific Northwest Research Station on nonfederal lands. Details of the inventory data are described in a later section.

The IVMP mapped existing vegetation attributes for forest-capable land. The final IVMP products included canopy cover prediction maps by life form, an average-tree-size prediction map, and a canopy layering prediction map. Life form refers to the dominant type of vegetation (conifer, nonconifer, and total vegetation—the sum of conifer and nonconifer). The nonconifer class (also called broadleaf in the IVMP map data) includes hardwood trees, shrubs, grasses, and forbs. Each IVMP layer also included non-forest-capable land-cover classes (water, wetlands, urban, agriculture, prairie, barren, snow, sensor noise, topographic shadow, and smoke, fog, and clouds or cloud shadow), mapped by using a combination of supervised and unsupervised classification methods. Ground plots, local field knowledge, and aerial photographs were used as ground-training data for mapping non-forest-capable land-cover classes.

Average size of trees in the uppermost canopy, percentage of conifer cover, percentage of nonconifer cover, and percentage of total vegetation cover were predicted by following a regression modeling approach developed by Cohen and others (1995, 2001) and Cohen and Spies (1992). Canopy cover is the percentage of ground covered by the vertical projection of the vegetation foliage as measured from aerial photographs. Average topstory tree size is the quadratic mean diameter (inches) of the trees in dominant and codominant crown classes, measured from diameters of trees collected on inventory plots and related to spectral signatures from Landsat TM data, as described by Weyermann and Fassnacht (2000) and Fassnacht and others (n.d.). Canopy cover was mapped by using continuous values from 0 to 100 in 1-percent increments. For 7 of the 9 physiographic provinces, average tree size was mapped in 1-in diameter classes from 0 to 75 in. This continuous format allows maximum flexibility for end users to regroup the data for their specific applications. In two provinces (Eastern Cascades Oregon and Eastern Cascades Washington), sample sizes were insufficient to detect a significant relationship between the remotely sensed variables and tree size. In other words, there was too much variability in the data to fit regression models with acceptable r^2 values. Therefore, average tree size was mapped in wider class intervals for Eastern Cascades Oregon (0-4.9, 5-9.9, 10-19.9, 20-29.9, and 30+ in) and Eastern Cascades Washington (0-4.9, 5-9.9, 10-19.9, and 20+ in), by using a supervised classification approach.

For all provinces mapped by IVMP, a second iteration of modeling was performed for improving classification of the average-tree-size attribute. This was because for all provinces, a proportion (up to 30 percent in some provinces) of the potentially forested land was impossible to map into continuous average-tree-size classes by using the regression modeling approach. In most cases, these difficult cases were in forested areas without an adequate spectral signal of visible tree crowns resulting from one of several common conditions: either they were recently regenerated

clearcuts, green-tree retention cuts, or they were naturally open stands with scattered large trees and large confounding soil signature. The last condition was most prevalent in the Eastern Cascades provinces. Predictions for these areas were outside the reasonable range of the model, so the regression results were deemed unacceptable for these areas. A subsequent analysis was performed to reclassify these unknowns into broad average-tree-size classes (0-9.9, 10-19.9, 20-29.9, and 30 in and larger) by using a supervised cluster-busting classification approach. The proportion of potential forest for which average tree size could not be mapped was subsequently reduced to 5 percent or less of the forested area within each province.

Forest canopy layering refers to the vertical stratification of tree heights in a forest stand, classed in our analysis as either single-storied (stands having a tree canopy of uniform height) or multistoried (stands with two or more distinct tree canopies). Canopy layering was modeled following methods outlined in appendix 2. Reference data were the number of canopy layers computed from CVS plot data on Forest Service and Bureau of Land Management lands by using the Forest Vegetation Simulator (Crookston and Stage 1999). Canopy layering could not be mapped for two provinces (Oregon Willamette Valley and Washington Western Lowlands) because of insufficient inventory plots. The methods for modeling canopy layering differed substantially from those used in the cover and tree-size predictions, in that the modeling unit was the vegetation polygon rather than the individual pixel. Vegetation polygons were deemed more appropriate than individual pixels as the base unit for prediction, because canopy layering is naturally a stand-scale rather than pixel-scale phenomenon. Resulting canopy layering predictions for polygons were then resampled at the 25-m (82-ft) pixel scale so that they could be processed in combination with tree-size and cover data from the other IVMP map layers.

Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG)—

Existing vegetation for Northwest Forest Plan monitoring in northwestern California is derived from California's wildland vegetation classification system, known as the Classification and Assessment with Landsat of Visible Ecological Groupings, or CALVEG (USDA Forest Service 1981, 2000a). Remote sensing specialists at Forest Service-Region 5 conducted the CALVEG project in cooperation with the U.S. Fish and Wildlife Service, California Department of Fish and Game, California Department of Forestry and Fire Protection, Bureau of Land Management, National Park Service, California State Parks, and Humboldt State University. Unlike IVMP, CALVEG did not have its origin within the Northwest Forest Plan monitoring program. Instead, the attributes needed for monitoring and meeting the Vegetation Strike team standards for effectiveness monitoring (table 2) (Askren and others 1995, 1996) were derived from the existing CALVEG data (Schwind and others 1999). These standards ensured that the resulting data developed by CALVEG in California would be compatible with IVMP data in Washington and Oregon for planwide analysis. This compatibility was deemed essential to the ability to analyze the map data consistently despite differences in methodologies, mapping approaches, and resolution of map products. Many other attributes besides those listed above were classified for CALVEG map units but were not used in the Northwest Forest Plan monitoring analysis, and therefore are not mentioned here.

The following description highlights the features of CALVEG methods and map products that are most important in the monitoring analysis. Additional details are discussed in Schwind and others (1999). All CALVEG map data and supporting documentation are available online at http://www.fs.fed.us/r5/rsl/projects/mapping/.

Existing vegetation attributes derived from CALVEG for monitoring were average topstory tree size, canopy closure by life form, and canopy layering. CALVEG shares many important similarities in methodology with the IVMP project, as well as important differences. It classified existing vegetation from Landsat TM imagery (image dates were all from 1994—app. 1). The classification accuracies resulting from the 1994 data were checked, and some map labels were adjusted by using 1998 imagery (app. 1). Reference data for training the classification were map notes and aerial resource photos rather than inventory plot data. CALVEG map units differed in spatial resolution from IVMP map

units. CALVEG was a stand-based map, with vegetation polygons created through an image segmentation process to a minimum mapping unit of 2.5 ac (1 ha). The resulting vegetation polygons were labeled according to average topstory tree size (0-4.9, 5-11.9, 12-19.9, 20-29.9, and ≥30 in), canopy closure (10-percent classes), and canopy layering (single- or multistoried) by using a combination of modeling, supervised classification, and unsupervised classification methods. Note that there is a minor inconsistency in CALVEG size classes relative to the Vegetation Strike Team classes. CALVEG uses a breakpoint at 12 in instead of 10 in. In our analysis, map units labeled as 5-11.9 in were put in the <10-in class (table 1), and map units labeled 12-19.9 in were put in the 10-19.9-in class (table 1). Because the older forest definitions used in this analysis begin at 20 in, this discrepancy was not considered to be a major problem because it only pertained to classes not considered to be older forest. It should not therefore affect the estimates of older forest amounts. (It would, however, bias the small-diameter classes overestimating amounts in classes 2 through 4, and underestimating amounts in classes 5 through 10 in table 1).

Central to the CALVEG approach was the creation of stand-based polygons systematically derived from Landsat TM imagery (Schwind and others 1999). Vegetation polygons were generated by an image segmentation based on spectral similarity (Ryherd and Woodcock 1990) by using an algorithm by Frew (1990). The result was a layer of uniquely identified stands or regions that corresponded to intuitively recognizable landscape patterns. Classification and modeling of thematic attributes were performed separately and hierarchically for each additional attribute. Canopy closure was modeled by using the Li-Strahler canopy model (Li and Strahler 1985). The Li-Strahler model generates a continuum of values for each stand ranging from 0 to 100 percent. Continuous crown closure values were subsequently collapsed into 10-percent cover classes in the final CALVEG coverage (Schwind and others 1999).

Tree size was classified as a function of modeled crown width by using iterative unsupervised classification of the Landsat TM band data. The relationship between crown size and tree diameter for major forest types in California (Warbington and Levitan 1993) was used to infer stem diameter classes from mapped crown width classes for each tree type. Tree diameter classes were subsequently developed to be consistent with the Vegetation Strike Team class boundaries for average tree size (with the exception of the 12-in class break noted above (Schwind and others 1999). A two-class attribute for canopy layering (single- vs. multistoried) was spatially modeled with vegetation type, tree size, and canopy closure as inputs (Schwind and others 1999).

Accuracy Assessment of Existing Vegetation Maps

Assessment of a map's accuracy is important for informing users of the map's quality and, consequently, its suitability for intended uses. Both CALVEG and IVMP employed a quantitative comparison of predicted values or classes of sites on the map against independent reference observations for the same sites on the ground. The reference values are considered to be "truth" (Congalton and Green 1999).

For each map, three accuracy values are reported. Overall map accuracy is the proportion of correct classifications across all classes. For specific classes, two other types of accuracy are useful for helping the map user understand the quality of the classification. Producer's accuracy is the probability that a reference observation on the ground has been correctly classified on the map (summarizing errors of exclusion), and user's accuracy is the probability that a unit classified on a map actually represents that class on the ground (summarizing errors of inclusion). For further explanation, see app. 3.

IVMP map accuracies—

The IVMP accuracy analysis used a traditional error matrix approach to calculate the proportion of reference plots that were correctly classified on the map. It weighted overall accuracy, user's accuracy, and producer's accuracy by the sampling probabilities of reference plots (app. 3) (Browning and others 2002a, 2003a, 2003b, 2003c, 2003d; Fassnacht and others, n.d.; O'Neil and others 2001a, 2002a, 2002b).

A subset of inventory plots (about 25 percent, or 2,800) was reserved from the plot data used for modeling and classification to provide independent reference data for IVMP map accuracy assessment. Reference plots were systematically located across the area to be mapped by IVMP. Quantitative accuracy assessments were performed for percentage of canopy cover (conifer, nonconifer, and total vegetation), average tree size, and canopy layering.

The accuracy assessment documentation reported IVMP map error for the data collapsed into the following classes: 20-percent classes for cover; 0-4.9, 5-9.9, 10-19.9, 20-29.9, 30-49.9, and 50+ in diameter for average tree size; and two classes of canopy layering (single- or multistoried). In addition, accuracies were reported for wider classes for cover and average tree size. Accuracies reported for a two-class average-tree-size map analysis (0-19.9 vs. 20 in and greater), corresponding to the threshold used to distinguish young forest classes from older forests, are reported in appendix 3. Cover values reported in three classes (0-39, 40-69, and 70-100 percent), are also repeated here (app. 3).

Overall map accuracies for IVMP ranged from about 61 to about 87 percent for average tree size mapped into less than 20 vs. 20 in and larger (app. 3, table 1). These values are within the ranges of 60- to 80-percent classification accuracies commonly reported for mapping forest structure attributes from satellite data (see, for example, Moody and Woodcock 1995, Peterson and others 1999). There is considerable variation in accuracy among individual size classes, and between provinces. Usually, but not always, classification results are better for the <20-in class than for the ≥20-in class. Low user's accuracies were obtained for the ≥20-in class for Washington Eastern Cascades, Oregon Klamath, and Washington Western Lowlands, and low producer's accuracies for Washington Eastern Cascades, and Washington Western Lowlands (app. 3, table 3-1). These values warrant a closer look at the effect of base map errors on conclusions drawn from older forest maps derived from these data. The subject is treated in greater detail in the "Older Forest Map Accuracy Assessment" section and in the "Discussion" section. Overall map accuracies for three canopy cover classes range from about 57 to 79 percent (app. 3, table 3-2). The two-class canopy layering map (single- and multistoried) had overall map accuracies ranging from 50 to 87 percent (app. 3, table 3-3).

CALVEG map accuracies—
An independent subsample of some 1,250 field reference plots was used for CALVEG map accuracy assessment in the Northwest Forest Plan area (app. 3) (Franklin and others 2001, Milliken and others 1998, http://www.fs.fed.us/r5/rsl/projects/mapping/accuracy.shtml). The CALVEG analysis reported quantitative accuracy assessments for life form categories, tree size classes, and tree canopy closure classes. Overall map and class accuracies reported for CALVEG atttributes include both nonfuzzy (strictly correct or incorrect—"Max") and fuzzy rating values. Observations having a fuzzy rating of 3 or better were considered correct ("Right"). Overall map accuracies for CALVEG tree size ranged from 68 to 78 percent when using the fuzzy approach and 42 to 60 percent when using the Max approach (app. 3, table 3-4). For canopy closure, they ranged from 75 to 83 percent correct when using the fuzzy approach and 49 to 68 percent when using the Max approach (app. 3, table 3-5). The IVMP and CALVEG methods evaluated accuracies for different class widths. For example, CALVEG used an error matrix with six classes, rather than the two classes reported by IVMP (<20 in versus ≥20 in). Because CALVEG size classes are narrower, classification errors calculated for them are inherently higher. For this reason, direct comparison between the magnitudes of IVMP and CALVEG accuracy values was not possible. However, given differences in classification and map assessment approaches, resulting accuracies appear comparable for CALVEG and IVMP. Note also that CALVEG map project areas do not correspond directly with physiographic provinces used in Northwest Forest Plan monitoring.

Maps of Older Forests

We recombined the thematic data from IVMP and CALVEG to map all 22 classes shown in table 1. This produced a continuous map for the Plan area showing existing forest vegetation for all lands mapped by average topstory tree size, percentage of canopy cover, canopy layering, and

life form (conifer, deciduous, or mixed). Then we produced three older forest maps corresponding to the "medium and large older forest," "large, multistoried older forest," and "older forest with size indexed to potential natural vegetation type" definitions. The "medium and large" older forest map consists of the total amount mapped as classes 11-22 in table 1. The "large, multistoried" older forest map consists of the total amount mapped as classes 20-22 in table 1. The "older forest with size indexed to potential natural vegetation zone" map uses size classes with breaks shown in table 3. Each of the three map rules had a canopy cover threshold of at least 10 percent (Hemstrom and others 1998) to assure the presence of a minimally forested condition. Forest-capable areas with canopy cover less than 10 percent were classified as "potential forest" (that is, capable of being forested, but presently nonstocked), regardless of average tree size.

These maps were essential to the monitoring analysis. They were the basis for estimates of older forest amounts at the start of the Plan (expressed as the percentage of forest-capable area occupied by older forest). They were combined with other spatial data to examine older forest distribution by province, land use allocation, natural vegetation community, and fire regime. We also used these maps to analyze the degree of fragmentation between older forest patches. And finally, other monitoring programs used the IVMP and CALVEG existing vegetation data to create maps of habitat suitability for northern spotted owls (Lint 2005) and marbled murrelets (Huff, in press). The combination of older forest maps and their habitat counterparts presents a much more complete picture of the status of the older forest network and its contribution to habitat maintenance than would be available if no spatial data were available.

Older Forest Map Accuracy Assessment

There is a saying attributed to statistician George Box that, "all models are wrong; some models are more useful than others." Using satellite imagery to model vegetation structure is a common practice for producing maps for the purpose of displaying general patterns and differences in vegetation conditions. In fact, there are few alternatives if a wall-to-wall map is needed. However, it is important to reemphasize that the older forest maps are models that contain prediction error. Given that knowledge, satellite imagery can yield useful results for characterizing forest structure.

We quantified the classification accuracies of the three older forest maps by using an error matrix approach to compare the proportion of map units labeled as older forest compared to reference values, for each of the three definitions. The reference observations were the more than 7,000 Current Vegetation Survey and Forest Inventory and Analysis plots on Forest Service and Bureau of Land Management lands (table 6). We computed the accuracy within each province map and across the combined provinces. Three provinces did not have a sufficient number of reference plots to quantify map accuracy (California Coast Range, Oregon Willamette Valley, and Washington Western Lowlands). To perform the accuracy assessment, we intersected inventory plot locations with the older forest map and compared the class label from the map with the class label derived from the inventory measurements. For each definition, we compared two classes—"older forest," and "not older forest." For a plot on the map to be labeled "older forest," more than half of the 13 pixels composing the 1-ha (2.47-ac) plot had to be in the older forest class; otherwise the entire plot on the map was labeled "not older forest." Reference values for average topstory tree size, percentage of canopy cover, and canopy layering were calculated from attributes of the inventoried tree list. Based on the results, the reference plot was assigned a label of either "older forest" or "not older forest."

The map accuracies are reported in table 6. Map quality, as assessed by overall map accuracy, within-class producer's accuracy (the probability that a reference observation on the ground has been correctly labeled on the map) and within-class user's accuracy (the probability that a unit labeled on a map actually represents that class on the ground) varied greatly by province and by older forest definition.

Overall map accuracy of the "medium and large" older forest map (the proportion correctly labeled by using "older

Table 6—Accuracy assessment of older forest maps

Province	N	Older forest class		Not older forest class		Overall	*k*	Test of H0: *k*=0	
		Producer's	User's	Producer's	User's			Z	Pr > Z
		Percent							
Medium and large older forest definition									
California Cascades	130	65.8	39.1	67.5	86.2	67.1	0.27	286.2	< .0001
California Coast Range	3	—	—	—	—	—	—	—	—
California Klamath	527	70.9	51.9	64.4	80.3	66.7	0.33	653.4	< .0001
Oregon Coast Range	751	72.5	80.1	87.6	82.2	81.5	0.61	735.5	< .0001
Oregon Eastern Cascades	640	31.6	35.2	90.9	89.5	82.8	0.23	287.5	< .0001
Oregon Klamath	990	69.2	48.0	74.2	87.5	72.9	0.38	556.7	< .0001
Oregon Western Cascades	1,945	76.2	68.8	73.3	79.9	74.6	0.49	980.4	< .0001
Oregon Willamette Valley	5	—	—	—	—	—	—	—	—
Washington Eastern Cascades	858	11.3	85.3	99.7	87.6	87.5	0.17	412.7	< .0001
Washington Olympic Peninsula	260	77.3	70.4	83.2	87.6	81.2	0.59	423.4	< .0001
Washington Western Cascades	1,068	73.3	62.6	73.7	82.1	73.6	0.45	721.5	< .0001
Washington Western Lowlands	0	—	—	—	—	—	—	—	—
Northwest Forest Plan	7,177	68.6	59.6	78.2	84.1	75.1	0.45	1962.3	< .0001
Older forest with size indexed to vegetation zone									
California Cascades	130	52.0	40.1	58.9	98.8	58.8	0.01	27.0	< .0001
California Coast Range	3	—	—	—	—	—	—	—	—
California Klamath	527	77.2	53.9	54.8	96.1	56.8	0.11	355.1	< .0001
Oregon Coast Range	751	67.1	75.1	87.1	93.0	83.8	0.48	586.7	< .0001
Oregon Eastern Cascades	640	40.2	30.2	85.9	93.2	81.6	0.20	251.2	< .0001
Oregon Klamath	990	55.4	43.0	76.1	96.0	74.7	0.13	252.5	< .0001
Oregon Western Cascades	1,945	69.1	64.8	74.2	88.4	73.0	0.37	769.4	< .0001
Oregon Willamette Valley	5	—	—	—	—	—	—	—	—
Washington Eastern Cascades	858	33.9	81.3	87.4	95.1	84.0	0.14	218.7	< .0001
Washington Olympic Peninsula	260	77.8	65.1	89.4	96.3	87.8	0.56	410.5	< .0001
Washington Western Cascades	1,068	75.8	61.1	74.1	93.3	74.5	0.37	632.7	< .0001
Washington Western Lowlands	0	—	—	—	—	—	—	—	—
Northwest Forest Plan	7,177	67.0	59.6	73.4	93.6	72.6	0.25	1271.8	< .0001

Table 6—Accuracy assessment of older forest maps (continued)

Province	N	Older forest class		Not older forest class		Overall	*k*	Test of H0: *k*=0	
		Producer's	User's	Producer's	User's			Z	Pr > Z
		Percent							
Large multistoried older forest definition									
California Cascades	130	0.0	0.0	96.1	96.7	93.1	-0.04	-35.4	< .0001
California Coast Range	3	—	—	—	—	—	—	—	—
California Klamath	527	25.2	22.6	91.4	92.4	85.4	0.16	306.3	< .0001
Oregon Coast Range	751	56.0	35.1	85.4	93.2	81.7	0.33	411.3	< .0001
Oregon Eastern Cascades	640	20.2	11.1	99.0	99.5	98.5	0.14	174.7	< .0001
Oregon Klamath	990	53.9	18.2	81.8	96.8	83.4	0.20	342.8	< .0001
Oregon Western Cascades	1,945	42.4	30.2	87.5	92.2	82.3	0.25	517.1	< .0001
Oregon Willamette Valley	5	—	—	—	—	—	—	—	—
Washington Eastern Cascades	858	0.0	0.0	99.0	99.6	98.6	-0.01	-8.9	< .0001
Washington Olympic Peninsula	260	43.3	40.0	92.6	93.5	87.6	0.35	247.7	< .0001
Washington Western Cascades	1,068	53.3	29.4	88.0	95.3	85.0	0.30	501.6	< .0001
Washington Western Lowlands	0	—	—	—	—	—	—	—	—
Northwest Forest Plan	7,177	41.3	26.7	90.9	95.1	87.2	0.26	1146.1	< .0001

Note: N = number of reference observations.

Producer's accuracy is the probability that a reference observation on the ground has been correctly classified on the map, and user's accuracy is the probability that a unit classified on a map actually represents that class on the ground.

Kappa is a test statistic for verifying that agreement between older forest map and reference values exceeded chance levels.

Medium and large older forest map—minimum 10-percent canopy cover, minimum average tree size 20 in (quadratic mean diameter), single- or multistoried canopies.

Older forest with size indexed to vegetation zone—minimum 10-percent canopy cover, minimum average tree size varies by vegetation zone.

Large, multistoried older forest—minimum 10-percent canopy cover, minimum average tree size 30 in, multistoried canopy.

— = not enough reference plots available (≤5) to calculate accuracies for California Coast Range, Oregon Willamette Valley, or Washington Western Lowlands.

forest" versus "not older forest" classes) was about 75 percent for all provinces combined, and all province maps were at least two-thirds accurate, overall (table 6). Producer's accuracies were above 50 percent for the older forest class for all provinces but two. In the Eastern Cascades provinces of Oregon and Washington, the low producer's accuracy indicated a low probability of correctly mapping the older forest class. Low user's accuracies in the California Cascades, Eastern Cascades of Oregon and Washington, and the Oregon Klamath indicated that many areas mapped as older forest were in fact misclassified on the map. The implication of these classification errors is that the older forest class will tend to be underpredicted compared with reference values in these provinces. The effect of the error depends on the use made of the results. Although the true magnitude of the error is unknown, it can be reasonably approximated with the values from the quantitative accuracy assessment. We did this by bracketing the amounts of older forest obtained from the maps by the magnitude of the inaccuracy in the error matrix. In our subsequent discussion of results, we make every effort to disclose the obvious inaccuracies in results, and what effect they might have on conclusions drawn from those results.

Map accuracy results for the definition known as "older forest with size indexed to potential natural vegetation zone" were similar in pattern to the mapping errors for the "medium and large" older forest map (table 6). Overall accuracies were between 57 and 89 percent (73 percent for the range). In terms of magnitude, producer's and user's accuracies were a little worse than for the "medium and large" older forest map. For the same provinces noted above, there was less than a 50-percent chance that a pixel identified on the map as older forest was actually older forest (user's accuracy). On the other hand, more than two-thirds of older forest reference values were correctly labeled on the map (overall producer's accuracy equaled 67 percent).

The ability to correctly map the older forest class according to the "large, multistoried" older forest definition was lowest of the three definitions (table 6). Overall accuracies were between 82 and 99 percent (87 percent for the range), but the high overall accuracies reflected the predominance of reference values (93 percent) that were "not older forest." In that map, map units labeled as "older forest" were correctly labeled less than half the time in every province.

For any of the definitions, the "not older forest" class was classified correctly more often than the "older forest" class. This result was expected, because the majority of reference values were "not older forest" for each of the definitions (68 percent for "medium and large," 87 percent for "size indexed to potential natural vegetation zone," and 93 percent for "large, multistoried"). In other words, the probability of getting a correct classification strictly by chance is proportional to the presence of the class in the population. To protect against good classification accuracies being due to random chance, we used a kappa statistic for verifying that agreement between older forest map and reference values exceeded chance levels. We did not use kappa for quantifying strength of agreement, a practice that is very controversial. This is because the test of the proportion of times that map and reference values would agree by chance alone is only relevant if the values are independent—which clearly they are not. Therefore, we report only the significance of the test of the null hypothesis that there is no more agreement between the map and reference values than might occur by chance given random guessing, rather than the absolute values of kappa themselves. An excellent primer on appropriate use of the kappa statistic can be found online (http://ourworld.compuserve.com/homepages/jsuebersax/kappa.htm). For all but two combinations of older forest definitions and provinces, the kappa statistic showed that there was better than random agreement between reference and map values (table 6). The exceptions were those provinces with weakest map results noted above—California Cascades and Washington Eastern Cascades for the "large multistoried" map (both had negative kappa values). No reference values labeled as "large multistoried" older forest in these provinces were predicted by the map to be that class. We expected this result, because there were very few reference plots with average tree size 30 in and greater, the cutoff for the "large multistoried" older forest definition.

Only 3 percent of reference plots were classified as "large multistoried" older forest in California Cascades, and less than 1 percent in Washington Eastern Cascades. With such small reference values in the population, the chance of misclassification is very high.

In summary, the "medium and large" older forest classifications were the most accurate maps, and they were most accurate for the coastal provinces and western Cascades provinces. Some improved accuracies were gained by the eastern Cascades provinces and Klamath provinces in the "older forest with size indexed to potential natural vegetation zone" map as compared with the "medium and large" map. As expected, the "large multistoried" map was least accurate in the eastern Cascades provinces, and to some extent the Klamath provinces. Finally, we conducted one final assessment of the maps, by comparing the amounts (total acres) of older forest estimated by the maps, with acres estimated by using the plot data, for the portions of the landscape that had adequate inventory plot samples. This approach and its results are discussed in subsequent sections.

Landscape Patterns

Along with older forest amounts, the importance of landscape patterns of older forests was also recognized in the Plan. Using the older forest maps created from remotely sensed data, we assessed the distribution and degree of fragmentation of older forests within the federal landscape. We used FRAGSTATS (McGarigal and Marks 1995) to determine the size, number, spatial arrangement, and isolation of mapped blocks of older forests.

We evaluated the fragmentation metrics of contiguous blocks of older forest of any size, and all blocks of at least 1,000 ac. The particular metrics we chose were related directly to Plan expectations for connectivity (see sidebar 1):

- Distribution of older-forest blocks smaller than 1,000 ac.
- Distribution of older-forest blocks larger than 1,000 ac.
- Mean edge-to-edge distance between older-forest blocks larger than 1,000 ac.
- Proportion of adjacent physiographic provinces connected with large older-forest blocks.

We mapped the largest blocks, calculated both within individual provinces, and across the entire Plan area. The latter allowed us to examine the arrangement of large older-forest blocks that cross physiographic province boundaries.

The resolution of a map influences the definition of a patch (block). The area defined as a contiguous forest block depends both on the grain size of a map and on the connection rules that determine whether or not adjacent map elements are considered to be contiguous (that is, part of the same block). The influence of these factors on fragmentation measurements has received much attention in the landscape ecology literature, but there has been little agreement on the best approach. Generally, landscape ecologists agree that the scale of analysis should be matched to the scale of the phenomenon of interest (see, for example, Spies and others 1994).

Older forests in Oregon and Washington were mapped from the IVMP data to a pixel size of 25 m (82 ft on a side or 0.15 ac); in California, the minimum polygon resolution mapped from CALVEG was 100 m (328 ft on a side or 2.47 ac). In conducting the block analysis, we converted the California map from polygons into a raster data set of 100-m cells. Then we resampled the Oregon and Washington maps from 25-m cells to 100-m cells to match the California maps by using a majority aggregation rule. We confirmed that although this aggregation reduced the number of small patches of older forests on the landscape in the Oregon and Washington portion, the overall area of older forests and the number of large blocks was nearly identical at the two grain sizes. In addition to allowing direct comparison between the three states, the use of a common 100-m cell size also dramatically reduced computation time.

In combination with cell sizes, we also tested two connection rules for combining adjacent cells. One rule considered a cell that was older forest to be a member of a block if at least one of the eight surrounding cells was also older forest. In the other rule, a neighboring older forest cell had to be connected at one of the four cardinal directions (that is, directly to the north, east, south, or west, and cells

on the diagonal were not considered). The more liberal eight-neighbor connection rule resulted in block sizes weighted more heavily toward small size classes and linear map features compared with the more restrictive four-neighbor connection rule. We found that using a combination of a 100-m cell with an eight-neighbor connection rule produced results that were not very different from using a 25-m cell and a four-neighbor connection rule. That is, the use of a larger grain size and more liberal connection rule tended to offset using a smaller grain size and more restrictive connection rule, and the resulting maps appeared very similar. Therefore we conducted the fragmentation analysis by using the eight-neighbor rule.

Plot Analysis Methods

In addition to constructing and analyzing older forest maps, we also conducted a statistical analysis of older forest amount and distribution by using detailed ground inventory data collected in the Northwest Forest Plan area. Mapped data are conducive to characterizing spatial patterns of older forest on the landscape. However, the inherent inaccuracy of vegetation maps derived from remotely sensed data reduces the reliability of acreage estimates made from them. A map accuracy value of two-thirds is considered realistic for maps derived from satellite imagery (although we always strive for higher accuracies). Fortunately, we also had data from a rigorous, statistically robust sample of forests on lands managed by the Forest Service in Oregon, Washington, and California, and Bureau of Land Management in Oregon. We used these data to estimate the acres, and confidence bounds around the acres, of federal land occupied by older forest. Unfortunately, the inventory data available for the monitoring analysis did not sample the complete population of federal lands affected by the Plan. However, for those lands that were sampled, the acreage estimate is both more accurate and more precise than estimates derived from the map data. Thus, on portions of the Plan area containing inventory samples, the plot data gave us another independent means for confirming the map estimates of older forest.

Inventory Data Sources

Plot data used in this report came from three agency inventory programs—Current Vegetation Survey administered by the Forest Service in Region 6 (Max and others 1996; USDA Forest Service 1998, 2001), Current Vegetation Survey administered by Oregon Bureau of Land Management (Max and others 1996, USDI Bureau of Land Management 2001), and Forest Inventory and Analysis administered by Forest Service-Region 5 (USDA Forest Service 2000b). Each inventory program maintains a collection of permanent sample plots installed on a systematic grid across the land the agency manages. The three inventory programs have subtle differences in sample design but have significant, common features that make the data very useful for monitoring analysis.

A 3.4-mi grid sample is common to all the inventories, resulting in a sampling intensity of about 1 plot for every 7,400 ac. In Washington and Oregon, the CVS sampling intensity is increased fourfold on nonwilderness lands (one plot every 1,850 ac) (fig. 6). The plots are installed by using a rotating panel system. The sampling design is to remeasure every plot on a 10-year (for Forest Inventory and Analysis plots) or 12-year (for CVS plots) periodic cycle. Remeasurement produces information that can be used to analyze the amount of change in vegetation between measurement cycles.

Each inventory plot samples a 1-ha (2.47-ac) area. Five sample points are installed within each plot with nested concentric subplots that sample different components of vegetation (fig. 7). Sample measurements are recorded for individual trees, snags, and logs on sample points. Each full plot has an area-expansion factor, and each point represents one-fifth of the total area-expansion factor. In the monitoring analysis, we exploited the sampling variability inherent in this 5-point design to compute a nonparametric confidence envelope around each acreage estimate. Confidence intervals were constructed by using a stratified two-stage bootstrapping routine that resamples inventory data from sample points by using a Monte Carlo approach programmed by one of the authors (J. Alegria). Bootstrapping

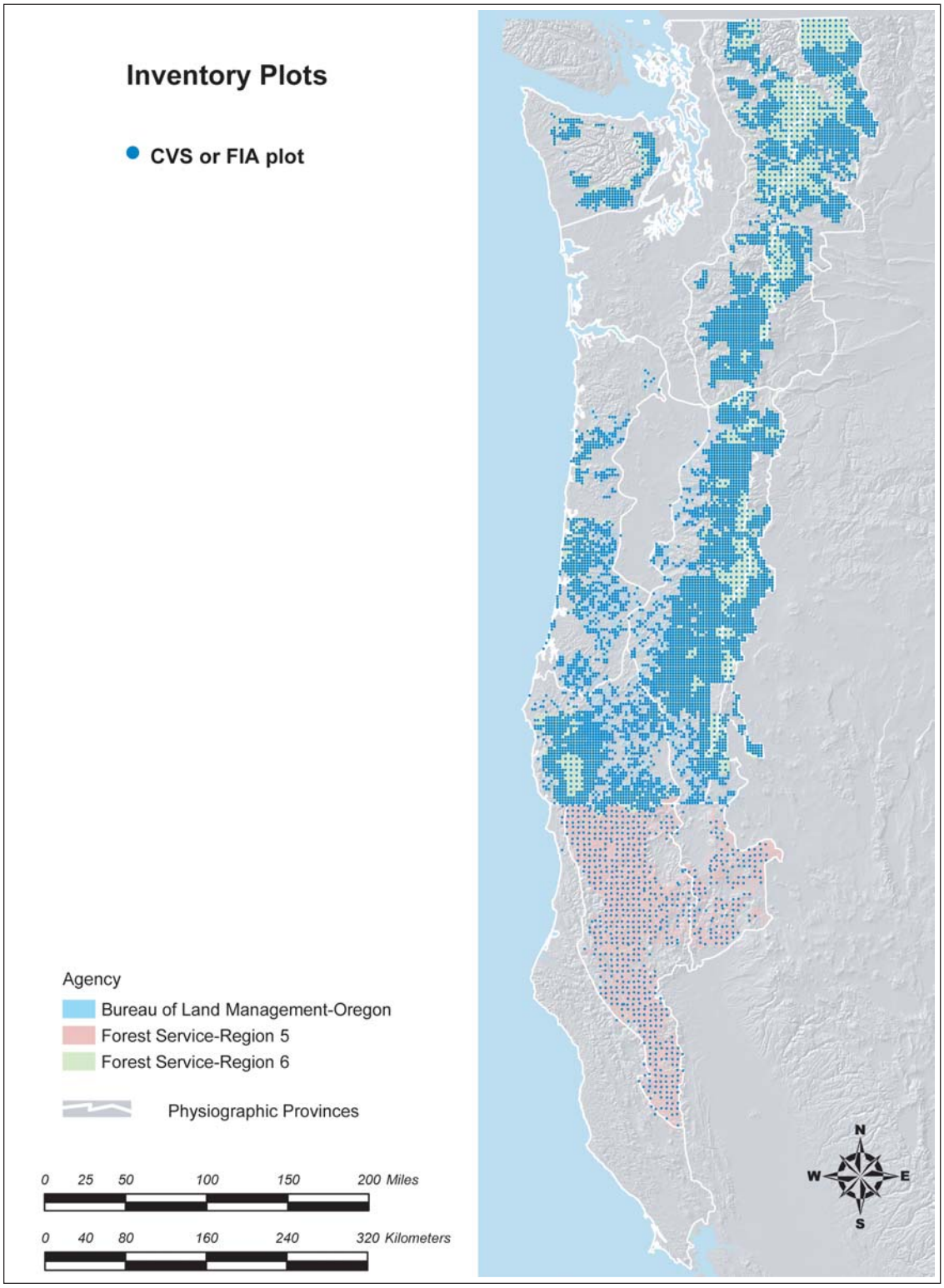

Figure 6—Current Vegetation Survey (CVS) and Forest Inventory and Analysis (FIA) plots. The FIA plots are installed on a 3.4-mi grid on lands administered by Forest Service-Region 5. The CVS Plots are installed on a 3.4-mi grid on wilderness lands administered by Forest Service-Region 6 and Bureau of Land Management-Oregon. On nonwilderness lands in Washington and Oregon, there is one plot every 1.7 mi.

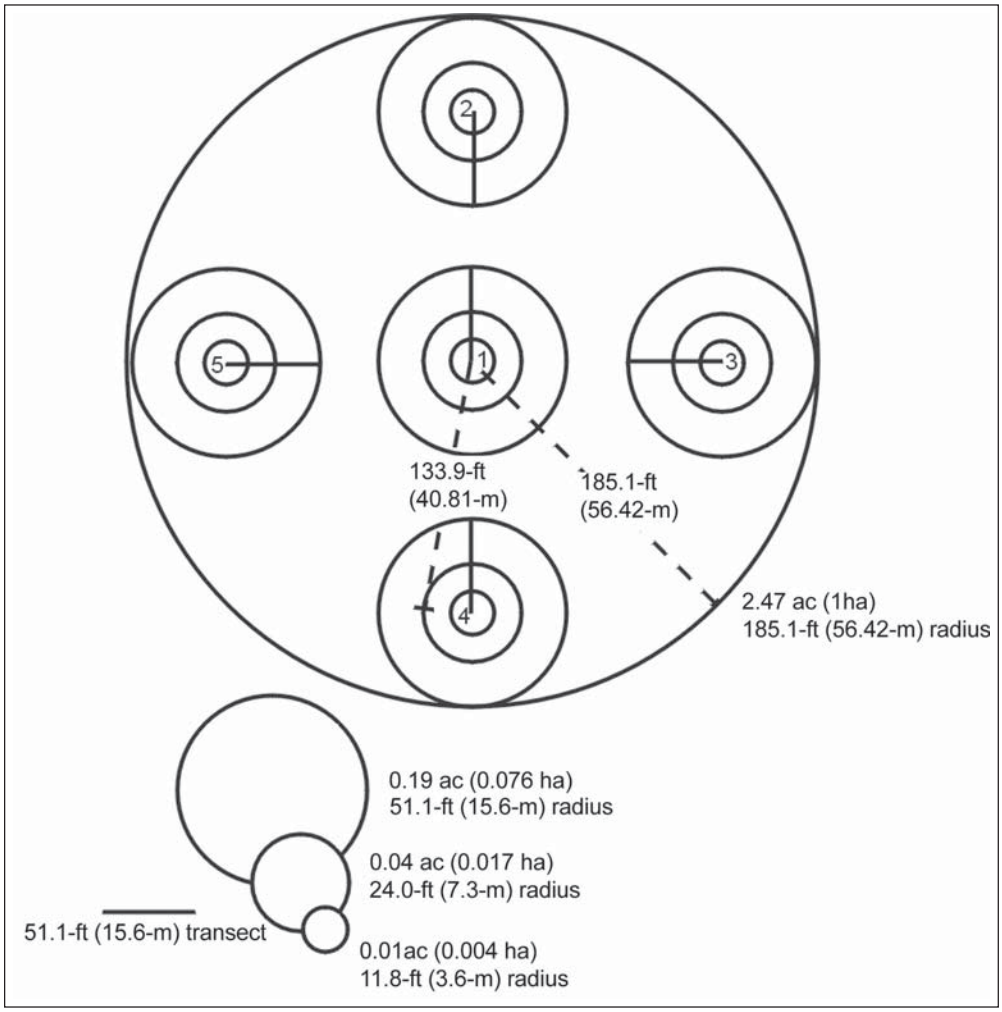

Figure 7—Generalized layout of Current Vegetation Survey (CVS) plot showing five sampling points on a 1-ha full plot (from Max and others 1996).

is a well-accepted statistical approach for exploiting available sampling data to increase precision of estimates (Efron and Tibshirani 1993). In our approach, each first-stage bootstrap sample consisted of n_h randomly selected sample plots with replacement from each of the *h* strata to produce one bootstrap estimate. The strata were land allocation groups, or reserve categories (table 5), within physiographic provinces. This computation was repeated 1,000 times. For each first-stage sample plot, five sample points were randomly selected with replacement from among the possible sample points. The results were adjusted by using the bias-corrected and accelerated method (Bc_a) as detailed in Efron and Tibshirani (1993). Confidence intervals were calculated at the 90-percent value for all acreage estimates.

Data from all plots within the Plan area from the three inventories were combined into a master database. Just as with the map data, the primary attributes compiled from the inventory data used to assess forest condition were average topstory tree size, percentage of canopy closure, canopy layering, and life form, as per table 1. Average tree size was calculated as the quadratic mean diameter of all trees on the sample point having dominant or codominant crowns. Computing the average size for trees only in the upper story produces a size metric that closely parallels the

average tree size measure modeled by the existing vegetation maps based on remotely sensed information. Canopy closure and canopy layering were compiled by processing the tree data from each sample point through the Forest Vegetation Simulator (Crookston and Stage 1999, Dixon 2003, Teck and others 1996, Wykoff and others 1982). The Forest Vegetation Simulator reports canopy closure in 1-percent increments from 0 to 100, and canopy layering as the number of canopy layers present (0 = non-stocked, 1 = single-storied, ≥2 = multistoried). Life form was determined by calculating the proportion of total canopy closure accounted for by conifers versus hardwoods: 80 percent or more of total canopy cover in conifers was classified as conifer-dominated, 80 percent or more of total canopy cover in hardwoods was classified as deciduous, otherwise was classified as mixed (table 1).

Once the plot data were compiled, each sample point was assessed for its membership in each of the older forest classes ("medium and large older forest," "large, multistoried older forest," and "older forest with size indexed to potential natural vegetation zone"). All available plots were included, even if they were nonforested. The attributes of nonforested plots resulted in a label of "potentially forested" (table 1). Then the total acres represented by sample points meeting each older forest definition were summed by province and land allocation group. A bootstrap estimate of sampling variance was calculated around each estimate and used to construct 90-percent confidence limits.

The inventory data were also analyzed to address the monitoring question about structural and compositional characteristics of older forests—large-tree diameters, canopy structure, snags, and logs (see sidebar 2). This analysis followed the accuracy assessment of the older forest maps. Samples that were labeled as "older forest" both on the map and on reference plots were assigned to one class. Samples that were labeled as "not older forest" both on the map and on reference plots were assigned to another class. Samples with conflicting plot versus map labels were dropped from the analysis. Then we computed means and confidence intervals for the following attributes by the two classes for each older forest definition:

Average size (quadratic mean diameter) of topstory trees
Average age of topstory trees
Average number of canopy layers
Density of trees (trees per acre) in several size classes (3-9.9, 10-19.9, 29-29.9, and 30+ in)
Snag densities (snags per acre) in 3-9.9, 10-29.9, and 30+ in diameter classes
Tons per acre and cubic foot volume per acre of logs.

A practical discussion of the inventory data—
It is important to point out that amounts of older forest, whether determined from map data or from plot data, are

Forest structure can be characterized by attributes such as tree sizes and canopy layering.

estimates. They are models of what we can infer about the resource, given the best available information. However, all sources of information have flaws. Some are known, and some are unknown. We know the map data is inherently limited in accuracy owing to the imprecision of the classification of remotely sensed data, and the variation in actual conditions that cannot be captured adequately by map models. The plot data is collected according to a sample design that meets rigorous statistical assumptions, with a sampling intensity intended to capture important variation in the population. Thus sample data yield an unbiased estimate of the population. However, even plot data have limitations that must be disclosed in analyses and results. The major limitation affecting use of plot data for the monitoring analysis is that the data we used did not, at the time, sample the total population of federally managed lands included in the Northwest Forest Plan area. Current Vegetation Survey and Forest Inventory and Analysis plots sampled only lands managed by Forest Service-Region 6,

Bureau of Land Management-Oregon, and Forest Service-Region 5. Together these lands accounted for 90 percent of the Plan total federal land area. At the time of the inventory, there were no samples installed on National Park Service lands (Park Service lands accounted for about 9 percent of the total federal land base).[1] Data from Bureau of Land Management-California lands (about 1 percent of the total) were not included either.[2] Thus our statistical estimates excluded Park Service and Bureau of Land Management-California lands. National parks do contribute significantly to the older forest network on federal land, because they make up a large portion of the congressionally withdrawn land allocation (wilderness in national forests is the other significant component of congressionally withdrawn lands). However, the Plan does not and cannot influence management of national parks (USDA and USDI 1994b). Although having missing data is never desirable, our plot analysis does cover all but 1 percent of land (that is, on Bureau of Land Management land in California) where scheduled timber harvest must be considered in the range of management alternatives. All our plot-based results are therefore applicable only to Forest Service-Region 6, Bureau of Land Management-Oregon, and Forest Service-Region 5.

On federal ownerships that were sampled, data were incomplete owing to the fact that some plots could not be measured. For example, where access is hazardous, such as on rock piles, glaciers, or even on the other side of a large river with no bridge crossings, it may have been impossible to install a plot. These uninstallable plots represented a certain number of acres for which no information was known about the conditions on the ground. Of the approximately 22.3 million ac of public land administered by Forest Service-Region 5, Forest Service-Region 6, and Bureau of Land Management-Oregon, 90 percent was represented by a sample (table 7). The remaining 10 percent of land had plots allocated, but not installed, usually because of access issues. A notable exception was in the Washington Eastern Cascades province. On the Wenatchee National Forest in that province, one-quarter of CVS plots were missing from the first measurement occasion because of contractor default (http://www.fs.fed.us/r6/survey).

The unmeasurable areas pose an obvious problem for reporting population estimates of older forest amounts. We made the assumption that most area not sampled because of hazardous access is from a different statistical population, that is, usually permanently nonforested and therefore not capable of supporting older forest. This is a legitimate assumption for most, but not all, conditions where plots were not installed because of access problems. We recognize that we may have slightly underestimated older forest area based on this assumption, but argue that the discrepancy is small enough to be discounted.

The year of installation and initial measurement for the inventory plots used in the monitoring analysis ranged from 1993 to 2001 (table 8). We used all sample plots measured during the initial measurement occasion to represent conditions at or near the start of the plan. More than 90 percent of samples were collected within a 5-yr period around Plan implementation (from 1993 through 1998). In the long term, monitoring results should not be very sensitive to variation caused by sampling information collected over a range of

[1] There were no inventory plots on national park land at the time of the Northwest Forest Plan implementation. Forest Inventory and Analysis has recently begun sampling all ownerships, including national park land, as a component of their National Strategic Inventory program (http://www.fs.fed.us/pnw/fia/publications/fieldmanuals.shtml). This national annual inventory began in 1999 in California, followed by Oregon in 2000, and Washington in 2001. According to this schedule, the first installation on national park lands in the Plan area will be completed in 2009-11. Thus, most of the inventory information for national parks will be available for analysis in the next monitoring cycle ending in 2009.

[2] On Bureau of Land Management land in California, there were 15 sample plots belonging to the periodic inventory (3 in the California Cascades province, 7 in the Coast Range, and 5 in the Klamath). The periodic inventory became obsolete with the advent of the national annual inventory, and we decided that no periodic data would be used in this monitoring analysis in order to avoid problems associated with differences in sample design and compatibility with the other inventories. Besides, the vast majority of lands sampled by Forest Inventory and Analysis plots at the start of the Plan were in state and private ownerships, and these lands were not a focus of the status and trends monitoring program. As with the Park Service land, data on Bureau of Land Management land in California from the national annual inventory will be included in the next monitoring cycle.

Table 7—Distribution of acres sampled by inventory plots in the Northwest Forest Plan area

Province	Sampled	Not sampled	Total	Percentage sampled
	Acres			*Percent*
California Cascades	1,005,900	98,900	1,104,800	91.1
California Coast Range	73,800	6,900	80,700	91.5
California Klamath	3,908,000	470,100	4,378,200	89.3
Oregon Coast Range	1,403,100	84,200	1,487,300	94.3
Oregon Eastern Cascades	1,537,400	93,200	1,630,600	94.3
Oregon Klamath	2,102,700	93,100	2,195,800	95.8
Oregon Western Cascades	4,238,900	220,500	4,459,400	95.1
Oregon Willamette Valley	13,800	0	13,800	100.0
Washington Eastern Cascades	2,600,900	769,000	3,369,900	77.2
Washington Olympic Peninsula	588,300	42,600	631,000	93.2
Washington Western Cascades	2,617,100	347,800	2,964,900	88.3
Washington Western Lowlands	0	0	0	0.0
Northwest Forest Plan	20,090,000	2,226,300	22,316,300	90.0

Note: Includes Current Vegetation Survey plots on Forest Service-Region 6 and Bureau of Land Management-Oregon lands and Forest Inventory and Analysis plots on Forest Service-Region 5 lands.

Table 8—Acres sampled on inventory plots during the first measurement occasion

Year	Area sampled	Percentage of total
	Acres	*Percent*
1993	855,800	4.3
1994	2,644,900	13.2
1995	4,515,300	22.5
1996	6,720,900	33.5
1997	2,198,000	10.9
1998	1,292,000	6.4
1999	281,400	1.4
2000	971,300	4.8
2001	610,400	3.0
Total	20,090,000	100.0

years. Also, use of all occasion-one inventory data to compile the Plan baseline establishes a monitoring approach into the future. Our monitoring protocol calls for remeasured plots to be used for change estimation by assigning them to the correct 5-yr monitoring cycle, disregarding the specific year they were remeasured.

Trend Analysis: Forest Disturbance Map Methods

Assessing changes over time in older forests under the Plan is a two-step process. First, baseline conditions must be established, and second, there must be a means for tracking changes to the baseline. We analyzed changes by using both plot (table 9) and mapped data (table 10). Remote sensing of changes allows examination of substantial changes in forest vegetation over space and time. Related spatial analysis, such as comparison of rates of harvest activity by ownership, or fire occurrence trend by physiographic setting, are possible with this type of spatial information. Information from remeasured inventory plots is a better source of data than are maps for assessing subtle vegetation change (for example, resulting from understory disturbance that does not disturb the canopy, or from forest growth and development).

In this section, we describe how disturbance maps developed from remotely sensed data were used for tracking losses of older forests since the start of the Plan.

Table 9—Distribution of remeasured plot data

Period	Area remeasured	Percentage of area by period
Years	*Acres*	*Percent*
1	623,000	6.7
2	1,080,500	11.6
3	1,252,300	13.4
4	2,371,600	25.4
5	2,981,000	31.9
6	342,600	3.7
7	402,400	4.3
8	284,700	3.0
9	1,500	0.0
Total	9,339,600	100.0

Note: Period is the number of years between initial measurement and remeasurement. The mean remeasurement period, weighted by acres, is 4.08 years.

Table 10—Summary of change cycles in the remote sensing change-detection analysis

Area	Period
California	
CALVEG baseline	1994
Change-detection cycles:	
North Coast project area	1994-1998
	1998-2003
Cascade Northeast	1994-1999
	1999-2003
Washington and Oregon	
IVMP Baseline:	
2 scenes	1992
1 scene	1994
1 scene	1995
13 scenes	1996
Change-detection cycles:	
Oregon	1995-2000
	2000-2002
Washington	1996-2000
	2000-2002

Remotely Sensed Change Detection

We used information from broad-scale remote-sensing disturbance-mapping projects to assess loss of older forest in the first decade after the Plan. As was done for mapping existing vegetation attributes from IVMP and CALVEG, data were drawn from two separate projects—one in Washington and Oregon, and another in California. In the approach used in Washington and Oregon, the type of change detection we conducted for monitoring was sensitive to land cover changes resulting from regeneration harvest (that is, clearcutting), land use conversion (e.g., forested land cleared for nonforest use), and wildfire severe enough to remove the forest canopy. It was not sufficiently sensitive to reliably detect less severe disturbances that did not remove the canopy, such as partial harvest, thinnings, or groundfires. Mortality associated with insect and disease damage was not detectable either unless it resulted in full canopy removal. In the California approach, changes were mapped according to magnitude (amount of canopy change) as well as direction (decrease or increase). In other words, the California methodology was sensitive enough to detect partial change. However, for this monitoring assessment, we resorted to the least-common-denominator use of the remotely sensed change-detection data: that is, mapping stand-replacing disturbances, only.

Old-growth ponderosa pine in eastern Oregon

In general terms, the approach used in remotely sensed change detection analyzes spectral differences in paired satellite images captured at multiyear intervals (Cohen and Fiorella 1998; Cohen and others 1998, 2002; Levien and others 1998, 1999). Disturbances severe enough to remove the existing canopy appear as clearly demarcated events in multitemporal imagery, and are easily mapped with a high degree of accuracy (fig. 8). The causes of change are labeled by integrating information from other data sources like aerial photos, agency activity records, and fire perimeters.

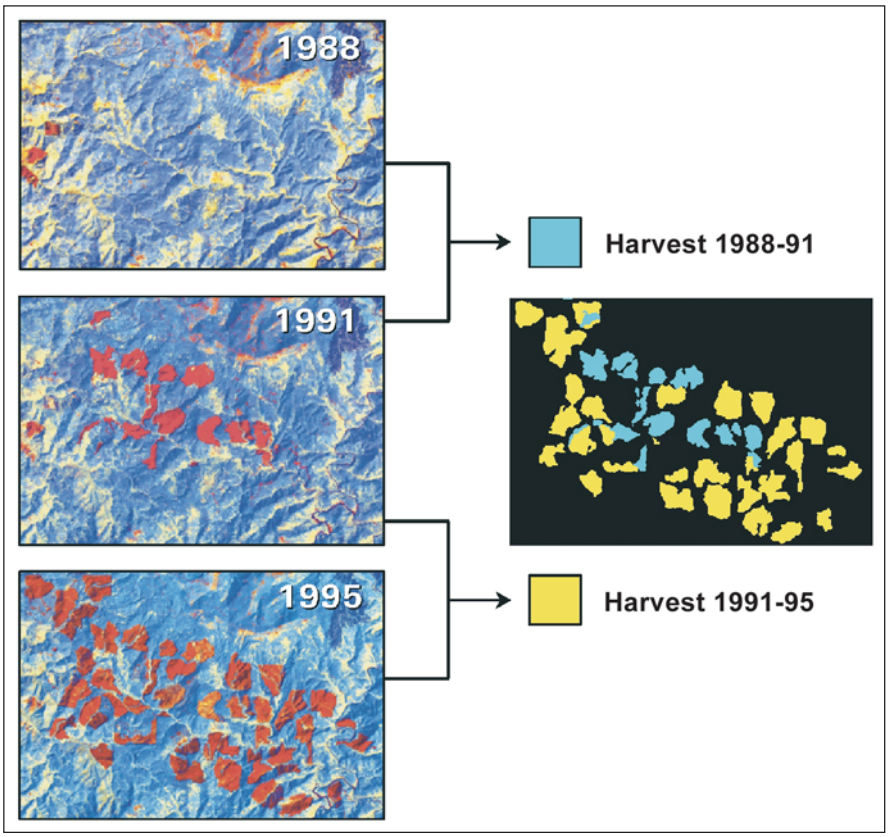

Figure 8—Schematic of remotely sensed change-detection approach using simultaneous image differencing (Cohen and others 2002).

Change detection in Washington and Oregon– In Washington and Oregon, a change-detection project was undertaken to support the late-successional and old-growth forest monitoring analysis. We mapped stand-replacing disturbances resulting from fire and harvest in the Washington and Oregon portion of the Plan area (fig. 9). The analysis built upon earlier research that had mapped disturbances in western Oregon between 1972 and 1995 (Cohen and Fiorella 1998; Cohen and others 1998, 2002). Using this groundwork, we extended the methodology in time (from 1972 through 2002) and in space (encompassing the complete Plan area in Washington and Oregon).

The Oregon and Washington disturbance map resulting from the change-detection project covers a 30-year span, from 1972 through 2002. Although we report results only for the decade after the Plan in this document, other publications in preparation will include a retrospective comparison of rates of change in the decades preceding the Plan and after the Plan on both public and private lands (Haynes and others, in press; Healey and others, n.d.).

The change-detection project in Oregon and Washington used a technique called composite analysis, where imagery from several time steps was georegistered and stacked into a single multitemporal image that was then classified in a way that highlighted forest loss in specific time intervals. Methodological details and results for Western Oregon through 1995 have been published by Cohen and others (2002). We used Landsat TM and Enhanced Thematic Mapper (ETM+) imagery, converted to a single spectral band per year by using the disturbance index transformation (Healey and others 2005). This transformation maximizes the spectral separation of disturbed and undisturbed forest pixels. Change was detected in each Landsat scene by submitting multitemporal disturbance index composites to a maximum likelihood-based supervised classification. Training of this classification was accomplished by using Landsat data transformed with the disturbance index

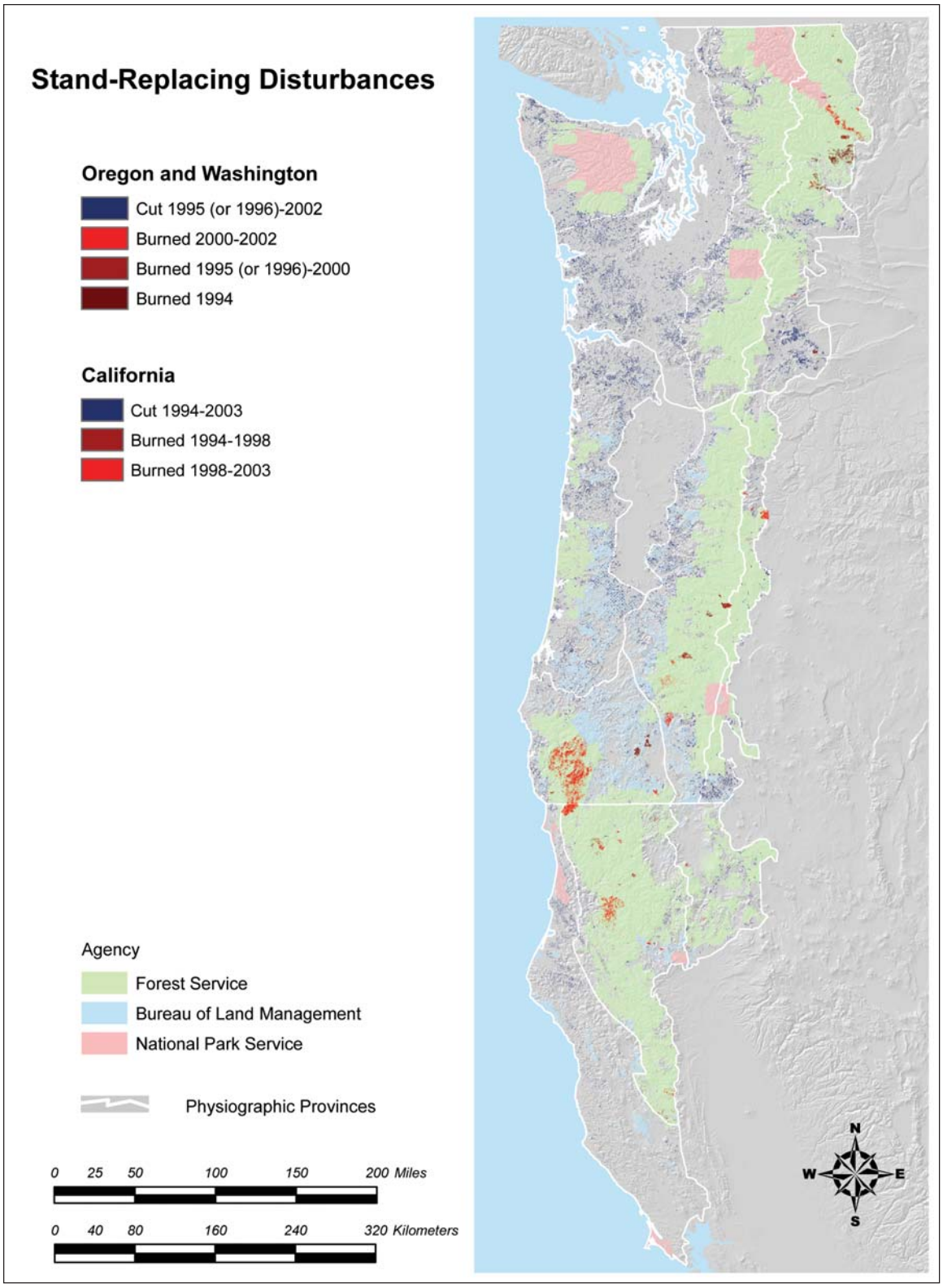

Figure 9—Disturbance map for Northwest Forest Plan monitoring. Washington and Oregon was mapped by Healey and others (n.d.); California was mapped by Levien and others (2003a, 2003b).

Continues

Continue to Part B