Environmental Relationships in Forests of Early 20th Century Coos County, Oregon, Based on Timber Cruise Data

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Abstract

Timber cruise data can provide useful information not available elsewhere. Measurements of timber volume (timber cruises) from the early 20th century for Coos County, Oregon, were used to assess the degree to which tree species distribution and timber volume varied with edaphic and climatic factors. The study area has diverse geology in a moderate maritime climate, and represents an area of forest transition between the Coast Range and the Klamath Mountains. Species distribution was determined from 629 cruised 1-mi^2 (2.59 km^2) sections, and timber volume from 252 sections of old-growth forest. Most forests were dominated by Douglas-fir (*Pseudotsuga menziesii*); Sitka spruce (*Picea sitchensis*), although least frequent, had the second-most timber volume. All six commercial conifer species differed substantially in distribution in relation to geography and to environment. Both distribution and volume of grand fir (*Abies grandis*) varied with geologic unit and general soil type: Sitka spruce, with soil and maximal summer temperature (– sign); Douglas-fir, with temperature (+) and summer precipitation (+); western hemlock (*Tsuga heterophylla*), with precipitation (+); Port-Orford-cedar (*Chamaecyparis lawsoniana*), with precipitation (–); and western redcedar (*Thuja plicata*), with no factor. Importance of Douglas-fir and hemlock increased on geologic units with sediments from inland plutonic sources, which reduced importance of Port-Orford-cedar. Some species varied significantly among soil units within a geological formation, and vice-versa. When choosing which species to plant, these cruise data can supplement or replace guidelines based on plant associations.

Keywords*:* environmental relationships, forest composition, planting-site selection, species distribution, timber volume

Introduction

Knowing the properties of pre-settlement vegetation can help to address important issues in ecology and land management, such as determining the natural distributions of species and forest types and assessing changes caused by European immigrants and climatic change. Here, I use data from a timber cruise in the early 20th century to answer the question: Which environmental factors are most closely associated with tree species distribution? I use the result to assist in answering a practical question: Which forest tree species should be planted in a given habitat?

Understanding the apparent causes of plant distribution is important for many reasons. In forest, rangeland and conservation management, it allows one to match species to site with good assurance of success, including planting to help compensate for climatic change (e.g., Chmura et al. 2011). An emphasis on effects of climate on species' distribution is understandable in this time of rapid climatic change, but single-factor considerations in ecology often do not work out well. This seems likely for climate-change-induced plans for assisted species migration that are based only on analysis of climate, as discussed, for example, by Erickson et al. (2012). Past vegetation response to major long-term natural climatic change differed between ultramafic and more fertile edaphic types in the Klamath Mountains of Oregon and California (Briles et al. 2011). Considering the effects of edaphic factors, in addition to climate, seems critical in regions with much geologic or soil diversity (Mathys et al. 2014).

Current tree distributions in Oregon reflect changes in land use by Euro-American settlers and, even within areas that are still forested, by forest management practices including harvest and planting. Introduced tree diseases, fire and fire suppression, escape of exotic species, and even

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recent changes of climate (Lintz et al. 2016) also have modified species distributions. Thus, using current geographic ranges of trees to study the causes of natural distribution has serious drawbacks. Sampling and classification of old forests can produce a system of units of potential natural vegetation; such a system is widely used for forest management on federal lands (e.g., Atzet et al. 1996), but its use relies on inferences from current tree composition and associated understory plants to specify the potential tree composition of old forest on a site. Data about forests before recent disturbances would avoid such problems.

Data about forests at the time of Euro-American settlement, however, are anecdotal and fragmentary. In Oregon, older land surveyors' records date from near the time of Euro-American settlement; they list witness trees by species and size, and note the location of vegetation boundaries. Such information has been used to classify and map vegetation at the time of settlement over substantial areas (e.g., Habeck 1961). On the other hand, survey corners are widely spaced, data may be biased by selective use of species for witness trees, and there are no details about overall species composition or timber volumes. Somewhat later, but still before much western forest was disturbed by activities of Euro-Americans, came the earliest measurements of timber volumes (timber cruises; Shaw 1910), which used more intensive sampling, included all commercial species of trees, estimated timber volumes, and provided information about disturbance and some site properties. Data from timber cruises, coupled with modern estimates of climatic and edaphic conditions within the cruised area, can be used to estimate species tolerances near the time of Euro-American settlement.

Early timber cruises in the Pacific Northwest provided data summarized by township (6 x 6 miles = 9.7 x 9.7 km) (e.g., Langille et al. 1903), areas large enough to include major changes in elevation, climate and edaphic conditions; relating forest composition or timber volume to environment using township values would be subject to great uncertainty. There are cruises, however, from the first decades of the 20th century for which original data still exist; the cruise used here included estimates for 40-acre (16.2 ha) blocks within the area cruised, and provided data for over 40% of an area > 1500 mi^2 (3885 km^2). These cruises followed the land survey system still in use (Zobel 2016). The cruised areas are covered by detailed modern studies of geology, soils and climate that allow the environment of each cruised unit to be assessed. This paper reports the forest patterns from Coos County, along the coast of Oregon, ranging from tidewater to > 900 m elevation and including a wide variety of geologic types associated with the Klamath Mountain region, the Coast Range and coastal lowlands (Baldwin 1974). This area includes a major transition in forest types (Franklin and Dyrness 1973), and has been an important source of timber for both domestic use and export (Robbins 1988).

In this paper, cruise data were used to map species distributions and determine relationships among species' importance; in addition, cruise data were combined with modern environmental data to determine the relative degrees of association of species with edaphic factors and climate. Consequences of the results for choice of planting sites were assessed for six conifer species, in an effort to supplement or provide an alternative to current federal plant association-based systems for making such decisions. This is an expansion and modification of the analysis used by Zobel (2016) to address edaphic variation in importance of one tree species.

Methods

Study Area and Data Source

Coos County, on the south-central coast of Oregon, has diverse forests and geology within an area of moderate maritime climate, with wet winters and dry periods in summer (Baldwin et al. 1973, Franklin and Dyrness 1973). Its southern portion lies in the Klamath Mountains; farther north, the land rises eastward from beaches, wave-cut terraces and lowlands on the west into the Coast Range. The Klamath region includes a complex of Mesozoic rock types, including serpentinite and other ultramafic rocks, which support a distinctive forest structure and composition. Rocks north of the Klamath region include early Cenozoic basalts, but are primarily sedimentary, laid down in the large, inland Tyee basin that extended far north of Coos County and the smaller, more coastal Coos Bay basin. The major early source of sediments that produced these rocks was the ancestral Klamath Mountains; later, an inland plutonic source became important; and, finally, products from early Cascades volcanism were added to the mixture (Heller and Ryberg 1983). Forest tree diversity typical of the Coast Range is augmented by the coastal Sitka spruce (*Picea sitchensis*) and the northernmost populations of Port-Orford-cedar (*Chamaecyparis lawsoniana*), along with a substantial evergreen broadleaf tree component that is unusual farther north (taxonomic nomenclature from Little 1979). The study area is within the *P. sitchensis* and *T. heterophylla* vegetation zones (Franklin and Dyrness 1973); federal agency ecologists have recognized seven plant series that appear to be present, named for the dominant reproducing tree species (Douglas-fir, western hemlock, western redcedar, grand fir [or white fir], shore pine, and Port-Orford-cedar) (Atzet et al. 1996, Christy et al. 1998, McCain and Diaz 2002). Each series is comprised of several plant associations, the units upon which management is based, each recognized primarily by its dominant understory species. About 36 associations described by these workers appear to occur within the study area; however, these probably provide an incomplete description, as the study area is outside the zone of sampling for the two general classifications, the third is confined to sand dunes within the study area, and no plant association manual has been developed for most of the study area. Thus, the potential natural forest vegetation of the study area is incompletely known within this landscape with its localized edaphic conditions and transitional forests.

Estimation of timber volume (a "timber cruise") in Coos County dates back to at least 1905 (Robbins 1988), but the earliest data have not been found. Information from 1909–1913 and 1925–1927 was available about disturbances for 878 square-mile ($2.59\ km^2$ = 640 acres = 259 ha) sections; about the general age of timber stands for 612 sections; and about timber volumes for 629 sections (Anonymous 1909–1927). Cruise records were preserved by the Coos County forester and were available at the county courthouse in Coquille, Oregon. The cruise lay within a 42 x 36 mile (67.6 x 57.9 km) area in central and northern Coos County, located from the Douglas-Coos county line south to include Township 29S, about 7 mi (11.3 km) south of the town of Bandon. Type of disturbance (timber harvest [cutting], burning, or both) were noted; sections with partial or complete disturbance of each type were tallied. In addition, I designated sections by timber age, as old-growth, second-growth, mixed, or undetermined, based on the relative volumes of old-growth and second-growth Douglas-fir timber (and based on volume of other species where Douglas-fir was absent). Many partially disturbed sections retained substantial timber volume and were measured. On the other hand, not all undisturbed sections with timber were measured for volume. I used all 629 sections with timber information to determine species distribution, but only the 252 old-growth sections to analyze the relationship of timber volumes to environment.

These cruise records, apparently made for the county (Robbins 1988), provided timber volumes by 40-acre (16.2 ha) blocks (Anonymous 1909–1927). For sections re-surveyed during the 1920's, only the earlier data were used. Tree species names in the cruise records were interpreted as follows: "S.G. fir" and "O.G. fir" = Douglas-fir (second-growth and old-growth, respectively); hemlock = western hemlock; redcedar = western redcedar; white cedar = Port-Orford-cedar; white fir = grand fir; and spruce = Sitka spruce. Scientific names and abbreviations used in this paper are listed in Table 1. Although widespread on sandy coastal habitats within the cruised area (Christy et al. 1998), shore pine (*Pinus contorta*) had no volume in the cruise data. Angiosperm tree volume was reported for few sections and was not considered here.

No statement of methods was provided with this and other early cruise records I have consulted. A contemporary manual for the region (Shaw 1910) describes a variety of alternative methods. Methods could vary with time, even within the

TABLE 1. Names and abbreviations (used in text and tables) of tree species, geologic units and general soil types, with the number of sections (*n*) out of 629 in which a species occurred or where a unit was the dominant geologic or soil type. The second *n* value is the number of old-growth sections out of 252 in which the species, geologic unit or soil type occurred. Tree species abbreviations are the first two letters each of generic and specific names. Plant nomenclature follows Little (1979). Abbreviations for geologic units and soil types are the symbols used on the maps consulted. Geologic units dominant in < 5 sections of the total set, and in < 2 old-growth sections, were excluded; all general soil types were included.

Item	Scientific Name	Name(s) and Abbreviations Used in Text and Tables	*n*
Tree species	*Abies grandis*	Grand fir, *Abgr*	109/35
	Chamaecyparis lawsoniana	Port-Orford-cedar, *Chla*	258/76
	Picea sitchensis	Sitka spruce, spruce, *Pisi*	96/30
	Pseudotsuga menziesii	Douglas-fir, *Psme*	606/244
	Thuja plicata	Western redcedar, redcedar, *Thpl*	343/174
	Tsuga heterophylla	Western hemlock, hemlock, *Tshe*	396/202
Geologic unit	Bastendorf formation	Teob	9/5
	Coaledo formation, Lower	Tecl	18/9
	Coaledo formation, Middle	Tecm	16/6
	Coaledo formation, Upper	Tecu	44/24
	Coaledo formation	Tec	14/5
	Elkton formation	Tee	25/1
	Flournoy formation	Tef	119/58
	Lookingglass formation	Telg	45/6
	Otter Point formation	Jop	11/2
	Quaternary fluvial terraces	Qft	3/3
	Quaternary marine terraces	Qmt	53/8
	Roseburg formation	Ter	69/17
	Serpentinite	Jsp	6/1
	Submarine basalts	Terv	18/7
	Tyee formation	Tet	170/98
General soil type	Bullards-Bandon-Blacklock	2	34/5
	Coquille-Nestucca-Langlois	3	9/2
	Digger-Preacher-Remote	11	55/19
	Dune land-Waldport-Heceta	1	8/0
	Etelka-Whobrey	6	12/3
	Honeygrove-Blachly-Dement	8	59/25
	Kirkendall-Chismore-Wintley	4	13/5
	Milbury-Bohannon-Umpcoos	9	108/60
	Preacher-Bohannon	10	188/70
	Rinearson-Etelka	5	35/11
	Serpentano-Digger	12	2/0
	Templeton-Salander	7	85/41
	Umpcoos-Rock outcrop-Digger	13	21/11

same area and agency, as in eastern Oregon in 1915–1922 (Hagmann et al. 2013). U.S. Forest Service employees who carried out region-wide forest inventory in the late 1920 to 1930s used earlier cruises extensively and commented that earlier cruises often listed no standards (Andrews and Cowlin 1940). The minimal diameter at breast height recorded in western Oregon by the 1930s region-wide inventory was the 16 inch (40.6 cm) diameter class (15.1–17.0 inches; 38.4–43.2 cm), smaller than the 20 and 24 inch (50.8, 61.0 cm, respectively) classes used by earlier cruisers, size varying with species.

I copied volume per section by species for all 629 sections in the data set. I used data for all major commercial conifer species for all cruised sections to investigate the geographic distribution of species and the relationships of geology, soils and climate to their presence. Volumes for sections with other than a 640 acre area were adjusted to volume per 640 acres. Timber cruisers estimated volumes as board feet (1 bd ft = 0.00236 m^3). The system of timber volume estimation was not specified, so I did not convert volumes to metric units.

Data Analysis

I looked for patterns in frequency (% of sections where a species was present) and old-growth timber volume related to latitude, longitude, edaphic conditions, and climate. Spearman rank correlations were used to determine significance of variation of presence with latitude, distance from the coast, and climatic variables. The dominant geologic unit for each section was identified from maps in Baldwin et al. (1973), Beaulieu and Hughes (1975), Black and Priest (1993), Black (1994a, b), Wiley et al. (1994), Black and Madin (1995), Madin et al. (1995), and Wiley (1995). Where possible, units were referred to the types recognized by Beaulieu and Hughes (1975) (Table 1). I also determined the dominant General Soil Type for each section from Haagen (1989), using the 13 soil types displayed in his General Soils Map (Table 1). A cross-tabulation analysis was used to determine whether the geographic patterns of geologic units and soil types differed significantly. I analyzed data for the dominant geologic and soil unit in each section to determine the species' frequency and mean old-growth timber volume associated with each edaphic unit. I used logistic regression of presence/absence data (1 = present, 0 = absent) and analysis of variance of timber volume data to determine whether differences among edaphic units were significant. To determine the variability among soils within a geologic unit, and vice-versa, I analyzed frequency values for the more important soil types within the Tyee Formation (Tet), the most extensive geologic unit within the study. Likewise, I determined the variation among important geologic units within the most common general soil type (Preacher-Bohannon = type 10). I repeated the analysis for timber volume in old-growth sections. I excluded geology x soil combinations that occurred in fewer than six sections.

I also sought to determine whether there was a climatic pattern that might help to explain species distribution in the study area. The only weather station is near Coos Bay at 2 m elevation 5 km from the ocean. Thus, I used 1971–2000 climate normals as modeled by the PRISM program (Daly et al. 1994, PRISM Climate Group 2010), which presents interpolated climatic data for a specified location. PRISM outputs were used to determine the mean maximum temperature of the warmest month, the mean minimum temperature of the coolest month, and the total precipitation in the three driest months. Analysis used PRISM data from centers of 37 sections included in the cruise. A multiple regression was run to relate climatic variables to section latitude and longitude; from the resulting equations, climatic variables were calculated for each cruised section.

To determine to what degree edaphic and climatic factors were related to species importance, I ran a logistic regression for presence/absence data and a general linear model for the volume in old-growth sections of each species and total volume, using the dominant geologic and soil units as categorical factors and the maximum temperature of the warmest month and precipitation in the three driest months as quantitative factors. The minimal temperature of the coolest month was strongly related to the warmest month maximum ($r = -0.997$); it was used in place of maximal temperature in a separate analysis.

To determine whether edaphic units differed in ways that might affect tree distribution and growth, I used reports on the composition of sandstones within several of the geologic units: Burns and Ethridge (1979) reported 27 properties of the Flournoy, Lookingglass and Roseburg formations; Van Atta and Newton (1980), nine properties of the Coaledo, Flournoy and Roseburg formations; and Heller and Ryberg (1983), eight properties of the Coaledo, Elkton, Flournoy, Lookingglass, Roseburg and Tyee formations. Using results of each of the geological studies separately, Spearman rank correlations were calculated between the frequency and old-growth timber volume of each species in each geologic unit and each property of sandstones in the unit.

Statistical analyses were carried out using Statgraphics Plus for Windows, version 5.1 (Manugistics 2005). Analyses with P values ≤ 0.05 were considered significant.

Results

General Characteristics of the Forest

TABLE 2. Percentage of sections in which the presence of burning or cutting was indicated, and in which there was definitely old-growth and second-growth timber. Timber volume estimates (cruises) were provided for 629 sections for which a condition was listed. Of cruised sections, 252 were designated as only old-growth.

Criterion	Condition	% of Total	% of Cruised	% of Old-growth
Disturbance	Burn	26	15	12
	Cut	27	20	17
	Burn + Cut	6	5	2
Timber Age	Old-growth only	32	40	100
	Old- + Second-growth	10	13	0
	Second-growth only	28	26	0

Of the 878 sections for which level of disturbance was noted, 59% were at least partially disturbed (Table 2, Figure 1). Sections with entirely old-growth timber were widely distributed throughout the study area, representing 32% of sections, while 28% supported wholly second-growth. (Table 2, Figure 2). Percentage of disturbance declined somewhat in cruised and even more in old-growth cruised sections.

Total timber volume in all 629 measured sections varied from 0.6 to 717 million bd ft per section, with a mean of 196 million bd ft (Table 3). Undisturbed sections averaged 261 million bd ft, significantly greater than disturbed (75 million bd ft); disturbance types did not differ significantly. Old-growth sections had greater total volume for all species (Table 3) than those with some or all second-growth (195 million bd ft) and those with undesignated age (mostly disturbed) (46 million bd ft). Total volume in all 629 sections increased toward the north and east (Spearman rank correlation coefficients $r = 0.33$ and 0.44, respectively; $P < 0.0001$ for both directions). Total volume in old-growth increased toward the east ($r = 0.42$, $P < 0.0001$).

Forests were dominated by Douglas-fir (Table 3). Other species were far from ubiquitous. Hemlock and redcedar were moderately frequent, with Port-Orford-cedar more limited; grand fir and spruce were present in relatively few sections. However, volume of spruce was high where it occurred, giving it the second highest mean volume. Volume varied among sections (coefficient of variation, CV in Table 3) most for spruce and grand fir, least for Douglas-fir.

Species Distributions Related to Geography and Presence of Other Species

The six species showed distinctive patterns of distribution (Figures 3–8). Douglas-fir was absent only occasionally (Figure 3). Hemlock (Figure 4) was absent from much of the southern part of the study area, the north-central section and some parts of the coast. Redcedar (Figure 5) had a more diffuse presence than hemlock, seldom present along the coast. Port-Orford-cedar (Figure 6) was important along the coast and in the south. Spruce (Figure 7) was almost confined to the coastal regions. Grand fir (Figure 8) was widely scattered and sparse except in the south-central region.

Presence of hemlock and redcedar increased to the north and east; spruce, to the north and west; and Port-Orford-cedar and grand fir, to the south and west. Douglas-fir presence increased to the east. Total timber and Douglas-fir volume in old-growth forests increased significantly to the east. For hemlock and redcedar, volume in old-growth increased to the north; for spruce, to the north and west; for grand fir, to the south and west; and for Port-Orford-cedar, to the south. Within old-growth sections, timber volumes for Douglas-fir and hemlock increased as total timber volume increased ($r = 0.92$ and 0.49, respectively). Others species did not change significantly with total timber volume.

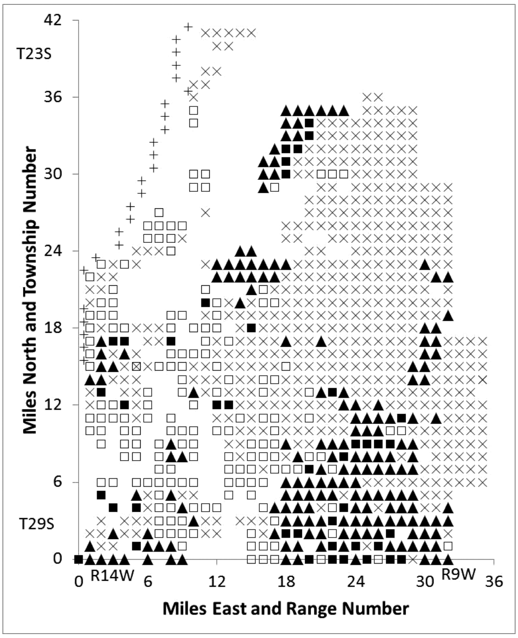

Figure 1. Locations of sections partially or completely disturbed by burning and timber harvest (cutting). Solid squares = cut and burned, open squares = cut, solid triangles = burned, X = not disturbed; + = eastern-most full section of ocean. Many, but not all, disturbed sections were excluded from measurement of timber volume. Axes give the miles E and N from the southwestern-most point in the cruise, the SW corner of Section 31, Township 29S, Range 14W. Each 6 mile x 6 mile square is a township, ranging N to S from T23S to T29S, and E to W from R9W to R14W. Selected townships and ranges are noted along the y- and x-axis, respectively.

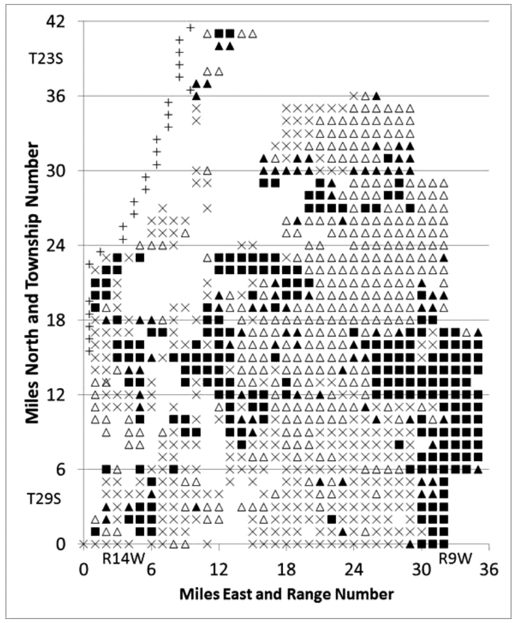

Figure 2. Location of sections that were wholly old-growth (solid squares), wholly second-growth (open triangles) or mixed (solid triangles). Sections without a designated age class were marked X. Sections noted as + were the eastern-most full section of ocean within the mapped area. See Figure 1 for further explanation.

Presence of some species was significantly associated with the presence of others (Table 4, lower left); here I mention only those pairs with Spearman rank correlation coefficients > 0.20. Port-Orford-cedar showed the strongest relationships based on presence, positively with spruce and hemlock, negatively with redcedar. Hemlock and redcedar were associated with each other. Spruce was significantly dissociated with Douglas-fir. Based on timber volume in old-growth sections (Table 4, upper right), Douglas-fir was positively related to hemlock and negatively to spruce. Hemlock was positively associated with redcedar and spruce and dissociated with grand fir. Port-Orford-cedar was positively associated with spruce and negatively with redcedar and grand fir. Grand fir volume was negatively related to hemlock, spruce and Port-Orford-cedar, as noted above.

Relationships Among Geologic and Soil Units

A cross-tabulation of the dominant general soil type in a section with the dominant geologic unit in that section showed that the distribution of soils on geology was not random (Chi-square test, $P < 0.0001$). For four general soil types, more than half the occurrences were on a single geologic unit. On the other hand, most soil types dominated in sections with a variety of geologic units and most dominant geologic units were associated with more than one dominant soil type. Therefore, I considered general soil types to represent environmental information not available from the pattern of geologic units, and to be worthy of consideration in addition to geology.

TABLE 3. Frequency (% of cruised sections where each species was present), mean timber volume section^{-1} (million bd ft), and coefficient of variation (CV) for timber volume for each species across all 629 sections and across 252 old-growth sections. Species abbreviations are identified in Table 1.

Item/Species	*Psme*	*Tshe*	*Thpl*	*Pisi*	*Chla*	*Abgr*	All Species
Frequency (%)							
All sections	96	63	55	16	41	17	-
Old-growth only	97	80	69	12	30	14	-
Timber volume section^{-1}							
All sections	173.1	5.9	1.8	9.1	4.7	1.0	196
Old-growth only	227.7	7.6	2.6	11.5	3.3	1.1	253
CV Volume (%)							
Old-growth only	65	142	158	477	306	466	60

Species Distribution in Relation to Geology and Soils

Frequency—All species except spruce were present on all geologic units, but their relative frequency varied widely (Table 5). Douglas-fir was the most frequent species on most geologic units. In many units, hemlock was the second most frequent species. In three units, redcedar was the most frequent species other than Douglas-fir (Tec [redcedar tied with hemlock], Tef, Terv). Spruce was absent or rare on eight units. Grand fir occurred on all geologic units but never in more than half the sections in any one unit. Frequency was least variable among units (coefficient of variation [CV]; Table 5) for Douglas-fir and most variable for spruce and Port-Orford-cedar.

Tree species frequency appeared to be more closely associated with general soil types than with geologic units (Table 5), based on several criteria. CV for general soil types was higher for three species than for geologic units, and substantially lower only for Port-Orford-cedar. Four species were absent from at least one soil type, while only spruce was absent from a geologic unit. The maximal frequencies on a soil type for spruce and grand fir were well above maxima on geologic units. Douglas-fir and Port-Orford-cedar had the highest frequency on six soil types (2, 5, 6, 11, 12, 13), but strongly dominated on only two geologic units. In only one type (7) did Port-Orford-cedar and redcedar both grow in more than half the sections. For two types (4, 8), grand fir was the most widespread species other than Douglas-fir, a situation not true for any geologic unit. Thus, species distributions were more closely associated with soil types than with geologic units.

Timber Volume—There was almost a four-fold difference among geologic units in total old-growth stand volume, the highest unit being the widespread Tyee formation (Tet) (Table 6). All species except hemlock and redcedar differed significantly among geologic units, with variation among units (CV) for grand fir, spruce and Port-Orford-cedar being greater than for the more widespread species. On only one unit (Qmt) did another species have more volume than Douglas-fir, spruce having 54% compared to 25% for Douglas-fir; Port-Orford-cedar was also important on Qmt with 14% of the volume. For hemlock, the maximal relative timber volume on a single geologic unit was 9% of the total, for grand fir, 8%, and for redcedar, only 3%.

Total timber volume varied among general soil types by more than four-fold, being highest in soil type 13, greater than for any geologic unit (Table 6). Hemlock and redcedar, however, did not differ significantly among soil types. Douglas-fir represented > 90% of total volume on eight of 11 general soil types compared to five of 13 geologic units (Table 6). Hemlock and redcedar, the two most widespread species besides Douglas-fir, had maximal volumes of 14.6 and 4.5 million bd ft section^{-1}, respectively, on any soil type; the less widely distributed spruce had high volumes on types 2 and 7; Port-Orford-cedar had high volume on type 2; and grand fir had substantial timber on only two types. Variation among soil types (CV; Table 6) was lower for the more widespread species.

Variation Within Edaphic Units

There was variation in species importance among units of one edaphic type (i.e., soils or geology) within a given unit of the other edaphic type.

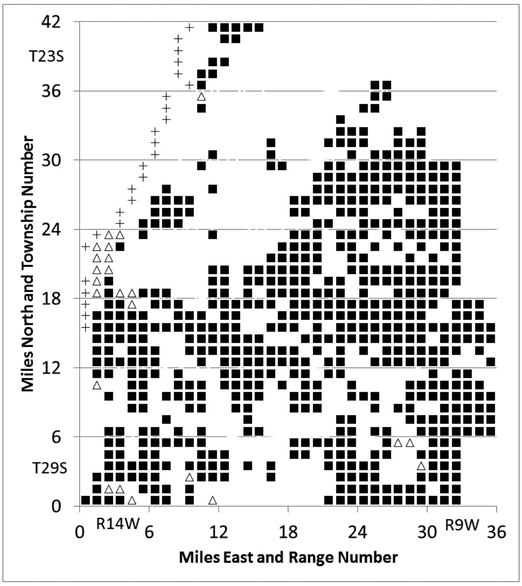

Figure 3. Distribution of Douglas-fir in the cruised area, Coos County, Oregon. Each symbol represents a square-mile section. Filled squares represent sections where the species was present in the timber volume data; open triangles, where it was absent; and + indicates the eastern-most full section of ocean where it is within the map area. For further information, see Figure 1.

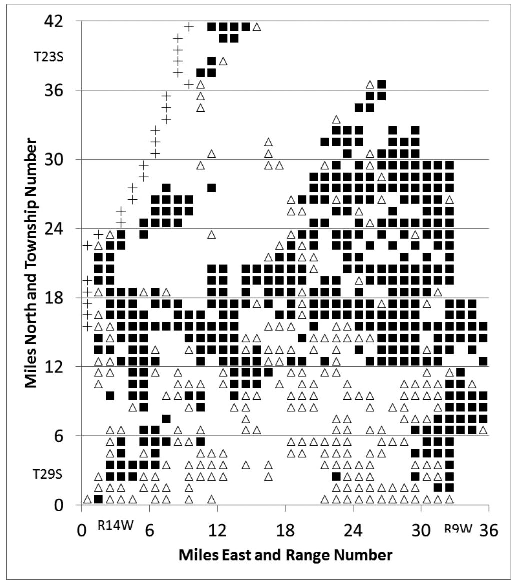

Figure 4. Distribution of western hemlock in the cruised area, Coos County, Oregon. Filled squares represent sections where the species was present in the timber volume data; open triangles, where it was absent; and + indicates the eastern-most full section of ocean where it is within the map area. For further information, see Figure 1.

Within the Tyee formation, species frequency varied significantly among four general soil types for hemlock, redcedar and Port-Orford-cedar; patterns among soils differed among species. For redcedar and Port-Orford-cedar, soil types within Tyee formation rocks also differed for old-growth timber volume, again differently between species. A similar analysis among geologic units within the Preacher-Bohannon general soil type (type 10) showed substantial significant differences for frequency for species except Douglas-fir and spruce, and differences among old-growth volumes for Douglas-fir, Port-Orford-cedar and total volume.

Climatic Patterns

Estimated climatic attributes showed some statistically significant variation (Table 7). Minimal temperature of the coolest month declined and maximal temperature during the warmest month increased away from the coast. Precipitation during the three driest months increased to the north. Even though statistically significant, differences within the cruised area were small.

Species Distribution in Relation to Climate and Edaphic Factors

Some geologic and soil patterns parallel those of climate, with locations of many geologic units and soil types restricted primarily to inland, coastal or southern locations. Means of all climatic variables differed at $P < 0.0001$ among geologic units and general soil types (Kruskal-Wallis test). To reduce the influence on interpretations caused by such inter-correlations of edaphic and climatic variables, multivariate analyses were used to determine the significance of relationships when both climatic and edaphic variables were in the analysis together. Because the two temperature variables were highly correlated, only one at a time was used in the multivariate analyses; I chose to report results primarily using the warm month maximum.

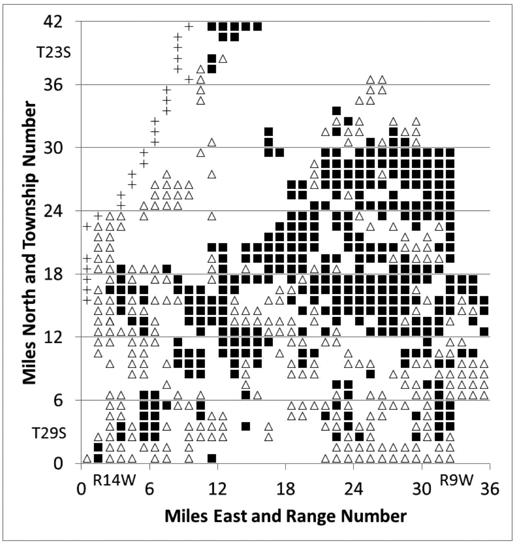

Figure 5. Distribution of western redcedar in the cruised area, Coos County, Oregon. Filled squares represent sections where the species was present in the timber volume data; open triangles, where it was absent; and + indicates the eastern-most full section of ocean where it is within the map area. For further information, see Figure 1.

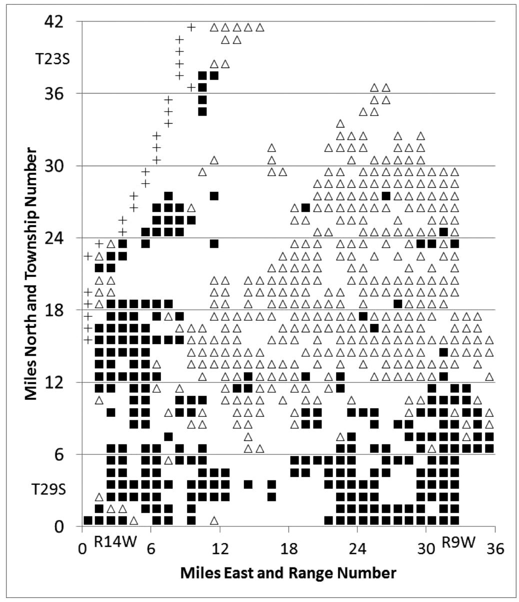

Figure 6. Distribution of Port-Orford-cedar in the cruised area, Coos County, Oregon. Filled squares represent sections where the species was present in the timber volume data; open triangles, where it was absent; and + indicates the eastern-most full section of ocean where it is within the map area. For further information, see Figure 1.

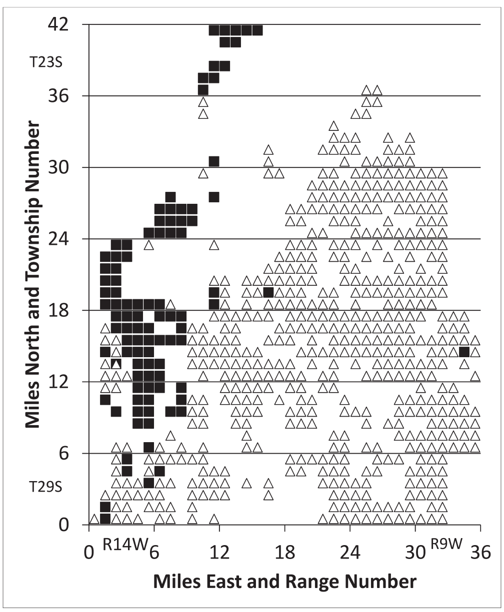

Figure 7. Distribution of Sitka spruce in the cruised area, Coos County, Oregon. Filled squares represent sections where the species was present in the timber volume data; open triangles, where it was absent; and + indicates the eastern-most full section of ocean where it is within the map area. For further information, see Figure 1.

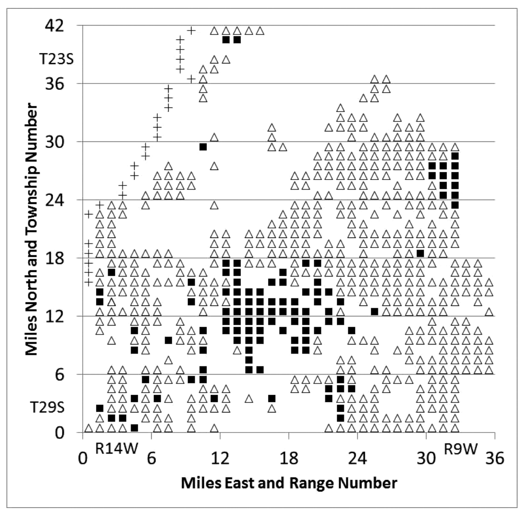

Figure 8. Distribution of grand fir in the cruised area, Coos County, Oregon. Filled squares represent sections where the species was present in the timber volume data; open triangles, where it was absent; and + indicates the eastern-most full section of ocean where it is within the map area. For further information, see Figure 1.

Presence of all species was highly significantly associated with general soil types, both in univariate and multivariable analyses (Table 8). Geologic units lacked significance with presence only for spruce. Precipitation in the three driest months lacked significance for redcedar and grand fir. Maximal temperature in the warmest month was not significant for hemlock and redcedar. The model was more effective at accounting for variation in the less widely distributed species, based on Percentage Deviance Explained values from the logistic regression: Douglas-fir 19%, hemlock 20%, redcedar 14%, spruce 57%, Port-Orford-cedar 44% and grand fir 30%.

TABLE 4. Spearman rank correlation coefficients between species pairs for presence (lower left, italic type) and for timber volume section^{-1} in old-growth (upper right, regular type). Bold values are significant at $P < 0.05$. Species abbreviations are identified in Table 1.

Species	*Psme*	*Tshe*	*Thpl*	*Pisi*	*Chla*	*Abgr*
Psme	-	**0.34**	0.05	**–0.34**	–0.09	–0.09
Tshe	*–0.05*	-	**0.17**	**0.21**	0.00	**–0.14**
Thpl	***0.12***	***0.22***	-	–0.11	**–0.19**	–0.08
Pisi	***–0.27***	***0.18***	***–0.19***	-	**0.33**	**–0.15**
Chla	***–0.08***	***0.24***	***–0.41***	***0.31***	-	**–0.16**
Abgr	*0.07*	***–0.15***	*–0.01*	***–0.11***	***–0.09***	-

Analyses for timber volume in old-growth forests showed that only spruce and grand fir were significantly associated with geologic units and general soil types (Table 8). Maximal temperature in the warmest month was significant for only two species (Table 8), while precipitation in the three driest months was significant for four. The ability of models to account for variability of old-growth timber volume within species (R^2) differed among species: Douglas-fir 30%, hemlock 13%, redcedar 3%, spruce 29%, Port-Orford-cedar 17% and grand fir 35%. For both presence and volume, redcedar was the least effectively modeled.

Each species had a unique pattern in relation to environmental factors for both presence and volume (Table 8). Presence had twice the number of significant relationships as did volume in old-growth (19 vs. 10). Patterns differed between presence and volume for all species. Only presence of Douglas-fir and Port-Orford-cedar were significantly associated with all four variables. At the opposite extreme, redcedar volume was unrelated to any factor considered. Generalizing still further, considering only the factors for which both presence and volume in old-growth showed a significant relationship, also produced a unique pattern for each species:

a. grand fir was related to geology and soils;
b. spruce was related to soils and temperature;
c. Douglas-fir was related to both temperature and precipitation;
d. hemlock was related only to precipitation;
e. Port-Orford-cedar was related only to precipitation, but negatively; and
f. redcedar had no significant relationships.

Re-analysis using the minimum temperature for the coolest month, rather than the maximum for the warmest, did not change the pattern of significance. Therefore, we can refer to a general relationship with the temperature pattern, rather than a relationship to a particular attribute of temperature.

Species' Relationships with Sandstone Composition

Across six geologic units (Heller and Ryberg 1983), frequency of two species varied significantly with the importance of components of sandstones; Douglas-fir and hemlock increased with importance of plagioclase and K-feldspar, respectively, both indicative of an inland plutonic source area for sediments; in addition, hemlock declined with the concentration of heavy minerals, an indicator of a Klamath Mountain source. Old-growth timber volume did not show any significant relationships in this comparison.

Two analyses using three geologic formations each also showed significance between species importance and sandstone composition. Among the Coaledo, Flournoy and Roseburg formations (Van Atta and Newton 1980), grand fir frequency and volume and Douglas-fir volume increased as both metamorphic and sedimentary rock fragments increased, whereas hemlock and redcedar declined. When comparing Flournoy, Lookingglass and Roseburg formations (Burns and Ethridge 1979):

a. Douglas-fir frequency increased as occurrence of epidote increased, whereas redcedar volume declined;
b. grand fir frequency increased with the importance of sedimentary rock fragments, while spruce volume declined; and
c. hemlock and Douglas-fir frequency increased as percent of volcanic rock fragments increased, whereas frequency and volume of Port-Orford-cedar declined.

Thus, Douglas-fir and hemlock grew better on sediments from sources other than the ancestral Klamath Mountains, whereas Port-Orford-cedar grew less well with those other sources.

TABLE 5. Frequency of species (% of sections with a species present) by the dominant geologic unit and general soil type in that section. All species differed among geologic units and soil types with $P < 0.0001$. Abbreviations of species and edaphic unit names are identified in Table 1. CV = coefficient of variation among geologic units and soil types for each species. Geologic units with < 6 occurrences were excluded from the table.

		Species					
Edaphic type	Unit	*Psme*	*Tshe*	*Thpl*	*Pisi*	*Chla*	*Abgr*
Geologic	Jop	82	9	9	9	82	31
	Jsp	100	17	17	0	100	33
	Qmt	89	66	13	66	92	9
	Tec	100	79	79	57	14	29
	Tecl	83	72	56	33	56	28
	Tecm	88	94	56	50	63	25
	Tecu	100	70	45	41	36	30
	Tee	100	96	80	0	8	40
	Tef	100	73	87	3	6	2
	Telg	91	16	31	2	78	24
	Teob	78	67	56	22	22	33
	Ter	97	28	30	10	57	46
	Terv	100	56	78	0	1	44
	Tet	100	77	59	3	36	1
	CV	9	50	53	112	72	52
Soil	1	100	75	38	88	63	0
	2	82	56	3	53	94	6
	3	100	44	33	56	56	44
	4	100	23	38	0	15	69
	5	94	40	46	26	86	20
	6	92	0	25	8	83	25
	7	89	87	52	65	51	15
	8	100	49	56	2	12	68
	9	100	81	83	0	11	7
	10	99	69	62	1	26	9
	11	96	38	35	2	84	11
	12	100	0	0	0	100	50
	13	95	38	48	0	71	0
	CV	6	60	57	135	56	99

Discussion

Importance of Studying Environmental Correlates of Species Ranges

If one knows how species distribution is related to environment, one can improve effectiveness of planting a species outside of those habitats where its performance is known. Vegetation in North America changed following European settlement, often drastically and even in un-managed areas, well before ecological studies and forest cruises began. Thus, understanding factors affecting species distribution is useful when considering all types of management that invoke the manipulation of species composition, such as forest management and ecological restoration. Given the increasing intensity of climate change and the concern over suitability of future climates for currently important species, translocation of species into new habitats is being advocated, based on predictions of future climates (Chmura et al. 2011). Such assisted migration will bring species into habitats for which managers have no experience with them. Information about how edaphic conditions were related to performance of the six commercial conifers included in this study should be of substantial practical use.

Factors Related to Tree Species Distribution

Climate has long been considered the primary factor affecting plant distribution, edaphic conditions being of secondary influence (e.g., Meyen 1846).

TABLE 6. Timber volume (million bd ft section^{-1}) for each species by geologic unit and general soil type in 252 sections of old-growth forest, with the *P* values for variation among geologic units and soil types. Geologic units Jsp, Qal and Tee were represented by only a single old-growth section and are excluded. Soil types 1 and 12 dominated no sections of old-growth. Geologic unit, general soil type and species abbreviations are identified in Table 1. CV = coefficient of variation among geologic units and soil types for each species.

Edaphic type	Unit	*Psme*	*Tshe*	*Thpl*	*Pisi*	*Chla*	*Abgr*	Total
Geologic	Jop	91.1	0	0	0	3.2	0	94
	Qft	79.7	0	2.5	0.8	2.4	0	85
	Qmt	37.1	10.8	1.1	81.5	20.6	0	151
	Tec	204.4	8.8	5.6	15.8	0	0	235
	Tecl	135.7	9.5	5.7	86.0	8.0	1.4	246
	Tecm	135.8	18.6	3.4	40.2	15.2	0	213
	Tecu	156.0	6.2	2.1	12.5	1.1	2.3	180
	Tef	226.9	6.3	3.6	0	0.2	0.03	237
	Telg	235.8	1.7	2.3	0	4.2	1.0	245
	Teob	52.3	4.2	2.6	18.7	0.1	4.2	82
	Ter	222.7	3.2	1.0	21.0	4.2	2.9	255
	Terv	163.8	16.3	3.2	0	0	16.7	200
	Tet	298.4	8.5	2.1	3.7	3.5	0.003	316
	P value	< 0.0001	0.069	0.15	0.001	0.0001	< 0.0001	0.0001
	CV	50	79	61	142	132	209	37
Soil	2	9.5	14.6	1.8	36.0	19.4	0	81
	3	107.2	5.8	4.5	2.0	2.8	0	122
	4	175.7	1.1	1.4	0	0	4.3	183
	5	181.3	2.0	4.1	1.3	7.7	0.4	197
	6	125.3	0	1.4	0.5	5.9	0	133
	7	124.1	9.5	2.3	65.7	6.3	0.7	209
	8	216.6	9.7	2.2	0	0.1	8.5	237
	9	249.0	5.1	3.2	0	0.4	0.04	258
	10	268.3	9.2	2.9	0.01	2.0	0.01	282
	11	297.3	8.8	1.4	0	6.8	0	314
	13	346.6	4.7	0.9	0	7.3	0	359
	P value	< 0.0001	0.09	0.59	< 0.0001	0.003	< 0.0001	0.002
	CV	51	69	50	224	104	213	39

This does not mean, however, that edaphic conditions are unimportant (Jenny 1980, Kruckeberg 2002). The study area, where climate is mild and moist, provides a good opportunity to explore the forest patterns produced by edaphic variability. For example, an earlier study (Imper 1981) found that redcedar and Port-Orford-cedar seldom grew together and their habitats could be distinguished by soil chemical properties.

The analyses here, which considered responses of both presence and timber volume to edaphic and climatic factors, showed that the pattern of significant relationships with environment was unique for each of six major conifer species (Table 8). Such differences, and the difference between patterns for presence and volume, suggest the complexity of control of species importance and, therefore, the difficulty of predicting species behavior with changing climate: within the cruised area, some species were not related to climate, some varied with temperature and others with precipitation, and some responded in opposite directions to changes in one climatic variable. Differences in response to edaphic variables were complex (Tables 5, 6). Some responses differed from those suggested by Mathys et al. (2014): while spruce and grand fir lack sensitivity to a water-related variable in both studies and hemlock shows sensitivity in both,

TABLE 7. Mean and extremes for three climatic variables estimated from PRISM data (1971–2000) among centers of all cruised sections. *P* values and R^2 (adjusted for degrees of freedom) are from a multiple regression on original PRISM data for 37 sections using the miles north and east of the southwestern-most section in the study (df = 2/34).

Property	Mean	Minimum	Maximum	*P* value, Latitude	*P* value, Longitude	R^2 (%)
Mean minimum, coolest month (°C)	2.4	1.4	3.4	0.38	< 0.0001	66
Mean maximum, warmest month (°C)	23.7	21.1	26.0	0.17	< 0.0001	57
Precipitation, 3 dry months (mm)	88.1	75.4	100.8	0.0095	0.33	17

TABLE 8. Sensitivity of each species' presence and old-growth volume to environmental factors. A species attribute was considered sensitive only if both the uni- and multi-variate analyses showed a significant relationship. * = significant for an edaphic factor; + or – = significant for a climatic factor and shows the direction of the correlation; 0 = not significant (NS) for either uni- or multi-variate analysis or both. Geology = geologic units; Soils = general soil types; Temperature = estimated mean maximum temperature in the warmest month; Precipitation = estimated mean total precipitation during the three driest months.

	Presence						Volume					
Factor	*Psme*	*Tshe*	*Thpl*	*Pisi*	*Chla*	*Abgr*	*Psme*	*Tshe*	*Thpl*	*Pisi*	*Chla*	*Abgr*
Geology	*	*	*	0	*	*	0	0	0	*	0	*
Soils	*	*	*	*	*	*	0	0	0	*	0	*
Temperature	+	0	0	-	-	-	+	0	0	-	0	0
Precipitation	+	+	0	-	-	0	+	+	0	0	-	-

redcedar (sensitive to estimated soil moisture in theirs) was not associated with precipitation here. The importance of such forest variation with edaphic factors is substantial for those who study effects of past climate and seek to predict such effects for the future (Briles et al. 2011).

Volume was significantly related to environmental factors less frequently than was presence (Table 8); the difference was especially large for edaphic factors. This may be due to the difference in sample size, 252 sections sampled for volume in old-growth compared to 629 for presence in all sections. Some geologic units and soils had as few as two sections in the mean for volume, compared to a minimum sample size of six sections for presence.

Details of species' biology may further complicate interpretations; an example is Port-Orford-cedar's loss of importance as dry-season precipitation rises (Table 8). This species is limited to sites that lack severe moisture stress (Zobel et al. 1985) and has small, late-germinating seedlings that require surface moisture year-round (Zobel 1990); thus, an increase in summer rain should aid seedling establishment. In the study area, however, the highest precipitation is in the north, where much of the area is beyond the northern edge of the species' natural range (Figure 6), where factors other than summer water apparently exclude the species (Zobel 2016). One of these factors may be a positive response by its competitors to increased summer moisture, as shown for Douglas-fir and hemlock (Table 8) and suggested for hemlock by Mathys et al. (2014). Thus, in this case, a complex of factors, including the relationship with precipitation of other species, apparently outweighs the ecophysiological correlation known from other research.

The importance of edaphic factors seems clear in this area of high geologic diversity and muted climatic variability; presence of all species and volume of grand fir and spruce were related significantly to edaphic factors (Table 8). Both geologic units and soil types were considered here; neither soils nor geology alone would suffice, as the pattern of soils did not match closely with that of geologic units. Furthermore, the patterns of distribution of species on geologic units and on

TABLE 9. Species x geologic unit and species x general soil type combinations where the species performed particularly well or poorly, compared to its performance on other units: * = well, where the species had both frequency and old-growth timber volume > 50% of the maximal value on any unit; O = poorly, where the species had both frequency < 50% of its maximum among edaphic units and old-growth timber volume < 10% of its maximum among edaphic units. Blank = failed to meet one or both criteria for good or poor performance. # = the species with the best performance in units where no species performed well. Abbreviations for species and edaphic type names are identified in Table 1.

Edaphic type	Unit	*Psme*	*Tshe*	*Thpl*	*Pisi*	*Chla*	*Abgr*
Geologic	Jop	#	O	O	O	#	O
	Qmt		*		*	*	O
	Tec	*		*		O	O
	Tecl		*	*	*		O
	Tecm		*	*		*	O
	Tecu	*				O	
	Tef	*		*	O	O	O
	Telg	*	O		O	O	
	Teob	#			#	O	
	Ter	*					
	Terv	*	*	*	O	O	*
	Tet	*			O		O
Soil	2	O	*		*	*	O
	3	O		*	O		O
	4	*	O		O	O	*
	5	*		*	O		O
	6	#	O		O	#	O
	7		*	*	*		O
	8	*	*		O	O	*
	9	*		*	O	O	O
	10	*	*	*	O		O
	11	*			O		O
	13	*			O		O

soil types differed (Table 5), and for presence of five species the influence of both soils and geology remained significant with the other factor in the multivariate equation (Table 8). I conclude that these two edaphic categories give different information, and are likely to be more useful in combination than either alone, as exemplified by the variation among soils within a single geologic unit. Distribution of most species' presence was more closely related to general soil type than to geologic unit. Because soil properties are a function of several factors (Jenny 1980), including geology, this could be expected. Port-Orford-cedar is an exception (Table 5). Timber volume did not show such a stronger association with soils.

Another question about edaphic control in the study area is whether any features of soils or geology can be identified that differ among edaphic units in a way that correlates with species' distribution patterns and that are likely to influence plant behavior directly. Haagen (1989) presented little to allow one to run statistical correlations between soil properties and species' importance. In contrast, correlations of species importance with individual properties of sandstones in different geologic units were sometimes significant. Some negatively related species pairs (Table 4) had significant correlations with a single sandstone component but with opposite signs (e.g., hemlock and grand fir); other negatively related species pairs had none (redcedar, Port-Orford-cedar). Some positively related species pairs had correlations with sandstone properties with the same sign (hemlock, redcedar). For other species pairs, different sandstone properties were correlated differently.

Perhaps the most useful implication of such correlations with sandstone components was their association with changes in sediment source with time. Early sediments (Roseburg, Lookingglass formations) came primarily from the adjacent ancestral Klamath Mountains, while sediments of intermediate age (Flournoy, Tyee, Elkton) indicated a major inland, plutonic source of sediments that diluted the Klamath contribution (Heller and Ryberg 1983). The most recent sediments (Coaledo) included early Cascades volcanics. The Klamaths include a large component of serpentinite and other ultramafic rocks, outcrops of which profoundly affect forest composition (Franklin and Dyrness 1973, Atzet et al. 1996, Kruckeberg 2002): pine species often dominate there; Douglas-fir is present but grows more slowly than Port-Orford-cedar, opposite the situation on more productive soils (Zobel et al. 1985); Port-Orford-cedar may dominate moist-site forests; and hemlock and redcedar are rare. It seems reasonable to expect that the proportion of Klamath-sourced sediments in parent material, which changed through time and with location, both among and within geologic units, could be responsible for substantial variability in soil chemistry that modified species composition of the cruised forests. For example, Port-Orford-cedar grew less well where volcanic fragments in sandstone were more common, while Douglas-fir and hemlock grew better.

Implications for Forest Management

The dominance of Douglas-fir was overwhelming in most cruised forests, and one might be tempted not to manage less dominant species. These forests, however, were more diverse than Coast Range forests farther north (Franklin and Dyrness 1973); their diversity was important to the regional ecology and economy. Which species contributed to that diversity varied with location and edaphic conditions (Figures 3–8, Tables 5, 6). In addition, Douglas-fir was absent in some section-sized areas and had distinctly lower timber volumes on some edaphic types. Analysis of cruise data can provide a solid basis for answering the question "Which species should we plant where?"

Within this 42 x 36 mile area, there were major differences in forest composition and timber volume, despite its mild coastal climate with limited variation. Edaphic restriction of the five species besides Douglas-fir was common (Table 5): 15 of 70 species x geologic unit combinations had < 10% of sections in that unit supporting a given species; eight of 14 geologic units had at least one species with < 10% frequency; two units (Jop, Tef) had three species that were sparse; and all five species were present in < 10% of sections on at least one geologic unit. Similar analysis of presence on soil types and of timber volume on geologic units and soil types demonstrated equal or greater edaphic restriction (Tables 5, 6). Given that climate is mild and relatively uniform, edaphic variation probably captures most of variation in site potential.

Foresters in southwestern Oregon have long dealt with the severe restriction to forest composition and growth on ultramafic rock types such as peridotite and serpentinite (e.g., Atzet et al. 1996). But most of the edaphic restriction in the cruised area did not involve explicitly ultramafic rocks. Thus, a more complex consideration is required to avoid planting species in conditions where they grew only marginally in pre-management forests. Federal ecologists have developed classifications of plant associations, which serve as a basis for management for much federal forest in the Pacific Northwest (e.g., Atzet et al. 1996, McCain and Diaz 2002); identifying the plant association present allows foresters to estimate a site's potential for growing various tree species. Such systems classify sites based on which tree species are regenerating and on importance of major understory species.

In the study area, plant association analyses have not been thoroughly applied: much of the area is outside federal ownership; coverage by Atzet et al. (1996) and McCain and Diaz (2002) ends several miles outside the study area; Christy et al. (1998) sampled only sand dunes within the cruised area, and their plant associations with similar names to those from elsewhere differed significantly; and, finally, the major federal land management agency in the cruised area has not produced a plant association classification, but does use Atzet et al. (1996) and McCain and Diaz (2002) as guidance (J. Kirkpatrick, Bureau of Land Management Coos Bay District, personal communication, 2018). In addition, much of the study area differs geologically from areas considered by plant association classifications.

Data presented here allow an alternative approach to designating which species should be grown in different environments. In fact, the tree composition in the 252 old-growth sections defines the condition for those sites that plant association classifications are designed to estimate: the tree composition in old forests. These old-growth data can be used directly to indicate appropriate species composition for those locations, and can be used to check results from plant association classification applied to those locations. In addition, old-growth data should be useful in identifying species x site combinations from which species have been removed by disease or harvest (e.g., Port-Orford-cedar and spruce), and where future climate change may prevent long-term success (e.g., hemlock and redcedar in the southern end of the cruised area).

These old-growth forests included combinations of conifers not suggested by the applicable plant association guides. Based on information about plant association distributions (Atzet et al. 1996, Christy et al. 1998, McCain and Diaz 2002), 36 associations can be expected to occur in the cruised area**.** Lists of trees for these 36 associations fit only seven of the 20 combinations of tree species present in cruised old-growth, although these seven match those in 63% of the old-growth sections. Many of the unpublished tree species combinations were rare, but three occurred in ≥ 14 sections each: Douglas-fir, hemlock, redcedar and grand fir (18 sections); Douglas-fir and redcedar (18); and Douglas-fir, hemlock, redcedar and Port-Orford-cedar (14). In addition, 12 sections with five conifer species support more conifer species than any local published plant association.

Where old forests were absent, average species compositions for particular edaphic types (Tables 5, 6) can be used to plan management. An example follows. One can choose a range of criteria for selecting which species to favor and which to exclude on a particular edaphically-defined site. Examples (Table 9) met the following criteria: 1) excluded a species from a planting regimen on a particular geologic unit or general soil type where it both was present at less than half its maximum frequency and had < 10% of its maximum timber volume in old-growth; and 2) favored a species on an edaphic type where it was present in more than half of its maximal frequency and had more than half its maximal old-growth timber volume. These analyses (Table 9) showed that planting should produce good results at 30% of species x edaphic unit combinations, and that at 32% of combinations planting would be unproductive; the remaining situations had intermediate conditions.

Such criteria should be useful within the cruised area and beyond it to a lesser extent. Inland and farther south, where water restriction becomes more severe, conditions change (Atzet et al. 1996). Practical considerations also limit using these data beyond Coos County. The general soil types are defined differently for surrounding counties and thus cannot be used directly there. Several geologic units are confined to the study area. In contrast, the Tyee formation (Tet) extends far north in the Coast Range (Wells et al. 2008); Douglas-fir grew well on Tyee rocks, although spruce and grand fir met the criteria for exclusion. Planting Port-Orford-cedar northward beyond its native range on Tyee formation areas should be a successful attempt at assisted migration. Quaternary marine terraces (Qmt) are widespread farther north also, but they are of lower elevation and closer to the coast, and more subject to recent sand dune activity and salt spray than those cruised. The situation on submarine volcanics (Terv, Table 9), with Douglas-fir, hemlock, and grand fir well-represented, and spruce and Port-Orford-cedar poorly represented, may also apply to volcanic rocks that are common farther north (Wells et al. 2008).

Given the substantial variability among soils within geologic units and vice-versa, one may wish to develop planting rules based on combinations of geologic unit and general soil type, such as "Soil type 7 within the Tyee formation". To determine the potential importance of this extra level of precision, I calculated the frequency for all species in all 27 such edaphic units (combinations of geologic unit and general soil type) represented by five or more sections. Frequency information alone would change the classification of whether to plant a species (favor, avoid, or not determined, as in Table 9) for 23 of the 138 species x edaphic unit combinations. All except one change was to "avoid" from "favor" or undetermined; nine changes involved redcedar, eight hemlock, three spruce, two grand fir and one Port-Orford-cedar. Using only guidelines from Table 9, thus, one would choose to plant in apparently unsuitable edaphic conditions about 17% of the time.

For each species, however, other considerations besides the general edaphic types will determine a suitable planting site. Detailed consideration for Port-Orford-cedar (Zobel et al. 1985, Huff

2011, Zobel 2016), for example, involved exposure to a virulent disease organism attacking Port-Orford-cedar, water supply, and disease problems of alternative species. As another example, plant association manuals lump grand fir with populations intermediate to white fir (*Abies concolor)*, which can grow in distinctly different environments. Identifying which taxon grew in the cruised areas could probably be determined using site elevation.

Importance of Cruise Data and Caveats for Their Use

Timber cruise records may inform studies of forest history (Zybach 2000); provide baseline data for comparison with current vegetation and a basis for ecological restoration (Hagmann et al. 2013); give insight into species distributions and forest management (Zobel 2016), the way they are used here; and provide insight into an anthropological question (Zobel 2002). More generally, publication and use of this type of information provides an effective, documented way to counteract the 'shifting baseline syndrome', a continuing degradation of the conditions understood by the current generation to have been "normal" before disturbance by modern civilization (Soga and Gaston 2018).

However, detailed data about forest composition from the era of this cruise are rare. Ecologists had yet to describe forests using quantitative methods. Earlier surveys of timber volume in Oregon (e.g., Langille et al. 1903) did not include coastal lands and provided data at the township (36 mi^2 = 93.2 km^2) scale. I could find no overall list of areas sampled by early 20th century timber cruises in western Oregon. Methods were summarized in overview form (Shaw 1910) but not for individual cases. Original data from at least a few other county-based cruises still exist (Anonymous 1908, Bagley 1915), as well as for substantial areas east of the Cascade Range (Hagmann et al. 2013).

These cruises provide data from 40-acre (16.2 ha) blocks, which were aggregated into totals for each section, the form of data I used. Although a 40% cruise was recommended (Shaw 1910), earlier cruises often covered 10 or 20% of the study areas (Shaw 1910, Hagmann et al. 2013); cruises in the Pacific Northwest by the U.S. Forest Service in the 1930s, done to adjust earlier cruise data (Andrews and Cowlin 1940), covered 10% of the area checked. Such cruise data appear to have been more extensive and intensive than any sampling done across areas of this dimension until the 1930s inventory described by Harrington (2003).

Intensity of sampling may affect results where some species are rare. As one example, a pocket of large redcedar in southwestern Tillamook County, Oregon, missed in an early cruise (Anonymous 1908), was picked up by a 1934 cruise (USDA Forest Service 1938). A species within the sampled area also would not be listed if trees were smaller than a commercially acceptable size at the time, usually diameters > 20–24 in (50.8–61.0 cm), varying among species (Andrews and Cowlin 1940). Omitting small or rare trees would probably not change conclusions about timber volumes, but could make a significant difference in the presence/absence data, and thus in perceived distributions.

Data from the Coos County cruise should not be evaluated without understanding the history of the region. Much of the cruised forests was affected by arrival of Euro-American settlers in the early 1850s (Peterson and Powers 1952); timber harvest to clear fields and for local use, mining and shipbuilding began early. Export of Port-Orford-cedar from neighboring Curry County began in 1853 (Zobel 1986) and from Coos County by 1856. In addition, forest fires increased after settlement, especially in the late 1860s (Robbins 1988), producing widespread second growth forest (Figure 2). Large-scale cutting was delayed by lack of capital for large mills, lack of access to a transcontinental railroad and a deep-channel harbor, and primitive technology for moving huge timber to the waterways that led to mills (Robbins 1988). Large-scale cutting began after the construction of a major mill in 1908, which doubled mill capacity in Coos County, and the advent of high-lead logging with steam donkey engines (Anonymous 1911). The mill and timberland owner, the C.A. Smith Company, first harvested along the sloughs off Coos Bay and expanded inland after 1914 when the railroad was extended into the South Fork Coquille River valley.

This history raises questions about the extent to which tree distributions were influenced by cultural factors; for example, was the edaphic specificity of distribution intensified by early forest clearing? Much of the agricultural land, cleared early, had been dominated by hardwoods, especially Oregon myrtle (*Umbellularia californica*) (Robbins 1988). Early logging was mainly along waterways. Neither of these practices appears to have affected most edaphic units.

Early cruise data provide a substantial resource for those who need descriptions of early forests (Hagmann et al. 2013). My study did not take full advantage of their potential, due to limited resources. The use of 40-acre blocks as units for analysis, rather than of sections, would have increased sample size and reduced the variability within sample units, reducing the influence of less dominant geologic and soil types on the species and volumes recorded for each sampling unit, adding considerable precision to the relationships between edaphic units and species distribution. Also, soil texture and topographic data were available for 40-acre blocks. Such a detailed analysis has been illustrated for 59 old-growth sections including Port-Orford-cedar (Zobel 2016). Data have been used from only a small part of Tillamook County (Zobel 2002). Early cruise data were widespread (Andrews and Cowlin 1940), including private as well as government projects; additional such data may yet be discovered. The potential for use of cruise data from little-disturbed forests remains substantial.

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Literature Cited

Andrews, H. J., and R. W. Cowlin. 1940. Forest Resources of the Douglas-fir Region. USDA Miscellaneous Publication 389, Washington, DC.

Anonymous. 1908. Timber Cruise, Tillamook County. Unpublished Report, on file at the Pioneer's Museum, Tillamook, OR.

Anonymous. 1909–1927. Cruisers' Reports, Coos County. No. 1 and No. 2, plus an unlabeled volume. Unpublished Report, on file at the Coos County Courthouse, Coquille, OR.

Anonymous. 1911. The realization of a great commercial dream. American Lumberman 1904:43-142.

Atzet, T., D. E. White, L. A. McCrimmon, P. A. Martinez, P. R. Fong, and V. D. Randall . 1996. Field Guide to the Forested Plant Associations of Southwest Oregon. USDA Forest Service Technical Paper R6-NR-ECOL-TP-17-96. Pacific Northwest Region, Portland, OR.

Bagley, J. H. 1915. 1915 Timber Cruise of Benton County, Oregon. 2 Volumes. Benton County Archives, Corvallis, OR.

Baldwin, E. M. 1974. Eocene stratigraphy of southwestern Oregon. Oregon Department of Geology and Mineral Industries Bulletin 83. Portland.

Baldwin, E. M., J. D. Beaulieu, L. Ramp, J. Gray, V. C. Newton and R. S. Mason. 1973. Geology and mineral resources of Coos County, Oregon. Oregon Department of Geology and Mineral Industries Bulletin 80. Portland.

Beaulieu, J. D., and P. W. Hughes. 1975. Environmental geology of western Coos and Douglas Counties, Oregon. Oregon Department of Geology and Mineral Industries Bulletin 87. Portland.

Black, G. 1994a. Geologic map of the Kenyon Mountain quadrangle, Douglas and Coos Counties, Oregon. Geologic Map Series GMS-83, Oregon Department of Geology and Mineral Industries, Portland.

Black, G. L. 1994b. Geologic map of the Remote quadrangle, Coos County, Oregon. Geologic Map Series GMS-84, Oregon Department of Geology and Mineral Industries, Portland.

Black, G. L., and I. P. Madin. 1995. Geologic map of the Coos Bay quadrangle, Coos County, Oregon. Geologic Map Series GMS-97, Oregon Department of Geology and Mineral Industries, Portland.

Black, G., and G. Priest. 1993. Geologic map of the Camas Valley quadrangle, Douglas and Coos Counties, Oregon. Geologic Map Series GMS-76, Oregon Department of Geology and Mineral Industries, Portland.

Briles, C. E., C. Whitlock, C. N. Skinner, and J. Mohr. 2011. Holocene forest development and maintenance on different substrates in the Klamath Mountains, northern California, USA. Ecology 92:590-601.

Burns, L. D., and F. G. Ethridge. 1979. Petrology and diagenetic effects of lithic sandstones: Paleocene and Eocene Umpqua Formations, southwest Oregon. Society of Economic Paleontologists and Mineralogists, Special Publication 26:307-317.

Chmura, D. J., P. D. Anderson, G. T. Howe, C. A. Harrington, J. E. Halofsky, D. L. Peterson, D. C. Shaw and J. B. St. Clair. 2011. Forest responses to climate change in the northwestern United States: Ecophysiological foundations for adaptive management. Forest Ecology and Management 261:1121-1142.

Christy, J. A., J. S. Kagan and A. M. Wiedemann. 1998. Plant Associations of the Oregon Dunes National Recreational Area. USDA Forest Service, Technical Paper R6-NR-ECOL-TP-09-98. Pacific Northwest Region, Portland, OR.

Daly, C., R. P. Neilson, and D. L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33:140-158.

Erickson, V., C. Aubry, P. Berrang, T. Blush, A. Bower, B. Crane, T. DeSpain, D. Gwaze, J. Hamlin, M. Horning, R. Johnson, M. Mahalovich, M. Maldonado, R. Sniezko, B. St. Clair. 2012. Genetic Resource Management and Climate Change: Genetic Options for Adapting National Forests to Climate Change. USDA Forest Service, Forest Management. Washington, DC.

Franklin, J. F., and C. T. Dyrness. 1973. Natural Vegetation of Oregon and Washington. USDA Forest Service General Technical Report PNW-8. Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Haagen, J. T. 1989. Soil Survey of Coos County, Oregon. USDA Soil Conservation Service, Washington, DC.

Habeck, J. R. 1961. The original vegetation of the mid-Willamette valley, Oregon. Northwest Science 35:65-77.

Hagmann, R. K., J. F. Franklin and K. N. Johnson. 2013. Historical structure and composition of ponderosa pine and mixed-conifer forests in south-central Oregon. Forest Ecology and Management 304:492-504.

Harrington, C. A. 2003. The 1930s survey of forest resources in Washington and Oregon. USDA Forest Service General Technical Report PNW-GTR-584. Pacific Northwest Research Station, Portland, OR.

Heller, P. L., and P. T. Ryberg. 1983. Sedimentary record of subduction to forearc transition in the rotated Eocene basin of western Oregon. Geology 11:380-383.

Huff, T. 2011. Port Orford cedar and western white pine can provide some diversity. Northwest Woodlands 27:24-25.

Imper, D. K. 1981. The Relation of Soil Characteristics to Growth and Distribution of *Chamaecyparis lawsoniana* and *Thuja plicata* in Southwestern Oregon. M.S. Thesis, Oregon State University, Corvallis.

Jenny, H. 1980. The Soil Resource. Origin and Behavior. Springer, New York.

Kruckeberg, A. R. 2002. Geology and Plant Life: The Effects of Landforms and Rock Types on Plants. University of Washington Press, Seattle.

Langille, H. D., F. G. Plummer, A. Dodwell, T. F. Rixon, and J. B. Leiberg. 1903. Forest conditions in the Cascade Range Forest Reserve, Oregon. U.S. Geological Survey Professional Paper 9.

Lintz, H. E., A. N. Gray, A. Yost, R. Sniezko, C. Woodall, M. Reilly, K. Hutten, and M. Elliott. 2016. Quantifying density-independent mortality of temperate tree species. Ecological Indicators 66:1-9.

Little, E. L. 1979. Checklist of United States Trees (Native and Naturalized). USDA Forest Service, Agriculture Handbook 541.

Madin, I. P., G. W. Mcinelly, and H. M. Kelsey. 1995. Geologic map of the Charleston quadrangle, Coos County, Oregon. Geologic Map Series GMS-94, Oregon Department of Geology and Mineral Industries, Portland.

Manugistics. 2005. Statgraphics Plus for Windows, version 5.1. Manugistics Group Inc., Rockville, MD.

Mathys, A., N. C. Coops and R. H. Waring. 2014. Soil water availability effects on the distribution of 20 tree species in western North America. Forest Ecology and Management 313:144-152.

McCain, C., and N. Diaz. 2002. Field Guide to the Forested Plant Associations of the Northern Oregon Coast Range. USDA Forest Service Technical Paper R6-NR-ECOL-TP-03-2. Pacific Northwest Region, Portland, OR.

Meyen, F. J. F. 1846. Outlines of the Geography of Plants. M. Johnston, translator. The Ray Society, London, UK.

Peterson, E. R., and A. Powers. 1952. A Century of Coos and Curry. Binfords and Mort, Portland, OR.

PRISM Climate Group. 2010. Time series datasets. Oregon State University, Corvallis. Available online at http://prism.oregonstate.edu (accessed 14 July 2010).

Robbins, W. G. 1988. Hard Times in Paradise: Coos Bay, Oregon, 1850-1986. University of Washington Press, Seattle.

Shaw, J. H. 1910. How to Cruise Timber. No publisher listed, Portland, OR.

Soga, M., and K. J. Gaston. 2018. Shifting baseline syndrome: causes, consequences, and implications. Frontiers in Ecology and the Environment 16:222-230.

USDA Forest Service. 1938. A Guide to the Cascade Head Experimental Forest. Pacific Northwest Forest Experiment Station, Portland, OR.

Van Atta, R. O., and V. C. Newton, Jr. 1980. Petrographic analysis of sandstones, Roseburg, Flournoy, and Coaledo formations, southwestern Oregon. Oil and Gas Investigations. Prospects for Oil and Gas in the Coos Basin, Western Coos, Douglas, and Lane Counties, Oregon 6:35-36.

Wells, R. E., A. R. Niem, G. R. Priest, L. Ma, C. A. Niewendorp, and I. P. Madin. 2008. Preliminary digital compilation map of part of Western Oregon. Open-File Report O-08-13, Oregon Department of Geology and Mineral Industries, Portland.

Wiley, T. J. 1995. Reconnaissance geologic map of Dora and Sitkum quadrangles, Coos County, Oregon. Geologic Map Series GMS-98, Oregon Department of Geology and Mineral Industries, Portland.

Wiley, T., G. Priest and G. Black. 1994. Geologic map of the Mt. Gurney quadrangle, Douglas and Coos Counties, Oregon. Geologic Map Series GMS-85, Oregon Department of Geology and Mineral Industries, Portland.

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Zobel, D. B. 1986. Port-Orford-cedar: A forgotten species. Journal of Forest History 30:29-36.

Zobel, D. B. 1990. Effects of low temperature, seed source and seed age on germination of *Chamaecyparis lawsoniana*. Canadian Journal of Forest Research 20:1053-1059.

Zobel, D. B. 2002. Ecosystem use by indigenous people in an Oregon coastal landscape. Northwest Science 76:304-314.

Zobel, D. B. 2016. Planting guidelines for Port-Orford-cedar based on cruise data from early 20th-century forests. Forest Science 62:92-98.

Zobel, D. B., L. F. Roth and G. M. Hawk. 1985. Ecology, Pathology and Management of Port-Orford-cedar (*Chamaecyparis lawsoniana*). USDA Forest Service General Technical Report PNW 184. Pacific Northwest Research Station, Portland, OR.

Zybach, B. 2000. Using Oral Histories to Document Changing Forest Cover Patterns: Soap Creek Valley, Oregon, 1500-1999. M.A. Thesis, Oregon State University, Corvallis.