



United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-790
June 2009



Characteristics of Remnant Old-Growth Forests in the Northern Coast Range of Oregon and Comparison to Surrounding Landscapes

Andrew N. Gray, Vicente J. Monleon, and Thomas A. Spies



The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW, Washington, DC 20250-9410 or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

Authors

Andrew N. Gray is an ecologist and **Thomas A. Spies** is a research forester, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Vicente J. Monleon** is a research mathematical statistician, Forestry Sciences Laboratory, 620 SW Main St., Suite 400, Portland, OR 97208.

Cover photograph by Andrew Gray.

Abstract

Gray, Andrew N.; Monleon, Vicente J.; Spies, Thomas A. 2009. Characteristics of remnant old-growth forests in the northern Coast Range of Oregon and comparison to surrounding landscapes. Gen. Tech. Rep. PNW-GTR-790. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 45 p.

Old-growth forests provide unique habitat features and landscape functions compared to younger stands. The goals of many forest management plans in the Pacific Northwest include increasing the area of late-successional and old-growth forests. The goal of this study was to describe existing old-growth forests in the northern Oregon Coast Range that might serve as examples of desired future conditions and developmental pathways. In addition, the abundance of specific stand attributes associated with old-growth stands was estimated from regional inventory data. Most of the old-growth stands had experienced moderately severe disturbances during their development resulting in mid- and understory trees belonging to cohorts younger than those of overstory trees. Most of the stands had the full complement of old-growth attributes (large shade-intolerant trees, shade-tolerant trees, snags, and down wood), although the dead wood attributes tended to be less abundant in drier stand types. Thresholds for at least four of the five old-growth attributes were met on 7 percent of the inventory plots on federal lands, but on only 0.4 percent of the inventory plots on nonfederal lands. Shade-intolerant trees in particular were low in abundance in mature stands of intermediate diameter class (10 to 30 in). Large-diameter class stands (>30 in) were more abundant near the coast than near the Willamette Valley margin. Results suggest that although old-growth forests can develop along multiple pathways, stand composition and productivity constrain development such that expecting all late-successional stands to have the full complement of old-growth attributes may not be realistic.

Keywords: Old growth, late-succesional forest, inventory, habitat, disturbance.

Introduction

Old-growth forests are stands dominated by trees of advanced age, and their abundance is important throughout the world. Old-growth forests often provide unique habitat features for a wide variety of organisms and unique functions on the landscape that are not provided as well by younger stands at earlier successional stages of development (Ruggiero et al. 1991). Old-growth forests have declined dramatically in abundance in many regions in the last several centuries, owing mostly to logging and land conversion, and they can take a long time to grow back (Gray 1998, Spies and Franklin 1996). It is important to study remaining stands because there are not many left, and we need to be able to describe their structure and composition. Many land managers are tasked with increasing the area of old-growth (or late-successional) stands, so it is important to define those targets in sufficient detail.

The current management emphasis for large portions of federal land in the coastal Pacific Northwest under the Northwest Forest Plan (NWFP) is the maintenance and restoration of late-successional forests (USDA Forest Service and USDI Bureau of Land Management 1994). Late-Successional Reserves were created to protect existing late-successional and old-growth forests and provide for development of new ones from younger stands. Although management was allowed in those younger stands to promote old-growth characteristics, the processes responsible for old-growth development, how they differ regionally, and how to encourage them with management, are topics of debate (Carey et al. 1999, Gray 2000, Spies and Franklin 1996). In the Oregon Coast Range, where evidence of the structure of presettlement forests across much of the landscape has been erased by subsequent wildfires and logging, determining the natural abundance and characteristics of old-growth forests is contentious as well. Some studies suggest that old-growth stands formed at much lower densities than those currently found in young and mature forests (Tappeiner et al. 1997). Other studies indicate that old-growth stands in the Coast Range are younger and less structurally diverse than those in other parts of the Pacific Northwest (Spies and Franklin 1991). Additional information on the structure, composition, and disturbance history of existing old-growth stands could provide a useful reference for desired future conditions of Coast Range forests.

A variety of approaches have been used to define, classify, and quantify the abundance of old-growth forests. The simplest approach is to apply a threshold for a single attribute to classify stands as old-growth. For example, Bolsinger and Waddell (1993) classified all plots in the region that sampled stands 200 years or older as old growth, using readily available inventory plot data. Other approaches to quantify old-growth forest abundance have used stand structural stages either

The processes responsible for old-growth development, how they differ regionally, and how to encourage them with management, are topics of debate.

inferred from remote sensing or assessed on inventory field plots (Moeur et al. 2005). Additional approaches have described old-growth forests using a variety of stand structural attributes that tend to be present in old-growth. This was initially developed for Douglas-fir forests (Franklin et al. 1986), and subsequently extended to other forest types and refined to account for differences in site productivity (USDA Forest Service 1993). An alternative to describing thresholds for attributes is to use an index of the degree to which stands contain high-quality old-growth attributes (i.e., “old-growthiness”), either derived solely from stand variables (Spies and Cohen 1992), or through ratios of calculated stand attributes to those found in old-growth stands (Acker et al. 1998, Pabst 2005). It is not clear how well these different approaches work in a variety of forest types or how they compare to each other.

The objectives of this study were to (1) survey and describe the composition and structure of existing old-growth stands found along an east-west gradient across the northern Oregon Coast Range, (2) compare attributes of old-growth stands in the northern Coast Range with data from an earlier study conducted to the south, and (3) determine the abundance of old-growth stand attributes in the Oregon Coast Range from regional inventory data.

Our analysis of old-growth forest characteristics focuses on a variety of stand structural attributes found in ecological definitions of old growth. The Old-Growth Definition Task Group (Franklin et al. 1986) (referred to as “PNW-447” based on the issue number of the research paper) listed several attributes that were relatively easy to measure and that could be used as minimum criteria for classifying Douglas-fir¹ dominated stands as old-growth. Although few old-growth stands would meet all criteria, it was expected that most old-growth stands would meet most of the criteria. For Douglas-fir dominated stands on western hemlock zone sites, the criteria were:

- a. Two or more tree species in a range of sizes and ages
- b. Douglas-fir trees ≥ 32 in diameter at breast height (DBH) or ≥ 200 yr old: eight or more per acre
- c. Shade-tolerant associates (western hemlock, western redcedar, Pacific silver fir, grand fir, or bigleaf maple) ≥ 16 in DBH: 12 or more per acre
- d. Deep, multilayered canopy
- e. Conifer snags ≥ 20 in DBH and ≥ 15 ft tall: four or more per acre
- f. Biomass of downed logs: ≥ 15 tons per acre
- g. Downed logs ≥ 24 in diameter at large end and ≥ 50 ft long: four or more per acre

¹ See “Common and Scientific Names” in appendix tables 9 and 10.

Slightly different criteria were provided in the same publication for Douglas-fir-dominated stands in the drier Douglas-fir or grand fir zones:

- a. Two or more tree species in a range of sizes and ages
- b. Douglas-fir, ponderosa pine, or sugar pine trees ≥ 30 in DBH or ≥ 200 yr old: eight or more per acre
- c. Intermediate and small size classes of white fir, Douglas-fir, or incense-cedar present
- d. Multilayered canopy
- e. Conifer snags ≥ 20 in DBH and ≥ 15 ft tall: one or more per acre
- f. Biomass of downed logs: ≥ 10 tons per acre
- g. Downed logs ≥ 24 in diameter at large end and ≥ 50 ft long: two or more per acre

Subsequent efforts developed similar criteria adjusted by stand productivity class (site class) for most of the vegetation zones in Oregon and Washington (USDA Forest Service 1993) to reflect differences in the speed of stand development with site class. As the purpose of this paper was not to classify stands but compare structural attributes of stands in different forest types, the simpler levels presented in PNW-447 for the western hemlock zone were used for comparison.

Methods

Study Area

The Coast Range rises between the Pacific Ocean and the Willamette Valley in Oregon; the study area we selected was bounded by the ocean on the west, the Willamette River on the east, the Columbia River on the north, and the North Umpqua River on the south (fig. 1). This study focuses primarily on federal lands in the portion of this area north of the city of Newport and is referred to as the “northern” Coast Range. The area between Newport and the North Umpqua River is referred to as the “central” Coast Range, and old-growth and inventory data from this area were compared with data collected in the northern area. The Coast Range consists of steep, dissected mountains ranging from sea level to 4,000 ft in elevation. Climate follows the regional pattern of cool, wet winters and warm, dry summers but varies significantly with elevation and distance from the coast. Forests along the coast are dominated by Sitka spruce and western hemlock, with most forests away from the coast dominated by Douglas-fir and western hemlock (Franklin and Dyrness 1973). Drier Douglas-fir, grand fir, and Oregon white oak communities occur in the eastern foothills of the range. The coastal stands are among the most productive forests in the world, with aboveground biomass production of 4.5 to 6.7 tons $\cdot$ ac⁻¹ $\cdot$ yr⁻¹ in mature (about 100-yr-old) stands (Gholz 1982).

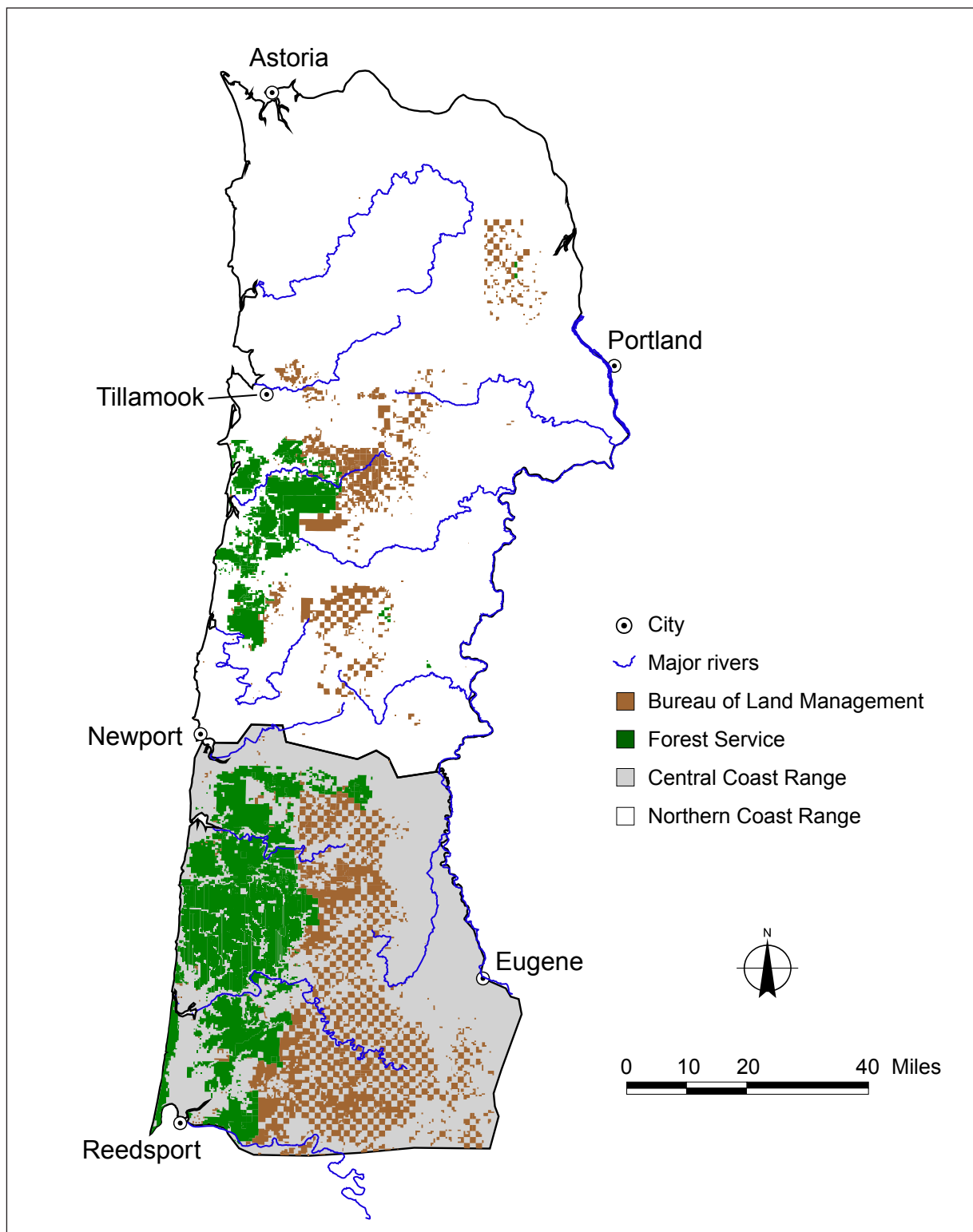


Figure 1—Study area showing delineation of northern and central Oregon Coast Range zones, lands managed by the Bureau of Land Management and the U.S. Forest Service, and selected cities.

Large high-intensity fires in the mid-1800s had a significant impact on the northern Coast Range (Holbrook 1943, Morris 1934, Teensma et al. 1991); much of the heavily burned land was designated national forest in 1905. Similarly, much of the Tillamook Burn of 1933 reverted to state ownership and was designated state forest. The valley margin has changed substantially in the last 150 years, from being open prairie-savanna maintained by Native American burning to being dominated by closed forests (and agriculture) (Thilenius 1968). The federal forest lands in the study area are administered by the USDA Forest Service (FS) and the USDI Bureau of Land Management (BLM). Much of the BLM lands are mixed with private industrial forest land in a checkerboard pattern.

Large high-intensity fires in the mid-1800s had a significant impact on the northern Coast Range.

Stand Selection and Measurement

An extensive effort was undertaken to locate old-growth stands on publicly owned lands across the climatic and vegetation gradient from the coast to the valley margin. The primary selection criterion was for stands with a fairly continuous distribution of trees greater than 40 in DBH over a 1-ha (2.47-ac) area. In some cases, the oldest stands found in a vegetation zone were sampled, even if many of the old-growth structural attributes were not apparent. Small patches (i.e., patches that did not cover most of a 1-ha circular plot), stands where dead trees had been salvage logged, and stands with scattered large trees at low density were not sampled.

Potential stands for sampling were identified by investigating a variety of sources, including initial models of stand size class from satellite images (Cohen et al. 2001), data from forest inventory plots, agency stand maps (developed from aerial photo-interpretation), aerial photos, word-of-mouth from agency employees and researchers, and published studies and reports (Greene 1982, Juday 1976, Quaye 1982, Thomas et al. 1993, Wood 1991). Potential sites were visited, and dominant trees were measured for diameter and increment-cored for age. Permission was obtained from the land managers for plot installation in the Cascade Head Scenic Research Area, in the BLM research natural areas (RNAs) and areas of critical environmental concern, and in Oregon State University's McDonald-Dunn Forest. Thirteen stands were selected and measured during the summers of 1997 and 1998 (table 1, fig. 2). No stands were identified in the northern half of the northern Coast Range study area. Within each stand, four points were identified and one was randomly selected as plot center; in most cases, however, stands were so small that the plot footprint would have overlapped substantially from any selected point. Large gaps (about 60 ft in diameter) fell within the plot area in three of the stands (VOG, Moon, and ElkCk), while part of a plot (about 0.25 ac) crossed into a younger age class in one of the stands (Rowell2).

Table 1—Locations and site characteristics of measured old-growth plots, and groupings used in some analyses

Site code	Site name	Owner ^a	Latitude	Longitude	Elevation	Precipitation ^b	Slope	Aspect	Slope position	Plant association ^c	Zone group	Moisture group ^d
					<i>Feet</i>	<i>Inches</i>	<i>Percent</i>	<i>Degrees</i>				
Nesk	Neskowin Crest	USFS	45.0741	-123.9793	1,200	110	41	73	Slope, upper 3 rd	PISI/OXOR	Spruce	
CliffCk	Cliff Creek	USFS	45.0631	-123.9830	1,500	112	30	297	Slope, upper 3 rd	PISI/OXOR	Spruce	
VOG	Valley of Giants	BLM	44.9402	-123.7108	1,300	137	11	193	Bench	TSHE/OXOR	Hemlock	Wet
Bear	Bear Creek	USFS	44.8813	-123.8500	1,180	118	59	150	Slope, lower 3 rd	TSHE/OXOR	Hemlock	Wet
LtGrass	Little Grass Mountain	BLM	44.7479	-123.5969	1,860	145	39	154	Bench	TSHE/OXOR	Hemlock	
Moon	Moon Creek	BLM	45.3410	-123.6623	1,320	110	71	181	Slope, lower 3 rd	TSHE/ACCI/POMU	Hemlock	Wet
ElkCk	Elk Creek	BLM	45.3050	-123.5675	1,400	107	41	200	Bench	TSHE/ACCI/POMU	Hemlock	Mesic
Rock	Rock Creek	USFS	44.9849	-123.9391	480	105	52	215	Slope, lower 3 rd	TSHE/GASH	Hemlock	Mesic
Rowell1	Rowell Creek #1	BLM	44.9808	-123.5805	1,300	88	54	215	Slope, middle 3 rd	TSHE/RHMA3-GASH	Hemlock	Mesic
Rowell2	Rowell Creek #2	BLM	44.9713	-123.5880	1,570	97	59	133	Slope, middle 3 rd	TSHE/MANE2-GASH	Hemlock	Mesic
Dorn	Dorn Peak	BLM	44.9767	-123.5507	2,030	90	49	154	Slope, upper 3 rd	TSHE/ACCI-COCO6	Hemlock	Dry
McDon1	McDonald Forest #1	OSU	44.6361	-123.3015	1,100	61	41	329	Slope, upper 3 rd	ABGR/COCO6/VAHE	Valley	Dry
McDon2	McDonald Forest #2	OSU	44.6269	-123.3154	1,200	65	31	29	Rounded ridge top	ABGR/COCO6/VAHE	Valley	Dry

^a USFS = U.S. Forest Service; BLM = Bureau of Land Management; OSU = Oregon State University.

^b Annual precipitation estimated from overlay of plot locations on PRISM maps (Daly et al. 1994).

^c Plant Associations determined from vegetation using McCain and Diaz (2002); species data and codes identified in appendix table 10.

^d Identified only for Douglas-fir-dominated stands >200 yr old.

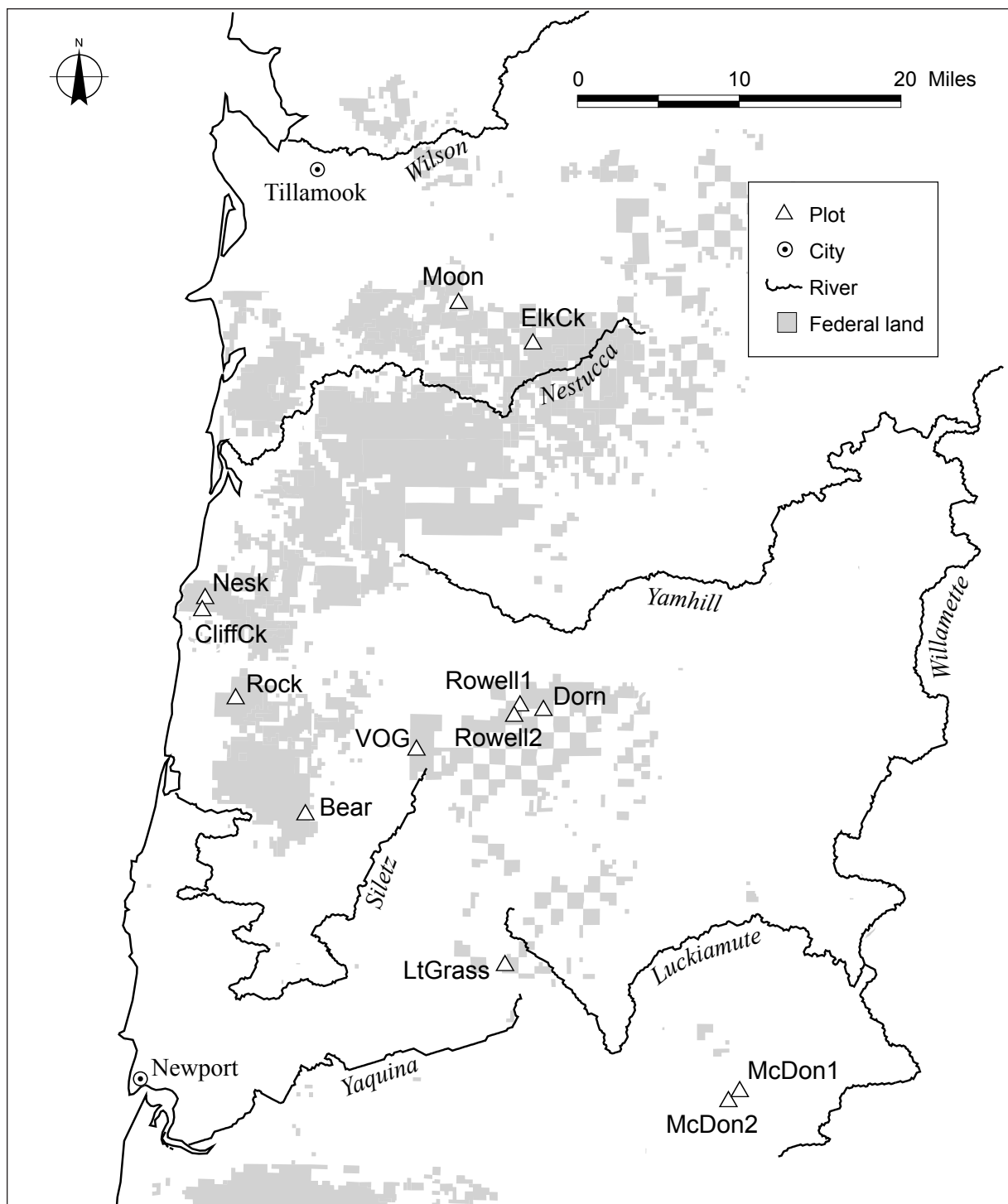


Figure 2—Location of old-growth plots sampled for this study in the northern Oregon Coast Range.

The field measurement protocol was based on the Current Vegetation Survey (CVS) forest inventory design used on federal lands at the time (Max et al. 1996). The plot design consisted of a cluster of five points within a 2.47-ac (1-ha) circle, with four points spaced 133.9 ft in cardinal directions from the central point. Slope, aspect, and slope position were recorded for each point. At each point, trees and snags of different sizes (<3 , 3 to 12.9, and 13 to 47.9 in DBH) were measured in a set of three nested plots of different sizes (0.01, 0.05, and 0.19 ac, respectively). In addition, all trees and snags ≥ 48 in DBH were measured on the full 2.47 ac. Owing to time limitations, all sampling was done using slope distances, and actual horizontal plot areas were calculated during analysis using the slope at each point. The use of slope distances resulted in horizontal plot areas that ranged from 81.5 to 99.3 percent of the nominal, 2.47-ac horizontal area for the 13 stands, with a mean of 90.6 percent. Up to three trees of each species across the range of diameters present were bored for age (largest borer used was 24 in long) and cores taken back to the lab for analysis. If available, nearby stumps of the same size classes were examined for age.

Logs were tallied using the line-intercept method on two transects oriented north-south and east-west, that crossed the width of the 2.47-ac plot, resulting in a total transect slope length of 740 ft, and the slope of each transect was measured. This sometimes resulted in the same log being tallied on two different transects, and the data were used from both samples. The common concern that sampling with multiple transects introduces bias is unfounded; estimates derived from each individual transect are unbiased and the mean of two unbiased estimates can never be biased (Woodall and Monleon 2008). Because plot centers are usually randomly located, multiple transects are a random sample of a stand; they are exactly analogous to sampling with a cluster of subplots, or a cluster of prism plots that occasionally tally the same large tree. There is a substantial body of literature on line-intercept sampling in which clusters of transects are used, and they appear to be most efficient in both variance reduction and field implementation (e.g., Bell et al. 1996, Hazard and Pickford 1986). Logs, or portion of logs, ≥ 3 in diameter were selected, and the species; decay class; large-end, intersect, and small-end diameters (or 3 in, whichever was greater); and length between small- and large-end diameters were recorded. The cover of each vascular plant species was recorded on three of the five points (the central point and two randomly selected from the remaining four) using the 0.05-ac plot size.

Other Data Sets

Plots were established in old-growth stands in the central Coast Range and areas south of the study area in the 1980s for the U.S. Forest Service, Pacific Northwest Research Station's Old Growth Wildlife Habitat Program (Spies and Franklin 1991; referred to as "OGWH" plots). Data from the OGWH plots were analyzed to compare old-growth attributes with stands sampled in the northern Coast Range for this study. In the OGWH study, stands 10 to 50 ac in area were selected to span a range of site-moisture conditions. Within each stand, up to five points were systematically located 100 or 150 m (328 or 492 ft) apart, depending on stand area. At each point, trees and snags of different sizes (<20 or ≥ 20 in DBH) were measured in two nested plots (0.12 and 0.25 ac, respectively). Portions of down wood pieces that fell within the 0.12-ac plot were measured. All sampling was done using slope distances, and actual horizontal plot areas were calculated during analysis using the slope at each point. Twenty-four stands in the Coast Range that were sampled with four or five points were selected for analysis. Roughly half of the plots used in the analysis were installed south of the study area, between Coos Bay and Reedsport.

Forest inventory plots that fell within the study area were analyzed to assess the distribution and abundance of old-growth structural characteristics on the landscape. The CVS plots were established on FS and BLM lands using the same basic plot design as that used in the north coast old-growth stands. The CVS plots were located on a systematic 1.7-mi grid (3.4-mi in wilderness) between 1993 and 2001. The only differences between the CVS and north coast field protocols were that one 51.1-ft-long line-intercept transect was used at each CVS point, resulting in a total transect length of 256 ft, and all lengths and plot areas were horizontally corrected for slope in the field. Five hundred and eighty-four CVS plots, on which at least four out of the five points were classified as forested plant associations (McCain and Diaz 2002), were selected for analysis.

In 2001, the Forest Inventory and Analysis (FIA) Program began installing a nationally standardized inventory across all forest lands in the region (Bechtold and Patterson 2004, USDA Forest Service 2006). The consistent plot design allows for more robust comparisons of attributes between federal and nonfederal lands than was possible using the CVS and earlier FIA inventories. Six-tenths of the plots on a systematic 3.3-mi grid were measured by FIA between 2001 and 2006 (all Western States are sampled on a 10-yr cycle). The plot design consisted of a cluster of four points within a 1-ha (2.47-ac) circle, with three points spaced 120 ft from center at 0, 120, and 240 degrees. At each point, trees and snags of different sizes (<5 , 5 to 30, and ≥ 30 in DBH) were measured in a set of three nested plots of different sizes

Forest inventory plots that fell within the study area were analyzed to assess the distribution and abundance of old-growth structural characteristics on the landscape.

(0.003, 0.04, and 0.25 ac, respectively). Woody debris was measured on two 58.9 ft-long transects per point, resulting in a total transect length of 471 ft. All lengths and plot areas were horizontally corrected for slope in the field. Two hundred and seventy-one FIA plots, on which at least 75 percent of the plot area was forested and in nonfederal ownership, were selected for analysis of nonfederal lands. The same criterion was applied to federal lands, resulting in 99 selected plots.

Data Analysis

All analyses of the northern Coast Range old-growth plot tree data were based on horizontal sample areas, calculated using the slope at each point and the (slope length) radius of each plot. The different plot areas were used to create a tree-level expansion factor (“tpa,” trees per acre), calculated as one divided by the horizontal sample area, in acres. Tree densities in different categories were calculated by summing tree tpa, and individual tree basal areas were multiplied by tpa before summing to the plot level. Calculations of quadratic mean diameter (QMD) and standard deviation of diameter used weighted means with tpa as the weight. Quadratic mean diameter was calculated for trees in dominant and codominant crown classes. Standard deviation of diameter was calculated separately as an indicator of canopy layering, using all live trees ≥ 1 in DBH; the divisor used for the calculation was the sum of weights (tpa) minus 1 (“vardef = wdf” in the MEANS procedure in SAS (1999)), which in effect provides an estimate of the standard deviation of DBH for a tree of mean tpa.

Descriptive statistics of forest structure and composition were calculated for each old-growth plot. Tree age at breast height was estimated for many of the large trees where the 24-in-long increment borer did not come near the pith. Missing age was calculated by extrapolating the growth rate of the two in nearest the pith to the missing distance to the pith (estimated as tree radius - core length). In cases where extrapolations were >100 yr, dominant or codominant trees of the same species and diameter as the uncored (e.g., relatively small diameter) portion of each tree were selected from regional inventory data (Waddell and Hiserote 2005) from plots in the Coast Range of similar site class, and the median age calculated. If this age was 25 percent different from the extrapolated age of the uncored radius, it was used for the age of the uncored portion instead. The ages on the smaller diameter trees are more accurate and may be a better indicator of maximum tree age (e.g., a 413-yr-old, 41-in DBH Douglas-fir compared to a 296-yr-old, 71-in DBH Douglas-fir on the Rock Creek plot). Some Douglas-fir trees were cored outside the stand being sampled to estimate timing of intermediate disturbances (ages noted with an asterisk in the diameter distribution graphs).

The slope of each transect and the transect slope length were used to calculate the horizontal length of each transect. Down log volume was calculated for each piece using the diameter-at-line-transect intercept. Highly decayed class-V logs were assumed to be flattened in cross section, with vertical diameter 0.439 times the measured horizontal diameter (Spies et al. 1988). Log biomass was calculated using the estimated log volume, species-specific wood densities from the Forest Products Laboratory (USDA Forest Service 1987), and decay-class biomass discounts from Waddell (2002). For class-V logs, the biomass discount for softwoods was based on the ratio for Douglas-fir (0.33), and the discount for hardwoods was based on the overall mean for multiple species (0.3) (Harmon and Sexton 1996). Volume per acre, mass per acre, and density were calculated from slope-corrected transect lengths (Woodall and Monleon 2008).

The variables used in the PNW-447 old-growth definition were calculated from the tree, snag, and woody debris data, except for the criterion of two or more tree species in a range of sizes and ages, which was not readily quantifiable. A few adjustments were made to apply the criteria to the broader range of forest composition found across the Coast Range. Because Sitka spruce often dominates early in succession in coastal stands, it was included in the calculation of the second criterion (“b”) as an estimate of large shade-intolerant tree density, and Pacific yew was included in the third criterion with the other shade-tolerant species. Because tree heights were only measured for a subset of trees, and crown ratio estimates were not very precise, the data were not suitable to assess crown layering directly. The standard deviation of tree DBH was used as an indicator of multilayered canopy, although no threshold was specified and the criterion was not included in the determination of old-growth status. The criterion related to down wood was split into two variables (mass and density) as not all of the data sets analyzed for this paper allowed calculation of log density.

Three indices of degree of “old-growthiness” were calculated with the northern Coast Range plot data: the canopy height diversity index (CHDI), (Spies and Cohen 1992), the old-growth index (OGI) (Acker et al. 1998), and the old-growth habitat index (OGHI; structure only, not using stand age) (Pabst 2005). The CHDI estimates crown area in different height classes, assigns weights that increase with height class, and sums values that result in an index ranging from 0 to 15. Tree heights were estimated from equations in Garman et al. (1995) assuming that all plots were of intermediate site class III. The OGI is based on values of standard deviation of DBH, density of early-seral trees >39.3 in DBH, density of all trees ≥ 2 in DBH, and mean DBH; the index is based on where the calculated values lie between the mean for selected young and old-growth stands, and ranges from 0

to 100. The OGHI is based on values of density of trees >39.3 in DBH, density of snags >19.6 in DBH and >49 ft tall, density of trees in four DBH classes (2 to 10, 10 to 20, 20 to 40, and >40 in) combined into a diameter distribution index, and volume of down wood. The OGHI index for a stand is based on where the calculated values lie in relation to the mean for selected young, mature, and old-growth stands in the Coast Range, and ranges from 0 to 100.

The same calculations and procedures were used on the other data sets (OGWH old-growth plots, and CVS and FIA inventories within the study area). Because these plots span an even greater range of composition than the northern Coast Range old-growth plots, the species used in criteria “b” and “c” were expanded. Noble fir and incense-cedar were included in the shade-intolerant species category, and California laurel was included in the shade-tolerant species category.

For some analyses of the different old-growth and inventory data sets, data were grouped into three forest zones, called “spruce,” “hemlock,” or “valley.” If Sitka spruce or lodgepole pine made up 5 percent or more of the basal area, the plot was classified as a “spruce” type. Otherwise, if western hemlock made up 5 percent or more of the basal area or if the plot was in the Coast Range ecoregion section (Cleland et al. 2005), then it was classified as a “hemlock” type. All remaining plots (in the margins of the Willamette Valley) were classified as “valley” types.

Results

Tree Composition and Structure

The northern Coast Range old-growth plots are described and shown in all figures and tables in order from moist to dry sites, as inferred from plant associations and topography. This generally meant a progression from west to east, particularly at the ends of the gradient (fig. 2), and from the spruce to hemlock to valley zones. Abbreviated plot names (“site codes”) are used in the figures, tables, and text; codes are defined in table 1.

The Neskowin Crest (Nesk) and Cliff Creek (CliffCk) plots were the only plots that were dominated by Sitka spruce; western hemlock was the only other species present (table 2). Sitka spruce trees tended to be the largest trees in each plot and were usually in the overstory canopy layer. Although spruce were abundant in the seedling pool (table 3), none were found in the 1 to 20 in DBH range (fig. 3a). Live and dead trees spanned the range of tree sizes at Nesk, whereas at CliffCk live trees occurred only in the middle size classes and snags occurred in the smallest size classes.

Table 2—Basal area of live trees and snags by site and species^a

Site code	PSME	TSHE	PISI	THPL	ABGR	TABR	ACMA	ALRU	CONU	UNKN	Total
<i>Basal area (ft²/ac)</i>											
Live trees:											
Nesk		185	186								371
CliffCk		98	415								513
VOG	300	212									512
Bear	290	187		53				12			542
LtGrass	320	115					8	6			449
Moon	254	134					6	3			397
ElkCk	250	123		0.3							374
Rock	333	221	1	2							557
Rowell1	311	99			1						410
Rowell2	227	209				8					444
Dorn	356	24					2				382
McDon1	179				11		47		0.4		237
McDon2	333				2		40				376
Standing dead trees:											
Nesk		80	29							16	124
CliffCk		14	10								25
VOG	190	23								23	236
Bear	162	16		24				2		7	210
LtGrass	168	14					1	7		3	192
Moon	176	27	4								207
ElkCk	103	14								17	134
Rock	121	121								17	259
Rowell1	57	12				24					93
Rowell2	168	18				12					198
Dorn	77	0.4						4		13	94
McDon1	12						9				21
McDon2	2						4				7

^a Species codes are defined in appendix table 9.

The rest of the plots were dominated by Douglas-fir. For the nine plots in the middle of the Coast Range moisture gradient (VOG, Bear, LtGrass, Moon, ElkCk, Rock, Rowell1, Rowell2, Dorn), the second-most important species was western hemlock (table 2). The only other species to constitute more than 5 percent of the basal area was western redcedar at Bear. Two of these plots (Rowell1 and Rowell2) also had a substantial component of Pacific yew, but most of these trees had been killed by having their bark removed, probably the result of bark collection for production of taxol, a cancer-inhibiting compound (Bolsinger and Jaramillo 1990). Red alder was found in two of the plots that had fairly large gaps in them and were close to perennial streams (Bear and Moon).

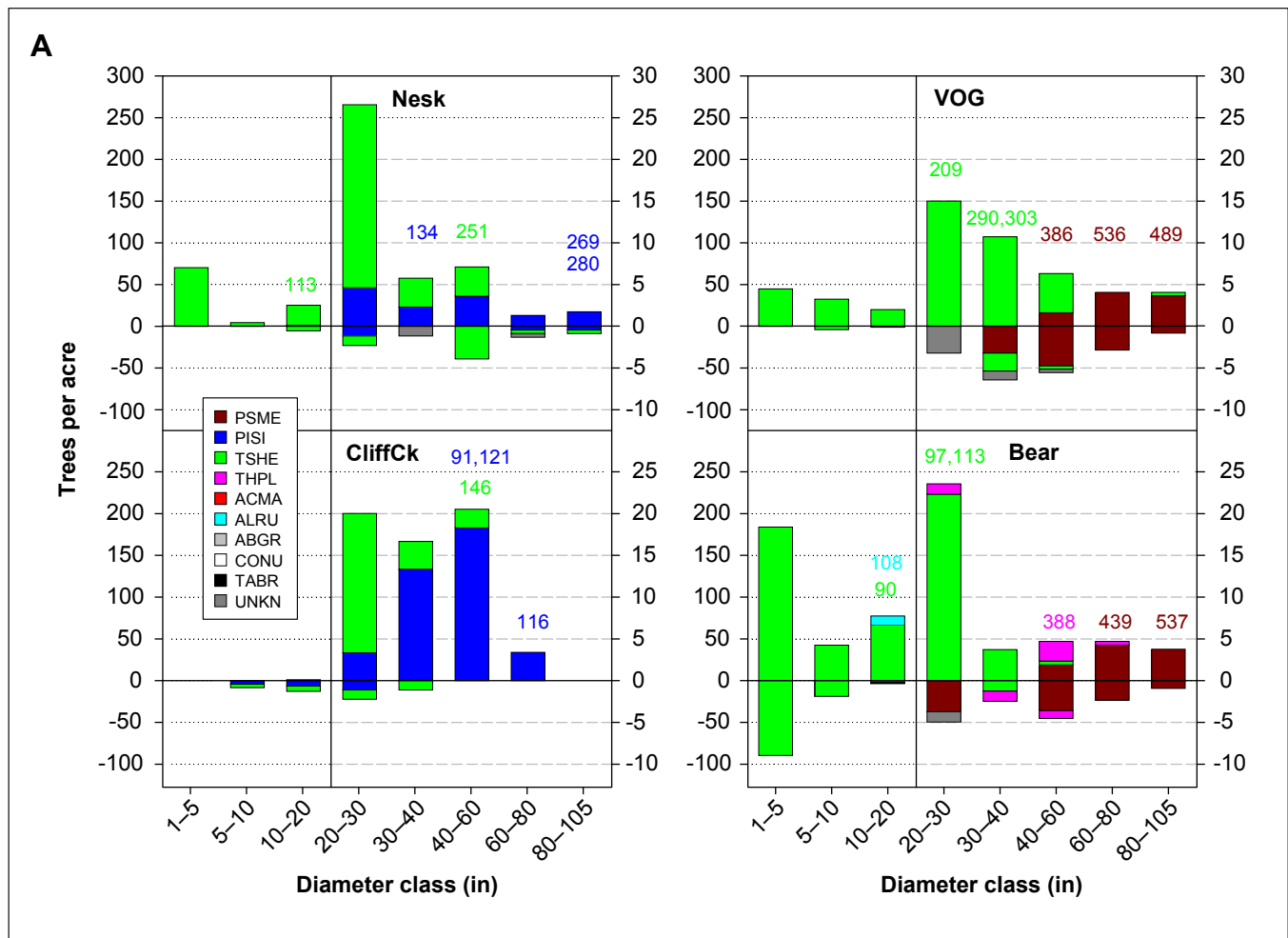


Figure 3 (a–d)—Density of trees by diameter class and species for sampled old-growth plots. Note the change in scale between diameter classes less than 20 in (left side of figure) or greater than 20 in (right side of figure). Species are designated by color (codes defined in appendix table 9), live trees are shown as positive values, standing dead trees (snags) as negative values, and numbers above bars are estimated ages for trees cored in the respective diameter class and species (indicated by color).

For most of the nine hemlock zone plots, Douglas-fir (and the occasional hemlock) was found in the largest size classes, and hemlock and other species were found in the intermediate and smallest size classes (fig. 3a–c). The exception was Dorn, where Douglas-fir occurred in all size classes. Despite its high elevation, abundant precipitation, and northerly aspect, this stand was located in a ravine that seemed to consist of exceedingly well-drained soils, and an abundance of dry-site shrubs grew there (e.g., vine maple, California hazel, oceanspray, and dwarf Oregon grape—see appendix). Except for Dorn, where Douglas-fir seedlings (trees <1 in DBH) were recorded, only hemlock was found in the seedling size class; no seedlings were detected at Moon or ElkCk (table 3). Snags were found across the range of diameter classes in most of the plots.

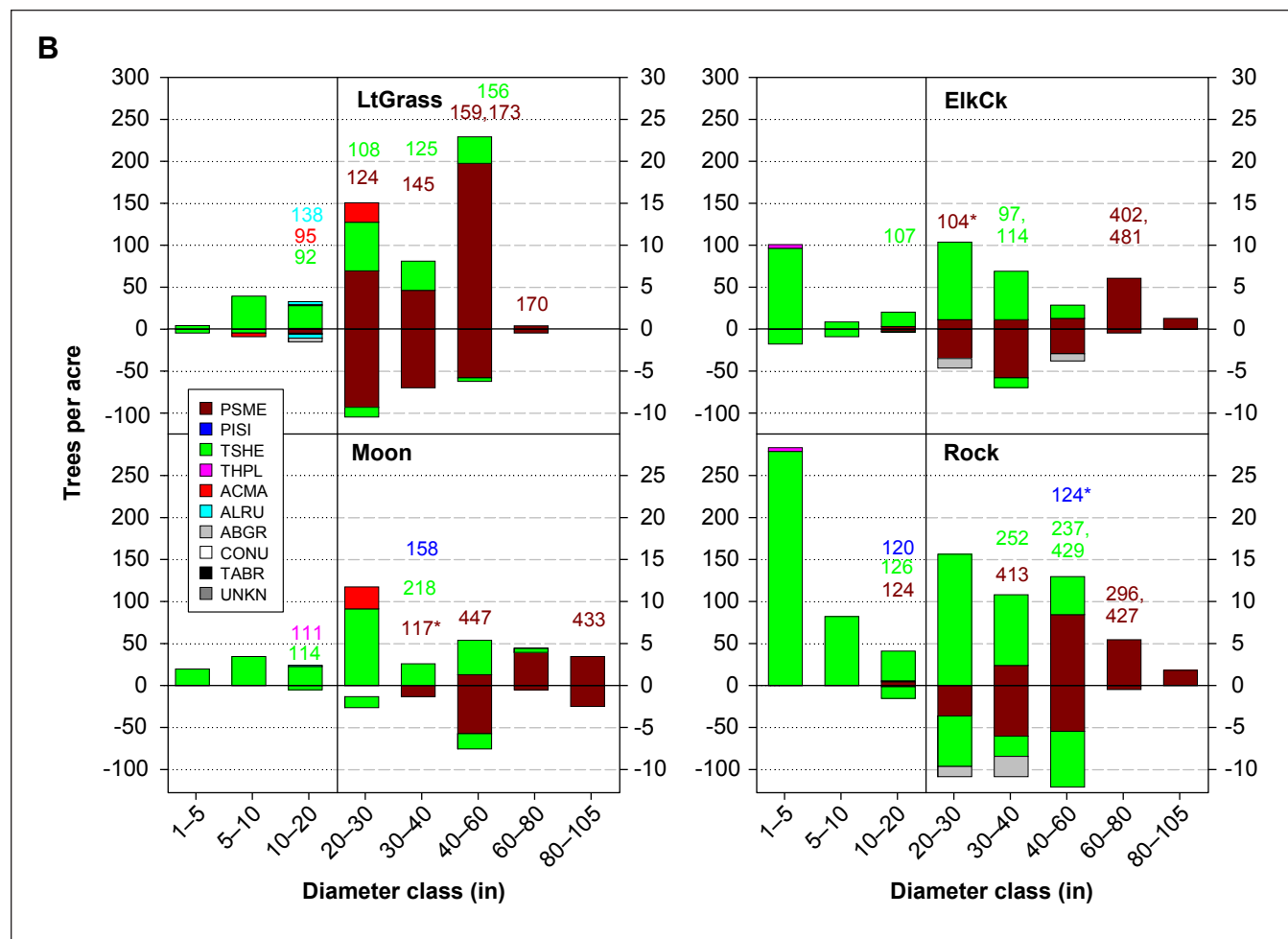


Figure 3—Continued.

The two plots in the Willamette Valley margin (McDon1 and McDon2) were dominated by Douglas-fir in the largest diameter classes, with substantial amounts of bigleaf maple and grand fir in the intermediate- and small-diameter classes (table 2, fig. 3c–d). No seedlings were recorded in either plot (table 3). Very few snags were present, and they tended to be in the smallest size classes.

Age Structure and Intermediate Disturbance

Pit-and-mound topography was evident at the Sitka-spruce-dominated sites (Nesk and CliffCk), probably a result of past windstorms in these coastal locations. The largest spruce and hemlock trees that were aged at Nesk ranged from 251 to 280 yr old, suggesting stand establishment following intense disturbance around 1710 (fig. 3a). Younger trees of both hemlock and spruce appeared to be present, raising the possibility that chronic wind disturbance created multiple opportunities for spruce

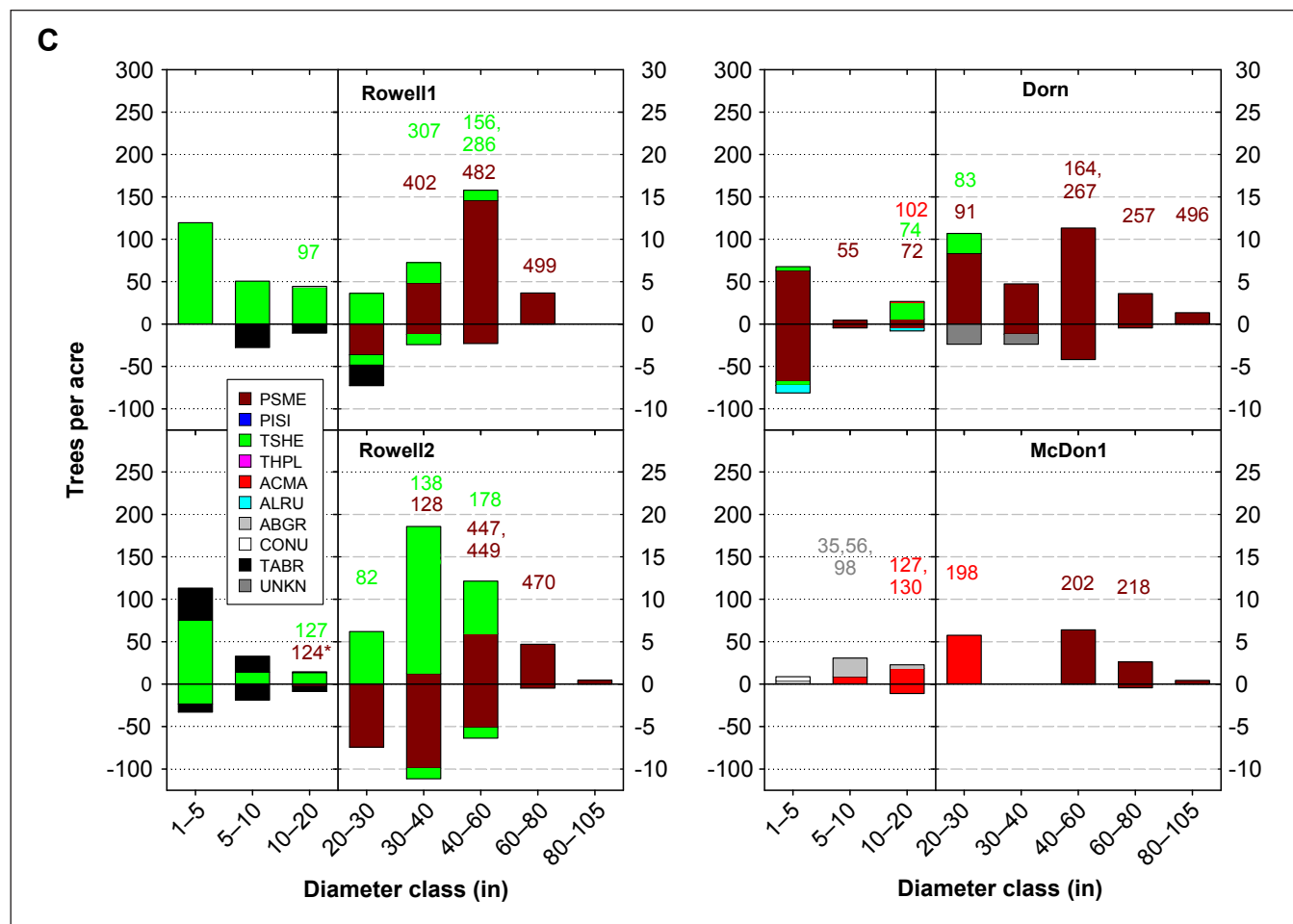


Figure 3—Continued.

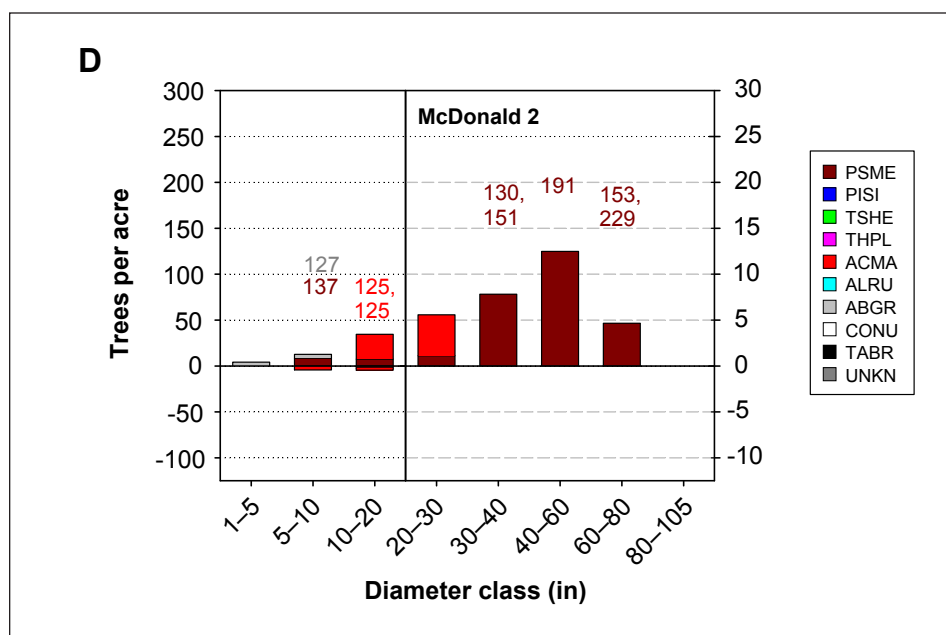


Figure 3—Continued.

Table 3—Density of seedlings (trees <1 in DBH) by site and species^a

Site code	PSME	PISI	TSHE	Total
<i>Trees per acre</i>				
Nesk		2,502	1,470	3,972
CliffCk		63	21	84
VOG			1,304	1,304
Bear			613	613
LtGrass			22	22
Moon				0
ElkCk				0
Rock			320	320
Rowell1			920	920
Rowell2			2,213	2,213
Dorn	248		45	293
McDon1				0
McDon2				0

^a Species codes are defined in appendix table 9.

regeneration, since spruce appears to be less shade-tolerant than hemlock (Minore 1979). The CliffCk plot was substantially younger than Nesk, with the largest aged trees ranging from 91 to 146 yr old. The lack of trees in small-diameter classes and the low volume of woody debris (table 4) suggest this stand experienced little mortality since establishing after an intense disturbance around 1850.

Table 4—Volume of down wood by site and decay class group^a

Site code	I and II	III and IV	V	Total
<i>Log volume (ft³/ac)</i>				
Nesk	5,830	1,109	407	7,346
CliffCk	364	1,719	304	2,387
VOG	6,221	19,302	532	26,055
Bear	4,916	4,283	303	9,502
LtGrass	787	4,405	180	5,371
Moon	1,660	3,557	307	5,523
ElkCk	2,170	6,786	469	9,425
Rock	5,857	4,483	1,097	11,437
Rowell1	2,001	5,084	21	7,106
Rowell2	21	4,148	1,962	6,131
Dorn	753	3,960	471	5,184
McDon1	1,928	630	0	2,559
McDon2	532	295	0	827

^a Decay classes described in Woodall and Monleon 2008.

The estimated maximum tree ages for eight of the nine mid-Coast Range sites ranged from 429 to 537 years old.

The estimated maximum tree ages for eight of the nine mid-Coast Range sites (excluding LtGrass) ranged from 429 to 537 yr old, suggesting these stands established following intense disturbances in the period 1460 to 1570 (fig. 3a–c). (The general stand age at VOG was corroborated by counting rings on a recent tree-fall that had been cut about 30 ft from the base where it crossed a trail; the age was estimated at 538 yr.) In most of these plots, the ages of the largest hemlock (and an occasional small Douglas-fir) were substantially younger than those of the dominant Douglas-fir; the hemlock and small Douglas-fir could have established following a moderate-intensity fire. If any hemlock had been present at the time of such a fire, most would have been killed. Char was noted on the bark of Douglas-fir in most of these eight plots, but not for VOG or Rock. Most of the codominant and intermediate hemlock at VOG appeared to have germinated on top of logs or snags, suggesting high levels of understory competition on the ground (Gray and Spies 1997), which might have occurred following a windthrow event. Several large trees at VOG fell over in recent windthrow events, possibly with root rot as a contributing factor. Despite being small and surrounded by substantially younger stands, the Rock stand appeared to not have experienced much disturbance in its history.

The maximum age of the LtGrass plot was substantially younger, at 173 yr, than the other mid-Coast Range sites. The aged dominant and codominant hemlock and Douglas-fir ranged in age from 108 to 173 yr, and char was noted on heavily-decomposed Douglas-fir snags, suggesting generally even-aged stand establishment following an intense fire around 1820.

The two plots in the Willamette Valley margin (McDon1 and McDon2) had maximum ages of 218 and 229 yr, respectively, indicating stand establishment in the late 1700s. (The general stand age at McDon2 was corroborated by counting rings on three stumps in an adjacent clearcut; estimated ages ranged from 190 to 200 yrs.) Tree density was lower in these plots than in most of the other plots in this study, and the largest Douglas-fir had large dead limbs less than 20 ft above the ground, indicating a long period of growth in open conditions. The low abundance of snags and down wood in older decay classes (table 4) suggests these stands may have slowly filled in from a previously nonforest grassland/savanna condition.

Old-Growth Criteria and Indices

Most of the plots sampled for this study exceeded most of the PNW-447 criteria for old-growth structure (table 5, fig. 4). All except Nesk had more than eight shade-intolerant trees per ac (tpa) ≥ 32 in DBH (and Nesk was close at 7.8). However, old-growth criteria have not been developed specifically for coastal Sitka spruce-western hemlock stands, where both species commonly establish during stand

Table 5—Stand characteristics, old-growth criteria and old-growth indices by plot

Variable	Old-growth criteria	Nesk	CliffCk	VOG	Bear	LtGrass	Moon	ElkCk	Rock	Rowell1	Rowell2	Dorn	McDon1	McDon2
General stand structure:														
Maximum tree age (yr)		280	146	536	537	173	447	481	429	499	470	496	218	229
Quadratic mean DBH dominants and codominants (in)		40.2	41.6	49.2	40.2	38.1	45.8	47.9	37.6	43.4	40.0	43.5	45.1	47.6
Maximum tree DBH (in)		97.4	75.1	101.2	92.3	64.0	100.0	93.6	91.9	72.7	83.0	89.8	90.8	70.9
Standard deviation DBH (in)		16.8	12.4	20.0	14.1	15.7	19.6	17.3	12.6	14.2	16.2	18.1	16.6	17.6
Maximum tree height (ft)		244	185	258	220	219	248	241	286	223	214	179	247	222
Herb cover (percent)		73	85	65	47	67	57	37	16	2	6	5	74	80
Shrub cover (percent)		10	18	30	11	3	16	31	43	50	56	72	42	37
Old-growth criteria (PNW-447):														
Intolerants ≥ 32 in DBH (n/ac)	8	7.8	33.9	9.4	9.9	24.8	8.7	9.9	17.0	23.1	11.1	18.7	9.4	25.0
Tolerants ≥ 16 in DBH (n/ac)	12	37.0	23.3	39.4	51.7	20.6	24.2	22.4	39.4	14.5	37.2	3.6	18.4	8.9
Canopy layers	2													
Snags ≥ 20 in DBH and ≥ 15 ft tall (n/ac)	4	7.5	2.2	13.0	8.9	11.6	7.9	11.1	18.4	5.9	12.6	3.0	0.4	0
CWD mass (ton/ac)	15	71.6	18.8	270.4	91.2	37.8	56.5	93.9	112.6	67.6	41.4	37.9	26.9	8.8
CWD ≥ 24 in dia. (lg. end) and ≥ 50 ft long (n/ac)	4	4.1	4.2	24.5	11.4	10.4	3.8	14.6	8.3	6.2	2.5	5.2	1.6	1.4
Old-growth indices:														
Canopy Height Diversity Index ^a		9.1	7.1	14.0	13.3	9.6	13.8	13.2	13.8	11.4	11.7	10.8	5.6	8.6
Old-Growth Index ^b		97	99	100	80	100	100	97	50	88	98	100	100	100
Old-Growth Habitat Index ^c		82	79	91	91	92	84	88	99	90	86	85	60	56

Note: Values in boldface fall below the old-growth criteria.

^a Spies and Cohen 1992.

^b Acker et al. 1998.

^c Pabst 2005.

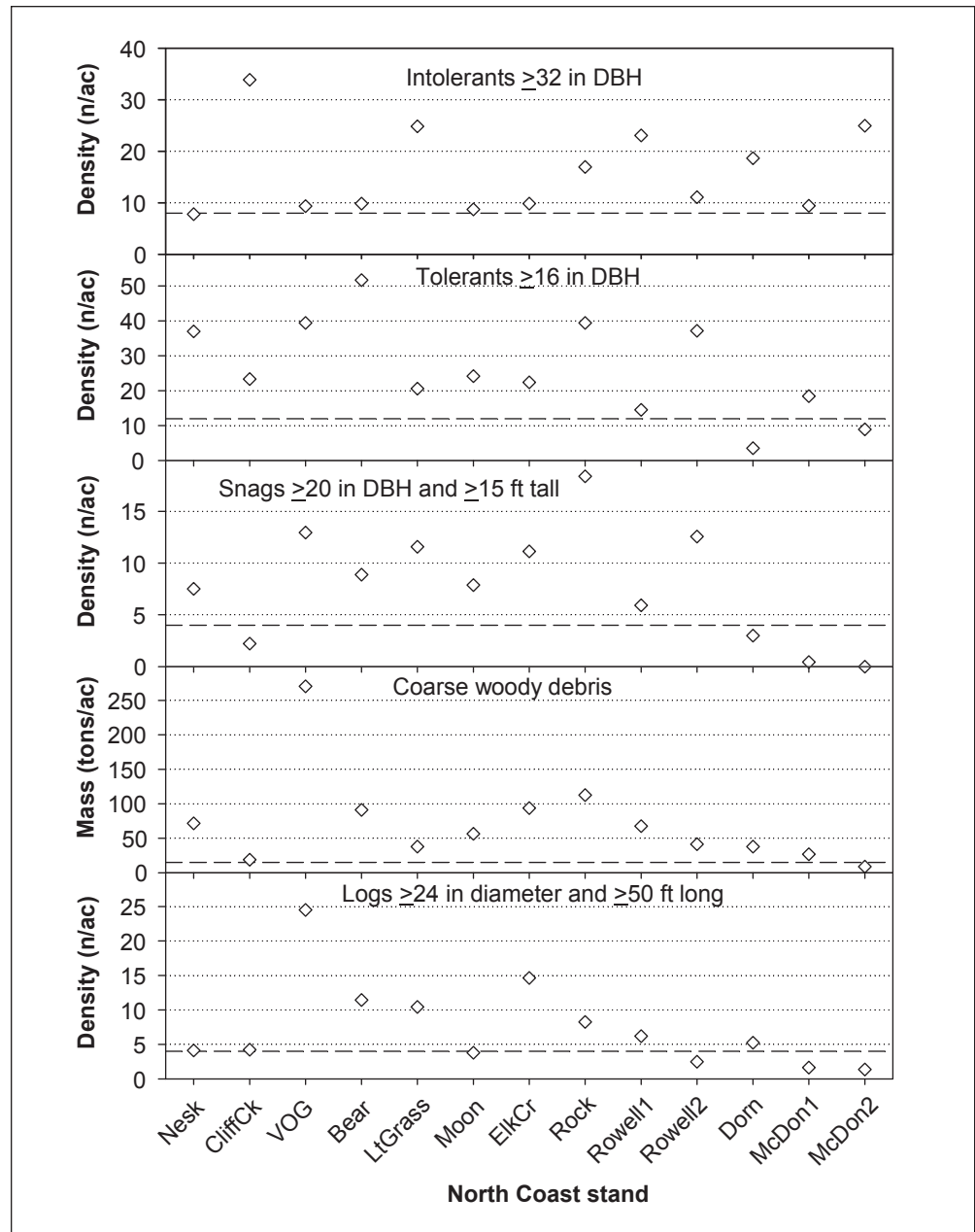


Figure 4—Values for old-growth criteria in PNW-447 (Franklin et al. 1986) for old-growth plots sampled in this study. Horizontal dashed lines mark the thresholds for moist Douglas-fir old-growth forests given in PNW-447.

initiation or following intermediate disturbances. For both western hemlock and Sitka spruce, the density of trees ≥ 32 in DBH at Nesk was 13.6 per acre. All plots except Dorn and McDon2 met the criteria of ≥ 12 shade-tolerant tpa ≥ 16 in DBH. As mentioned above, Dorn appeared to be a very dry site despite having an understory plant community keying out to the hemlock zone (species are in appendix, table 10; keys are from McCain and Diaz 2002). Both Dorn and McDon2 met the less

stringent PNW-447 criterion for dry Douglas-fir forests by having Douglas-fir or grand fir present in intermediate and small size classes.

Most of the plots met the PNW-447 snag criterion (≥ 4 snags per acre ≥ 20 in DBH and ≥ 15 ft tall). The exceptions included three relatively young plots (CliffCk, McDon1, and McDon2) and Dorn (which did meet the less stringent one-per-acre criterion for dry Douglas-fir forests). All except McDon2 had more than 15 tons/ac of down wood, but four plots did not meet the large log density criteria (Moon, Rowell2, McDon1, and McDon2).

Six of the thirteen plots met all five of the old-growth criteria examined here, while ten plots met four of the five criteria. Using the dry-site criteria for Dorn, McDon1, and McDon2 meant that Dorn met all criteria but McDon1 and McDon2 still fell short of the necessary levels of down wood and snags. This is not too surprising given the relative youth of these plots (about 200 yr old) and their likely establishment in a previously nonforested site. However, the two other relatively young plots (CliffCk and LtGrass) met most or all of the old-growth criteria.

The standard deviation of DBH, a possible surrogate for canopy layering, ranged from 12.4 to 20.0 (table 5). Different plots seemed to have similar values for very different reasons. The three plots with the lowest values were CliffCk, Bear, and Rock. While CliffCk had a narrow diameter range, Rock and Bear had wide diameter ranges but high densities in the smallest size class and moderate densities in the intermediate classes, suggesting substantial canopy layering. The plots with the highest standard deviations were VOG, Moon, and Dorn, and all tended to have the most even distribution of tree densities across a wide range of size classes, suggesting high levels of canopy layering.

The Canopy Height Diversity Index (CHDI) ranged from 5.6 to 14.0, with the highest scores going to those plots with the highest densities of the largest Douglas-fir (VOG, Moon, and Rock), reflecting the higher weights given to the largest trees (table 5, fig. 5). Plots with low CHDI scores either had few trees in the largest diameter classes or no Douglas-fir, so estimated tree heights were low (CliffCk and Nesk), or tree densities were low in general (McDon1 and McDon2). The Acker et al. (1998) Old-Growth Index (OGI) did not vary much among the plots and differed substantially from the other indices. The Rock plot had the lowest OGI score. The high density of small trees in this plot led to high total tree density and low mean DBH, resulting in low scores for those attributes. The Old-Growth Habitat Index (OGHI)(Pabst 2005) scores ranged from 56 to 99. In this case, the Rock plot had the highest OGHI score, caused by the high density of trees in all size classes, high density of snags, and high volume of down wood. The lowest scores were for McDon1 and McDon2, caused primarily by the low levels of down wood and snags.

Six of the thirteen plots met all five of the old-growth criteria examined here, while ten plots met four of the five criteria.

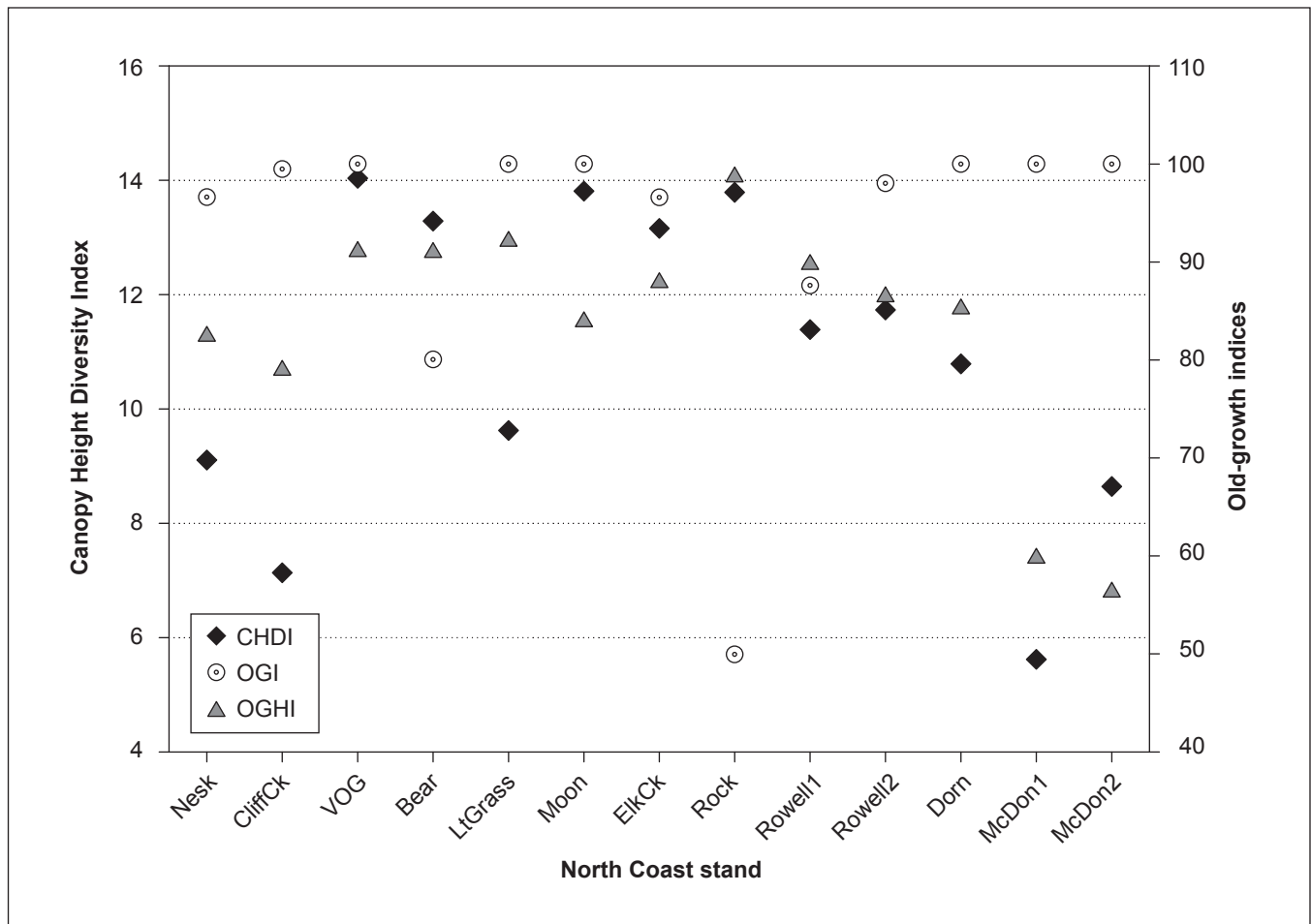


Figure 5—Values for three different old-growth indexes for the old-growth plots sampled in this study. CHDI = Canopy Height Diversity Index (Spies and Cohen 1992), OGI = Old-Growth Index (Acker et al. 1998), Oghi = Old-Growth Habitat Index (Pabst 2005). Values for CHDI are shown on the left axis and values for OGI and Oghi on the right axis.

The other relatively young plots, CliffCk and LtGrass, had relatively high scores that were similar to older plots.

Comparison With Old-Growth Wildlife Habitat Plots

The Old-Growth Wildlife Habitat (“OGWH”) plots from the central Coast Range and areas to the south were grouped into moisture classes by Spies and Franklin (1991), based on plant associations. Applying the same moisture classes to the northern Coast Range (“NCoast”) plots dominated by Douglas-fir and ≥ 200 yr old classified Dorn, McDon1, and McDon2 into the “dry” category; ElkCk, Rock, Rowell1, and Rowell2 into the “mesic” category; and VOG, Bear, and Moon into the “wet” category (table 1). The OGWH plots were younger on average than the NCoast plots, with several in the 200- to 300-yr age class and only 2 of the 24 stands with ages greater than 450 yr old (table 6). Although we found few stands

Table 6—Comparison of selected attributes of old growth stands from this study (NCoast) and from the stands sampled in the Old-Growth Wildlife Habitat Program (OGWH)^a

	Dry		Mesic		Wet	
	OGWH	NCoast	OGWH	NCoast	OGWH	NCoast
Stand age (yr)	276 (48)	314 (157)	384 (98)	470 (30)	310 (55)	507 (52)
Basal area (ft ² /ac)	336 (43)	331 (82)	362 (104)	446 (79)	318 (55)	483 (77)
Quadratic mean DBH of dominants (in)	38.9 (4.8)	45.4 (2.1)	38.2 (5.6)	42.2 (4.5)	41 (8.3)	45.1 (4.6)
Intolerants ≥32 in DBH (n/ac)	20.4 (5.2)	17.7 (7.8)	14.5 (10.3)	15.3 (6.1)	13.8 (7.7)	9.3 (0.6)
Tolerants ≥16 in DBH (n/ac)	4.1 (4.3)	10.3 (7.5)	18.8 (11)	28.4 (11.9)	17.6 (13.8)	38.4 (13.8)
Standard deviation DBH (in)	14.3 (3.2)	17.5 (0.8)	13.6 (3.6)	15.1 (2.1)	15.3 (3.6)	17.9 (3.3)
Snags ≥20 in DBH and ≥ 15 ft tall (n/ac)	2.7 (1.8)	1.1 (1.6)	3.6 (3.1)	12 (5.1)	4.6 (3)	9.9 (2.7)
Coarse woody debris mass (ton/ac)	19.7 (12)	24.5 (14.7)	32.6 (21.5)	78.9 (31.1)	32.1 (11.4)	139.4 (114.8)

^a Means (with standard deviations in parentheses) are shown by site moisture class (n = 3 or 4 for NCoast, 8 for OGWH).

in the NCoast in the 200- to 300-yr age class, it is possible that stand selection was more focused on older stands in the north. Stand basal areas were similar in dry stands, but substantially higher for NCoast wet stands than for OGWH wet stands. The density of shade-intolerant trees was slightly higher and the density of shade-tolerant trees was substantially lower in the OGWH plots than in the NCoast plots. The higher standard deviation of DBH for the NCoast plots probably results from the higher density of shade-tolerant trees. NCoast plots in the mesic and wet classes had substantially greater density of snags and mass of coarse wood than the OGWH plots.

Comparison With Forest Inventory Plots

Most of the forests in the Coast Range were smaller in mean diameter than the old-growth plots. Quadratic mean diameters greater than 40 in were found on 2.7 percent of the CVS inventory plots on federal lands, and 0.4 percent of the FIA plots on nonfederal lands (fig. 6). (FIA plots on federal land are not shown in fig. 6 because the lower number of plots sampled to date [n = 99] distributed among the 30 diameter/location classes resulted in an irregular frequency distribution.) The proportion of plots in different size classes on federal lands was more balanced in the central Coast Range than in the northern Coast Range. The proportion of plots in the >30 in QMD classes declined from the spruce to the hemlock to the valley zones. Inventory plots in the >30 in QMD classes on federal lands had substantially lower basal areas than those found on the old-growth plots (table 7). Mean basal areas by stand size class were similar between federal and nonfederal inventory plots, however. In addition, the federal land estimates for basal area were similar for the CVS and FIA inventory plot designs.

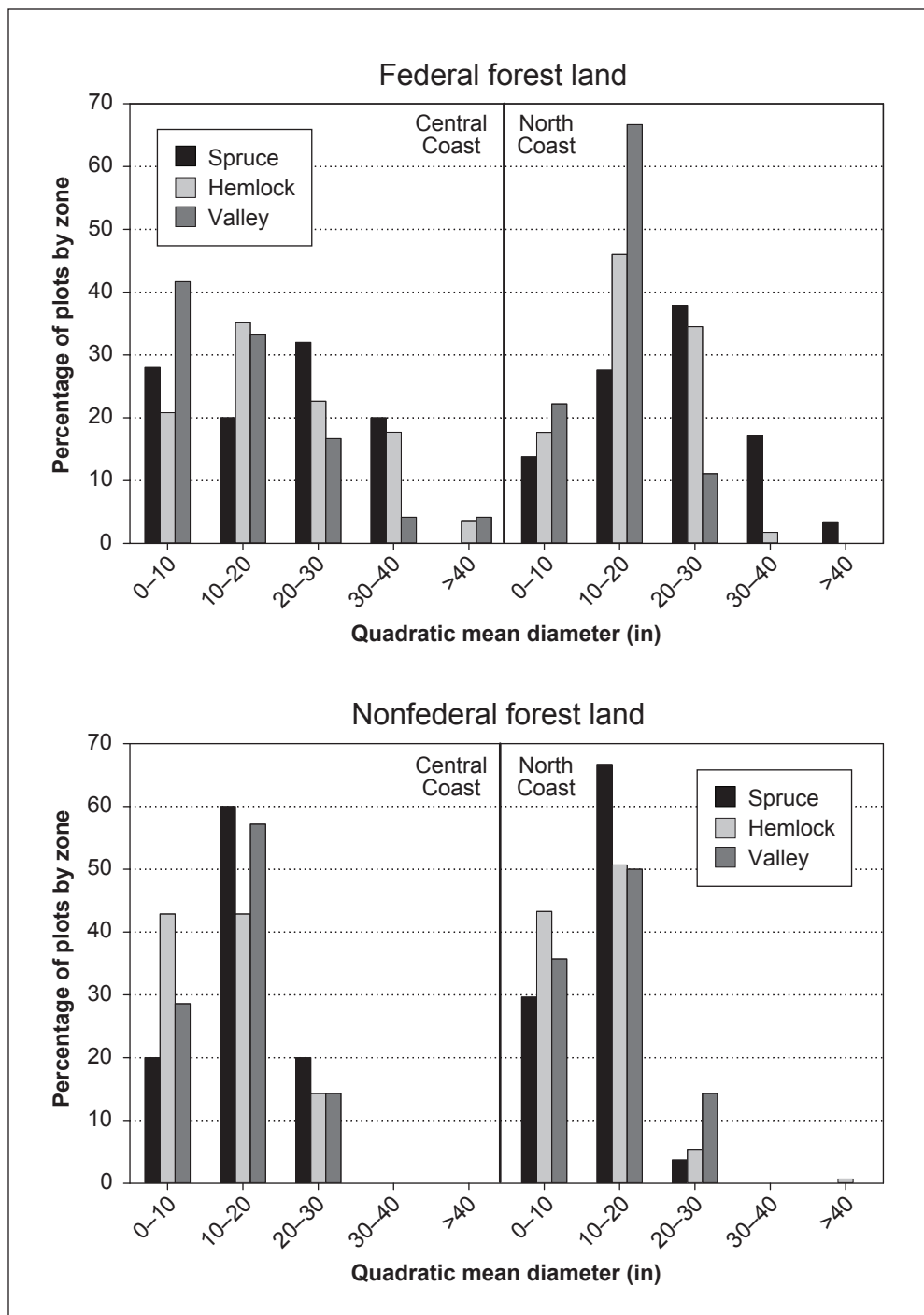


Figure 6—Distribution of Current Vegetation Survey inventory plots on federal land and Forest Inventory and Analysis (FIA) inventory plots on nonfederal land in the northern and central Oregon Coast Range by quadratic mean diameter and vegetation zone. The FIA plots on federal land are not shown because the lower number of plots sampled to date ($n = 99$) resulted in an irregular frequency distribution among the 30 classes in this figure.

Table 7—Mean live tree basal area on inventory plots on federal and nonfederal lands by inventory type and stand quadratic mean diameter class (standard deviation in parentheses)^a

Stand diameter class	Federal lands, CVS ^b inventory	Federal lands, FIA ^c inventory	Nonfederal lands, FIA inventory
<i>Inches</i>	<i>----- Basal area (ft²/ac) -----</i>		
0–10	67 (54)	97 (58)	73 (63)
10–20	170 (63)	179 (65)	173 (67)
20–30	235 (74)	217 (83)	226 (97)
30–40	281 (85)	261 (102)	—
>40	291 (63)	276 (67)	105 (0)

^a Number of plots for each inventory type and owner group from left to right were 584, 271, and 99.

^b CVS = Current Vegetation Survey.

^c FIA = Forest Inventory and Analysis.

Because of differences in plot design, old-growth attributes on federal lands are shown for both the CVS and FIA inventories; the CVS results are most comparable with the northern Coast Range old-growth plots, and the FIA results are most comparable with the nonfederal FIA plots. On federal lands, 1.7 percent of the CVS inventory plots exceeded all five of the PNW-447 thresholds evaluated, while 7.0 percent exceeded at least four of the five thresholds (for FIA plots, the figures were 0 percent and 11.1 percent, respectively). The threshold for density of large shade-intolerant trees was exceeded on 28 percent of the CVS plots, whereas the threshold for density of shade-tolerant trees was only exceeded on 14 percent of the CVS plots (fig. 7a; for FIA plots, the figures were 25 percent and 23 percent, respectively). The large snag criterion was met on 22 percent of the CVS plots and 20 percent of the federal FIA plots. Interestingly, at least one live tree ≥ 48 in DBH was recorded on 41 percent of the CVS plots and 38 percent of the federal FIA plots. Standard deviation of DBH was greater than 12 in (the lower end value for the old-growth plots) on 15 percent of the CVS and federal FIA plots (fig. 7b). The PNW-447 thresholds for coarse wood mass and density of large logs were exceeded on 35 percent and 17 percent of the CVS plots, and 44 percent and 12 percent of the federal FIA plots, respectively. Five percent of the CVS and federal FIA inventory plots on federal lands had an OGHI score of 70 or greater.

Old-growth forest attributes were less common on nonfederal lands than on federal lands. None of the inventory plots met all five of the PNW-447 thresholds, while 1 out of 271 (0.4 percent) met four and 4.4 percent met three. The thresholds for large shade-intolerant tree density and large snag density were met on 2 percent and 6 percent of the plots, respectively, whereas the threshold for shade-tolerant density was met on 18 percent of the plots (fig. 7a). However, 5.5 percent of the plots

On federal lands, 1.7 percent of the CVS inventory plots exceeded all five of the PNW-447 thresholds evaluated, while 7.0 percent exceeded at least four of the five threshold.

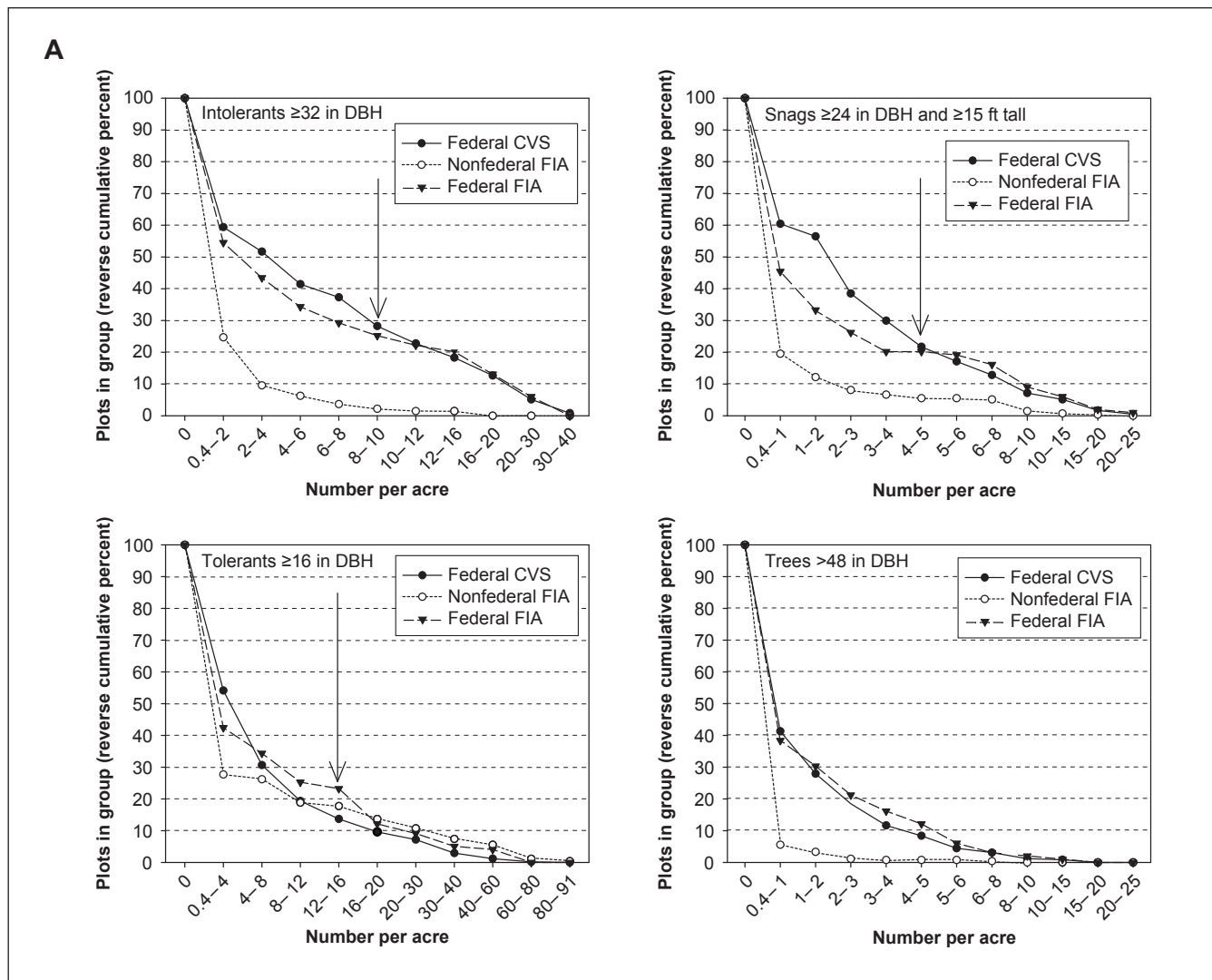


Figure 7—Abundance of selected old-growth structural characteristics on Current Vegetation Survey (CVS) and Forest Inventory and Analysis (FIA) inventory plots on federal and nonfederal land in the northern and central Oregon Coast Range. Figures are reverse cumulative distributions; each point on the line shows the percentage of plots that exceeded the value on the horizontal axis. The thresholds suggested for old-growth in PNW-447 (Franklin et al. 1986) are shown with an arrow.

had at least one tree ≥ 48 in DBH recorded on them. Standard deviation of DBH was greater than 12 in (the lower end value for the old-growth plots) on 1.5 percent of the plots (fig. 7b). Whereas the PNW-447 threshold for coarse wood mass was exceeded on 35 percent of the plots, the threshold for density of large logs was met on only 3.3 percent of the plots. One (0.4 percent) of the inventory plots on nonfederal lands had an OGHl score of 70 or greater.

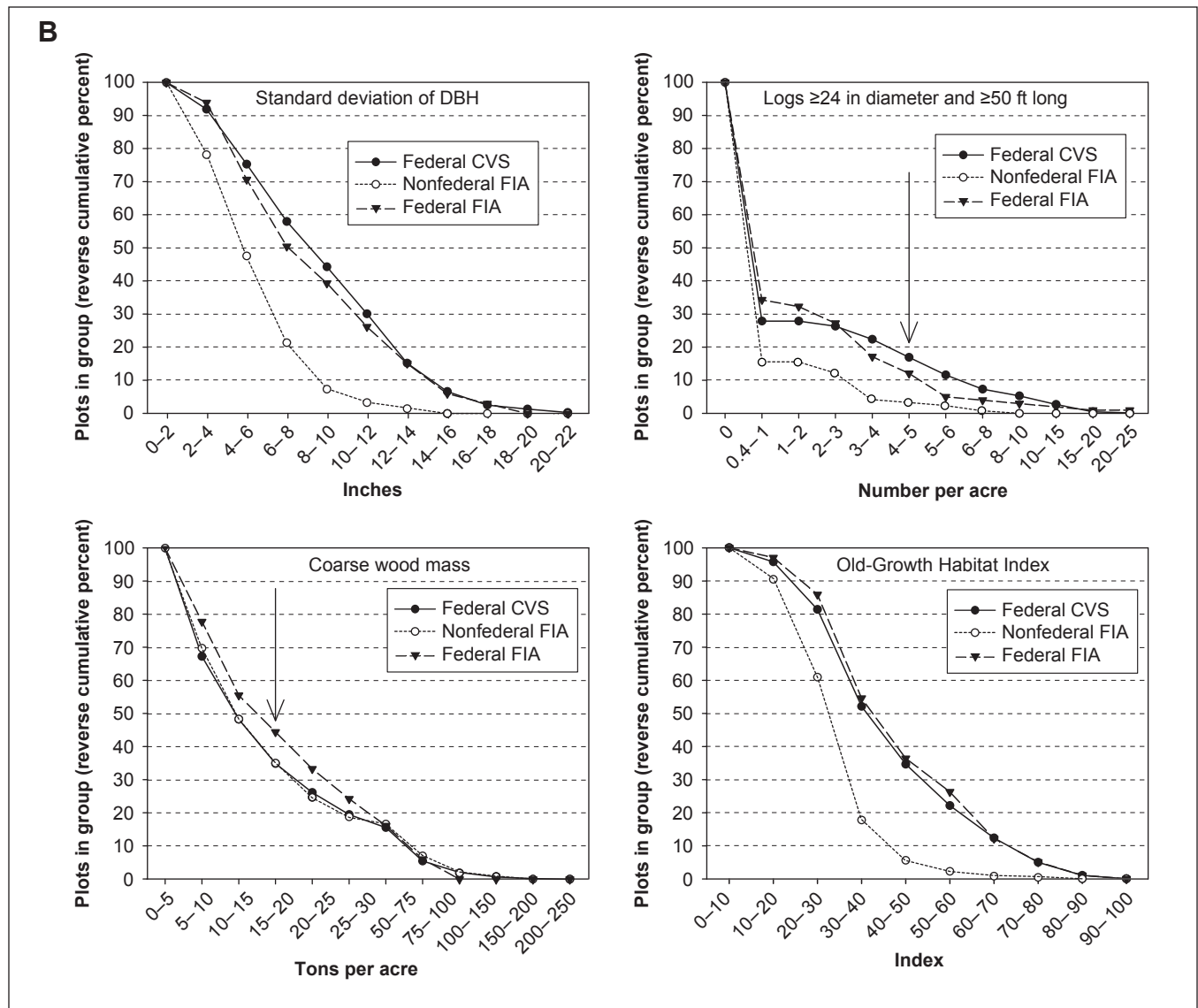


Figure 7—Continued.

There is a common perception that mature stands in the Coast Range are lacking in shade-tolerant mid- and under-story trees. Additional analyses were conducted on the abundance of shade-tolerant trees, and hemlock in particular, for inventory plots in the hemlock zone with QMD ≥ 20 in. The proportions of these plots with hemlock basal area less than 10 percent of the total basal area were estimated as 81 percent, 66 percent, and 75 percent for federal CVS, federal FIA, and nonfederal FIA plots, respectively (table 8). Estimates of the density of hemlock seedlings and saplings were 47, 58, and 23 tpa for federal CVS, federal FIA, and nonfederal FIA plots, respectively.

Table 8—Measures of shade-tolerant tree abundance, and of hemlock alone, on inventory plots in the hemlock zone with quadratic mean diameter ≥ 20 in^a

Variable	Federal lands, CVS ^b inventory	Federal lands, FIA ^c inventory	Nonfederal lands, FIA inventory
Number of plots	210	35	16
Percentage of plots by amount of hemlock:			
Plots with hemlock basal area = 0	38.1	45.7	56.3
Plots with hemlock basal area <10 percent	42.9	20.0	18.8
Plots with hemlock basal area ≥ 10 percent	19.0	34.3	25.0
Mean hemlock basal area (percent)	6.2 (0.8)	12.6 (3.4)	9.7 (5.4)
Mean shade-tolerant basal area (percent)	14.2 (1.2)	19.7 (3.9)	24.2 (9)
Mean hemlock seedling+sapling density (n/ac) ^d	47 (10)	58 (29)	23 (11)
Mean shade-tolerant seedling+sapling density (n/ac) ^d	58 (12)	58 (29)	37 (17)

^a Means are shown with standard errors in parentheses.

^b CVS = Current Vegetation Survey.

^c FIA = Forest Inventory and Analysis.

^d Seedlings and saplings are trees ≥ 0.5 ft tall and < 5 in DBH.

Discussion

Our study of old-growth forest in the northern Oregon Coast Range found substantial variation in stand structure, composition, and disturbance history across the different ecological zones from west to east. The detailed descriptions of individual old-growth plots could provide useful reference points for stands being managed for late-successional attributes in this area, where such information has been lacking. Our results suggest differences between stands studied in the northern Oregon Coast Range and areas to the south, which may result from differences in fire history and site productivity. Our analysis indicates that published indices of old-growth do not behave similarly and may be useful for different purposes. Finally, the analysis of inventory data indicates the overall abundance of different late-successional forest attributes in the region. We first discuss some of the limitations of the analyses before addressing the results in greater detail.

Limitations of the Comparisons

The attributes of a forest are rarely fully enumerated. Instead, they are measured with plots and are thus subject to sample error. For example, just by chance, five fifth-acre plots may detect no large snags in a 40-ac stand in which the true density is four per acre. Therefore all analyses that use individual plots as representative of stand conditions should be interpreted with caution. There is also some ambiguity for the size of area or the criteria used to delineate a “stand,” so that the true stand attributes could differ, depending on whether one included riparian zones or stand

edges with reduced large-tree density. Every forest attribute that is either measured or calculated at the plot level is sensitive to the size of plot (or length of transect) with which the data were collected (Gray 2003). For example, if there was a target of ≥ 10 small trees per acre (tpa) and the plot area for small trees was one-sixth of an acre, the estimated densities for tallies of 0, 1, 2, or 3 trees would be 0, 6, 12, or 18 tpa. However, the improvement in accuracy that results from using larger plot sizes levels off eventually, particularly for attributes that are abundant (e.g., sampling a tree size class present at 500 tpa will result in essentially the same estimate whether one uses a 1-ac plot or a 0.25-ac plot). Most sample protocols deal with this by using larger plots for attributes that are either rare or more important and smaller plots for those that are abundant or less important. These effects must be kept in mind when comparing individual-plot results from studies that use very different plot designs.

This paper compares estimates of stand attributes obtained from studies that differed in how plots were selected and in the areas and transect lengths used for each plot. The old-growth studies selected specific stands that met some initial criteria for old growth and were not randomly selected from a population of objectively identified candidate stands. Although researchers attempted to select representative stands, inference to a larger population cannot be assumed. The inventory plots, on the other hand, were systematically located and constitute a true representative sample of the population of forested lands in the Coast Range. The studies also differed in the amount of within-plot variability encountered. Although there was some randomization in where old-growth plots were located within a stand, stand edges were avoided; in the north coast study, many stands were so small that there was only one relatively confined intact area where the plot was placed. In contrast, systematically placed inventory plots may straddle two or more stand conditions, or include features that are usually avoided in a targeted sample like rock outcrops, streams, or roads. Indeed an early study of natural “immature” (average age 80 yr) Douglas-fir stands in western Oregon and Washington found that randomly selected “real” stands had about 85 percent of the basal area that would be expected from “normal” (i.e., fully-stocked) stands, and that small openings consisting of creeks, rock outcrops, and unstocked areas amounted to about 6 percent of stand area (Meyer 1930). An alternative sampling approach that captures within-stand variability better than cluster plots is strip-transect sampling, which we have applied in large mature stands in the Coast Range (Monleon et al. 2002). The old-growth stands sampled for this paper were too small to be sampled well with strip transects, however. Thus, using the results from the old-growth plots as a target for management might be appropriate for a uniform, fully stocked stand condition, but are probably somewhat high for the average forest condition.

Using the results from the old-growth plots as a target for management might be appropriate for a uniform, fully stocked stand condition, but are probably somewhat high for the average forest condition.

Most of the plots appeared to have experienced at least one moderate-severity fire since establishment.

Old-Growth Stand Characteristics

The plots measured in the northern Coast Range differed substantially, illustrating the role of environment and history in shaping stand structure. Eight of the plots could be called “mature” or “classic” Douglas-fir old-growth, with trees ≥ 80 in DBH and ≥ 400 yr old, multiple species in a wide range of diameters, and abundant large snags and down wood. Despite relatively low densities of Douglas-fir in a few of these plots (VOG, Bear, Moon, ElkCk), Douglas-fir still dominates the plot in terms of basal area and, assuming background mortality rates, likely will continue to do so for some time. Most of the plots appeared to have experienced at least one moderate-severity fire since establishment, possibly resulting in most of the hemlock being substantially younger and smaller than the dominant Douglas-fir.

The two Douglas-fir plots in the Willamette Valley margin (McDon1 and McDon2) might be considered “early” old-growth based on age alone, but the developmental history of these stands puts them in a different ecological type and pathway. Those stands developed from an open-grown savanna and likely underwent frequent low-severity fire early in development, followed by heavy grazing in the late 1800s and early 1900s. As a result, they have fairly low tree densities in the overstory and understory, and low amounts of dead wood (snags or logs). It is not clear how different these stands would be if these locations had been forested longer, or if the disturbance regime had been different during development. Nor is it clear how unique they are, although forest encroachment on old savanna could be quite extensive in the Willamette Valley margins (Zybach 2003).

Although younger than the other Douglas-fir plots and with fewer trees in the ≥ 60 in DBH size, the LtGrass plot contained a diverse mix of species and tree sizes with an abundance of large snags and logs. The apparently high productivity and varied topography of this site, the establishment of hemlock and maple early in stand development, and the abundant wood legacy from a prior old-growth stand (14 class 4 and 5 snags ≥ 40 in DBH were recorded on the plot) contributed to its structural diversity.

The oldest of the two Sitka spruce plots shared many attributes with the Douglas-fir old-growth plots, although the number of large spruce was somewhat lower than the number of large Douglas-fir in the other plots. It is likely this plot experienced strong windstorms in the past that thinned the overstory sufficiently for spruce to establish and grow into the overstory. The younger spruce plot, despite having a large number of large spruce and hemlock and moderate levels of snags and logs, had the appearance of a mature stand rather than old growth. The lack of trees < 30 in DBH resulted in most of the tree canopy being in a single layer, rather than a multilayered arrangement.

Comparison With Other Coast Range Old-Growth Plots

The plots measured for this study in the northern Coast Range were older than the OGWH plots measured by Spies and Franklin (1991) in the central Coast Range and areas farther south, which may also explain the lower density of Douglas-fir and higher density of large shade-tolerant trees found in the north. The higher basal areas in the mesic and wet stands in the north might reflect differences more in sampling than in biology. In this study, 1-ha (2.47-ac) plots were installed in small remnant patches, whereas in the OGWH study, sample plots were distributed across larger stands, thus picking up more variation. Intermediate disturbances in the form of moderate-intensity fires appear to have played a role in old-growth forest composition and structure in both areas, particularly with increasing distance from the coast (Impara 1997).

Abundance of Old-Growth in the Coast Range

Most of the forests in the Oregon Coast Range have been heavily disturbed and are lacking many of the characteristics of old-growth forests. This is not surprising, given the large fires of the mid-1800s and 1933 (Morris 1934), the creation of public forests from these burns, and the extensive timber harvesting on public and private lands.

The 1936 forest type map made as part of the first comprehensive forest inventory of the region (Andrews and Cowlin 1940) indicates that by the 1930s, most of the remaining Douglas-fir old growth in the northern Coast Range was primarily found on private land, much of it in the Siletz River drainage (around the site of the town of Valsetz). Other blocks of old growth were located on BLM land in the upper Siletz and Rowell Creek drainages, and on land currently in state ownership at the southern edge of the original Tillamook Burn (the latter stands may have been killed in subsequent reburns). Locating enough old stands of sufficient size to sample for this study was challenging, although it is possible there are others; the part of the Moon Creek RNA which the BLM lists as old growth (Schuller 2006) was not reconnoitered for this study owing to washed-out roads. Another BLM RNA, the Butte, is found in a small block of federal land in the northern part of the study area and was not examined either because of oversight.

Plots with mean diameters greater than 30 in were very rare on nonfederal lands. On federal lands, these plots were more abundant in the central than in the northern Coast Range, where they were more frequent in spruce stands than in hemlock or valley-margin stands. Old-growth attributes that were particularly lacking on federal lands were shade-tolerant trees ≥ 16 in DBH, large logs, and deep, multilayered canopies (as indicated by standard deviation of DBH). The low density

of shade-tolerant tree species, even in large-diameter mature stands, could reflect a general lack of seed source and be a reflection of the large historical fires that occurred in the area, as well as the common historical practice of primarily planting Douglas-fir after logging (Schrader 1998, Wimberly and Spies 2002). Although occurring at low density, the proportion of inventory plots with trees ≥ 48 in DBH on federal land (38 percent) as well as on nonfederal land (6 percent) was surprising. A related study of inventory plots in the Coast Range also found a substantial imprint of legacy trees on current forest structure across ownerships (Ohmann et al. 2007). Although one or two old trees do not contribute much to stand structure, they may be refugia for slow-dispersal organisms such as lichens and provide habitat for some organisms that can then spread into the maturing stand around them (Silett et al. 2000).

Old-Growth Indices

Old-growth indices can be useful tools for monitoring the abundance of old-growth characteristics in individual stands or across landscapes. The three old-growth indices calculated for this paper behaved differently across the northern Coast Range old-growth plots. Both the Canopy Height Diversity Index (CHDI) (Spies and Cohen 1992) and the Old-Growth Index (OGI) (Acker et al. 1998) are based solely on live trees, so do not evaluate the snag and log components of stands. The CHDI puts the heaviest weights on tall trees and sums the scores from different tree sizes, so seems to function better as an index of total crown volume in a stand rather than height diversity per se. The OGI was primarily developed to classify how closely young and mature stands resemble old growth, so it did not vary much among the stands. This index gave the lowest score to an old-growth stand with high tree densities and did not differentiate the younger stands from the older ones. The Old-Growth Habitat Index (OGHI) (Pabst 2005) performed quite well in relation to expectations based on the abundance of individual stand structure elements, giving the lowest values to the Willamette Valley margin plots that had few snags and down logs. The OGHI did not seem to distinguish structural differences between the two other younger plots and the older plots (however there is a version of the index that includes stand age as a criterion). It is also interesting to note that the standard deviation of DBH, which has been proposed as an indicator of canopy layering, did not always perform as expected. A high value seems to reflect layering, but the low values were caused by low layering as well as high density of small trees and clumpy diameter distributions.

Conclusions

Quantification of the stand characteristics in old-growth plots in the northern Oregon Coast Range for this study may provide useful information for management practices designed to restore late-successional forests in the region. Although we believe that we measured most of the remaining old-growth stands in the northern Oregon Coast Range, the stands included in this study are what were left after an intense selection by natural and human disturbance. Strictly speaking, each plot is an individual case study and inference has to be limited to the plots actually observed, not to the hypothetical population of historical (or potential) old-growth stands in the study area. Our results suggest that the composition, structure, and productivity of a current stand places some important constraints on the character of future late-successional forests; expecting all stands to have the full complement of late-successional attributes may not be realistic. Disturbance history is a particularly important consideration. Many of the north coast stands experienced moderately severe fire during their development. Although these disturbances may have temporarily reduced the abundance of some late-successional attributes (e.g., multilayered canopies and shade-tolerant cohorts), most stands had the full complement of attributes at five centuries of age.

Some stands on productive sites in the Coast Range are able to develop most desired late-successional attributes relatively quickly (<200 yr), particularly when a mix of species and an abundance of legacies from previous stands are available early in stand development (e.g., the Little Grass Mountain plot). However, it is not clear how well stands that develop old-growth characteristics early in stand development will be able to retain them, especially if the shade-intolerant Douglas-fir decreases in importance through natural mortality. Thus it may be important to have mature stands with a variety of stand compositions and structures across the landscape. The relatively low abundance of shade-tolerant trees, and hemlock in particular, in many of the mature stands in the Coast Range suggests that planting may be needed if accelerated development of understory tree cohorts and multiple canopy layers are goals.

Selecting simple thresholds for classifying stands as “old growth,” for example age, or quadratic mean diameter, can be useful because they are relatively easy to calculate and use for monitoring trends over time. Using criteria that combine thresholds for several late-successional attributes, or that calculate indices based on their amounts, can be a more powerful way to assess the attainment of the combination of conditions that provide wildlife habitat and ecosystem function in old-growth forests. However, it is important to understand the stand types to which the indices apply, the components that are included in them, their behavior

Expecting all stands to have the full complement of late-successional attributes may not be realistic.

under different conditions, and their sensitivity to sampling methods—particularly plot size. Analysis of multiple individual late-successional attributes can provide a more complete understanding of the relative abundance of specific habitat and structural features across the landscape, or in any subset of stand types. Some of the late-successional forest attributes examined here are also important in natural early-successional stands. Current management in the Coast Range is focused on increasing the area of old growth on federal lands and producing commodities on nonfederal land, but alternative management approaches—for example, creating a variety of vegetation structures and habitats within and among ownerships—might be more effective at maintaining native biodiversity and local commodity production at the same time (Spies et al. 2007).

Acknowledgments

Thanks to Cindy McCain, Connie Harrington, Stuart Johnston, Melinda Moeur, and David Mladenoff for critical reviews of an earlier version of this manuscript. Rob Pabst provided many insightful suggestions and comments. Y. Bulatov, W. King, and N. Matzke assisted with field data collection. Funding was provided by the PNW Research Station and Northwest Forest Plan research funds (USDA Forest Service, Region 6; USDI Bureau of Land Management, Oregon State Office).

Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Acres (ac)	0.4047	Hectares (ha)
Square feet per acre (ft ² /ac)	0.2296	Square meters per hectare (m ² /ha)
Cubic feet per acre (ft ³ /ac)	0.07	Cubic meters per hectare (m ³ /ha)
Tons	0.9072	Tonnes
Tons per acre	2.2417	Tonnes per ha

References

Acker, S.A.; Sabin, T.E.; Ganio, L.M.; McKee, W.A. 1998. Development of old-growth structure and timber volume growth trends in maturing Douglas-fir stands. *Forest Ecology and Management*. 104: 265–280.

Andrews, H.J.; Cowlin, R.W. 1940. Forest resources of the Douglas-fir region. Misc. Publ. 389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 169 p.

- Bechtold, W.A.; Patterson, P.L., eds. 2004.** The enhanced Forest Inventory and Analysis Program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.
- Bell, G.; Kent, A.; McNickle, D.; Woollons, R. 1996.** Accuracy of line intersect method of post-logging sampling under orientation bias. *Forest Ecology and Management*. 84: 23–28.
- Bolsinger, C.L.; Jaramillo, A.E. 1990.** *Taxus brevifolia* Nutt., Pacific yew. In: Burns, R.M.; Honkala, B.H., tech. coords. *Silvics of North America*. Volume 1: Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 573–579.
- Bolsinger, C.L.; Waddell, K.L. 1993.** Area of old-growth forests in California, Oregon, and Washington. *Resour. Bull. PNW-RB-197*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.
- Carey, A.B.; Lippke, B.R.; Sessions, J. 1999.** Intentional systems management: managing forests for biodiversity. *Journal of Sustainable Forestry*. 9: 83–125.
- Cleland, D.T.; Freeouf, J.A.; Keys, J.E.; Nowacki, G.J.; Carpenter, C.A.; McNab, W.H. 2005.** Ecological subregions: sections and subsections for the conterminous United States [1:3,500,000] [CD-ROM]. Washington, DC: U.S. Department of Agriculture, Forest Service.
- Cohen, W.B.; Maieresperger, T.K.; Spies, T.A.; Oetter, D.R. 2001.** Modeling forest cover attributes as continuous variables in a regional context with Thematic Mapper data. *International Journal of Remote Sensing*. 22: 2279–2310.
- Daly, C.; Neilson, R.P.; Phillips, D.L. 1994.** A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology*. 33: 140–158.
- Franklin, J.F.; Dyrness, C.T. 1973.** Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 417 p.
- Franklin, J.F.; Hall, F.C.; Laudenslayer, W.F., Jr.; Maser, C.; Nunan, J.; Poppino, J.; Ralph, C.J.; Spies, T.A. 1986.** Interim definitions for old-growth Douglas-fir and mixed-conifer forests in the Pacific Northwest and California. Res. Note PNW-447. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 7 p.

- Garman, S.L.; Acker, S.A.; Ohmann, J.L.; Spies, T.A. 1995.** Asymptotic height-diameter equations for twenty-four tree species in western Oregon. Research contribution 10. Corvallis, OR: Oregon State University, College of Forestry. 22 p.
- Gholz, H.L. 1982.** Environmental limits on aboveground net primary production, leaf area, and biomass in vegetation zones of the Pacific Northwest. *Ecology*. 63: 469–481.
- Gray, A.N. 1998.** Old-growth/ancient forests, conservation. In: Calow, P., ed. *Encyclopedia of Ecology and Environmental Management*. Oxford, United Kingdom: Blackwell Science: 494–497.
- Gray, A.N. 2000.** Adaptive ecosystem management in the Pacific Northwest: a case study from coastal Oregon. *Conservation Ecology* [Online] 4: 6. <http://www.consecol.org/vol4/iss2/art6>. (May 11, 2009).
- Gray, A.N. 2003.** Monitoring stand structure in mature coastal Douglas-fir forests: effect of plot size. *Forest Ecology and Management*. 175: 1–16.
- Gray, A.N.; Spies, T.A. 1997.** Microsite controls on tree seedling establishment in conifer forest canopy gaps. *Ecology*. 78: 2458–2473.
- Greene, S.E. 1982.** Neskowin Crest Research Natural Area. Supplement No. 13. In: Franklin, J.F.; Hall, F.C.; Dyrness, C.T.; Maser, C., eds. 1972. *Federal research natural areas in Oregon and Washington: A guidebook for scientists and educators*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.
- Harmon, M.E.; Sexton, J. 1996.** Guidelines for measurements of woody debris in forest ecosystems. U.S. LTER Publ. No. 20. Seattle, WA: College of Forest Resources, University of Washington, U.S. LTER Network Office. 73 p.
- Hazard, J.W.; Pickford, S.G. 1986.** Simulation studies on line intersect sampling of forest residue, part II. *Forest Science*. 32: 447–470.
- Holbrook, S.H. 1943.** *Burning an empire: the story of American forest fires*. New York, NY: MacMillan Co. 229 p.
- Impara, P.C. 1997.** Spatial and temporal patterns of fire in the forests of the central Oregon Coast Range. Corvallis, OR: Oregon State University. 354 p. Ph.D. dissertation.

- Juday, G.P. 1976.** The location, composition, and structure of old-growth forests of the Oregon Coast Range. Corvallis, OR: Oregon State University. 206 p. Ph.D. dissertation.
- Little, E.L., Jr. 1979.** Checklist of United States trees (native and naturalized). Agric. Handb. 541. Washington, DC: U.S. Department of Agriculture, Forest Service. 375 p.
- Max, T.A.; Schreuder, H.T.; Hazard, J.W.; Oswald, D.D.; Teply, J.; Alegria, J. 1996.** The Pacific Northwest region vegetation and inventory monitoring system. Res. Pap. PNW-RP-493. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.
- McCain, C.; Diaz, N. 2002.** Field guide to the forested plant associations of the northern Oregon Coast Range. R6-NR-Ecol-TP-03-02. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 250 p.
- Meyer, W.H. 1930.** A study of the relation between actual and normal yields of immature Douglas-fir forests. *Journal of Agricultural Research*. 41(9): 635–665.
- Minore, D. 1979.** Comparative autecological characteristics of northwestern tree species—a literature review. Gen. Tech. Rep. PNW-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 72 p.
- Moeur, M.; Spies, T.A.; Hemstrom, M.; Martin, J.R.; Alegria, J.; Browning, J.; Cissel, J.; Cohen, W.B.; Demeo, T.E.; Healey, S.; Warbington, R. 2005.** Northwest Forest Plan, the first ten years (1994–2003): status and trend of late-successional and old-growth forest. Gen. Tech. Rep. PNW-GTR-646. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 142 p.
- Monleon, V.J.; Gitelman, A.I.; Gray, A.N. 2002.** Multi-scale relationships between coarse woody debris and presence/absence of western hemlock in the Oregon Coast Range. In: Gatsonis, C.; Carriquiry, A.; Gelman, A.; Higdon, D.; Kaas, R.; Pauler, D.; Verdinelli, I., eds. *Case studies in Bayesian statistics*, Volume VI. New York: Springer-Verlag: 311–318.
- Morris, W.G. 1934.** Forest fires in western Oregon and western Washington. *Oregon Historical Quarterly*. 35(4): 311–339.
- Ohmann, J.L.; Gregory, M.J.; Spies, T.A. 2007.** Influence of environment, disturbance, and ownership on forest vegetation of coastal Oregon. *Ecological Applications*. 17: 18–33.

- Pabst, R. 2005.** Methodology for developing the old-growth index. Appendix 1. In: Franklin, J.F.; Spies, T.; Van Pelt, R. Definition and inventory of old-growth forests on DNR-managed state lands. Olympia, WA: Washington State Department of Natural Resources. <http://www.dnr.wa.gov/htdocs/lm/oldgrowth/index.html>. (April 26, 2007).
- Quaye, E.C. 1982.** The structure and dynamics of old-growth Sitka spruce (*Picea sitchensis*) forest of the Oregon Coast Range. Corvallis, OR: Oregon State University. 109 p. Ph.D. dissertation.
- Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M.H., tech. coords. 1991.** Wildlife and vegetation of unmanaged Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-285. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 533 p.
- SAS Institute Inc. 1999.** SAS/STAT user's guide, version 8. Cary, NC.
- Schrader, B.A. 1998.** Structural development of late-successional forests in the Oregon Coast Range: abundance, dispersal, and growth of western hemlock (*Tsuga heterophylla*) regeneration. Corvallis, OR: Oregon State University. 175 p. Ph.D. dissertation.
- Schuller, R. 2006.** High Peak/Moon Creek Research Natural Area: guidebook supplement 30. Gen. Tech. Rep. PNW-GTR-673. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 25 p.
- Silett, S.C.; McCune, B.; Peck, J.E.; Rambo, T.R.; Ruchty, A. 2000.** Dispersal limitations of epiphytic lichens result in species dependent on old-growth forests. Ecological Applications. 10: 789–799.
- Spies, T.; Cohen, W.B. 1992.** An index of canopy height diversity. Coastal Oregon Productivity Enhancement (COPE) Report. 5: 5–7.
- Spies, T.A.; Franklin, J.F. 1991.** The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington. In: Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M.H., tech. coords. Wildlife and vegetation of unmanaged Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-285. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 91–109.
- Spies, T.A.; Franklin, J.F. 1996.** The diversity and maintenance of old-growth forests. In: Szaro, R.C.; Johnston D.W., eds. Biodiversity in managed landscapes: theory and practice. New York: Oxford University Press: 296–314.

Spies, T.A.; Franklin, J.F.; Thomas, T.B. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. *Ecology*. 69: 1689–1702.

Spies, T.A.; Johnson, K.N.; Burnett, K.M.; Ohmann, J.L.; McComb, B.C.; Reeves, G.H.; Bettinger, P.; Kline, J.D.; Garber-Yonts, B. 2007. Cumulative ecological and socioeconomic effects of forest policies in coastal Oregon. *Ecological Applications*. 17: 5–17.

Tappeiner, J.C.; Huffman, D.; Marshall, D.; Spies, T.A.; Bailey, J.D. 1997. Density, ages and growth rates in old-growth and young-growth forests in coastal Oregon. *Canadian Journal of Forest Research*. 27: 638–648.

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

Thilenius, J.F. 1968. The *Quercus garryana* forests of the Willamette Valley, Oregon. *Ecology*. 49: 1124–1133.

Thomas, T.B.; Lehmkuhl, J.F.; Raphael, M.G.; DeBell, D.S. 1993. Sites for retrospective studies: opportunities for research in western Washington and Oregon. Gen. Tech. Rep. PNW-312. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

U.S. Department of Agriculture, Forest Service. 1987. Wood handbook: wood as an engineering material. Agric. Handb. 72. Rev. 1999. Washington, DC: Forest Products Laboratory. 466 p.

U.S. Department of Agriculture, Forest Service. 1993. Region 6 interim old-growth definition[s] [for the] Douglas-fir series, grand fir/white fir series, interior Douglas-fir series, lodgepole pine series, Pacific silver fir series, ponderosa pine series, Port Orford series, tanoak (redwood) series, western hemlock series. Portland, OR: Pacific Northwest Region. [Irregular pagination].

U.S. Department of Agriculture, Forest Service. 2006. 2006 field instructions for the annual inventory of Washington, Oregon, and California. Portland, OR: Pacific Northwest Research Station. http://www.fs.fed.us/pnw/fia/local-resources/pdf/field_manuals/2006_field_manual.pdf. [Irregular pagination].

- U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994.** Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl and standards and guidelines for management of habitat for late-successional and old-growth-forest-related species within the range of the northern spotted owl. Portland, OR.
- U.S. Department of Agriculture, Natural Resources Conservation Service. 2000.** The PLANTS database. Baton Rouge, LA: National Plant Data Center. <http://plants.usda.gov>. (January 1, 2000).
- Waddell, K.L. 2002.** Sampling coarse woody debris for multiple attributes in extensive resource inventories. *Ecological Indicators*. 1: 139–153.
- Waddell, K.L.; Hiserote, B. 2005.** The PNW-FIA Integrated Database, Version 2.0. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis Program. <http://www.fs.fed.us/pnw/fia/publications/data/data.shtml>. (March 15, 2006).
- Wimberly, M.C.; Spies, T.A. 2002.** Landscape- vs gap-level controls on the abundance of a fire-sensitive, late-successional tree species. *Ecosystems*. 5: 232–243.
- Wood, W. 1991.** Walking guide to Oregon's ancient forest. Portland, OR: Oregon Natural Resources Council. 317 p.
- Woodall, C.W.; Monleon, V.J. 2008.** Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA Program. Gen. Tech. Rep. NRS-22. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 68 p.
- Zybach, B. 2003.** The great fires: Indian burning and catastrophic forest fire patterns of the Oregon Coast Range, 1491–1951. Corvallis, OR: Oregon State University. 458 p. Ph.D. dissertation.

Appendix

Table 9—Common and scientific names for tree species,^a and codes used in tables and figures

Common name	Species name	Species code
Bigleaf maple	<i>Acer macrophyllum</i> Pursh	ACMA
California laurel	<i>Umbeullularia californica</i> (Hook. & Arn.) Nutt.	
Douglas-fir	<i>Pseudotsuga menziesii</i> (Mirb.) Franco	PSME
Grand fir	<i>Abies grandis</i> (Dougl. ex D. Don) Lindl.	ABGR
Lodgepole pine	<i>Pinus contorta</i> Dougl. ex Loud.	
Noble fir	<i>Abies procera</i> Rehd.	
Oregon white oak	<i>Quercus garryana</i> Dougl. ex Hook.	
Pacific dogwood	<i>Cornus nuttallii</i> Audubon ex Torr. & Gray	CONU
Pacific silver fir	<i>Abies amabilis</i> Doubl. ex Forbes	
Pacific yew	<i>Taxus brevifolia</i> Nutt.	TABR
Ponderosa pine	<i>Pinus ponderosa</i> Dougl. ex Laws	
Red alder	<i>Alnus rubra</i> Bong.	ALRU
Sitka spruce	<i>Picea sitchensis</i> (Bong.) Carr.	PISI
Sugar pine	<i>Pinus lambertiana</i> Dougl.	
Western hemlock	<i>Tsuga heterophylla</i> (Raf.) Sarg.	TSHE
Western redcedar	<i>Thuja plicata</i> Donn ex D. Don	THPL
White fir	<i>Abies concolor</i> (Gord. & Glend.) Lindl. ex Hildebr.	
Unknown (snag or log)		UNKN

^a Source: Little 1979.

Table 10—Mean cover of understory plant species recorded at each site, sorted alphabetically by life form (n = 3 subplots)

[illegible]

Table 10—Mean cover of understory plant species recorded at each site, sorted alphabetically by life form (n = 3 subplots) (continued)

Species code ^a	Scientific name ^a	Common name	Nesk	CliffCk	VOG	Bear	LtGrass	Moon	ElkCk	Rock	Rowell1	Rowell2	Dorn	McDon1	McDon2
ADBI	<i>Adenocaulon bicolor</i> Hook.	pathfinder												4.7	16.0
ADPE	<i>Adiantum aleuticum</i> L.	maidenhair fern						1.0							
ANMA	<i>Anaphalis margaritacea</i> (L.) Benth.	western pearly everlasting						0.1							
ANDE3	<i>Anemone deltoidea</i> Hook.	Columbian windflower			0.1									0.1	0.1
ANLY	<i>Anemone lyallii</i> Britt.	Lyall's anemone													0.1
AQFO	<i>Aquilegia formosa</i> Fisch. ex DC.	western columbine												0.1	
ASCA2	<i>Asarum caudatum</i> Lindl.	wild ginger						0.1							
	Asteraceae	composite family						0.1							
ATFI	<i>Athyrium filix-femina</i> (L.) Roth	common ladyfern	0.1	0.7	1.0	1.0	0.1							0.7	
BLSP	<i>Blechnum spicant</i> (L.) Sm.	deer fern	2.7	0.1	0.1	1.7		1.0		2.4					
CASC7	<i>Campanula scouleri</i> Hook. ex A. DC.	Scouler's harebell						0.1					0.1		
CLSI2	<i>Claytonia sibirica</i> L.	Siberian springbeauty	9.0	22.7	0.1	0.7	0.1	0.1	0.7					0.1	2.7
CLUN2	<i>Clintonia uniflora</i> (Menzies ex J.A. & J.H. Schultes) Kunth	beadlilly	0.4		1.0	0.1									
DIFO	<i>Dicentra formosa</i> (Haw.) Walp.	bleeding heart			0.7		0.1	0.1							
DIPU	<i>Digitalis purpurea</i> L.	foxglove						0.1							
DIHO3	<i>Disporum hookeri</i> (Torr.) Nichols.	Hooker fairybell	0.7	0.1	1.3	0.1	0.1	0.3		0.4		0.1		6.3	5.0
DREX2	<i>Dryopteris expansa</i> (K. Presl) Fraser-Jenkins & Jermy	mountain woodfern	0.7	1.4	0.7	0.1	0.1		0.1						
EPCIW	<i>Epilobium ciliatum</i> ssp. <i>watsonii</i> (Barbey) Hoch & Raven	fringed willowherb					0.1								
FRVE	<i>Fragaria vesca</i> L.	woodland strawberry			0.1										
GAAP2	<i>Galium aparine</i> L.	stickywilly												0.4	
GATR3	<i>Galium triflorum</i> Michx.	fragrant bedstraw				0.1	0.1	0.4	0.1				0.1		2.7
GOOB2	<i>Goodyera oblongifolia</i> Raf.	rattlesnake plantain									0.1	0.1	0.1		
GYDR	<i>Gymnocarpium dryopteris</i> (L.) Newman	western oakfern							0.1						
HIAL2	<i>Hieracium albiflorum</i> Hook.	white hawkweed						0.3				0.1	0.1		
HYTE	<i>Hydrophyllum tenuipes</i> A. Heller	Pacific waterleaf												0.4	0.1
	Leguminosae	Pea family												0.1	
LIAP	<i>Ligusticum apiifolium</i> (Nutt. ex Torr. & Gray) A. Gray	celeryleaf licorice-root												0.1	0.3

Table 10—Mean cover of understory plant species recorded at each site, sorted alphabetically by life form (n = 3 subplots) (continued)

Species code ^a	Scientific name ^a	Common name	Nesk	CliffCk	VOG	Bear	LtGrass	Moon	ElkCk	Rock	Rowell1	Rowell2	Dorn	McDon1	McDon2
THOC	<i>Thalictrum occidentale</i> Gray	western meadow-rue												3.0	2.3
TITR	<i>Tiarella trifoliata</i> L.	threeleaf foamflower	0.7	0.1	0.4	0.1		0.4	0.3						
TRBOL	<i>Trientalis borealis</i> ssp. <i>latifolia</i> (Hook.) Hulten	broadleaf starflower					0.1	0.1			0.1	0.1	0.1	0.3	0.1
TROV2	<i>Trillium ovatum</i> Pursh	Pacific trillium		0.1	0.4	1.0	0.1	0.1	0.7	0.1	0.1	0.1	0.1	0.1	0.1
VAHE	<i>Vancouveria hexandra</i> (Hook.) Morr. & Dcne.	white insideout flower												21.3	24.0
VEVI	<i>Veratrum viride</i> Ait.	green false hellebore												0.4	0.1
VIOR	<i>Viola orbiculata</i> Geyer ex Holz.	darkwoods violet		1.4										0.4	0.7
VISE3	<i>Viola sempervirens</i> Greene	evergreen violet				0.4		0.3		0.1			0.1		0.7
2FORB	Unknown forb	Forb					0.1								
Graminoids:															
BRVU	<i>Bromus vulgaris</i> (Hook.) Shea	Columbia brome	6.0	9.3					0.1		0.1			0.1	10.3
	Unknown graminoid	Graminoid			0.1	0.1	0.1	0.4		0.1		0.1		0.1	

^a Species codes and nomenclature from USDA NRCS (2000).

Pacific Northwest Research Station

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



Federal Recycling Program
Printed on Recycled Paper

U.S. Department of Agriculture
Pacific Northwest Research Station
333 SW First Avenue
P.O. Box 3890
Portland, OR 97208-3890

Official Business
Penalty for Private Use, \$300