

Mesoscale Variation in Snag and Hardwood Densities and Sizes in Old-Growth Forests in Western Oregon

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ABSTRACT

Snags and hardwoods contribute to biological, structural, and functional diversity in old-growth forests. In the US Pacific Northwest, only general knowledge about regional patterns is available to determine target density of snags and hardwood trees. To investigate their variability at relevant scales for silviculture, we examined snag and hardwood densities and sizes in 20 old-growth units in northern and southern aspects in the Coast Range and the Willamette Valley foothills of Oregon. Snag densities varied largely between subregions and aspects, with aspect affecting densities more than subregion. In the Coast Range, snag density was 2.8 times greater on northern aspects than on southern aspects, whereas in the Willamette Valley foothills snag density was 1.4 times greater on northern aspects than on southern aspects. Density of snags larger than 101.6 cm in diameter was very low. Hardwood densities were also greater on northern aspects than on southern aspects. The negative exponential distribution of hardwood density frequency by size classes could be explained by cohort growth under a wide range of competitive pressures or repeated-recruitment events. Aspect and subregion should be taken into account when defining management targets. Allowing for flexibility at these smaller spatial scales would better reflect the variability in ecological conditions and land use history that led to the development of old-growth stands.

Keywords: forest management guidelines, aspect, sub-region

Old-growth forests in the Pacific Northwest region of the United States (PNW) are characterized by the presence of large trees, understory and midstory vegetation layers, high spatial heterogeneity, standing and downed dead wood, and diverse arrays of plant species with differing life forms and autecology (Franklin and Spies 1991, Spies et al. 2007). Snags and hardwoods are important components of these forests, as they contribute to biological diversity and late-successional habitat (McComb and Lindenmayer 1999, Wirth et al. 2009). Current information is limited to general trends at regional scales (e.g., Spies et al. 1988), but quantitative information about their densities and sizes at spatial scales that are relevant for silviculture is scarce. We refer to this scale as mesoscale, which applies to areas ranging in size from tens to thousands of hectares (Delcourt and Delcourt 1988) and is intermediate between local and regional scales. We choose the mesoscale because it is of prime interest for natural resource conservation and management (Comer and Schulz 2007).

Snags perform important functions in forest ecosystems, such as providing cavities for nesting, roosting, and denning by birds, small mammals (including bats), and bears (Davis 1996, Waldien et al. 2000). Vertebrates use snags as overwintering sites, lookout posts, and hunting perches (Neitro et al. 1985), whereas macrofungi, cryptogam, and invertebrate species—including some threatened taxa—use dead wood as a food substrate (Berg et al. 1994, Parks and Shaw

1996). Large-diameter snags are especially valuable for wildlife nesting and foraging (Mannan et al. 1980). With no apparent upper size threshold for cavity users, large snags provide more suitable habitat and better thermal insulation and protection from predators than small snags (Sharpe 1996, Hayes and Hagar 2002). Snags also contribute to mid- and long-term nutrient cycling, C sequestration, food webs, and lichen habitat (Berg et al. 1994, Krankina and Harmon 1995, Benke et al. 2001). Owing to the importance of snags when characterizing old-growth stands, the number of large snags per unit land area is included in the calculation of an old-growth index used to evaluate stand structure and development (Spies et al. 2007).

Broad-leaved hardwoods promote structural, functional, and biological diversity in conifer-dominated forests in the PNW (Hagar 2007, Betts et al. 2010). Hardwoods tend to occupy the lower- and mid-story canopy layers of old coniferous forests and increase diversity of foliage type and distribution, and branch structure within stands. In addition, hardwoods supply forage, fruits, nuts, and insects for vertebrates and invertebrates (Hayes and Hagar 2002). They also host several epiphytic lichen species, including old-growth-associated taxa (Neitlich and McCune 1997) that provide forage for a variety of species or fix atmospheric nitrogen (Peterson and McCune 2001). Inputs of nutrients and organic matter from hardwood foliage can maintain or improve soil characteristics (Perry et al. 1987, Fried et al. 1990, Niemiec et al. 1995),

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Table 1. Characteristics of ecological subregions in the study area.

	Coast Range	Willamette Valley foothills
Climate ^{a,b}	Mean annual precipitation is 2,000–3,800 mm. Winters are very wet, and summers are moist. Occasional high winds occur in winter.	Mean annual precipitation is 1,000–1,500 mm. Winters are moist, and summers are dry. High winds are uncommon.
Landforms ^{a,b}	Elevation ranges from 0 to 900 m. Relief is moderate, with high dissection.	Elevation ranges from 60 to 750 m; valley foothills have low relief and low to moderate dissection.
Vegetation ^{a,c}	Approximately 25% of area is in Douglas-fir/grand fir ^d series, and 75% is in western hemlock series.	Approximately 75% of area is in Douglas-fir/grand fir series, and 25% is in western hemlock series.
Soil ^b	Soils are shallow to deep, have fine to medium texture, and overlie impermeable bedrock. They have high biologic activity and biomass decomposition rates, and moderate to low accumulation of soil organic matter.	Soils are shallow to deep, have fine texture, and overlie moderately permeable bedrock. They have moderately high biologic activity and biomass decomposition rates, and low to moderate accumulation of soil organic matter.
Fire regime ^{a,b}	Fire occurs in low (100–200 years) to moderate (50–100 years) recurrence intervals. They are variable in severity.	Fire occurs in high (less than 50 years) recurrence intervals. They are variable in size, with low and variable severity.

^a Kertis 2000.

^b USDI Bureau of Land Management and US Forest Service 1997.

^c McCain and Diaz (2002)

^d *Abies grandis* (Dougl. ex D. Don) Lindl.

whereas detritus from broadleaf tree species decomposes rapidly in aquatic environments and supports invertebrate communities differing from those associated with other forest types (Giller and Malmqvist 2008).

A major challenge in designing management regimes aimed at the development of late-successional habitat in forests is defining structural and compositional targets. Complex ecosystems exhibit a large range of variability because of interactions occurring at various scales of space, time, and intensity (Levin 2005). Quantitative information for snag and hardwood abundance in old-growth forests of the PNW is available only as general summaries or averages across broad geographic areas and regional patterns of variation (Spies et al. 1988, Spies and Franklin 1991, Ohmann and Waddell 2002, Poage and Tappeiner 2005). Factors acting at intermediate scales, however, also determine snag and hardwood densities in natural stands. As managers are increasingly interested in alleviating concerns about the limited number of snags and hardwoods in managed stands (Kohm and Franklin 1997), detailed knowledge of snag and hardwood abundance at the mesoscale, e.g., on different aspects, becomes important. Toward this purpose, this study was focused on a small geographic area to evaluate within-region variation and gain insights into potential factors associated with mesoscale patterns. These can be inferred from historical cruise records that reflect spatial scales typical of forest management units and represent the natural variability associated with late-successional stands.

The first objective of this study was to document the range of densities and size distributions of snags and hardwoods in late-successional forests found in two subregions of Oregon. The second objective was to investigate whether snag and hardwood densities vary with aspect within subregions. This information will provide an improved basis for establishing the range of snag and hardwood targets for young forests when the development of late-successional habitat is a management objective.

Methods

We collected presale cruise records containing snag and hardwood density data from the US Department of the Interior (USDI) Bureau of Land Management (BLM), which manages about 1 million ha of forests and woodlands in Western Oregon, mostly in the Oregon Coast Range and lower Cascades (USDI Bureau of Land Management 2009). We focused on an area southwest of Eugene, Oregon, and gathered records for 111 forest units within spatially

distinct old-growth stands of natural origin. Records from 20 sample units were then randomly selected for analysis from two ecological subregions: the mid-coastal sedimentary portion of the Coast Range and the Willamette Valley foothills (Pater et al. 1998). These subregions were chosen because they make up areas typically managed by a single BLM district office and are spatially close, although they differ in climate, landform, vegetation type, soil characteristics, and fire regime (Table 1). All these factors, and especially fuels and fire history (Kertis 2000), affect vegetation composition and structure. Seventy-five percent of the units in the Coast range were in western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) series and 25% in Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) series according to the plant association classification in McCain and Diaz (2002). In the Willamette Valley foothills, 75% of the units were in Douglas-fir series and the rest in western hemlock series. The units averaged 12.1 ha (range, 6.1–24.2 ha) and 321 m³/ha of harvested wood volume (range, 263–479 m³/ha, or 44,600–81,200 board ft/ac). Stand timber was sold between 1976 and 1986. The vast majority of snags were Douglas-fir with occasional presence of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), and incense cedar (*Calocedrus decurrens* [Torr.] Florin) snags. Noted hardwood species were bigleaf maple (*Acer macrophyllum* Pursh), red alder (*Alnus rubra* Bong.), golden chinquapin (*Castanopsis chrysophylla* [Douglas ex Hook] Hjelmq.), and Pacific madrone (*Arbutus menziesii* Pursh).

Timber sale contracts terminated during 1981–1985 at BLM Eugene District and stored at the Federal Record Center in Seattle, Washington, were examined to identify presale cruise records, including snag and hardwood stem counts. We used the following information contained in contract files:

- Timber sale summary: type of cruise, harvest type (e.g., clearcut), and mean harvested wood volume per ha.
- Timber sale contract map: harvest unit number, unit location (township, range, and section), and unit area.
- Timber cruise records: stem counts for snags and hardwoods in either summary sheets or original cruise notes.

Each timber sale contract file referred to one or more separate harvest units. An individual harvest unit was considered for sampling if (1) the harvest type was clearcut, (2) timber cruising was done covering 100% of the area or by point-3P (probability, proportional, prediction) sampling (Mackisack and Wood 1990), (3)

Table 2. Mean snag density (trees/ha) by size in units on northern and southern aspects in the Coast Range and the Willamette Valley foothills in western Oregon.

Subregion/aspect	Total	dbh < 50.8 cm	dbh ≥ 50.8 cm	dbh ≥ 101.6 cm
Coast Range/north	9.1 ± 3.5 (4.9–13.6)	3.7 ± 2.0 (1.2–6.4)	5.4 ± 2.5 (2.2–8.7)	0.7 ± 0.2 (0.2–1.2)
Coast Range/south	3.2 ± 1.7 (1.0–5.2)	0.7 ± 1.0 (0–2.0)	2.5 ± 1.5 (0.7–4.2)	1.2 ± 0.7 (0.2–2.5)
Willamette Valley foothills/north	4.2 ± 2.7 (0.7–7.7)	1.7 ± 2.0 (0–4.2)	2.5 ± 1.2 (1.2–4.0)	0.5 ± 0.5 (0.2–1.0)
Willamette Valley foothills/south	2.9 ± 2.2 (0.2–5.4)	0.7 ± 0.5 (0.2–1.2)	2.2 ± 1.7 (0–4.4)	0.7 ± 0.7 (0–1.7)

dbh: diameter at 1.37 m above ground. Values are mean ± standard deviation; 95% confidence intervals are shown in parentheses.

mean harvested wood volume was greater than 234 m³/ha (estimate of minimum volume for late-successional stands worth harvesting at the time), (4) stem counts and dbh for snags and hardwoods were available, and (5) the unit was 4 ha or larger in size. Units were assigned either to a dominant northern or southern aspect as assessed by contour lines on timber sale maps. Units with eastern and western aspects were allotted to northern and southern aspects, respectively, because of their similarity in exposure to solar radiation and fire regimes. The BLM Forest Operations Inventory polygons were used to spatially represent each harvest unit in a GIS. A shapefile of units to be sampled was created using ArcMap. Then, each unit was assigned either to Coast Range or the Willamette Valley foothills subregions as assessed by overlaying the ecoregions shapefile obtained from the Oregon Geospatial Data Clearinghouse (Oregon Geospatial Enterprise Office 2011). ArcMap was also used to select units within 1.6 km on either side of the regional division line to create a transition zone that would not be sampled. Five units were randomly sampled from each combination of subregion and aspect (Coast Range/north, Coast Range/south, Willamette Valley foothills/north, and Willamette Valley foothills/south), for a total of 20 units. To confirm that all 20 units could be defined as old-growth forests, either supplemental information stating that the stand age was >200 years or cruise records were used to determine whether the stand met the minimum standard for Douglas-fir on western hemlock sites from the Old-Growth Definition Task Group (Marcot et al. 1991).

The cruise records contained stem counts of snags and hardwoods >30.5-cm dbh tallied in 10.2-cm classes. Snag size classes were selected to match those used in other studies of snag abundance and wildlife habitat (Spies et al. 1988, Carey et al. 1991). Hardwood species identifications were inconsistent with the exception of bigleaf maple. Therefore, all other hardwood species were grouped together for analysis. All stem counts were converted to density measures for snags and hardwoods, and basal area was also determined for hardwoods. Means and 95% confidence intervals were calculated to facilitate comparison of densities among diameter size-classes and between each region and aspect combination. We tested whether mean densities differed among subregions and aspects (main effects) using two-way analysis of variance in S-PLUS statistical software. A value of $\alpha = 0.05$ was used in the statistical analyses to determine significance of mean effects and interactions, with α values greater than 0.5 and lower than 0.10 considered marginally significant. Normality of observations and error terms were tested with the Shapiro-Wilk method (Shapiro and Wilk 1965). Plots of group standard deviations versus group means and of error residuals versus quartiles of standard normal values were used to examine equality of variances. On the basis of these analyses, data transformations were deemed unnecessary.

Results

Snag Density

Douglas-fir snags averaged 94% of total snag density in the 20 surveyed units. Snag densities differed between subregions and aspects. The effect of the interaction of subregion with aspect on snag densities was marginally significant ($P = 0.06$). Mean total snag density in the Coast Range was 2.8-fold greater in units on northern aspects than in units on southern aspects, whereas in the Willamette Valley foothills it was only 1.4-fold-times greater in units on northern aspects compared with units on southern aspects (Table 2). Ignoring this marginally significant interaction, snag densities were affected more by aspect ($P < 0.01$) than by subregion ($P = 0.03$).

Variations in snag densities were fairly consistent for the various size classes. Subregion ($P = 0.06$) and aspect ($P = 0.05$) affected densities of snags ≥50.8 cm in dbh, but the effect of the interaction of region and aspect was not significant ($P = 0.14$). Mean density of snags larger than 101.6 cm dbh was very low (0.5–1.2 snags/ha) in all sites (Table 2). Densities of these large snags tended to be greater in Coast Range units than in Willamette Valley foothills units, although differences were not significant.

The snag diameter distribution in Coast Range stands on northern aspects exhibits the shape of a negative exponential function. In contrast, the diameter distribution in stands on the southern aspects was mainly flat across all diameter classes (Figure 1). Thus, snags in the smaller dbh classes (e.g., snags ≤51 cm in dbh), that likely originated from intermediate and suppressed trees, were more common on northern aspects than on southern aspects. Stands in the Willamette Valley foothills did not show distinct patterns in snag diameter class distributions (Figure 1).

Hardwood Density and Basal Area

Hardwood densities appeared to be quite sensitive to mesoscale conditions and had patterns similar to those described for snags. The interaction between aspect and subregion for mean hardwood density was marginally significant ($P = 0.06$). Ignoring this interaction, Coast Range units had generally higher hardwood densities than units in the Willamette Valley foothills. Hardwood densities were greater in units on northern aspects in the Willamette Valley foothills than in units on southern aspects in the Coastal Range (Table 3, Figure 2). Also, hardwoods were more abundant in units on northern aspect than in units on southern aspects in both subregions.

Bigleaf maple averaged 53 and 54% of total hardwood density and basal area, respectively, in the 20 units. Bigleaf maples were more frequent in the Coast Range than in the eastern Willamette Valley foothills ($P = 0.06$) and more frequent in units on northern aspects than in units on southern aspects ($P = 0.04$).

The diameter distribution of hardwoods approximated the shape of a negative exponential function (Figure 2) for all regions

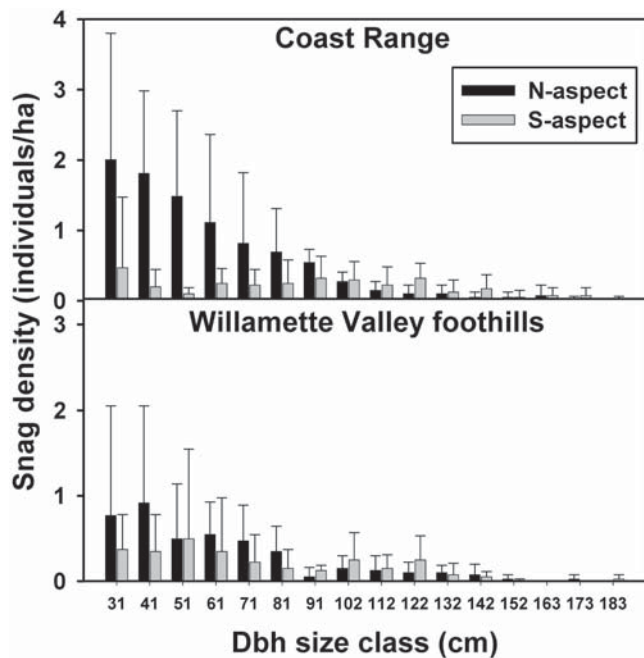


Figure 1. Frequency of snag density in dbh (diameter at 1.37 m above ground) size classes in northern (N) and southern (S) aspects in the Coast Range and the Willamette Valley foothills in western Oregon. Values are means and associated 95% confidence intervals. Unequal dbh size class intervals were the consequence of rounding and conversion from Imperial to metric units.

and aspects. Hardwood basal area was highly correlated to hardwood density ($r^2 = 0.99$). Mean hardwood basal area in units on northern aspects in the Coast Range therefore had greater mean basal area than any other combination of subregion and aspect for density of all hardwoods (1.8–4.2-fold), bigleaf maple (1.2–2.8-fold), and other hardwood species (2.8–10-fold).

Discussion

Snag and hardwood densities found in this study were generally lower than regional values reported for the PNW (Mannan et al. 1980, Hayes and Hagar 2002), suggesting that variations around regional estimates can be quite large and should be taken into account when designing management goals. Large snags (up to 101.6 cm dbh) are the most important size class for cavity nesting birds (Mannan et al. 1980), which are considered keystone species in the Coast Range of Oregon (Hayes and Hagar 2002). Reported densities of large snags in old-growth forests in the Coast Range include 11.1 snags/ha (Mannan et al. 1980), 17.3 snags/ha (Spies et al. 1988), and 7.4 snags/ha (Carey et al. 1991). The greatest density of large snags in this study (i.e., in units on northern aspects in the Coast Range) was similar to the lowest densities previously found. Densities in all other conditions were lower; e.g., density on southern aspects in the interior Coast Range was less than half of that found by Carey et al. (1991). Differences among studies were even more pronounced for very large snags. These snags were scarcely represented in the sample units in this study at about a third of the density reported for old-growth forests in the Coast Range (mean: 3.3 snags/ha; Carey et al. 1991). Interestingly, densities of snags <50.8 cm dbh in this study were similar to those in early- and midsuccessional forest in the Coast Range of Oregon (0.8–2.0 snags/ha; Ohmann et al. 2007), suggesting that the general

claim that managed stands lack the range of snags typical found in old-growth stands is an oversimplification.

Greater snag densities in units on northern aspects than in units on southern aspects corroborated previous research indicating that snag volumes increased from dry southerly aspects to moist northerly slopes in the Coast Range of Oregon and Washington (Spies and Franklin 1991). This can be attributed, at least partially, to greater solar radiation and evaporation rates on southern aspects, which results in less available soil water during the summer (Agee 1996). In contrast, in subalpine forests in the northern Cascades, which are not as likely to be moisture limited, density of dominant and codominant snags did not differ in northern and southern aspects, although the density of intermediate and suppressed snags was highest on steep south-facing slopes (Flanagan et al. 2002). In these forests, weather phenomena such as snow, ice, and wind were considered to cause greater tree mortality on northern aspects than on southern ones. In this study, most snag creation in moist sites (i.e., northern aspects of the Coast Range) may be caused by competition-related mortality because density-dependent mortality would result in greater mortality of small trees than of large trees. Patterns of snag densities on other sites suggested that frequent disturbances such as repeated fires may be more influential for snag creation than competition (Spies and Franklin 1991).

Part of the discrepancies among studies may relate to different definitions of snags. For example, no height criteria were specified in the cruise records used in this study. Because the cruise was aimed at estimating harvesting costs, it is likely that minimum height may have been influenced by the cruisers judgment on whether snags would interfere with felling and logging operations. Other studies that designed measurement protocols specifically to quantify snags, may have used various heights, e.g., snags in height classes >0.1, 5, and 15 m in Spies et al. (1988).

Variations in snag densities between the Coast Range compared with Willamette Valley foothills and between southern and northern aspects suggest that they reflect moisture conditions and associated disturbance regimes. This matches findings in other old-growth forests, where differences in stand structures also corresponded to a gradient of increasing summer drought and moisture stress from the Coast Range locations to those in the Willamette Valley foothills (Poage and Tappeiner 2005). Associated differences in fire regimes, wind exposure, or soil depth may have also affected forest structure and results of this study.

This study indicated that multiple mortality patterns were likely acting simultaneously in these stands (Franklin et al. 1987), as is evident from the wide range of snag sizes. Smaller diameter snags likely originated from competition-related mortality (Davis et al. 2007). At the same time other factors, such as mechanical damage or diseases, may have resulted in the death of larger trees (Lutz and Halpern 2006, Larson and Franklin 2010).

For the most part, recent forest management plans in the PNW have included landscape-level targets for snag densities (e.g., USDI Bureau of Land Management 2008) that do not necessarily account for fine-scale and mesoscale influences, such as aspects and subregions. The current guidelines for federal Late-Successional Reserves in the Oregon Coast Range (USDI Bureau of Land Management and US Forest Service 1997) are based on snag densities reported by Spies et al. (1988) for old-growth forests in the Coast Range. Results of this study suggest that ecological differences at the mesoscale are reflected in a range of snag densities. Consequently, management

Table 3. Mean hardwood densities (trees/ha) and basal area (m²/ha) in units on northern and southern aspects in the Coast Range and the Willamette Valley foothills in western Oregon.

Subregion/aspect	Total		Bigleaf maple		Other hardwoods	
	Density	Basal area	Density	Basal area	Density	Basal area
Coast Range/north	22.6 ± 11.9 (7.9–37.3)	3.4 ± 1.9 (1.1–5.8)	9.7 ± 4.7 (4.0–15.6)	1.4 ± 0.8 (0.5–2.5)	12.9 ± 9.9 (0.5–25.2)	2.0 ± 1.6 (0–4.0)
Coast Range/south	12.1 ± 9.4 (0.5–23.8)	1.9 ± 1.8 (0–4.1)	7.2 ± 7.4 (0–16.3)	1.2 ± 1.5 (0.6–3.1)	4.9 ± 3.2 (1.0–8.9)	0.7 ± 0.5 (0.1–1.3)
Willamette Valley foothills/north	8.9 ± 1.5 (6.9–10.9)	1.4 ± 0.3 (1.0–1.8)	4.9 ± 2.5 (1.7–8.2)	0.8 ± 0.4 (0.3–1.3)	4.0 ± 2.5 (0.7–7.2)	0.6 ± 0.4 (0.1–1.0)
Willamette Valley foothills/south	5.7 ± 4.2 (0.7–10.9)	0.8 ± 0.5 (0.1–1.7)	3.0 ± 3.7 (0–7.7)	0.5 ± 0.6 (0–1.3)	2.7 ± 3.0 (0–6.4)	0.2 ± 0.4 (0–0.9)

Values are mean ± standard deviation; 95% confidence intervals are shown in parentheses.

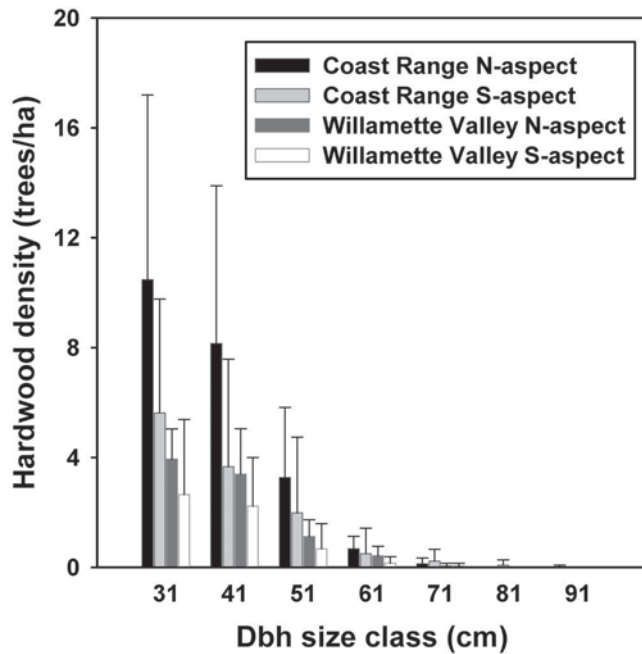


Figure 2. Frequency of hardwood density by dbh (diameter at 1.37 m above ground) size classes in northern (N) and southern (S) aspects in the Coast Range and the Willamette Valley foothills in western Oregon. Values are means and associated 95% confidence intervals.

prescriptions that consider these patterns would better reflect the range of natural, historical conditions.

Compared with snags, even less quantitative information is available for hardwood abundance and size in old-growth coniferous forests of western Oregon. Consequently, current guidelines do not provide specific quantitative criteria and are limited to suggestions to maintain the natural diversity in the overstory. Thus, it is even more important to understand historical presence of hardwoods in old-growth forest and how local conditions may have influenced hardwood establishment and growth. Similar to snags, hardwood density in this study followed trends in water availability at regional and intermediate scales. Bigleaf maple density varied between subregions and across aspects reflecting its known preference for sites with deep soils and high rainfall (Niemi et al. 1995). Further interpretation of causal factors influencing hardwood density, however, is difficult, as riparian tree species (e.g., red alder) were lumped with upland drier site species (e.g., Pacific madrone and golden chinquapin) in the cruise records. The common dominance of bigleaf maple (more than 50% of all hardwood density in most subre-

gions and aspect) in this study, however, suggested that the trends found in this study may be valid for hardwoods as a whole.

Compared with previous results for the Coast Range, mean hardwood basal area in units on northern aspects in this study was vastly greater (34-fold) than that found on moist sites (i.e., lower northerly slopes, wet benches, and river terraces) in previous studies (Spies and Franklin 1991). Even on southern aspects, hardwood basal area was more than 6-fold greater than that found by Spies and Franklin (1991) on a dry site, e.g., on steep upper slopes of southerly aspect. Higher basal area of hardwoods in this study compared with previous research may partially reflect the inclusion of environments where hardwoods are common such as gaps and riparian areas. We did not have quantitative information about the relative proportion of hardwoods in the stand, but to be considered for harvests, the stands had to be clearly dominated by conifers. For example, in similar stands in western Oregon hardwood basal area was less than 2% of the total stand basal area (Poage and Tappeiner 2005). On the other hand, snag and hardwood densities for the smaller size classes were likely underrepresented in this study because hardwoods were mostly tallied during the cruises for the purpose of falling cost estimates. At the same time, in terms of historical wildlife habitat, some snags and hardwoods may have been growing outside the unit boundaries and not reflected in the inventory data.

The presence of hardwoods across a wide range of sizes may provide some indication of stand development. Especially, shade tolerant hardwoods such as bigleaf maple may have become established as a cohort growing under a wide range of competitive conditions and that would result in a broad range of diameters. Alternatively, repeated disturbances may have resulted in more or less continuous hardwood recruitment, which would be expressed in the range of hardwood sizes.

Conclusion

Results of this study suggested that snag and hardwood abundance in central western Oregon was historically quite variable at the mesoscale, and patterns appeared to be related to moisture conditions and associated disturbance regimes. Thus, general guidelines should reflect this variability and allow flexibility for managers. Guidelines that reflect site-level factors, such as aspect and local moisture regimes, may reflect historical old-growth conditions better than a single target density of snags and hardwoods for every stand (e.g., 5 snags/ha, as recommended for best management practices in Oregon; Oregon Forest Resources Institute 2006).

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