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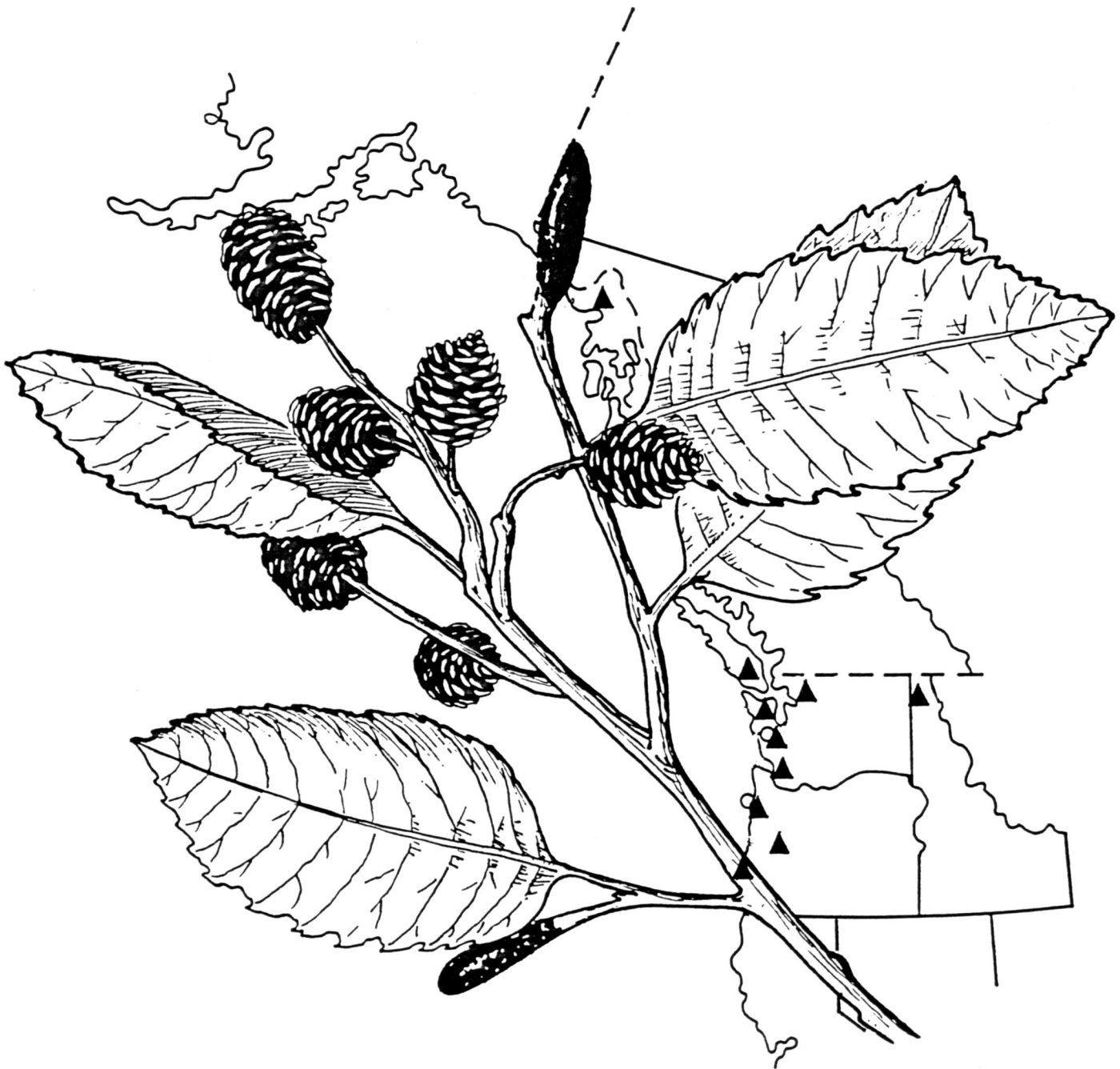
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Geographic Variation in Red Alder

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Abstract

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A test of 10 provenances was established in 1969 on the central coast of Oregon. The provenances tested included Juneau, Alaska, and Sandpoint, Idaho, in addition to eight well-spaced locations in Oregon, Washington, and the southern end of Vancouver Island, British Columbia. Periodic measurements through 15 years of plantation development revealed differences among provenances in height, diameter, and height/diameter ratio. The calculated variables, bole volume and aboveground biomass, showed large differences among provenances. Two provenances from northwestern Washington consistently were the most vigorous, two (Juneau, Alaska, and Sandpoint, Idaho) were the least vigorous, and the remaining six provenances shifted somewhat in ranking over time.

Keywords: Genetics, *Alnus rubra*, provenance.

Summary

A trial of 10 red alder provenances was established in 1969 at Cascade Head Experimental Forest, Oregon. The provenances tested included Juneau, Alaska, and Sandpoint, Idaho, in addition to eight well-spaced locations in Oregon, Washington, and the southern end of Vancouver Island, British Columbia. The experimental design consisted of eight randomized-complete blocks of 10-tree row plots. Survival, height, and diameter were measured periodically through age 15. The planting was systematically thinned to five-tree row plots (spacing 3.0 m by 3.0 m) at 8 years.

Survival by provenance ranged from 91 to 100 percent but changed little from age 8 (after thinning) to age 15. Provenances from northern Washington (Concrete and Sequim) were consistently tallest, and provenances from Juneau, Alaska, and Sandpoint, Idaho, were shortest. Diameter and height/diameter ratios also differed significantly among provenances. Calculated variables, bole volume and aboveground biomass, showed larger differences among provenances than did height or diameter alone. Aboveground biomass ranged from 6.5 kg tree⁻¹ to 101.0 kg tree⁻¹ for the Juneau and Concrete provenances, respectively, at age 15. Rankings of provenances for bole volume and aboveground biomass were identical. Relative performances of the Oregon, Washington, and Vancouver Island provenances are of greatest practical importance, and differences in traits among this subset were also statistically significant. The percentage of superiority of the Concrete provenance over the mean of all Oregon and Washington provenances was 15 percent for diameter and 32 percent for aboveground biomass. If total height alone had been used for selection at earlier ages, however, potential gain in biomass production would have been reduced by 50 percent.

Introduction

Red alder, *Alnus rubra* Bong., is distributed between latitudes 35° and 60° N. along the Pacific coast in humid or subhumid climates below 800 m elevation. The species extends inland 200 km or less except in northeastern Washington and Idaho where disjunct populations are found up to 500 km from the coast (USDA 1965).

Four reports of geographic variation have been published: two studies of populations at different elevations along a 45-km transect eastward from the central Oregon coast (Campbell and Ching 1980, Monaco and others 1981), an earlier report on the range-wide study discussed here (DeBell and Wilson 1978), and a study of variation in specific gravity (Harrington and DeBell 1980). In the first report, height at about 20 weeks after germination did not differ among populations. The second study, of the same transect, demonstrated genetic variation among provenances and between families within provenances for several traits of seeds, biomass at 14 weeks from germination, and nitrogen assimilation. In the third study (DeBell and Wilson 1978), height, diameter, and bark thickness (adjusted for diameter) showed significant provenance effects at a plantation age of 8 years; in addition, percentages of trees with multiple leaders and damage by a twig girdler (*Agrilus burkei* Fisher) and scores of stem form differed greatly among provenance means but were not analyzed statistically. Harrington and DeBell (1980) showed that specific gravity of breast-high wood samples does not vary significantly among the provenances used in the same range-wide provenance trial.

Our study summarizes periodic measurements up to age 15 years for 10 provenances at one location and estimates the impact of differences in height and diameter on stem volume and aboveground biomass. The pattern of provenance performance over time is discussed relative to benefits of early identification of the better provenances.

Materials and Methods

Natural seedlings, 30 to 75 cm in height, were collected from 10 locations during winter 1968-69, shipped to the Webster Nursery, State of Washington Department of Natural Resources, Olympia, WA, and stored at 2 °C until they were sorted and planted. The locations are identified in figure 1.

Because all seedlings of some provenances were obtained from very small areas (for example, less than 0.4 ha), they may represent a small portion of the gene pool at that general location. Procedures used to sample the local populations would thus tend to reduce variability within a provenance and may exaggerate differences among provenances.

A 4-ha site on the Oregon coast near Otis was chosen as one of two outplanting sites. The land is part of the USDA Forest Service Cascade Head Experimental Forest and is typical of coastal alder sites. Elevation is about 180 m, precipitation (primarily rain) averages about 2300 mm per year, and mean annual temperature is approximately 11 °C. Soils are derived from sedimentary materials. Originally, the area supported a mature stand of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.). After logging, a central 30- by 120-m area was cleared of all debris (except large stumps) to permit uniform spacing of the alder seedlings. The second site was a former forest nursery about 25 km southwest of Olympia, WA. This plantation was abandoned after most seedlings were killed by autumn frosts in 1969 and 1970 (DeBell and Wilson 1978).

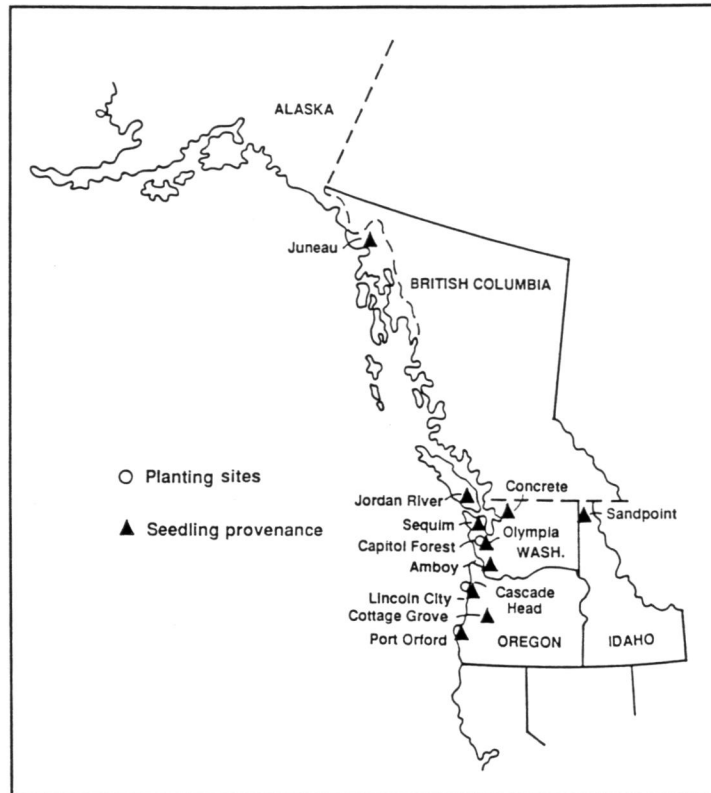


Figure 1—Locations of sources tested in red alder provenance trial.

The experimental design is eight randomized-complete blocks of 10-tree row plots. Initial spacing was 3.0 m between plots and 1.5 m between trees within plots. The trees were planted in March and April 1969. Before planting, roots of all seedlings were pruned to 20 cm in length; tops exceeding 60 cm were pruned to 45 cm. Seedlings were evaluated in July 1970 after nearly two growing seasons. Data were collected on survival, height, and general form. Multiple leaders and large suckers were removed because they probably resulted from top pruning and transplanting shock.

Height measurements were taken at Cascade Head annually from 1970 to 1974, biennially from 1976 to 1980, and in 1983. Measurements of breast-high diameter were begun in 1976, 8 years after planting. In December 1976, the test area was thinned to 3- by 3-m spacing by removing every other tree in each row.

Variation was partitioned among blocks, provenances, and block-provenance interactions by analysis of variance using a least squares program for unbalanced data (Wilkinson 1987). Only plot means were available for second- and third-year height. Individual tree measurements were used for all other analyses.

Inside-bark stem volume (V) was estimated as a function of stem diameter outside bark at breast height (d) and total height (h) by using the formula (Browne 1962):

$$\log_{10} V (\text{ft}^3) = -2.6728 + 1.9206 \log_{10} [d (\text{in})] + 1.0740 \log_{10} [h (\text{ft})]. \quad (1)$$

The inside-bark stem volume (V) was transformed to cubic meters.

Aboveground biomass is the sum of stem weight, estimated as stem volume times specific gravity (0.40) plus an additional 18 percent for stem bark, and crown weight (CW). The latter was estimated as a function of stem diameter in centimeters (Snell and Little 1983):

$$\ln \text{CW (kg)} = -4.5648 + 2.623 \ln [d(\text{cm})]. \quad (2)$$

Results and Discussion

Block Effects

Survival ranged from 95 to 99 percent by block and showed neither statistically significant differences nor trends in time.

Table 1 summarizes block effects for height, diameter, height/diameter ratio, and bole volume. Statistically, blocks differed significantly for height throughout the study period, whereas block effects for diameter, height/diameter ratio, and bole volume were not significant after age 8. Blocks located in a drainage path occupied by sedges (*Carex* spp.) generally were less vigorous. Although red alder can tolerate wet sites better than many species, its growth is reduced by waterlogged soil conditions (Minore and Smith 1971). The pattern became less evident over time, however; by age 10, one poorly drained block had the largest average diameter and maintained that advantage through age 15. The difference between tallest and shortest blocks at age 15 was 0.5 m, or less than 5 percent of mean height for the plantation.

Provenance Effects (All Provenances)

Survival by provenance ranged from 91 to 100 percent with the Sandpoint provenance having significantly higher mortality by age 6. After thinning (age 8), survival changed little through age 15.

Height growth patterns are outlined in figure 2a. The tallest provenance averaged about 1 m in annual increment. Such growth is equivalent to that of dominant and codominant trees on an average red alder site. Provenance means differed at a probability of 99 percent on all measurement dates. Three groupings of provenances were indicated. The Concrete and Sequim provenances, although alternating in rank, were the tallest provenances for eight of the nine measurements. Equally consistent was the Juneau provenance, which ranked last, and the Sandpoint provenance, which was second from last. Between the tallest and shortest groups, ranking changed most noticeably for Jordan River (eighth at age 8 to second at age 15) and Olympia (third at age 2 to seventh at age 15).

Diameter, averaging 1 cm per year for the most vigorous provenance, differed similarly among provenances (fig. 2b). Concrete and Sequim consistently were the largest; Juneau, Sandpoint, and Cottage Grove consistently were smallest; and the remaining provenances shifted among themselves in rank without clearly defined trends.

Table 1—Statistical significance of block, provenance, and block by provenance effects for 10 red alder provenances measured at 8 different ages

Trait	Age (years)				
	2,3,4,6	8	10	12	15
Blocks:					
Height	**a	*	*	**	*
D.b.h.	— ^b	*	NS	NS	NS
Height/d.b.h.	—	NS	NS	NS	NS
Bole volume	—	*	NS	NS	NS
Provenance:					
Height	**	**	**	**	**
D.b.h.	—	**	**	**	**
Height/d.b.h.	—	NS	**	**	**
Bole volume	—	**	**	**	**
Blocks by provenance:					
Height	**c	**	*	*	NS
D.b.h.	—	**	**	**	**
Height/d.b.h.	—	NS	**	**	**
Bole volume	—	**	*	*	NS

^a Means differ at a probability of 99 percent (**), 95 percent (*), or less than 95 percent (NS).

^b Measurements not taken.

^c Interaction estimated only for ages 4 and 6.

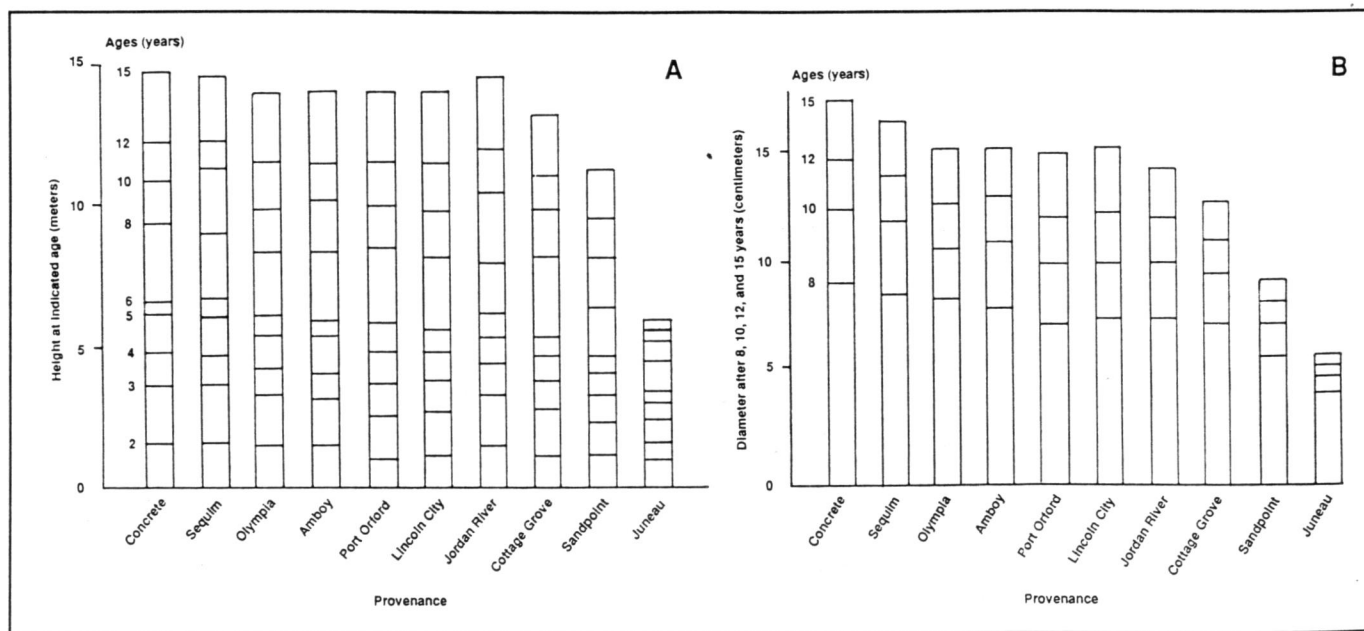


Figure 2—Cumulative height growth (A) and diameter growth (B) of red alder provenances at Cascade Head Experimental Forest to age 15.

The relation between height and diameter was examined through two variables, the height/diameter ratio and bole volume. Plantation means for height/diameter ratio varied from 8.5 to 10.1 at different ages; across all ages, provenance means varied from 7.1 to 11.6. At age 8, only two overlapping groups were recognized by a multiple-range test. Major changes in variation occurred after thinning at age 8 when the coefficient of variation declined from 33 to 16 percent and provenances began sorting more clearly. By age 15, six groups were identified in a multiple-range test. Juneau, Sandpoint, and Cottage Grove consistently had high ratios, whereas Concrete, Sequim, and Amboy were low.

The Concrete provenances annually produced an average of 0.01 m³ of bole wood per tree. All provenances produced bole wood at a faster rate between ages 12 and 15 than at earlier ages (for Concrete, the rate was 0.023 m³ per year for this period). Concrete and Sequim consistently produced the most wood. Among provenances shifting in intermediate positions, Lincoln City (the "local" collection) moved from seventh to third in rank but remained significantly lower in mean bole volume than Concrete.

Calculated aboveground biomass ranged from 6.5 kg to 101 kg per average tree at age 15. Ranking of provenances was identical to that for bole volume.

Provenance Effects (Oregon, Washington, and Vancouver Island Provenances)

Based on the foregoing results, the Juneau and Sandpoint sources cannot be recommended for timber or biomass production on the Pacific Northwest coast. The importance of geographic origin of alder within the area west of the Cascade Range is therefore the question of practical interest. Provenance was a significant source of variation (99 percent probability) for height, diameter, and bole volume at each measurement and for height/diameter ratio at ages after 8 years. Figure 3 illustrates the range of variation in biomass.

Block by Provenance Interaction

The interpretation of provenance effects is somewhat clouded by variation among block-provenance means when compared with tree-to-tree variation within plots. Table 1 shows that this interaction was usually statistically significant. The only exceptions were height and bole volume at age 15 and height/diameter ratio at age 8. Results were the same for analyses with all provenances as for analyses using only Oregon, Washington, and Vancouver Island provenances.

Two approaches were taken to identify a potential basis for interaction. In the first, provenance means were plotted by block and connected by lines to assess patterns of change in relative performance in various blocks. No consistent pattern emerged. A second analysis involved field mapping of the area dominated by sedge. Plots were coded as "wet" if more than one-half of a plot fell within the area mapped; other plots were coded as "dry." An analysis of variance using provenance and ground vegetation code revealed no significant differences in growth by vegetation type and no interaction of provenance with vegetation types for either all 10 provenances or Oregon, Washington, and Vancouver Island provenances only. We thus have no explanation of the provenance-block interaction and suspect it has little practical consequence.

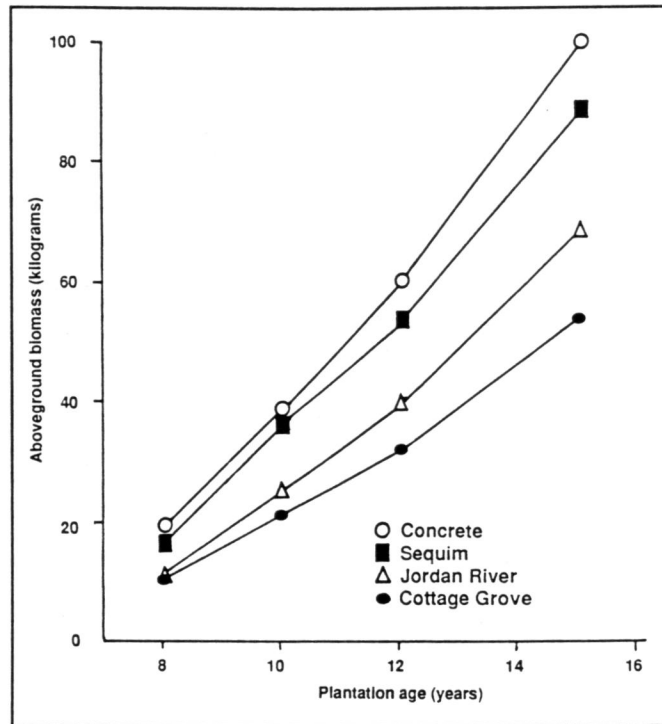


Figure 3—Mean aboveground biomass for the two provenances with the highest and lowest weights (excluding Juneau and Sandpoint) at four ages.

Tree Breeding Implications In addition to evidence that red alder varies genetically by geographic origin of seedlings, this study provided estimates of benefits from the use of tested provenances. Figure 4 shows the extent of advantage for the most vigorous provenance (Concrete) over the mean of provenances from Oregon, Washington, and Vancouver Island for height, diameter, and aboveground biomass. Note that the percentage of superiority declined over time yet remained substantial for diameter (15 percent) and biomass per tree (32 percent). For the top three provenances, the height advantage declined from 10 percent at age 4 to 3 percent at age 15; for biomass, the change was from 26 percent to 17 percent.

These data also provide estimates of the consequences of early provenance selection in the Cascade Head plantation. The Concrete provenance would have been selected as best on all measurement dates if diameter or aboveground biomass were the basis for selection. Selection based on total height at ages 2, 6, 10, or 12, when the Sequim provenance was slightly taller, would have resulted in yields reduced by 12 kg per tree at age 15. Such inappropriate use of total height to evaluate biomass productivity would have reduced potential biomass gains from provenance selection by about 50 percent.

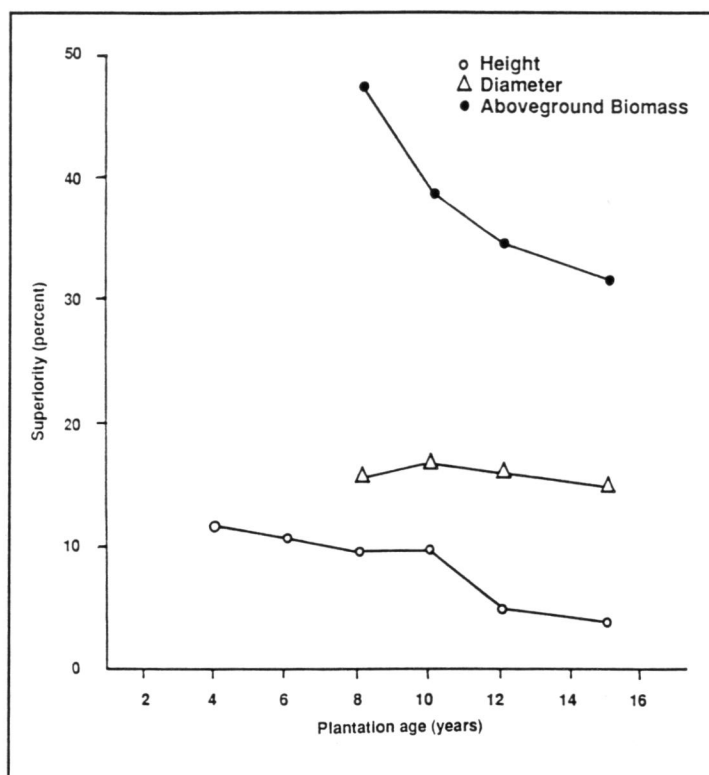


Figure 4—Superiority of the best provenance over the average provenance (excluding Juneau and Sandpoint) at four ages.

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